Growth of Space Science Research Publications in India since 1960s: A Scientometric Study

Thesis

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By

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DECLARATION

I hereby declare that this thesis entitled **"Growth of Space Science Research Publications in India since 1960s: A Scientometric Study"** is my original research work carried out under the supervision of Dr. Archana Shukla, Faculty of Department of Library and Information Science, IGNOU, New Delhi, for the award of the degree of Doctor of Philosophy in Library and Information Science, School of Social Sciences, Indira Gandhi National Open University (IGNOU), Maidan Garhi, New Delhi.

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CERTIFICATE

This is to certify that the thesis entitled **"Growth of Space Science Research Publications in India since 1960s: A Scientometric Study"**, submitted for the award of the degree of Doctor of Philosophy in Library and Information Science, School of Social Sciences, Indira Gandhi National Open University (IGNOU), is a record of bonafide research carried out by Mr. Md. Nurul Alam, under my supervision and no part of the thesis has been submitted for any other Degree or Diploma.

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List of Abbreviations and Acronyms

Abbreviations /Acronyms	Abbreviations and Acronyms Expanded
A&A	Astronomy & Astrophysics
ACM	Astrometry and Celestial Mechanics
AIMT	Astronomical Instrumentation, Methods and Techniques
AvgCPA	Average Citations Per Article
CAGR	Compound Annual Growth Rate
COSPAR	Composition of the Indian National Committee for Space Research
DAE	Department of Atomic Energy
DOS	Department of Space
IGY	International Geophysical Year
IMG	Ionosphere, Magnetosphere and Geomagnetism
IMPAP	Indian Middle Atmosphere Program
ISAC	ISRO Satellite Centre
ISM	Interstellar Medium
ISRO	Indian Space Research Organisation
MAR	Meteorology and Atmospheric Research
MAS	Meteorology and Atmospheric Science
MOM	Mars Orbiter Mission
NARL	National Atmospheric Research Laboratory
PACS	Physics Astronomy Classification Scheme
PDP	Physical Data and Processes

PRL	Physical Research Laboratory
PS	Planetary Systems
RUSFW	Resolved and Unresolved Sources as a Function of Wavelength
SAG	Space Astronomy Group
SJR	SCImago Journal Rank
SNIP	Source Normalized Impact per Paper
SPL	Space physics Laboratory
SPSS	Statistical Package for the Social Sciences
SSIF	Space Science Instrumentation Facility
TERLS	Thumba Equatorial Rocket Launching Station
TIFR	Tata Institute of Fundamental Resarch
UAT	Unified Astronomy Thesaurus
UPSO	Uttar Pradesh State Observatory
USO	Udaipur Solar Observatory
VSSC	Vikram Sarabhai Space Centre
WoS	Web of Science

Chapter 1

INTRODUCTION

1.1 Background

The research in Space Science is playing an important role in the development of modern technologies and has become an indicator of the advancement of scientific knowledge in a country. Space Science research in India has a long history since Independence. This area of study is related to both basic and applied research and can be utilised by the society or nation as a whole.

Defining Space Science is a difficult task and as such there is no single phrased definition for the subject. Different sources have defined it in different ways; a few of such definitions are given here: According to Lundquist (1966) in his book *The Physics and Astronomy of Space Science,*"Space Science is defined as the Study of natural phenomenon occurring in Space". Wikipedia defines Space Science as the study of everything in outer space.It has sometimes been called astronomy, but recently astronomy has come to be regarded as a division of broader Space Science, which has grown to include other related fields such as studying issues related to space travel and space explorationand studying the morphology of extra-terrestrial objects ('Outline of Space Science', n.d.).As per the Collins Dictionary,Space Science is defined as "any of the various science fields which relate to space flight or any phenomena occurring in space or on other planets. This would include for example fields such as Aeronautics, Astrophysics" ('Space Science', n.d). In other words Space Science can be understood as "any of several scientific disciplines, such as exobiology, that study phenomena occurring in the upper atmosphere, in space, or on celestial bodies other than Earth" ('Space Science', n.d.).

It is now universally accepted that the technological advances of a country largely dependon its basic science research.Space Science forms a unique subdivision within the universe of scientific and technological body of knowledge. It is made up of two different but interrelated structures, the basic science and the technology of Space Science. Thus, Space Science can be viewed as a "special universe" of knowledge of its own. These two interrelated structures of Space Science can be viewed as interplay of three professional activities in basic scientific and technological research, education, and services. This interplay of activities is embedded intwo different but interrelated structural fields - basic Space Science and Space Technology. The two fields have contributed to the phenomenal growth in both the knowledge and literature of Space Science during the past few decades. Space Science research has been an integral part of the Indian space programme. The goal of the Space Science programme is to promote research in Space Science, inspire and enthuse the young talented scientists and students to get involved in Space Science research. The Space Science research in the country has gained impetus with the successful launch of Chandrayaan-1, India’s first mission to the Moon which marked the commencement of India’s planetary exploration programme(Daniel, 1992; Obaka, 1984; Vikram Sarabhai Space Centre, 2016).

The continuing growth in both the knowledge and literature of Space Science and its effective utilisation, have become a matter of significant concern to the contemporary society, especially to the space scientists and other people engaged in the production, collection, storage, retrieval and utilisation of information.Present study aims at investigating the characteristics of Space Science literature in India, its growth pattern and its implications since 1960s by using Scientometric techniques. It would also explore the contribution of Indian researchers in this field.

1.2 Statement of the Problem

The Governments, Enterprises and Organisations decide their scientific priorities and finances based on nation's scientific output. The research capacity of a country determines its development, and influences the wealth creation and distribution. Determining the innovative activities in order to understand the role of scientists and researchers in a country is a crucial aspect of wealth creation. Scientists and researchers are potential wealth creators in an organisation as well as in a country. Therefore, there is a need to evaluate the performance and scientific activities of scientists and researchers. This is important in order to be aware of trend of activities by scientists and researchers to divert the innovative ones where the need is greater. The scientific output indicates towards the innovation, inventions, technologies and research. This output can be utilised to find out the extent to which the knowledge has diffused across the areas, countries, sectors and firms.

Scholarly communication is exceedingly important in the understanding of the genesis evolution and growth of disciplines. Studies in scientific astronomy in India are known to date back at least to the 5th century astronomer-mathematician Aryabhatta. A new development took place in the 1920s when S.K. Mitra in Calcutta initiated interesting activities in radio research, which led to the sounding of ionosphere using ground-based radio technique. The beginning of an organised approach of research in Space Science in India was nucleated and stimulated by two legendary scientists – HomiBhabha and Vikram A Sarabhai through the research programme on cosmic rays and this programme went on to become one of the most important fields of study and research in the country(Daniel, 1992). Over the course of nearly 54 years, there is a huge amount of literature that has been published on Space Science. However, there is no empirical study that has tried to identify how this field has developed over the course of time. Therefore, here is an attempt to illustrate the trend of Space Science literature in India written in English from 1960 to 2014.

1.3 Purpose of the Study

The purpose of this Scientometric analysis is to map the Indian literature on Space Science written in English from 1960 to 2014. The prime aimof the study is tofind out the publication characteristics of the Space Science literature. Another major purpose is to determine the characteristics of the development of the sub-fieldsby means of identifying the descriptive indicators in the Space Science literature.

1.4 Objectives of the Study

The main objective of the study is to assess the growth of Indian Space Science research publications since 1960s using Scientometrics analysis.

The objectives of the study are as follows:

- To identify the sub-domains of the subject and thereby the trend of research.
- To find out the core institutions devoted to the research in the sub-fields of Space Science.
- To find out the core journals of the sub-fields of Space Science.
- To find out the individual research output of highly prolific authors.

- To evaluate the research performance using citation data.
- To find out the collaboration pattern with other countries and continents.
- To find out the research hotspots and quick rising themes in the sub-fields of study.

1.5 Research Questions

Q1: What is the quantity of Space Science Research publications and citations since 1960?

Q2: Which growth trend is being followed? Have the growth trends changed overtime?

Q3: Which growth model can be used to describe the trend?

Q4: What are the specific characteristics of the literature of sub-fields of Space Science in terms of selected variables pertaining to the year, authors, titles, journals?

Q5: What are the characteristics of the literature of Space Sciencein terms of variables pertaining to the citation, average citation, h-index?

Q6: What is the status of globalisation of Space Science research?

Q7: Which research themes are prominent in Space Science research publications?

1.6 Significance of the Study

It is a known fact that research activities create wealth and wealth is a prerequisite for research. It is necessary for us to realise that the research capacity of a country determines its development, and influences wealth creation and distribution. Science policy makers need to determine an objective and reliable way to assess the performance of their national scientific system and to determine their real situation among other organisations and countries in the world. To achieve this goal, there is a need to evaluate the performance of scientists and researchers of countries and to map the growth of their scientific output. Another important factor for assessment of scientific output is to find out the loop holes and improve upon the research systems and promote research activities, so this evaluation can also help to plan further research projects. In this context the Growth of Space Science Research Publications in India also requires a scientometric assessment for the aforesaid reasons.

The significance of this study, thus, lies in the following facts:

- It will be the first descriptive overview of the characteristics of the literature of Space Science research in India.
- It will give an indication of the kinds of resources used in the literature of Space Science Research.
- It can serve as the basis of a comprehensive bibliography of the literature of Space Science research.
- It will help in identifying the aspects of Space Science research that have not yet been investigated or need to be reconsidered in the light of new developments.

1.7 Scope of the Study

- The study focuses on research publications (Scholarly Journal Articles only) in the fields and sub-fields of Space Science published by Indian Scientists or India as a country of affiliation.
- The articles that have been published only in English language have been considered for this study.
- The year 2014 has been taken as the cutoff year for this study considering the fact that almost all the papers published till 2014,would have been indexed in the WoS database by the time of data collection i.e. 2015. This is to ensure that no article gets missed upon from inclusion in the data set.
- The database Web of Science (WoS) has been chosen to carry out the study.
- The database was accessed through the Library of the Indian Association for the Cultivation of Science (IACS).

1.8 Definitions and Scope of the Terms Used:

The following conceptual and operational definitions have been utilised in this study:

1.8.1 Publication Pattern

Publication pattern is theoretically defined as the use of empirical data and quantitative analysis to map the development of the field of study over a certain period of time to determine the geographic locale as well as the key contributors to the field using various publication counts. The publication pattern is determined by counting the number of articles published over given time per country and articles published per author. The country of origin has been determined by the primary author's institutionalaffiliation (Fayland, 2008).

1.8.2 Growth in the Field

Growth in the field has beendefined as articles in defined categories (publication type) identifying an increase in publications over time. The concept, growth in the field, came into being with the counting of the number of articles over time(Fayland, 2008).

1.8.3 Journal Pattern

Journal patternare theoretically defined as the use of empirical data and quantitative analysis to trace formal communication in the form of published articles. The concept journal pattern is used by counting the number of Space Science articles published in each source journal in the established time period of the study. The list of journals is ranked in order of decreased productivity based on the total number of Space Science articles(Fayland, 2008).

1.8.4 Author Pattern

Author productivity is measured by counting the number of articles published per individual author. For author productivity, the whole-counting method was used giving each author a point for each article regardless of their position in the article as that of a primary or secondary author (Fayland, 2008).

1.8.5 Keywords Analysis

The articles published in the journals have a general feature of containing keyword(s), which represents the thought contents of publication and author's research preference.Keyword analysis is a quantitative method of summarising keywords data and then describing the content using statistics. It is the subjective interpretation of keyword data through the systematic classification process of coding and identifying themes or patterns.

This may serve several purposes:

- To identify hot topics.
- To identify quick rising themes.
- To simplify the detection of scientific research trends (Hsieh & Shannon, 2005).

The process of keyword analysis has been described by various authors in many ways. Li and Zhao performed the keyword analysis to demonstrate research trends and frontiers. The keywords analysis in their study utilised author keywords, which were provided by article authors as part of the articles and termed as Keywords (Li and Zhao, 2015). Another such analysis was used in a study by Montoya et al., 2014 in order to follow and search the trends in the science and engineering(Montoya et al., 2014). Yanhuaet al. (2012) used keyword analysis to reveal the trends and identify hot topics that draw most research efforts. In another study, the authors mention that the keywords provide a reasonable description of an article's theme and could reveal the profile of an author's research preferences. Therefore, Keyword analysis can be used to identify the subjective focus and emphasis specified by authors, explore research hotspots and discover scientific research trends (Niu, Loáiciga, Wang, Zhan, & Hong, 2014).

A. Hotspots

An analysis of the keywords was undertaken to pick out the hotspots that have attracted most research attention and to reveal the research tendencies in the fields.

B. Quick Rising Theme

CAGR is used to identify the quick rising themes of research topics which could be an indicator of future research directions. The CAGR provides smoothed growth rates free from the annual fluctuations of keywords occurrences during the study period (Niu, Loáiciga, Wang, Zhan, & Hong, 2014).

1.8.6 Performance (Impact) Indicator

Performance in research should be evaluated in terms of quality as well as quantity. Most commonly used indicator for evaluation of research performance is total number of publications (TP) accumulated in the SCI (Science Citation Index) of Web of Science.Citations are other very commonly used indicators to assess the quality of research. The idea of usage of citations lie on the fact that more times a paper is being cited, the better is its impact and hence the quality of the research. These, along with other indicators are discussed in the forthcoming sections.

A. h-index

Hirsch Index (h-index)is a distribution-based indicator that corresponds to the number of papers at or above a given citation level equals to the value of the citation threshold. This reflects the number of papers (N) in a given dataset having N or more citations. This measure attempts to reflect both productivity (number of papers) and impact (number of citations) in one number (Webster, 2011; Mingers&Leydesdorff, 2015). The index was suggested in 2005 by Jorge E. Hirsch. Figure 1.1shows the graphical illustration of h-index.

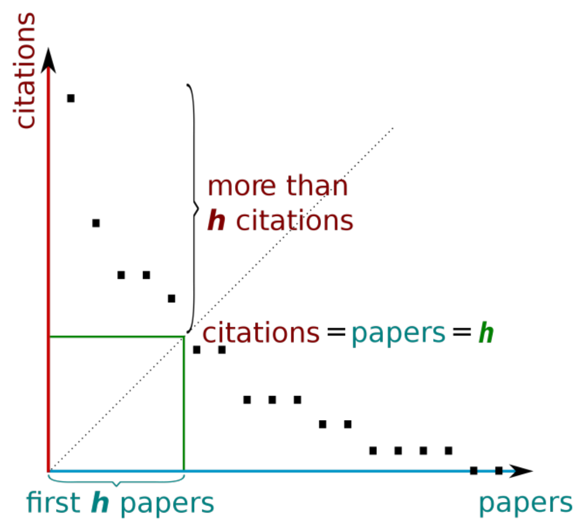

Figure 1.1: Graphical illustration of h-index

The advantages of h-index are:

- It combines both productivity and impact in a single measure that is easily understood and very intuitive.
- It is easily calculated by just knowing the number of citations either from WoS, Scopus or Google Scholar. In fact, all three of these now routinely calculate it.
- It can be applied at different levels –researcher, journal or department.
- It is objective and a good comparator within a discipline where citation rates are similar (Mingers&Leydesdorff, 2015).

B. Average Citations Per Article (AvgCPA)

AvgCPA sometimes called ‘impact’ or ‘CitationsPerPaper’ (CPP) is computed by dividing the sum of citations to a set of papers for a defined time period by the number of papers (paper count). The CPP score is an attempt to weigh impact in respect of output, since a greater number of publications tend to produce a greater number of citations(Webster, 2011).

C. SCImago Journal Rank (SJR)

SCImago Journal Rank (SJR) is a prestige metric based on the idea that 'all citations are not created equal'. It is a measure of scientific influence of scholarly journals that accounts for both the number of citations received by a journal and the importance or prestige of the journals where such citations come from. It is a size-independent indicator and it ranks journals by their 'average prestige per article' and can be used for journal comparisons in science evaluation processes (Scopus, 2016a).

D. Impact Per Publication (IPP)

The IPP measures the ratio of citations in a year (Y) to scholarly papers published in the three previous years (Y-1, Y-2, Y-3) divided by the number of scholarly papers published in those same years (Y-1, Y-2, Y-3). This metric uses a citation window of three years which is considered to be the optimal time period to accurately measure citations in most of the subject fields. The Impact per Publication measures the ratio of citations per article published in the journal (Scopus, 2016b).

E. Source Normalised Impact per Paper (SNIP)

Source Normalised Impact per Paper measures contextual citation impact by weighting citations based on the total number of citations in a subject field. As a field-normalised metric SNIP offers researchers, authors, and librarians the ability to benchmark and compare journals from different subject areas. This is especially helpful to researchers publishing in multidisciplinary fields (Scopus, 2016c).

1.8.7 Scientometrics

Scientometricsis the science of measuring science. It is often done using bibliometrics which is a measurement of the impact of a scientific publication. It includes all quantitative aspects of the science of science, communication in science, and science policy. The term Scientometricsoriginated as a Russian term for the application of quantitative methods to the history of science. It deals with analysis, evaluation and graphical representation of science and technology information. According to Tague-Sutcliffe, "Scientometrics is the study of the quantitative aspects of science as a discipline or economic activity. It is part of the sociology of science and has applications in science policy-making. It involves quantitative studies of scientific activities, including, among others, publication, and so overlaps bibliometrics to some extent" (Hood & Wilson, 2001).

1.8.8 Bibliometrics

The term 'bibliometrics' was coined by Alan Pritchard in the late 1960s. According to him, " to shed light on the processes of written communication and of the nature and course of development of a discipline (in so far as this is displayed through written communication), by means of counting and analysing the various facets of written communication ... the application of mathematics and statistical methods to books and other media of communication ... ". Bibliometrics studies are mainly employed to investigate the following areas.

- Scattering of articles
- Author productivity
- Citation analysis
- Measures of journal productivity etc. (Hood & Wilson, 2001).

1.8.9 Citation Analysis

Currently much attention is focused on citation analysis. Citations have been studied extensively because they are unobtrusive and readily available, do not require the cooperation of a respondent, do not contaminate the response, and can be counted precisely and objectively. This area of bibliometrics focuses on the relationship between cited documents and the citing documents (Smith, 1981).

1.9 Organisation of the Study

The present study has been organised as given below:

Chapter 1- Introduction:The chapter provides a brief introduction to the Space Science; summarises the definition of Scientometrics, objectives and purpose of the study; significance of the study, research questions and the scope and limitations of the study.

Chapter 2 –Literature Review on Space Science Research: This chapter is a discussion on 1) Study of the structure and scope of the subject Space Science research and 2) The review of literature which depicts a comprehensive review of the related literature for the study with subheads as: Discipline/Subject, Institution/Organisation, Author/Scientist, Journal and Database based studies.

Chapter 3- Research Methodology: In this chapter the following points are discussed. Various sections include introduction to the chapter; Scientometrics as a research method; study area; data collection instruments; data collection procedure; data analysis; statistical tools etc.

Chapter4 - Data Analysis and Interpretation: This chapter provides analysis and interpretation of data across a total of 13 sub-fields of Space Science literature under the heads of Publication Characteristics, Publication Pattern, and Growth Trends, Citations pattern, Publications Vs Citations Pattern, Top Institution, Top Journal, Top Authors, Collaboration, Frequently used Keywords and Quick Rising Themes. It also provides overall picture of Space Science research in India during 1960-2014 by mapping fields and sub-fields of Space Science in terms of total distribution of publications, citation metrics, descriptive statistics, etc.

Chapter 5 - Mapping of Space Science Literature, 1960-2014: This chapter explores the changes in the sub-fields of Space Science. It discusses in length the practical mapping of the growth of literature in the sub-fields of Space Science.

Chapter 6 – Summary, Discussion and Conclusion: This chapter briefly discusses the findings across all the sub-fields of Space Science.

1.10 Summary

Chapter 1 – Introduction commences with the background of the subject - Space Science, it further narrates the purpose of this research work followed by the objectives involved herein. It projects the research questions that need to be addressed and significance of this work. This chapter moves on with in-depth description of the basic concepts that are to be used in the following chapters. Narration of the concepts like Bibliometrics, Scientometrics, Citation analysis, keywords, Hotspots, etc. are included in this chapter. It further discusses the performance indicators like h-index, AvgCPA, IPP, etc. It also briefly introduces the work plan which will be used in the study and how the whole study will be presented in this thesis.

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Chapter 2

LITERATURE REVIEW ON SPACE SCIENCE RESEARCH

2.1 Introduction

The current chapter is a discussion on the review of Scientometrics and Bibliometrics related literature in the field of Space Science research. It deals with the attempt to draw a circumference of Space Science research and to dig out the studies in related fields if any so as to put forth a strong justification for the present study.

A literature review can be understood as an evaluative report of studies that have already been undertaken in the literature related to ones own selected area of research. A literature review aims to describe, summarise and evaluate the related studies. It should be able to give a theoretical basis for the research and help the researcher to determine the nature of his/her own research. A literature review essentially goes beyond the search for information and includes the identification and articulation of relationships between the literature and researcher’s field of research. It describes the role of scientific communication and how different disciplines use the scientific literature. Review of related literature, a significant and primary component of any research investigation enables the investigator to understand the earlier research interests, research pattern and magnitude of the research output in a field of knowledge. As far as the field of Scientometrics is concerned, the literature on the subject is constantly growing. A survey of the research trends is felt necessarily desirable to identify if any similar study already exists with a view to get knowledge of the process of application of quantitative analysis (CQ University, 2015).

Bless and Higson-Smith opines that the purpose of a literature review is one or a combination of the following:

- To sharpen and deepen the theoretical framework of the research in question.
- To update the researcher on the latest developments in related areas of research.
- To identify the gaps in knowledge, as well as weaknesses in studies already carried out, by establishing what has been done, what has not been done, and what needs to be improved.
- To discover connections, contradictions or other relationships between different research results by comparing various investigations.
- To identify variables that should be considered in a given study, as well as those that prove irrelevant. This finding is often achieved by comparing different investigations.
- To examine the definitions used in previous works as well as the characteristics of the population under investigation, with the aim of adopting them in a study. In doing so, homogeneity, which enables easier comparison, is obtained in different studies (Sitienei, 2009).

2.2 Study of Space Science Literature

This section deals with the methodology for understanding the scope of the subject-Space Science. The legendary information scientist G. Bhattacharyya from Documentation Research and Training Centre, Indian Statistical Institute, India, through a project on 'Study of Subjects' developed a methodology for identifying the structure and development of a Subject. Methodology for the study of subject is an important technique in the field of Library and Information Science (LIS) that helpsLIS professionals to understand the needs of the users and lend out better library services. This methodology includes systemic study of subjects through documents to acquire the knowledge on specific headings like scope of the subject, main branches and subdivisions within each branch, landmark in the evolution of the subject, technical terminology,etc.to know the highways and byways of subjects (IGNOU, 2010).The ‘study of subjects’ is very important in identifying the main branches and subdivisions within each branch which are termed as ‘field’ and ‘sub-field’.

In this study, Space Science is considered as a subject domain. Theresearch in this area in India started through the studies in scientific astronomy which are known to date back to the 5thcentury astronomer-mathematician Aryabhatta. With the beginning of research activities in radio research by S.K. Mitra in 1920s, this field of research took a giant leap. An overview of major developments in this field of research is discussed in the coming sections.

2.2.1 Development of Space Science Research in India, 1960-2014

With the advent of the 20th century, science and technology took a major leap for humanity. This technological leap was free from restrictions and thus motivated individuals to indulge in the gain. Europe as the leader, the nations all around the globe found science to be a powerful instrument for national development and defense preparedness. Thus the politically and economically rich nations started investing on systematic scientific research.

Space Science, Space Technology and Space Application have a very crucial role to play in the overall development of a Nation’s economy. For nations to continue experiencing their independent being, space research has a lot to offer. R. R.Daniel in 1992 rightly described this age as the space age.

2.2.2 Landmarks

A. The People behind the beginning

The Space Science research took a more organised approach with the eminent Indian scientists, HomiBhabha and Vikram Sarabhai. Both of them founded an institution each for the basic research, namely The Tata Institute of Fundamental research in Bombay by Bhabha in 1945 and the Physical Research Laboratory (PRL) in Ahmedabad by Sarabhai in 1947 which went on to become Institutions of international repute by yielding productive results (Daniel, 1992).

B. The nuclei for basic Space Science

In 1947, Tata Institute of Fundamental Research (TIFR) initiated studies on cosmic radiation which had two main approaches. One, to send instruments such as nuclear emulsions and electronic particle detectors to great altitudes in balloons to study the nature of the primary radiation. And two, to set up installations at mountain altitudes and deep underground in the Kolar Goldfields to study the nature of the very high energy nuclear interactions produced by primary cosmic rays in the atmosphere and the secondary particles that result from them.Similarly, PRL had two primary concerns. First was the long-term monitoring of secondary cosmic rays – the muons and neutrons at sea level as a function of latitude and longitude. And another, the upper atmospheric studies over low latitudes, including meteorology, ionosphere investigations, geomagnetism and solar-terrestial relations. During this period, atmospheric studies went up the ladder to produce interesting results.

For the first time, discovery of reflections from meteor trails by the research department of All India Radio Tashkent were observed. With the Colaba Observatory in Bombay in 1823, studies of the geomagnetic field begun at various stations all over India. Along with these, in 1954, Uttar Pradesh State Observatory (UPSO) was commissioned at Nanital for stellar and solar observations. The Rangpur Observatory of Osmania University at Hydrebad was also sanctioned in 1957 for a 1.20m telescope(Daniel, 1992; Kochhar&Narlikar, 1995).

C. DOS/ISROCentres for Space Science Research

Presently under the Department of Space (DOS), Space Science research is being carried out at:

1. Physical Research Laboratory (PRL), Ahmedabad
2. Udaipur Solar Observatory (USO), a major facility under PRL, Udaipur , Rajasthan
3. Space Physics Laboratory (SPL),Vikram Sarabhai Space Centre (VSSC), Thriuvananthapuram
4. Space Astronomy Group (SAG), ISRO Satellite Centre (ISAC), Bangalore
5. Space Science Instrumentation Facility(SSIF) , ISRO Satellite Centre (ISAC), Bangalore

6. National Atmospheric Research Laboratory (NARL), Gadanki (Indian Space Research Organisation, 2014)

2.2.3 Timeline of Space Science Research in India

Table 2.1: Timeline of developments in Space Science research in India

Decade	**Events**
1940 – 49	• The TIFR was founded in Bombay by HomiBhabha • The PRL was founded in Ahmedabad by VikramSarabhai
1950-59	• 1957-58 was observed as the International Geophysical Year (IGY) • Department of Atomic Energy (DAE) constituted a Board of research in Nuclear Science to provide funding for research projects from university scientists in nuclear science and mathematics and Space Science.
1960-69	• Indian National Committee for Space Science Research (INCOSPAR) was constituted by DAE. • The Thumba Equatorial Rocket Launching Station(TERLS) was commissioned near Trivandrum under UNESCO. • 1964-65 was observed as the International Quiet Sun Year(IQSY) • Vikram Sarabhai took over as the Chairman of the Atomic Energy Commission and Secretary, DAE, after the tragic death of Bhabha • The Experimental Satellite Communication Earth Station

	(ESCEES) became operational in Ahmedabad • The year 1968 was dedicated as a United Nations sponsored range by the Prime Minister (PM) of India • TIFR balloon launching station at Hyderabad and rocket experiments from Thumba, started for studies for X-ray sources. • Indian Space Research Organisation (ISRO) was constituted by the DAE • PRL put in operation a "Dicke-switched type" radiometer operating at 2800 MHz for patrolling solar flares.
1970-79	• PRL scientists carried out two significant experiments using the Skylab and Space lab platforms • A new component of energetic particles was discovered in Interplanetary Space • PRL decided to build a special telescope for astronomical observations • The first Indian Scientific satellite Aryabhatta was launched as the major landmark in the space programe in India • Government constituted an independent Space Commission and DOS requested Prof. S.Dhawan to head both alongwith being the chairman of ISRO • Scientists from PRL and Tata Institute of Fundamental research, Bombay jointly reported severe intro-red bursts alongwith Imperial College, London

1980-89	• ISRO constituted the Advisory Committee for Space Sciences(ADCOS) • The Indian Middle Atmosphere Program(IMPAP) was initiated a well-coordinated cooperative program.
1990-99	• Giant Metrewave Radio Telescope (GMRT) developed by NCRA, TIFR • IXAE developed jointly by TIFR and ISRO Satellite Center (ISAC)
2000-09	• Chandrayaan-1
2010-14	• Mars Orbiter Mission (MOM), India's first interplanetary mission to planet Mars was launched. • ASTROSAT, India's first dedicated astronomy satellite, launched. • Upcoming Chandrayaan-2, India's second mission to the Moon • The Aditya mission to the Sun is being proposed.

This timeline does not represent a comprehensive summary of all research and in the field, but illustrates the development of the Space Science and the diverse landscape using some selected examples(Daniel, 1992; Physical Research Laboratory, n.d.; PRL, n.d.; Department of Space, 2015; DOS, 2010; Datta and Chakravarty, 2008; Kochhar and Narlikar, 1995).

2.2.4 Related Resources of Space Science Literature

Since there is no subject category available for Space Science in any existing classification schemes, below sources are used in this study to develop taxonomy of literature on Space Science. A brief description of following resources is given below:

A. Meteorological Abstracts and Bibliography

The Meteorological Abstracts and Bibliography is a monthly publication whose purpose is to bring to the attention of meteorologists, current literature in their field and in related fields and to provide bibliographic information or various subjects, as interest demands. Part I contains abstracts of current literature in the fields of meteorology, oceanography, etc., arranged according to the Universal Decimal Classification. Part II of each issue comprises a special annotated bibliography of important references on a special subject. No attempt is made to prepare exhaustive bibliographies; instead, the aim is to include a representative cross section of the various aspects of a subject (American Meteorological Society,1954).

B. Vision Document on Atmospheric Sciences

This report was prepared for the Ministry of Earth Sciences to state the status and to envision the next decade of atmospheric sciences in India. The literature given in this report serves immensely important as it gives an insight into the structure of the field of atmospheric sciences, the research areas and also gives recommendations on further research in this field (Ministry of Earth Sciences, 2010).

C. Astronomical Subject Keywords

The keyword list was developed by American Astronomical Society for their Astronomy and Astrophysics Journals (ApJ, AJ, A&A, MNRAS, PASP, PASJ, and RMxAA) have adopted these subject keywords as a means of classifying articles in the journals. Revisions and updatesare made by agreement among the editors (Astronomical Subject Keywords, 2013).

D. Unified Astronomy Thesaurus

The Unified Astronomy Thesaurus (UAT) is an open, interoperable and community-supported thesaurus which unifies the existing divergent and isolated Astronomy and Astrophysics thesauri into a single high-quality, freely-available open thesaurus formalising astronomical concepts and their inter-relationships. The UAT has been build upon the existing IAU Thesaurus with major contributions from the Astronomy portions of the thesauri developed by the Institute of Physics Publishing and the American Institute of Physics. While the AAS has assumed formal ownership of the UAT, the work will be available under a Creative Commons License, ensuring its widest use while protecting the intellectual property of the contributors. The professional associations like (IVOA, IAU), learned societies (AAS, RAS), publishers (IOP, AIP), librarians and other curators working for major astronomy institutes and data archives have a direct stake in the development and maintenance of the UAT(Unified Astronomy Thesaurus, n.d.).

E. Physics Astronomy Classification Scheme (PACS)

The Physics and Astronomy Classification Scheme is a hierarchical subject classification scheme designed to classify and categorise the literature of physics and astronomy. PACS provides an essential tool for classification and efficient retrieval of literature in physics and astronomy; as such, PACS is used by AIP and other international publishers of journals in physics, astronomy, and related fields(American Institute of Physics, 2008).

F. Space Research in India: A Scientific Report

This report summarises the highlights of research activities carried out in India in the areas of Atmosphere and Climate, Astronomy and Astrophysics, Planetary Science and Exploration, Remote sensing of Earth's resources and Environment and Solar-terrestrial physics during the year 2010-2011 for the 38th COSPAR Scientific Assembly (Indian Space Research Organization, 2010).

G. Space Science Research in India: A Scientific Report

This report consists of two parts: Part-I: Earth's Environment and Geomagnetism and Part-II: Astronomy and Astrophysics. It deals with the Space Science research activities pursued at various institutions India. It summarises contribution in each field of Aeronomy and Astronomy and Astrophysics irrespective of the studies based on ground-based or space-borne techniques and also theoretical or analytical technique (Sharma et al., 1978).

H. Physical Research Laboratory (PRL) Annual Report

The Annual Report published by the Physical Research Laboratory every year is an important document giving a comprehensive account of research activities taking place in the Laboratory every year. It gives information on the year round achievements, science highlights, awards won, science outreach activities, etc.by the institution as a whole (PRL, 1988; PRL, 2008; PRL, 2010; PRL, 2011).

I. Department of Space (DOS) Annual Report

The DOS annual reports give insight into the annual scientific activities taking place under the aegis of DOS. These reports give first-hand information on the research taking place (Department of Space, 2008; DOS, 2011; DOS, 2015).

2.3 Scientometric Studies on Space Science Research

The purpose of this review of literature is to offer an overview of the related literature. This literature offers a variety of research productivity studies in all recognised disciplines that presents their findings in terms of four distinct categories or approaches:

- Discipline/Subject based studies
- Institution/Organisation based studies
- Periodicals based studies
- Author/Scientist based studies and
- Database based Studies

This section explores the review of literature on the Scientometric Studies related to the Space Science research. The data is drawn from numerous outlets such as journals and conferences.

2.3.1 Discipline/Subject Based Studies

Seven articles belonging to the discipline/subject based studies have been recorded. A study in this area has been conducted in the work entitled “Development of a method for detection and trend analysis of research fronts built by lexical or co-citation analysis”. This study presents a method combining structural analysis and trend detection by operating on a thick slice of time, starting from co-citation or co-word analysis; it addresses the significance of the trend of clusters through an analysis of publication delays and gives examples of a co-citation analysis in the field of astrophysics for the years 1986-89 (Zitt and Bassecoulard,1994).

Another paper discusses about six case studies of international cooperation in science in the subfields of astrophysics, geophysics, mathematical logic, polymers, soil science, and virology. These cases studies examine international collaboration by detailing co-authorship links among researchers by field, evidenced at the level of the nation. Scientometric and network analysis of linkages are presented and discussed for each of the six cases (Wagner, 2005).

A similar research work has been carried out in the field of Space Neuroscience research to identify the pattern of publication, authorship, citations and secondary journal coverage to give an insight into the dynamics of the area. The results reports the total number of papers published in the field of Space Neuroscience research, the average number of publications produced per year and the most productive author(Raja, Kumar, Gopalakrishnan and Viswanathan, 2013).

This review has located another bibliometric study that presents a quantitative analysis of physics publications in the domain of experimental particle physics, cosmic rays physics and accelerator and collision rings experiments. This paper reveals a more general study on publications in the various fields of physics separating contributions from experiment, theory and techniques (Six and Bustamante, 1996).

The Scientometric study of articles on Cosmology research in India spanning over the years 1999 to 2012 downloaded from Web of Science has been executed in a paper. The study covers a period of 1999-2012 and it examines collaborations with differentcountries, authorship pattern, document types and tests the Bradford law of scattering and Lotka's law (Dutta and Rath, 2013).

Another study was conducted to characterise world astronomy research during a span of 10 years by an analysis of papers in the Science Citation Index identified with a special filter and to study Indian output in order to identify the leading institutions and authors. The results reveal that the words added almost a quarter to the list of papers in specialist journals, also that the potential impact increased with more authors per paper and more addresses. This work opines that Indian astronomy output has increased in potential impact, partly through greater international co-authorship, but also through indigenous papers (Basu and Lewison, 2005).

This review has found another paper which addresses the scientific output in astronomy, immunology and oceanography during a decade. The study compares the two fields, it shows that the number of Brazilian researchers in astronomy has not grown from 1997-2002, but they are the most qualified and more than 90 per cent of them have a PhD degree. Most astronomy publications are in international journals and they are well cited. The most cited astronomy papers are on international topics (Leta, 2005).

2.3.2 Institutions /Organisations Based Studies

Three bibliometric and Scientometric studies have been found on the research outputs of various Institutions, Universities, etc. These studies generally try to evaluate the research output of these institutions over a period of time, on any particular topic or any division.

A research work reports that several studies have been conducted at the Australian National University on the performance indicators. One such study discusses Australia's shares of publications and citations and an analysis of astronomy publications in Australia(Bourke and Butler, 1996).

A research has been conducted wherein the authors have combined bibliometric techniques with a machine learning algorithm, the sequential information bottleneck, to assess the inter-disciplinarily of research produced by the University of Hawaii NASA Astrobiology Institute (UHNAI). The data has been taken from the Thomson Reuters Web of Knowledge subject categories as descriptive labels for astrobiology documents; they have assessed the individual researcher inter-disciplinarily, and determine where collaboration opportunities might occur. The results show that the majority of the UHNAI team is engaged in interdisciplinary research, and suggest that their method could be applied to additional NASA Astrobiology Institute teams in particular, or other interdisciplinary research teams more broadly, to identify and facilitate collaboration opportunities (GowanlockandGazan, 2013).

This study has undertaken a bibliometric investigation of the NASA Astrobiology Institute (NAI) funded research that was published between 2008 and 2012 (by teams of Cooperative Agreement Notice Four and Five). For this purpose, the study has created an inventory of publications co-authored through NAI funding and investigates journal preferences, international and institutional collaboration, and citation behaviors of researchers to reach a better understanding of interdisciplinary and collaborative astrobiology research funded by the NAI. The study draws conclusion on the journal preferences of the authors, astronomy and astrophysics subject categories being most preferred categories, collaboration pattern of the NAI authors and co-author networks etc. (Taşkın and Aydinoglu, 2015).

2.3.3 Periodicals Based Studies

Journals are considered as the core journals of a field. The papers published in these journals are highly cited and have high impact factors. Two periodical based studies have been recorded in the current review.

A study entitled "Integrating multiple sources of information in literature-based maps of science" has been undertaken. This study discusses the statistical model INDSCAL that combines multiple sources (e.g., citations, keywords, subject classification codes). In this work, the utility of INDSCAL is illustrated in an application to core journals in the field of astronomy and astrophysics. The study showcases some marked differences occur in the journal structure when based on more data sources than citations alone (Tijssen, van Raan, Heiser and Wachmann, 1990)

One Scientometric study has been carried out on the Pramana- Journal of Physics, wherein the authors have tried to identify the publishing trend; impact factor; authorship pattern; types of articles; institutional collaboration of authors; affiliated institutions of authors; countries of contributing authors; keyword analysis; and referencing pattern. The results discuss about the top leading fields i.e. Cosmology; super-symmetry; chaos; quantum chromo-dynamics; phase transition; and quark-gluon plasma (Kumar, Prakasan, KalyaneandKumar, 2008).

2.3.4 Author/Scientist Based Studies

There are many authors whose contributions stand aloof in the crowd tall and radiating. These scientists are renowned for their work. Bibliometricians have many times tried to assess their productivity using Bibliometric tools and techniques. Five studies related to such scientists have been noticed.

One such study based on authors is on the relationship between widely used 'Scientometric' measures and the 'reputation' of research groups within the scientific community. To this end, this work presents the results of a detailed comparison of 2 research groups of theoretical astrophysics in post World War 2 Japan. Although one of the 2 groups gained a much higher reputation within the research community, little difference could be found between the 2 groups' scores for the macroscopic indices such as the number of publications or the average citation index. This result suggests that widely used quantitative measures of productivity do not give a meaningful measure for the actual contribution of a research group to science (Makino, 1998).

A study has been conducted using 17 author-level bibliometric indicators to assess research in the areas of Astronomy, Environmental Science, Philosophy and Public

Health. Indicator scores and scholar rankings calculated in Web of Science (WoS) and Google Scholar (GS) were analysed. The results show that the rankings based on author-level indicators are influenced by (1) the coverage of papers and citations in the database, (2) how the indicators are calculated and, (3) the assessed discipline and seniority. The authors suggest that the indicator rankings display the visibility of the scholar in the database not their impact in the academic community compared to their peers. They advise extreme caution when choosing indicators and benchmarks in scholar rankings (Wildgaard, 2015).

An interesting research has been carried out on the activity of astronomers in the field of Herbig-Haro (HH) objects. The authors have used the NASA ADS and SCI databases to fetch out the results on the field using keywords. They have analysedan 11-year period, restricting the results to authors with at least 10 papers within the period. The work hasanalysed the number of papers and citations, as well as the h-index of the selected set of authors. Within this sample, the authors have identified the authors belonging to Mexican institutions. The results report the performance measures of the Mexican researchers and also the preferred journals in the field of astronomy(Sierra-Flores, Guzman, Raga and Perez, 2009).

Another study tests 16 bibliometric indicators with respect to their validity at the level of the individual researcher by estimating their power to predict later successful researchers. The work compares the indicators of a sample of astrophysics researchers who later co-authored highly cited papers before their first landmark paper with the distributions of these indicators over a random control group of young authors in astronomy and astrophysics. The results reveal that field and citation-window normalisation substantially improves the predicting power of citation indicators(Havemannand Larsen, 2015).

There is an article which presents a survey of publication and citation statistics for 835 UK professional astronomers. The work provides histogram for bibliometric indicators and also showcases the top bibliometric performers in the sample, usage of bibliometrics in a real world assessment excise etc.(Blustin, 2007).

2.3.5 Databases Based Studies

Two papers have been recorded in this field. A research of a somewhat different kind has been conducted; wherein the "Reads" Counts of the NASA Astrophysics Data System have been taken into consideration to find out the obsolescence function as measured by actual reads and show that it can be well fit by the sum of four exponentials with very different time constants. The authors have compared the obsolescence function as measured by readership with the obsolescence function as measured by citations. The findings prove that the citation function is proportional to the sum of two of the components of the readership function. This proves that the normative theory of citation is true in the mean. The study further examines in detail the similarities and differences among the citation rate, the readership rate, and the total citations for individual articles, and discuss some of the causes. The study shows a simple model to account for an individual's reads and cites and use it to show that the position of a person in the read-cite diagram is a function of age, innate productivity, and work history (Kurtz et al., 2000).

A study has been reported from the Scientometrics perspective on the Sloan Digital Sky Survey (SDSS). By analysing the bibliographic records of papers relevant to the Sloan Digital Sky Survey (SDSS), the authors have found that the SDSS helped scientists from many countries further develop their own research; investigators initially formed large research groups to tackle key problems, while later papers involved fewer authors; and the number of research topics increased but the diversity of topics remains stable. Furthermore, the entropy analysis method has proven valuable in terms of analysing patterns of research topics at a macroscopic level (Zhang, Vogeleyand Chen, 2011).

2.4 Conclusion

The ‘study of subjects’ is very important in identifying the boundary of any subject domain so as to visualise the structure of the subject, its branches, subdivisions or fields and sub-fields. Commencing from the Tata Institute of Fundamental Research (TIFR) founded in Bombay by HomiBhabha (1945) and the Physical Research Laboratory (PRL), founded in Ahmedabad by Dr. Vikram Sarabhai (1947) to the ASTROSAT, India’s first dedicated astronomy satellite, launched in 2015, the Space Science have come a long way of development, growth and changes, it is not an exaggeration to say that in India, this field has seen a meteoric growth. Though even a mere glance makes us realise about the grandeur of the growth of this subject, it still projects a question that what is the numerical quantity of this growth and what is the qualitative measure of this growth, these queries can be addressed to, with the application of scientometric techniques to the published Space Science literature. To embark upon these questions it is important to first survey that - has this area been explored and to what extent. To answer this, a literature review needs to be undertaken.

This review of literature for the present study displays a panorama of articles on diverse fields, topics and areas in the field of scientometric, bibliometric and citation analysis related to Space Science and allied areas. The length and breadth of the works range from micro topics in areas of Astronomy and Astrophysics. The review showcases various aspects of bibliometric analysis and citation analysis at the global level, it reveals that only one work in the field of Cosmology has been located for India that too for the period of 1990-2012(Dutta&Rath, 2013). None of the research works cover the field of Space Science as a whole anywhere in the world let alone India in the scope. Space Science is one of the most proliferating fields in scientific research today and loads of funds are being directed towards this area of research. This field has grown manifolds since independence and therefore like other fields of research an analytical assessment is essentially required to determine the structure of the Space Science, its evolution, growth pattern and current status, in other words this review strongly projects a justified need for a comprehensive Scientometric study of the subject.

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Chapter 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter discusses the research methodology used in the study of 'Space Science Research Publications in India science 1960s: A Scientometric Study'. The discussion includes Scientometrics technique as a research method, Taxonomy of Space Science research, Keyword Bank development, Data Collection procedure and Data Analysis. The merit of this evaluation is to undertake a scientometric and bibliometric investigation of the Space Science research in India for the last 54 years.The main question to be answered through the analysis is concerned with the performance of groups in two dimensions: 1) citation performance i.e. quality of research; and 2) research publication i.e. quantity of research. In order to perform a Scientometric analysis on the Space Science literature, various methodological search strategies were to be developed that were accurate, logistic and repeatable. Quantification of Space Science knowledge was carried out using the Web of Science (WoS) database and the quality was measured using the h-index, Average Citation Per Article (AvgCPA) from WoS database and SJR, IPP and SNIP from Scopus database. The flowchart (Figure 3.1) illustrated below gives a brief summary towards the methodological approaches that were undertaken to systematically retrieve data.

3.2 Scientometrics – As Research Method

In order to understand the evolution and growth of the Space Science research, Scientometric techniques are used. These techniques provide a set of measurement tools toobjectively analyse the growth of a discipline. They include citation and publication counts. Scientometrics has had a long and successful history in addressing the research questions concerning the intellectual profile, structure, and dynamics of scholarly specialties. Compared toother methodologies (e.g., historical research and delphi studies) used in science policy research that typically center on highly subjective data, Scientometrics provides an established framework to orchestrate the use of a wide range of robust techniques to collect and analyse the quantitative, as well as the qualitative data.

Traditionally, Scientometric research has mainly focused on bibliometric data such as publication and citation data. Scientometric studies employing bibliometric analyses such as co-citation analysis techniques have been used on many occasions to study scholarly specialty profiles, structures and dynamics.

Bibliometrics is a generic term that describes a series of techniques that seek to quantify the process of written communication. There are two types of bibliometric studies: publication analysis and citation analysis. Publication analysis focuses on the various aspects of creation and dissemination of the literature in a given field, whereas citation analysis focuses on the literature used by researchers in a given field. There are three basic techniques that are used for citation analysis: direct citation counts, bibliographical coupling and co-citation analysis. In this study only direct citation counts will be utilised. Direct citation counts determine how many citations a certain document, author, journal, etc. has received over a period of time (Fayland, 2008; Olijnyk, 2014; Reid, 1983).

Keeping all the above points in view, the present study has aimed to deploy Scientometric analysis to the space science data pertaining to the publication and citations collectedfrom the WoS database.

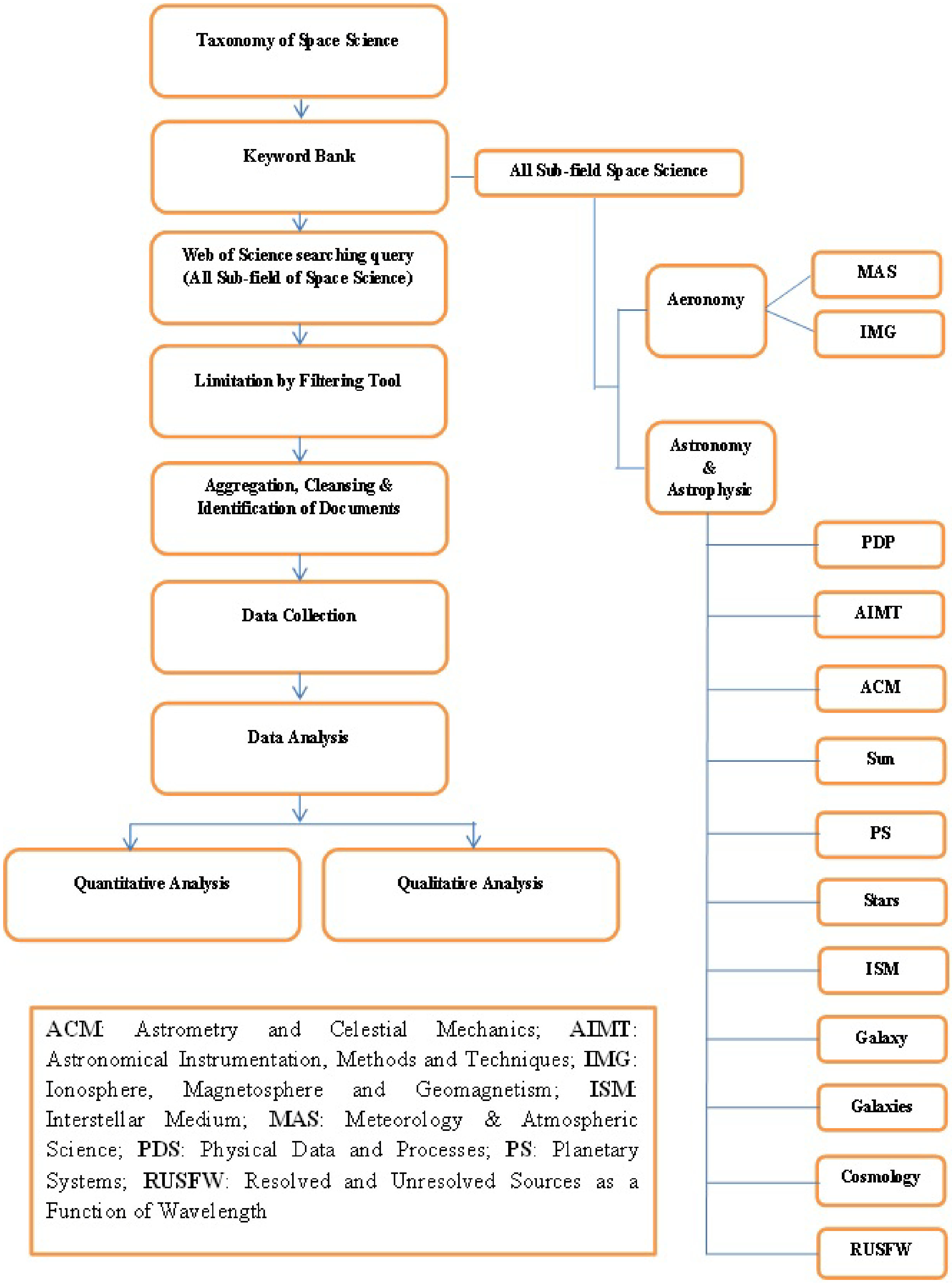

Figure3.1: Flowchart for the methodological approaches

3.3 Taxonomy of Space Science Research

The literature review of Space Science (Chapter 2, Section 2.3) concluded that there are no subject categoriesor classification schemeon Space Science available. Difference of opinions is found among the experts while discussing the boundaries of the field. To map the growth in any given field it is necessary to gain an understanding of the building blocks of that field. In case of Space Sciences, since no such information was found therefore it became important to first develop taxonomy of literature of Space Sciences in order to know the highways and byways of this subject. With the help of 'study of subjects' (as discussed in Chapter 3, Section 2.2) and opinions of subject experts, taxonomy has been developed, which is being illustratedbelow. This will eventually help in the identification of main branches and subdivision within each branch identified as 'field' and sub-field'.

3.1 Space Science

3.1.1 Aeronomy

- 3.1.1.1 Ionosphere, Magnetosphere and Geomagnetism (IMG)
- 3.1.1.2 Meteorology and Atmospheric Science (MAS)

3.1.2 Astronomy and Astrophysics

- 3.1.2.1 Astrometry and Celestial Mechanics (ACM)
- 3.1.2.2 Astronomical Instrumentation, Methods and Techniques (AIMT)
- 3.1.2.3 Cosmology
- 3.1.2.4 Galaxies
- 3.1.2.5 Interstellar Medium (ISM)

3.1.2.6 Physical Data and Processes (PDP)

3.1.2.7 Planetary Systems (PS)

3.1.2.8 Resolved and Unresolved Sources as a Function of Wavelength (RUSFW)

3.1.2.9 Stars

3.1.2.10 The Galaxy

3.1.2.11 The Sun

3.4 Keyword Bank

The Space Science is divided into broad fields and sub-fields (described in Section 3.3 above) and each field and sub-field is organised in a systematic order. Topics or keywords are acquired from each source (described in Chapter 2, Section 2.2.4) through literature review to construct a list of keywords (Appendix –II) called as Keyword Bank. Details on how many entries came from each field of Space Science can be found in Appendix –II. This list contains many duplicates that subsequently had to be removed in order to compile a listing of unique keywords. Hence a Keyword Bank is developed, which acts as a sample of keywords used to access a database of literature. In this way, the afore mentioned variety of search terms and specific source titles in Space Science are used in order to improve recall. A block diagram for the process of developing the keyword bank is illustrated in Figure 3.2.

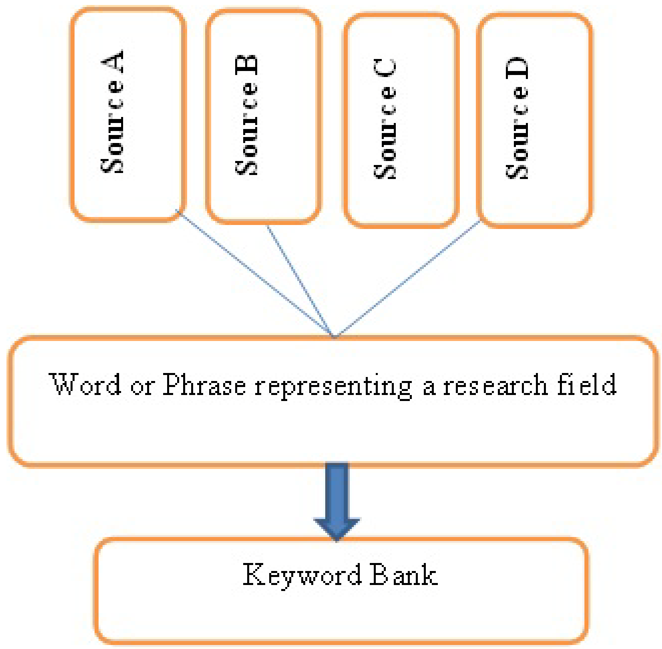

Figure 3.2: Basic framework for the development of Keyword Bank

3.5 Data Source: Web of Science

Data arecollected on each of the 13 sub-fields or specialties for the purpose of determining their institutional and productivity values. Productivity is measured on the basis of publication and citation indicators; the Web of Science database is used to locate this information.

The choice of search engines for keyword extraction is based on the two important criteria: the first is that they must index a large number of articles related to the field of interest and spanning a range of publisher. Secondly, their search results must be formatted in such a way as to allow related keywords to be readable in an automated manner. The first criterion would exclude small and publisher-specific databases such as IngentaConnect and SpringerLink. The second criterion excludes websites such as

Google Scholar, which presents its search results as links to the external websites, making the automated extraction of keywords difficult, if not impossible. Given these criteria, Web of Science has been chosen.

Web of Science (previously known as (ISI) Web of Knowledge) is an online subscription-based scientific citation indexing service maintained by Thomson Reuters that provides a comprehensive citation search. It gives access to the multiple databases that reference cross-disciplinary research, which allow for in-depth exploration of specialised sub-fields within an academic or scientific discipline (Web of Science,n.d.).

3.6 Data Retrieval from Web of Science

To gather the information on the state of a field of research, the first step is the identification of a set of related sub-fields within the domain of interest. Analysis is then performed to infer how quickly each of these sub-fields is growing in prevalence (2009-10). There are several approaches to identify the relevant documents howeverhere a keyword-based approach is used to identify the document sets relevant to both fields and sub-fields of Space Science research. The keywords, which are nominated by subject matter experts, are then subsequently used to construct the search queries.

To gather the relevant documents from online WoS database, the set of search term or keywords (from Keyword Bank) are first entered into designated search box named as ‘Topic’ search in double quotes (e.g. ‘Sun’) to ensure that the search term is treated as a single phrase rather than a set of disjoint words in the database search interface(Figure3.3).The same process is followed for the rest of the 25 search terms or keywords by combining ‘OR’ as Boolean operator. In the “TIME SPAN” tab “Year” field search is limited to 1960 to 2014. This restriction of the dataset ensures the currency of the literature.

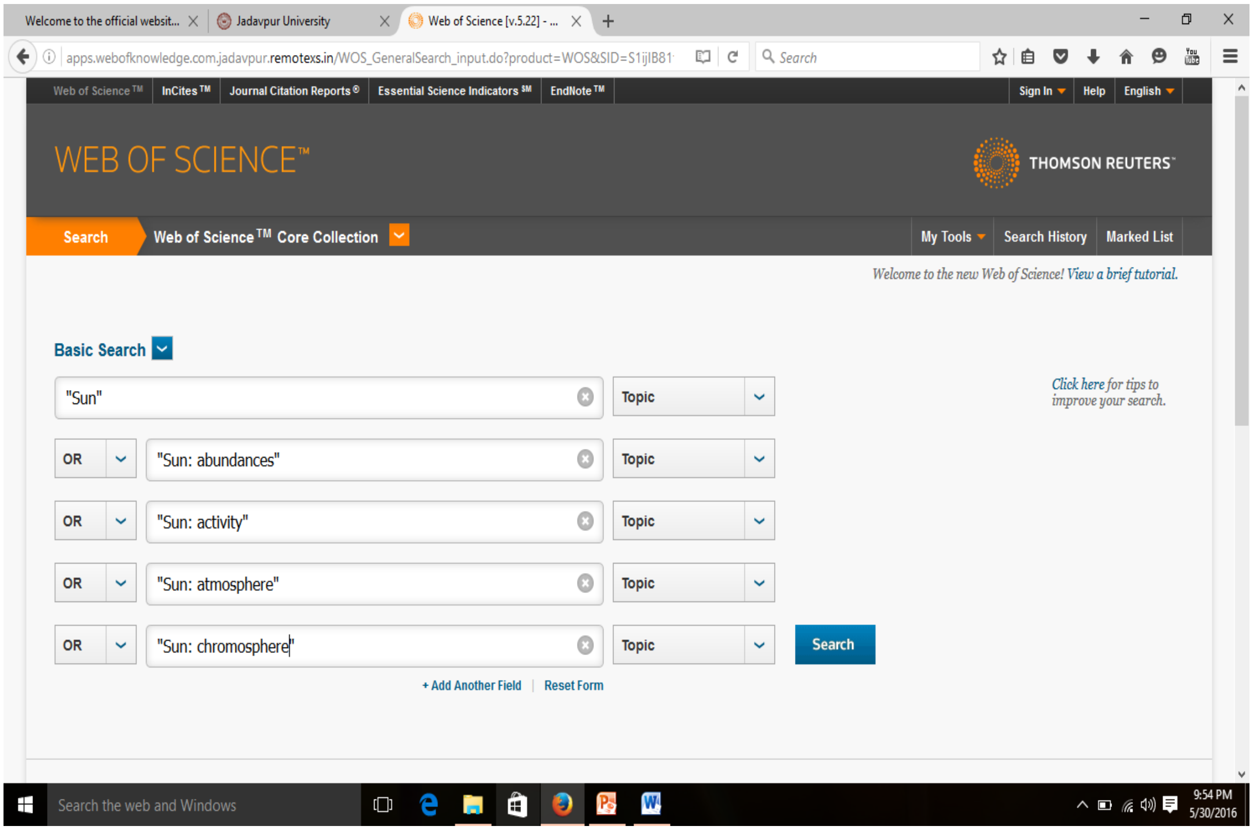

Figure 3.3: Basic search in WoS Search Window

After the search is executed, it provides one retrieved dataset for each chosen search term, which represents the sample of the field or sub-field of the Space Science literature (Figure 3.4). The various sets arethen aggregated into one comprehensive dataset for removing duplicates. The resulting datasets containing bibliographic records are subsequently refined by search parameters to calculate the metrics employed in this study. All searches are refined by Subject category of Web of Science (WoS) except for the sub-field IMG, which overlaps with the other categories of WoS like Astronomy and Astrophysics, Meteorologyand Atmospheric and Geophysics Sciences followed by

Document Types: (Article) (contrasted with, for example, “reviews”), and Languages: (English). The filtered publications were again filtered by Countries/Territories: (INDIA) for core collection of each sub-field produce by quering the site.

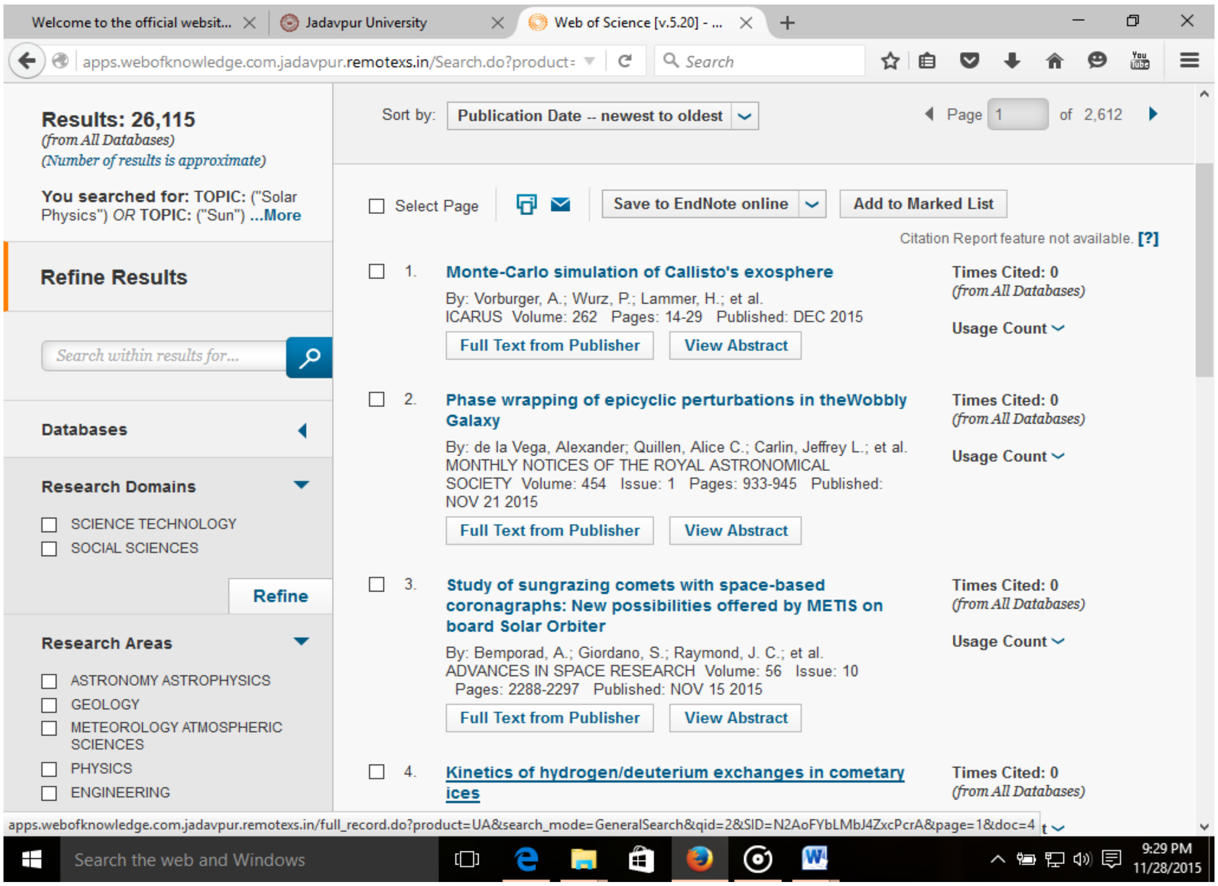

Figure 3.4: Data Retrieval Window (WoS) against the keyword search

3.7 Data Collection

3.7.1 Bibliometric indicator and Citation indicator

Web of Science article records include all of the relevant bibliographic information, e.g.author name,document title,keywords, source title, year, affiliation and country needed for this study in addition to corresponding citation data, e.g., Sum of the

Times Cited, Sum of Times Cited without Self-citations, Citing Publications, Citing Publications without Self-citations, Average Citations per Item, h-index and Top cited article. Moreover, Web of Science offers export functionality through the interface ‘Analyze Report’ and ‘Create Citation Report’ designed to assist the researchers in extracting document records for further analysis using third-party software. Data collection procedures in this study are illustrated in Table 3.1.

Table 3.1: Bibliometric Data Collection

Bibliometric Data Collection		
Sl.	**Procedure**	**Task**
1	Document Search	• Query posted to the web of science database using the search terms or keyword • Query posted to the Web of Science database for all documents indexed by Web of Science from sources titles on Space Science • Set search filter to collect only articles in document types • Specify record fields for data exporting
2	Aggregation, Cleansing Standardisationand Identification of Documents	• Combine the retrieved datasets • Remove duplicates and perform cleaning of data • Data Standardisation - To obtain accurate results, the data on authors, keywords, institutions etc. were pre-processed by merging the singular and plural forms of the same

		terminology, and those with the same meaning while using different expressions were classified as one. For exampleauthors (e.g. Rastogi, R.G. or Rastogi, RG or Rastogi Ram Gopal);keywords (‘‘coronal mass ejections’’ ,‘‘Coronal mass ejection’’ “Coronal mass ejections (CMEs), “cme” and “CMEs””,) and Institutions (ISRO or Ind.Spac.Res.Org. or Indian Space Research Organisation). • Ranking documents by frequency • Identifying top highly cited documents
3	Frequency Ranking of Bibliometric indicator	• Author Name • Source Title • Year • Affiliation • Affiliation Country
4	Frequency Ranking of Citation indicator	• Sum of the Times Cited • Sum of Times Cited without self-citations • Citing Publications • Citing Publications without self-citations • Average Citations per Item • h-index • Top cited article

All the bibliometric indicators and citation indicators are downloaded from ‘Analyze Report’ and ‘Create Citation Report’ of Web of Science comprising the information extracting from core collection of each sub-field produced by querying the site.

3.7.2 Keywords

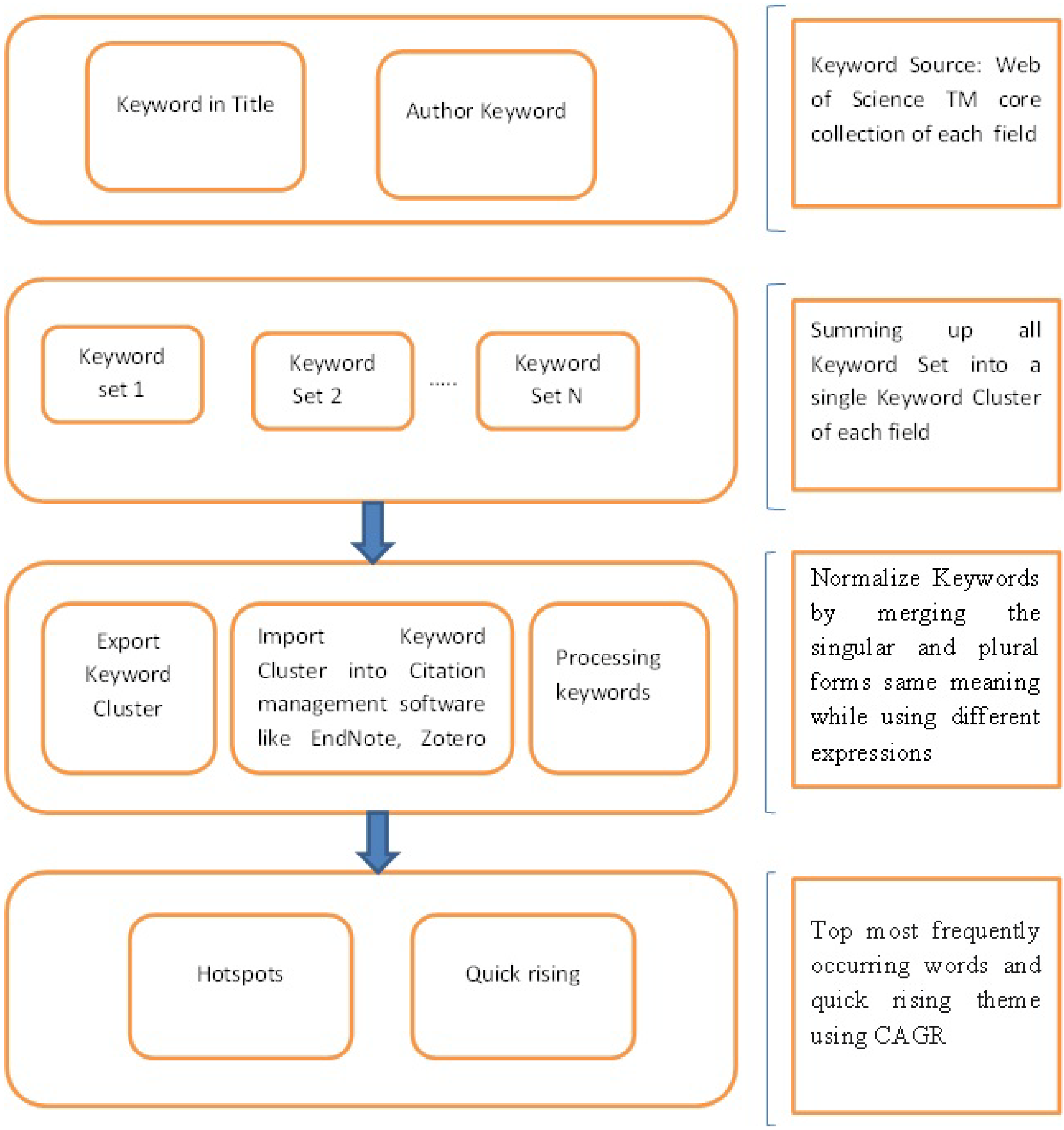

Figure 3.5: Flowchart of keyword analysis

The bibliometric data collected from WoS is revisited in this phase to undergo word extraction and frequency count. Words are extracted and compiled from the document title, keyword, and abstract fields in the records. Keywordsare then normalised by exporting them into EndNote and Zotero for further processing, later these are combined and sorted alphabetically. Editing for synonyms and homonyms is then carried out, keywords are ranked based on frequency in descending order and top 20 most frequently occurring words are selected. The flowchart shown in Figure 3.5 gives a brief summary of the keyword collection and data analysis procedure.

3.8 Data Analysis

The purpose of analysis in this study is to reduce data to a form where the relationships of research problems can be tested and studied. In this study, the data collected from the source documents and the citations are analysed in a variety of ways in order to adequately answer the stated research questions. The data analysis process started with the creation of frequency tables to summarise the data. Frequency tables are useful for detecting top authors, top cited articles, top contributing institutions, etc.Other tables comparing the data elements of publications within each of the sub-field were presented as needed. The analysis in this study has utilised the frequency distribution, mean, mode and percentage to analyse the data, graphs and tables.

Microsoft Excel is usedfor database creation for each sub-field of Space Science while sorting top journal, author, etc. The data was imported into the Statistical Package called OriginPro for publication pattern, citation pattern, etc.; EndNote used for publication characteristics; Zotero used for keyword analysis – quick rising theme, frequency ranking, etc.

3.8.1 Growth Models/ Trend Lines

Growth refers to an increase, expansion, or change over time. Time series analysis is comprised of various methods for analysing time series data to extract meaningful statistics and other characteristics of the data set. It displays a trend and is fit to suitable curve known as growth curve. Growth curves are used for a wide array of mathematical models useful for visualising and/or describing pattern of growth over time (Hook, Junchen,Oba and Snowden, 2011). Growth curve models can be utilised as forecasting tools. The six different trend line/growth curve equation are discussed below:

A. Exponential

General Exponential Equation of the form:

$Y=f(x)= a•b^{x}$, {**Equation 3.1:Exponential equation**}

where x is an exponent (not in the base as was the case for power functions) and a and b are constants. (Note that only b is raised to the power x; not a.) If the base b is greater than 1 then the result is an exponential growth(Figure: 3.6).If the base b is smaller than 1, the result is exponential decay.

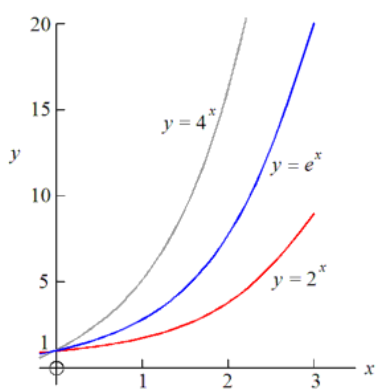

Figure3.6: Graphical illustration of exponential function

An exponential trendline is a curved line that is most useful when data values rise or fall at increasingly higher rates. It is impossible to create an exponential trendline if data contains zero or negative values(‘Graphs of eight basic types of functions’,n.d.; Microsoft, 2016).

B. Linear

General linear equation of the form:

$$y = m\,x + b,$$ {**Equation 3.2:Linear 2quation**}

where m and b are constants. A typical use for linear functions is converting from one quantity or set of units to another. Graphs of these functions are straight lines (Figure 3.7). m is the slope and b is the y intercept. If m is positive, the line rises to the right and if m is negative, the line falls to the right.

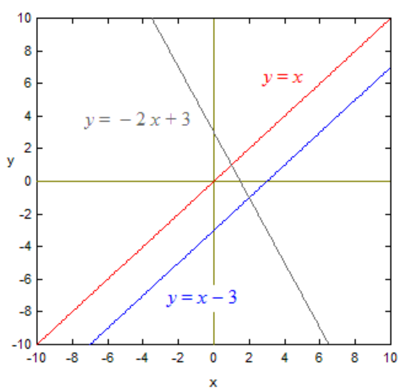

Figure 3.7: Graphical illustration of linear function

A linear trendline is a best-fit straight line that is used with simple linear data sets. The data is linear if the pattern in its data points resembles a line. A linear trendline usually shows that a given parameter or quantity is increasing or decreasing at a steady rate. Linear growth occurs when a quantity grows by the same absolute amount in each unit of time (‘Graphs of eight basic types of functions’,n.d.; Microsoft, 2016).

C. Logarithmic

There are many equivalent ways to define logarithmic functions. This can be defined to the form: $y = a \ln(x) + b$, {**Equation 3.3: Logarithmic equation**}

where x is in the natural logarithm and a and b are constants. They are only defined for positive x (Figure 3.8). For small x they are negative and for large x they are positive but stay small. Logarithmic functions accurately describe the response of the human ear to sounds of varying loudness and the response of the human eye to light of varying brightness.

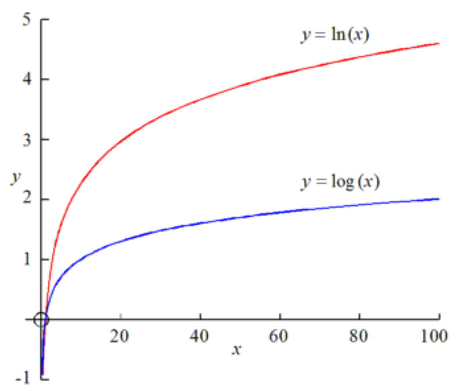

Figure3.8: Graphical illustration of logarithmic function

A logarithmic trendline is a best-fit curved line that is most useful when the rate of change in the data increases or decreases faster and then levels out. A logarithmic trendline can use negative and/or positive value ('Graphs of eight basic types of functions',n.d.; Microsoft, 2016).

D. Polynomial

General polynomial equation:

$y = a_n \cdot x^n + a_{n-1} \cdot x^{n-1} + \ldots + a_2 \cdot x^2 + a_1 \cdot x + a_0$, (**Equation 3.4: Polynomial Equation**}

where a_n, a_{n-1}, $\ldots$, a_2, a_1, a_0 are constants. Only whole number powers of *x* are allowed. The highest power of *x* that occurs is called the degree of the polynomial. The graph shown in the Figure 3.9 examples of degree 4 and degree 5 polynomials. The degree gives the maximum number of "*ups and downs*" that the polynomial can have and also the maximum number of crossings of the *x* axis that it can have.

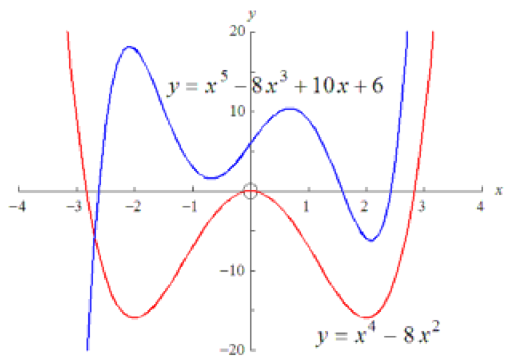

Figure 3.9: Graphical illustration of polynomial function

A polynomial trendline is a curved line that is used when data fluctuates. It is useful, for example, for analysing gains and losses over a large data set. The order of the polynomial can be determined by the number of fluctuations in the data or by how many bends (hills and valleys) appear in the curve. An Order 2 polynomial trendline generally has only one hill or valley. Order 3 generally has one or two hills or valleys. Order 4 generally has up to three ('Graphs of eight basic types of functions',n.d.; Microsoft, 2016).

E. Power

General Power Equationof the form:

$y = a\,x^b$, {**Equation 3.5: Power Equation**} where *a* and *b* are constants. They get their name from the fact that the variable *x* is raised to some power. Many physical laws (e.g. the gravitational force as a function of distance between two objects, or the bending of a beam as a function of the load on it) are in the form of power functions. It is assumed that $a = 1$ and then several cases of b :

The power b is a positive integer (Figure 3.10). When x = 0, these functions are all zero. When x is large and positive, the values of y are large and positive. When x is large and negative, the values of y for even values of b are large and positive, however it is negative for odd values of b.

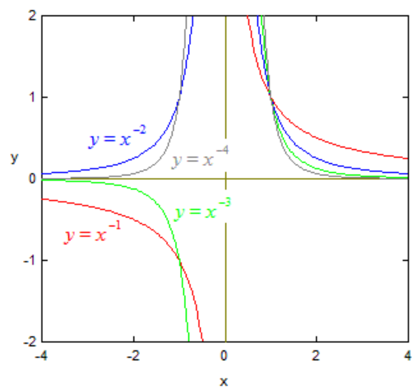

Figure 3.10: Graphical illustration of power function

A power trendline is a curved line that is best used with data sets that compare measurements that increase at a specific rate - for example, the acceleration of a race car at one-second intervals. A power trendline can not be created if the data contains zero or negative values (‘Graphs of eight basic types of functions’,n.d.; Microsoft, 2016).

3.8.2 Growth Rate

A. Simple Growth Rate

Growth rates, in general, express changes in values of a variable between two (or more) periods of time. Growth rates are widely published by statistical organisations, and it is popular among media outlets to report on growth or decline of various social or economic phenomena. Statistical theory introduces different methods that can be applied to compute growth rates between two or more periods of time. The appropriateness of each method for a given time series depends on the pattern of the differences in values between two successive periods (increments), and whether these increments are constant or changing. The most commonly used patterns are (Economic and Social Commission for Asia and the Pacific [ESCAP], 2015).

The formula for Growth Rate (GR) is as follow:

$$GR = \frac{(V(tn)-V(t0))}{V(t0)}$$

Formula 3.1: Growth Rate

t_0 : the initial (first) year
t_n : the last year
$V(t_0)$: Initial observed value
$V(t_n)$: last observed value

B. Annual Average Growth Rate (AAGR)

The AAGRis the arithmetic mean of a series of growth rates. AAGR is useful for determining trends. It can be applied to almost any financial measure, including revenue, profit, expenses, cash flow, etc.(InvestingAnswers, 2016). The AAGR is used nowadays to measure the publications growth in any given field.

The AAGR isexpressed as a percentage and is based ona model of continuous exponential growthbetween two points in time. It does not takeinto account the intermediate values of aseries, nor does it correspond to the annualrate of change measured at a one-yearinterval (Institute of Physics, 2014).

The formula for AAGR is: r $= [(\frac{V(tn)}{V(t0)})1/t - 1] \times 100$

Formula 3.2: Annual Average Growth Rate

r : Growth rate (in percent)
t_0 : the initial (first) year
t_n : the last year
$V(t_0)$: Initial observed value
$V(t_n)$: last observed value
t : $t_n - t_0$ = number of years

C. Compound Annual Growth Rate (CAGR)

CAGRis frequently used in business presentations andreports to demonstrate how a Particular part of the business has grown over time. CAGR takes growth rates from multiple periods and translates theminto a consistent growth ratewhich representsthe same growth (chartrecipes.com, n.d.). This growth is measured for the publication as well.

The formula to calculate CAGR is:

$$\mathrm{CAGR}(t_0, t_n) = (V(t_n)/V(t_0))^{\frac{1}{t_n - t_0}} - 1$$

Formula 3.3: Compound Annual Growth Rate

Where,

t_0 : the Initial (first) year
t_n : the last year
$V(t_0)$: Initial observed value
V(tn) : last observed value
$V(t_n)$:number of years

3.9 Methodological Limitations

- At the time of data collection using keywords from the Keyword Bank (Appendix –II), it was found that there were few articles in 60’s but the affiliation of those authors is not Indian. Therefore, the articles collected for this study effectively started appearing from 1971 onwards.
- The published literature taken into account here may not be able to represent all papers published by the Indian authors who have remained involvedin research activities in the Space Science fields because the first of all not everyone publishes in the journals and secondly not every journal that publishes gets indexed in the WoS database, therefore the paper falling out of this purview may not appear in this study.
- The keyword bank developed for this study is comprehensive in nature, yet it may so happen that due to a very huge dataset and human handling of such a big data some articles may have been missed upon.
- In this study the Bibliometrics is used for quantitative analysis and citation counts data is used to determine the qualitative aspects of the Space Science research. Nowhere the study has undertaken the content analysis to comment on the quality of the research in Space Sciences.

3.10 Bibliographical References

All the sources of information used for the present study have been duly acknowledged by the combination of both in-text citations and reference list. All the sources consulted for the present study are listed in an alphabetical order in the form of a bibliography. American Psychological Association (APA) referencing style has been adopted to compile the bibliography. The references in the text have been cited in parenthesis giving surname of the author (s) or editor (s) followed by year referring to the corresponding entry in the reference list (Publication Manual of the American Psychological Association (6th ed.)). Different types of documents were consulted for the present study such as books, books written by two authors, books by three authors, book chapters, journal articles, reports, dissertations, theses, conference proceedings, corporate authorship and e-resources. All these documents were documented in the bibliography in different formats as per APA style. Examples of all such documents cited therein are illustrated in the following text (UCOL Student Experience Team, 2015).

3.10.1 Books

In a reference list	In-text citation
Matthews, J. (1999). *The art of childhood and adolescence: The construction of meaning.* London, England: Falmer Press.	(Matthews, 1999)

3.10.2 Books written by Two Authors

In a reference list	In-text citation
Colclough, B., & Colclough, J. (1999). *A challenge to change.* London, England: Thorsons.	Colclough and Colclough, 1999)

3.10.3 Books written by Three to Seven Authors

In a reference list	In-text citation
Rosenthal, R., Rosnow, R. L., & Rubin, D. B. (2000). *Contrasts and effect sizes in behavioral research: A correlational approach.* Cambridge, England: Cambridge University Press.	(Rosenthal, Rosnow and Rubin, 2000)

3.10.4 Book Chapters

In a reference list	In-text citation
Kestly, T. (2010). Group sandplay in elementary schools. In A. A. Drewes, & C. E. Shaefer (Eds.), School-based play therapy (2nd ed., pp. 257-282). Hoboken, NJ: John Wileys & Sons.	(Kestly, 2010)

3.10.5 Journal Articles (Print)

In a reference list	In-text citation
Hanna, K. (2007). Adsorption of aromatic carboxylate compounds on the surface of synthesised iron oxide-coated sands. *Applied Geochemistry*, *22*, 2045-2053.	(Hanna, 2007)

3.10.6 Journal Articles (Online)

In a reference list	In-text citation
Sillick, T. J., & Schutte, N. S. (2006). Emotional intelligence and self-esteem mediate between perceived early parental love and adult happiness. *E-Journal of Applied Psychology, 2*(2), 38–48. Retrieved from http://ojs.lib.swin.edu.au/index.php/ejap/article/view/71/100	(Sillick and Schutte, 2006)

3.10.7 Conference Proceedings (Print)

In a reference list	In-text citation
Wilkinson, R. (1999). Sociology as a marketing feast. In M. Collis, L. Munro, & S. Russell (Eds.), *Sociology for the New Millennium.* Paper presented at The Australian Sociological Association, Monash University, Melbourne, 7-10 December (pp. 281-289). Churchill, VIC: Celts.	(Wilkinson, 1999)

3.10.8 Conference Proceedings (Online)

In a reference list	In-text citation
Balakrishnan, R. (2006, March 25-26). *Why aren't we using 3d user interfaces, and will we ever?* Paper presented at the IEEE Symposium on 3D User Interfaces. doi:10.1109/VR.2006.148	(Balakrishnan, 2006)

3.10.9 Dissertations/Theses

In a reference list	In-text citation
Cooley, T. (2009). *Design, development, and implementation of a Wireless Local Area Network (WLAN): The Hartford Job Corps Academy case study* (Doctoral dissertation). Available from ProQuest Dissertations and Theses database. (UMI No. 3344745)	(Cooley, 2009)

3.10.10 Reports

In a reference list	In-text citation
Radio New Zealand. (2008). Annual report 2007-2008. Retrieved fromhttp://static.radionz.net.nz/assets/pdf_file/0010 /1796761/Radio_NZ _Annual_Report_2008.pdf	(Radio New Zealand. 2008)

3.10.11 Corporate Authorship

In a reference list	In-text citation
International Labour Organisation. (2007). Equality at work: Tackling the challenges (International Labour Conference report). Geneva, Switzerland: Author.	(International Labour Organisation [ILO], 2007)

3.10.12 e-Resources (no author, no date)

In a reference list	In-text citation
Pet therapy. (n.d.). Retrieved from http://www.holisticonline.com/stress/stress_pet-therapy.htm	(Pet therapy, n.d.)

(UCOL Student Experience Team,2015;The University of Waikato, 2016; Murdoch University, 2016)

3.11 Summary

This chapter is a descriptive account of the research methodology that is to be undertaken to carry out the research. It commences with a discussion on Scientometrics and its role as a research method. The chapter progresses further with the understanding of the Taxonomy of the Space Science research which will help in defining the boundaries of the subject and collection of the data from the Web of Science (WoS) database. This chapter gives a narration on the topics – Keyword Bank development,keyword analysis, bibliometric data retrieval from WoS both in the form of description and self-developed flowcharts/tables. In this chapter various growth models likePolynomial, Exponential, Linear and Power lawetc. are also described using both plots and equations, and how the growth rates like the AAGR, AvgCPA, etc. are calculated and help in analysis of the growth of the subject. It further mentions the various methodological limitations associated with this study. In short it can be said that this chapter provides a systematic view of the methodologies that are to be to be viewed in the forthcoming chapters.

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The University of Waikato. (2016). *APA Referencing*. Retrieved from http://www.waikato.ac.nz/__data/assets/pdf_file/0014/236120/apa-quick-guide.pdf

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Chapter 4

DATA ANALYSIS AND INTERPRETATION

4.1 Introduction

This chapter presents a description on the scientometric analysis that has been undertaken in this study for the scientometric evaluation of the Space Science research in India over the period of fifty four years i.e. 1960-2014. Data has been collected from the Web of Science database. The analysis presents the evaluation of publication activities. Special attention is given to the research impact through h-index and average citation, as well as to the trends in yearly citations received. The chapter also highlights the sources of publications, international collaboration with other countries, top authors and top institutions.The characteristics of the source documents are presented first, followed by a discussion on the characteristics of the cited documents.

4.2 Aeronomy

The term “Aeronomy” was coined by the great geophysicist Sidney Chapman. It can be defined as the science dealing with atmospheric regions where photodissociation and ionization processes play a role. Aeronomy is, by definition, a multidisciplinary science which can be used to study the terrestrial atmosphere, as well as any planetary atmosphere and even the interplanetary space (Kockarts, 2002). In the Annual Report of the Physical Research Laboratory, Ahmedabad, India Aeronomy has been used as a broad term including studies of lower, middle and upper atmosphere and ionosphere (PRL, 1988).

4.2.1 Ionosphere, Magnetosphere and Geomagnetism (IMG)

The Earth's ionosphere is that part of the high altitude atmosphere, starting at about 90 km, which is strongly ionised. Electrons are stripped off the gas molecules, resulting in ions, by the ultra-violet radiation (1 -10 x 10-8 m) of the Sun as well as incident X-rays. The ionosphere is divided into different layers according to the electron density. The ionosphere can carry electrical currents as well as reflect, deflect and scatter radio waves (Lancaster, 2015).

The magnetosphere is the region that surrounds a planet and the magnetic field of that planet, in which charged particles are trapped and controlled by that planet's magnetic field, rather than the solar magnetic field. More specifically, the Earth's magnetosphere is the region of space where the Earth's magnetic field is confined by the solar wind plasma, blowing outward from the Sun. The magnetosphere prevents most of the particles from the Sun, carried by solar wind, from hitting the Earth. The Sun and other planets have magnetospheres, but the Earth has the strongest one of all the rocky planets ('Space weather models at CCMC,' n.d.).

Geomagnetism-The Earth's geomagnetic field is a combination of several magnetic fields generated by various sources superimposing on each other. More than 90% of the field is generated by the movement of conducting material inside the Earth's core, which is often referred to as the Main Field. Other important sources of the geomagnetic field include electric current flowing in the ionized upper atmosphere and currents flowing within the earth's crust (Hong Kong Observatory, 2012).

There were 2748 articles that met the selection criteria which appeared in the WoS database during 1960-2014 and these were analyzed.

A. Publication Characteristics

The Tables 4.2.a(i) and 4.2.a(ii) show the publication charecteristics of the output of 2748 papers, which received a total of 20705 citations during the period of study, with an average of 7.53 citations per paper. The average number of publications per year is 63.90 and Compound Annual Growth Rate (CAGR) is 0.06%.

Table 4.2.a(i): Bibliographic Records of IMG research in India during 1960-2014

Bibliometric Indicators `	**No.**
Total Number of Articles	2748
Total Number of Contributing Countries	73
Total Number of Contributing Authors	3332
Total Number of Contributing Institutions	1073
Total Number of Journals appeared	267
Total Number of Keywords (raw) appeared	5885

Source: WoS

Table 4.2.a(ii): Citation Metrics of IMG research in India during 1960-2014

Citation-based Indicators	**No.**
Sum of the Times Cited	20705
Sum of Times Cited without self-citations	14278
Citing Articles	11098
Citing Articles without self-citations	9355
Average Citations per Item	7.53
h-index	48

Source: WoS

B. Publications Pattern

Publication pattern of IMG research from 1960 to 2014 is presented in Figure 4.2.a(i). The initial publication in the sub-field of IMG research is observed in the year 1972. A near about seventeen times increase was observed over the study period, (from 9 in 1972 to 152 in 2014). The highest number of papers is published in the year 2014, with 152 publications and the lowest in 1972 with 9 publications.

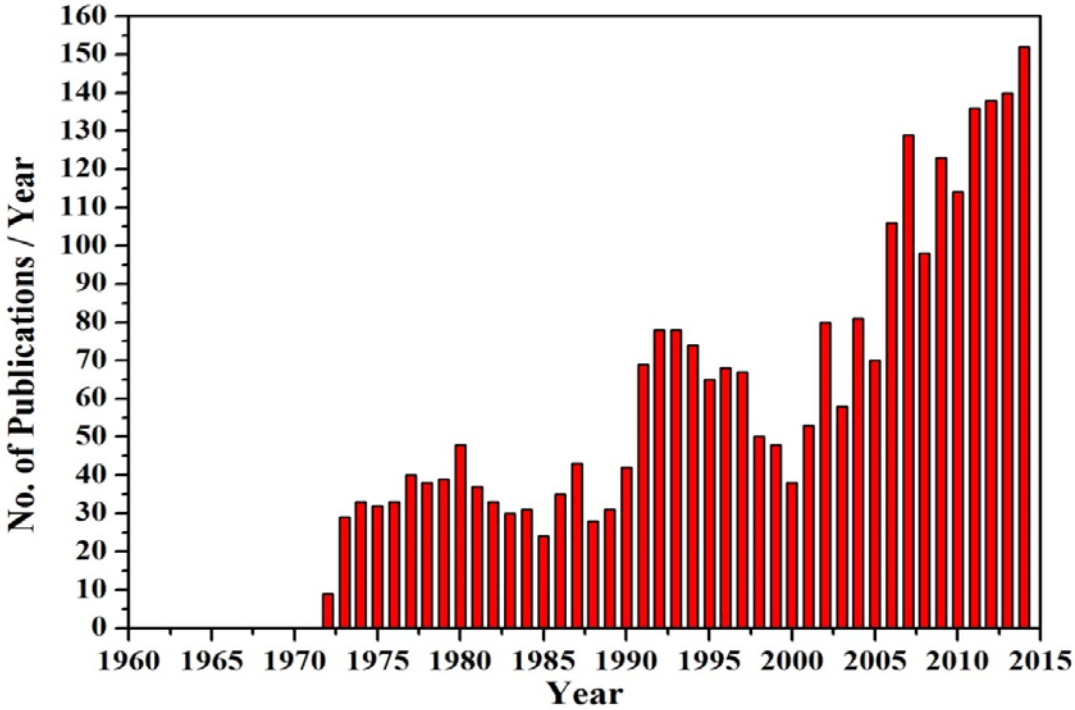

Figure 4.2.a(i): Publication Pattern of IMG research in India during 1960-2014. From the period 1960-1971, no publication appeared in the WoS database.

C. Growth Trend

The cumulative progression is represented by a 3rd degree power law distribution during 1960-2014 giving an idea of the polynomial growth curve as shown in Figure 4.2.a(ii). To choose the best fit growth model, various regression types with regression coefficient has been tested as shown in Table 4.2.a(iii). The best fit model is 3rd degree polynomial curve to the collected data set where $R^2 = 0.863$. The polynomial best fit for IMG research is found to be: $y = 0.003x^3 - 22.50x^2 + 44692x - 3E+07$, where y is the cumulative number of publications and x is the number of years. The growth of literature shown in Figure 4.2.a(ii) can be divided into two parts, 1st part (1960-1971), there is no literature published by Indian authors and in 2nd part (1972-2014), trend follows a polynomial growth curve.

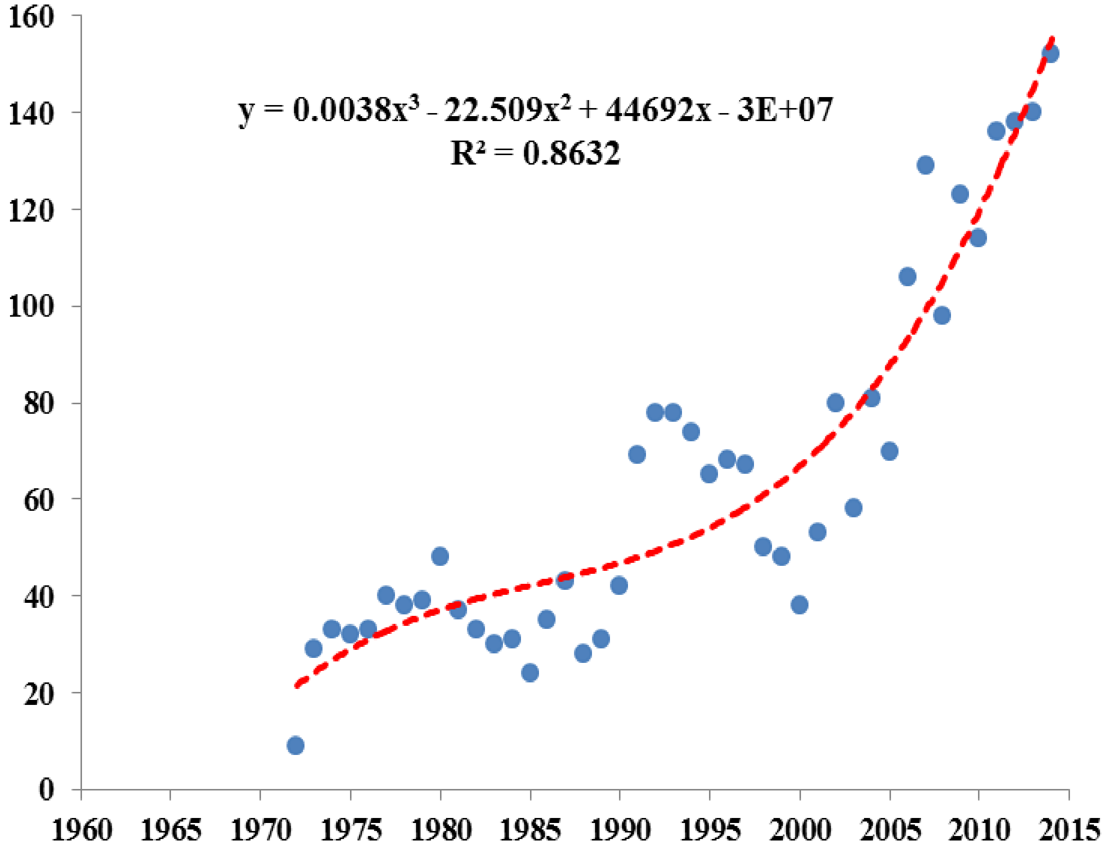

Figure 4.2.a(ii): Growth pattern of IMG research in India during 1960-2014. Blue dot describes the distribution of publications (observed value) and red dashed line describes the correlation of distribution of publications where regression coefficient $R^2 = 0.863$.

Table 4.2.a(iii): Different Regression Types with Regression Coefficient (R^2) of IMG research

Regression Type	Equation	(R^2)
Exponential	$y = 2E\text{-}34e^{0.041x}$	0.741
Linear	$y = 2.560x – 5039$	0.739
Logarithmic	$y = 5098.\ln(x) – 38668$	0.737
Polynomial	$y = 0.003x^3 - 22.50x^2 + 44692x - 3E+07$	0.863
Power	$y = 7E\text{-}26x^{81.79}$	0.741

D. Citations Pattern

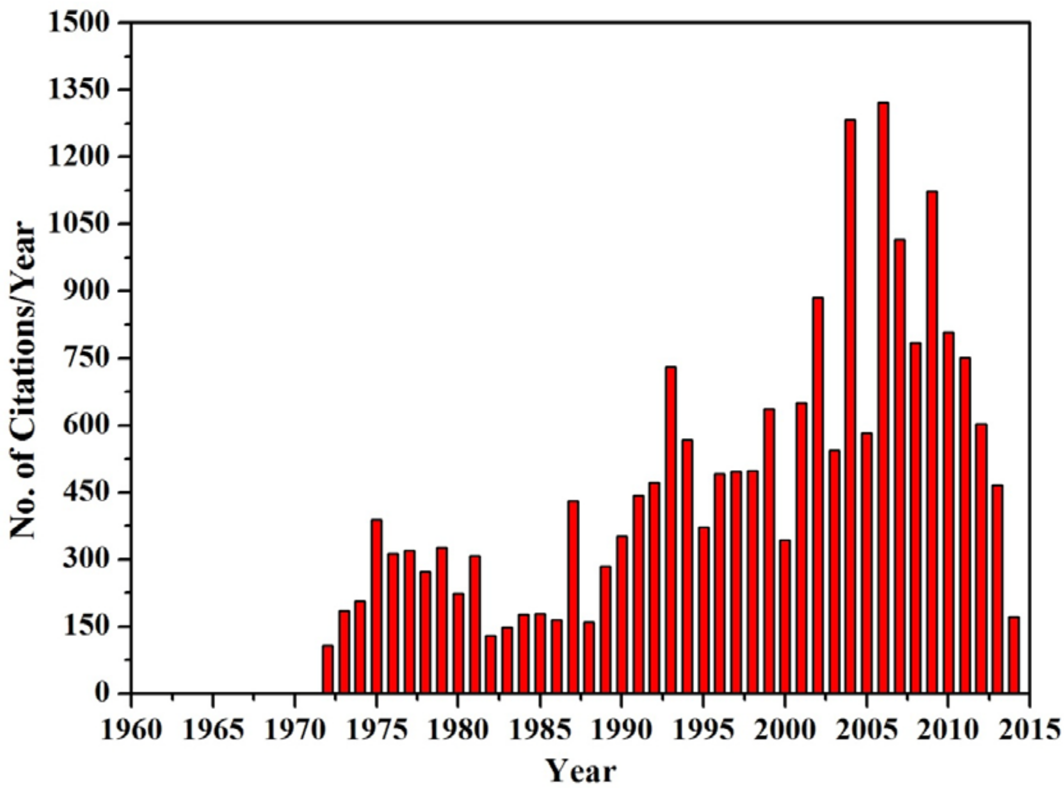

Figure 4.2.a(iii): Citation Pattern of IMG research in India during 1960-2014. From 1960-1971, no citation received as no publication appeared in the WoS database.

Figures 4.2.a(iii) and 4.2.a(iv) represent the citation pattern and number of citations vs. number of publications per year during 1960-2014 on IMG research. A total of 2748 research papers have received 20705 citations. The pattern of citations is very fluctuating. In the initial year 1972, the total number of citations received is 108 with an average citation of 12 which is the minimum citation received during the said period. The maximum citations are received in the year 2006 i.e. 1322 with an average citation of 12.47. It has been observed from Figure 4.2.a(iv) that after the year 2009, citations decrease while publications continue to increase.

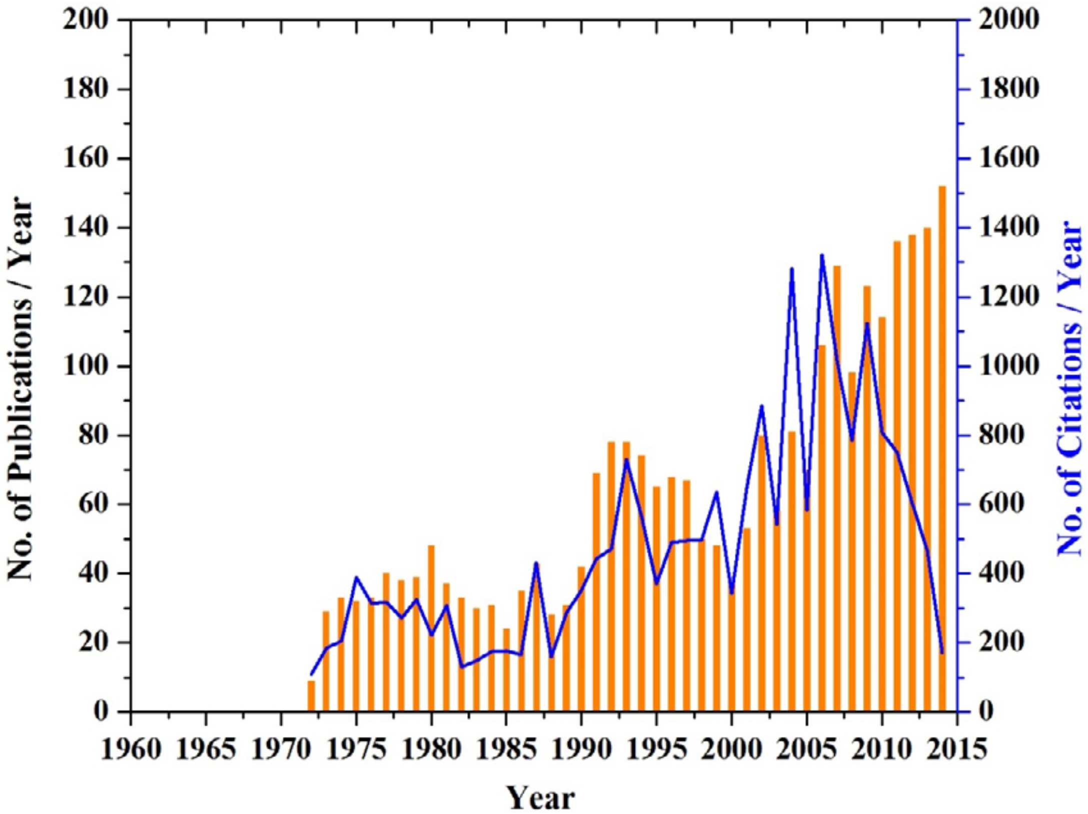

Figure 4.2.a(iv): Citation Pattern Vs Publication Pattern of IMG research in India during 1960-2014: Blue line (right Y axis) indicates the citation pattern against orange bar (left Y axis) that describes the publication pattern.

E. Top Institutions and their research impact

The contribution of different institutions is estimated by the affiliated institution of at least one author. A total of 2748 articles on IMG research appeared from 1073 institutions. Table 4.2.a(iv) shows the top 20 productive institutions during the last 54 years, 1960-2014. Out of these top 20 institutions, 16 are Indian. Indian Institute of Geomagnetism which contributed highest publications has published 532 paper followed by Physical Research Laboratory with (401), Vikram Sarabhai Space Center, (232), National Physics Laboratory (207), Banaras Hindu University (160) and Indian Institute of Astrophysics (98) publications each.

Table 4.2.a(iv): Top institutions on IMG research and their research impact, 1960- 2014

Institution	Region	TP (%)	TC	AvgCPA	h-index
Indian Institute of Geomagnetism	Indian	532(19.360)	4156	7.81	27
Physical Research Laboratory	Indian	401(14.592)	3782	9.43	28
Vikram Sarabhai Space Center	Indian	232(8.443)	2407	10.38	24
National Physics Laboratory	Indian	207(7.533)	1430	6.91	19
Banaras Hindu University	Indian	160(5.822)	713	4.46	14
Indian Institute of Astrophysics	Indian	98(3.566)	1266	12.92	20
National Aeronautics Space Administration	USA	94(3.421)	1838	19.55	23
Andhra University	Indian	88(3.202)	573	6.51	13
National Atmospher Research Laboratory	India	83(3.020)	465	5.60	11
University of Calcutta	Indian	81(2.948)	305	3.77	9
Tata Institute of Fundamental Research	Indian	65(2.365)	1123	17.28	2
National Geophysical Research Institute	Indian	61(2.220)	518	8.49	13
Instituto Nacional De Pesquisas Espaciais	Brazil	61(2.220)	857	14.05	15
University of Kerala	Indian	56(2.038)	614	10.96	15
Indian Institute of Technology IIT Delhi	Indian	54(1.965)	301	5.57	9
Gujarat University	Indian	50(1.820)	261	5.22	9
University of Delhi	Indian	47(1.710)	153	3.26	6
Goddard Space Flight Center	USA	46(1.674)	983	21.37	17
California Institute of Technology	USA	46(1.674)	872	18.96	18
Barkatullah University	Indian	45(1.638)	196	4.36	8

TP= *Total no. of IMG related articles published by an institution;* ***TC*** *= Total no. of citation received;* ***AvgCPA****= Average no. of citations per article; h-**index**=defined by the no. of h papers among an institution's no. of publications that have at least h citations each.* ***Source: WoS***

Comparatively less research was published by Barkatullah University(45) followed by University of Delhi (47), Gujarat University (50), Indian Institute of Technology Delhi (54) and University of Kerala (56) publications each, While the other four are foreign institutions. Among these, three belong to the USA namely National Aeronautics Space Administration (NASA) (94), Goddard Space Flight Center (46) and California Institute of Technology (46); and the fourth one is from Brazil namely Instituto Nacional De Pesquisas Espaciais (61).

Table 4.2.a(iv) reveals the impact of research in terms of quality of papers. The AvgCPA and h-index are used to identify which institution has the largest number of high quality articles in the IMG research. It is seen from the Table 4.2.a(iv) that IMG research related articles authored by NASA have the highest average impact (AvgCPA = 19.55). Among the Indian institutions, Tata Institute of Fundamental Research has the highest average impact (AvgCPA = 17.28) in AvgCPA index.

F. Top Journals and their research impact

IMG research papers have appeared in 267 journals. Table 4.2.5 shows the top 20 productive journals. These 20 out of the 267 journals have published 1871 of the total 2748 articles. The 'Journal of Geophysical Research Space Physics' ranks first with 324 (11.79%) papers; 'Indian Journal of Radio Space Physics 216 (7.86%)', 'Journal of Atmospheric and Solar Terrestrial Physics 175 (6.36%)', 'Advances in Space Research 150 (5.45%)' and 'Annales Geophysicae 128 (4.65%)' ranks at 2nd , 3rd , 4th and 5th places respectively.

Table 4.2.a(v) shows the citation impact of top 20 journals. The AvgCPA and h-index are used to identify which journals have the largest number of high quality articles in the IMG research. It is seen from the Table 4.2.a(v) that the 'Astrophysical

Journal' published by IOP Publishing for the American Astronomical Society in USA has the highest average impact (AvgCPA = 19.14) and though the "Journal of Geophysical Research Space Physics" has the highest number of publications but it ranks 4th in the AvgCPA index.

Table 4.2.a(v): Top Journals on IMG research and their research impact, 1960-2014

				Journal Metrics (2013)			
Journal	TP (%)	TC	AvgCPA	SJR	IPP	SNIP	Country
Journal of Geophysical Research Space Physics	324(11.790)	3400	10.49	-	-	-	USA
Indian Journal of Radio Space Physics	216(7.860)	449	2.08	0.408	0.604	0.487	India
Journal of Atmospheric and Solar Terrestrial Physics	175 (6.368)	1126	6.43	0.890	1.397	0.889	UK
Advances in Space Research	150(5.459)	689	4.59	0.727	1.506	1.237	Netherlands
Annales Geophysicae	128(4.658)	1234	9.64	0.996	1.441	0.855	Germany
Geophysical Research Letters	98(3.566)	1451	14.81	2.896	4.014	1.413	USA
Planetary and Space Science	83(3.020)	814	9.81	1.018	1.890	0.922	UK
Current Science	75(2.729)	275	3.67	0.293	0.841	0.771	India
Earth Planets and Space	73(2.656)	392	5.37	1.465	2.122	0.996	Japan
Journal of Geomagnetism and Geoelectricity	68(2.475)	387	5.69	-	-	-	Japan
Physics of Plasmas	63(2.293)	495	7.86	0.947	1.623	1.020	USA
Astrophysics and Space Science	62(2.256)	200	3.23	0.760	1.750	1.028	Netherlands
Annales Geophysicae Atmospheres Hydrospheres and Space Sciences	61(2.220)	738	12.10	-	-	-	Germany
Radio Science	58(2.111)	448	7.72	0.994	1.265	1.078	USA
Annales De Geophysique	52(1.892)	371	7.13	-	-	-	France
Earth Moon and Planets	46(1.674)	42	0.91	0.254	0.660	0.600	Germany
Proceedings of the Indian Academy of Sciences Earth and Planetary Sciences	43(1.565)	145	3.37	0.467	1.152	0.939	India
Astrophysical Journal	37(1.346)	708	19.14	2.808	4.494	1.192	UK
Indian Journal of Physics	30(1.092)	104	3.47	0.349	1.174	0.801	India
Advances in Space Research Series	29(1.055)	104	3.59	-	-	-	UK

TP**= Total no. of IMG research related articles published by a Journal; **TC** = Total no. of citation received; **AvgCPA**= Average no. of citations that IMG related articles in a journal received; **h-index**= no. of h papers among a journal's no. of publications that have at least h citations each. **SJR** = SCImago Journal Rank; **IPP** = Impact per Publication; **SNIP** = Source Normalized Impact per Paper; **Source: WoS and SCOPUS

G. Top Authors and their research impact

A total of 2748 articles included the author addresses having India as the country of affilation. Articles on IMG research have been contributed by 3332 authors. Table 4.2.a(vi) shows the top 20 productive authors during the last 54 years, 1960-2014. Top 20 productive authors are ranked based on the decreasing productivity of total publications. Rastogi, R. G. produced maximum number of publications - 165 and ranked 1st followed by Lakhina, G. S., Singh, R. P., Singh, A. K. and Sridharan, R. at 2nd, 3rd, 4th and 5th ranks respectively.

Table 4.2.a(vi): Top Authors of IMG research and their research impact, 1960-2014

Author	TP (%)	TC	TC woSC	CI	CIwoSC	AvgCPA	h-index
Rastogi, R.G.	165(6.004)	1585	1183	852	727	9.61	20
Lakhina, G.S.	105(3.821)	1600	1358	954	881	15.24	22
Singh, R.P.	82(2.984)	404	292	244	197	4.93	13
Singh, A.K.	82(2.984)	272	167	179	127	3.32	9
Sridharan, R.	78(2.838)	776	634	500	452	9.95	15
Patra, A.K.	70(2.547)	534	317	275	213	7.63	13
Chandra, H.	67(2.438)	573	511	455	420	8.55	14
Pant, T.K.	64(2.329)	366	299	270	235	5.72	11
Sastri, J.H.	58(2.111)	665	591	472	438	11.47	17
Gwal, A.K.	53(1.929)	241	223	216	203	4.55	8
Mahajan, K.K.	52(1.892)	291	261	240	218	5.60	10
Kumar, S.	52(1.892)	225	189	179	155	4.33	8
Dabas, R.S.	52(1.892)	498	418	354	319	9.58	13
Gurubaran, S.	51(1.856)	396	339	275	247	7.76	11
Arora, B.R.	51(1.856)	311	264	222	193	6.10	9
Pathan, B.M.	49(1.783)	308	266	243	222	6.29	9
Ravindran, S.	48(1.747)	403	356	309	281	8.40	11
Rao, D.R.K.	47(1.710)	389	363	338	321	8.28	10
Devasia, C.Y.	46(1.674)	558	502	384	355	12.13	14
Rangarajan, G.K.	45(1.638)	159	117	120	97	3.46	7

TP:** Total no. of IMG related articles published by a author; **TC:** Total no. of citation**;** **TC woSc:** Sum of Times Cited without self-citations**;** **CI:** Citing Articles **;** **CIwoSC:** Citing Articles without self-citations**;** **AvgCPA:** Average Citations per Article**;** **h-index :** no. of h papers among a author's no. of publications that have at least h citations each. **Source: WoS

In addition, Table 4.2.a(vi) reveals the impact of research in terms of quality of papers. The AvgCPA and h-index are used to identify which author has the largest number of high quality articles in the IMG research. It is seen from the Table 4.2.a(vi) that IMG research related articles authored by Lakhina, G.S. have the highest average impact (AvgCPA = 15.24) followed by Devasia, C.Y. (AvgCPA = 12.13) inspite of having the maximum number of publications but Rastogi, R.G. ranked 5th in the AvgCPA index.

H. Collaboration Pattern: Continents

Based on the author attributions, world-wide collaboration pattern of IMG research publications can be mapped. As shown in Figure 4.2.a(v), the major spatial clusters of research collaborations are located in Europe followed by Asia, Africa and South America. Minor clusters are distributed in North America and Australia.

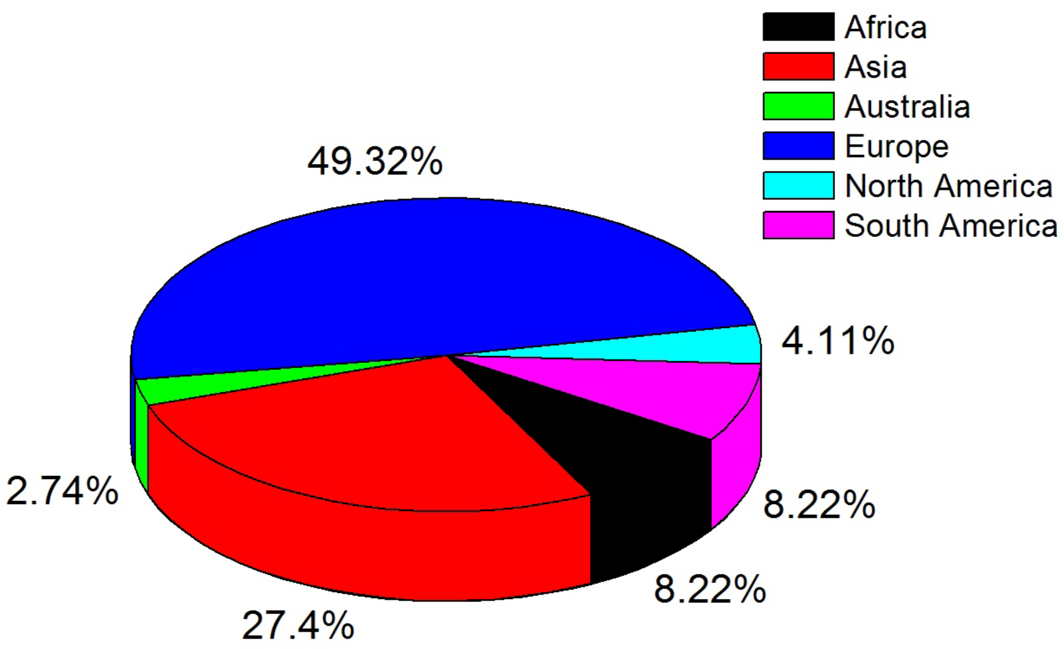

Figure 4.2.a(v): Continent wise Collaboration pattern of IMG research

I. Collaboration Pattern and research impact: Countries

There are 73 collaborating Countries/territories which participated in research on IMG research. As shown in the Table 4.2.a(vii), Top countries / territories are ranked based on the number of total articles, along with the citations and percentage of international collaboration. Out of these top countries / territories, the USA produced maximum publications - 274 which is 9.971% of the total publications with 4978 citations. The AvgCPA and h-index are used to identify which country has the largest number of high quality articles in the IMG research. It is seen from the Table 4.2.a(vii) that IMG research related articles authored in collaboration with Italy (Europe) have the highest average impact (AvgCPA = 50.58) followed by Australia (AvgCPA = 29.20) while the USA ranked 8th in the AvgCPA index.

Table 4.2.a(vii): Country wise Collaboration Pattern and research impact of IMG research

Country	Continent	TP (%)	TC	AvgCPA	h-index
USA	North America	274(9.971)	4978	18.17	36
Japan	Asia	114(4.148)	1399	12.27	21
England	Europe	73(2.656)	1950	26.71	24
Brazil	South America	67(2.438)	861	12.85	15
Germany	Europe	56(2.038)	1072	19.14	18
France	Europe	41(1.492)	841	20.51	17
Australia	Australia	40(1.456)	1168	29.20	16
Russia	Europe	37(1.346)	578	15.62	14
Taiwan	Asia	35(1.274)	223	6.37	7
Canada	North America	29(1.055)	433	14.93	13
South Africa	Africa	23(0.837)	418	18.17	10
Italy	Europe	19(0.691)	961	50.58	13
Peoples R China	Asia	17(0.619)	248	14.59	8
South Korea	Asia	16(0.582)	95	5.94	5
Sweden	Europe	14(0.509)	472	33.71	10
Poland	Europe	14(0.509)	213	15.21	7
Netherlands	Europe	14(0.509)	219	15.64	7
Hungary	Europe	13(0.473)	126	9.69	5
Fiji	Australia	12(0.437)	39	3.25	3
Belgium	Europe	12(0.437)	300	25.00	9

TP*= Total no. of IMG related articles published by a country;* ***TC*** *= Total no. of citation received;* ***AvgCPA****= Average no. of citations per Article;* ***h-index****= no. of h papers among a country's no. of publications that have at least h citations each.* ***Source: WoS***

J. Keywords Analysis

A total of 5885 different keywords, from 1960 to 2014 in the IMG have been identified. The number of analysed publications during the study period is 2748. Of them only 1964 have provided keyswords, while the rest (784) do not provide any keywords. To obtain accurate results, the keywords were pre-processed by merging the singular and plural forms of the same terminology, and those keywords with the same meaning while using different expressions. A total of 5474 unique Keywords are obtained. Among these unique keywords, 1587 (28.99%) appear once or twice at the most, it can be deduced that this can be a sign of lack of research continuity or of a wide range of research focus. Table 4.2.a(viii) shows the most used keywords during the considered period.

J.1 Hotspots

Table 4.2.a(viii): Top most frequently used keywords in IMG research

Keywords	NO	%	Ranking
Disturbances	103	1.88	13
Drifts	89	1.62	16
Electric-fields	101	1.84	14
Emissions	89	1.62	16
Equatorial electro jet	82	1.49	17
F-region	158	2.88	5
Instability	138	2.52	7
Ionization	81	1.47	18
Irregularities	248	5.43	3
Latitudes	109	1.99	12
Magnetic equator	54	0.98	19
Magnetic-field	156	2.84	6
Plasma	449	8.20	1
Propagation	135	2.46	8
Radiation	115	2.10	9
Scintillations	90	1.64	15
Spread-f	179	3.27	4
TEC	110	2.00	11
Thermosphere	113	2.06	10
Waves	364	6.64	2

NO: Number of time occurrences; R : rank; ***Source: WoS***

An analysis of the keywords has been undertaken to pick out the research hotsopts (Chapter 1, Section 1.8.5.A) which have attracted most research attention and to reveal the research tendencies in the fields of IMG. The top 20 most frequently used keywords for the study period are listed in Table 4.2.a(viii). The four most frequently used keywords were ‘waves’, ‘Plasma’, ‘Irregularities’ and ‘F-region’.

J.2 Quick Rising Themes

Table 4.2.a(ix): Top Quick rising themes in IMG research

Keywords	V (t_0)	V (t_n)	t_0	t_n	CAGR (%)	R
Disturbances	3	11	1991	2014	0.058	16
Drifts	2	8	1992	2014	0.065	14
Electric-fields	2	8	1991	2014	0.062	15
Equatorial electrojet	1	9	1991	2014	0.100	9
F-region	5	20	1991	2014	0.062	15
Ionization	3	12	1991	2014	0.062	15
Irregularities	7	26	1991	2014	0.058	16
Latitudes	1	11	1990	2014	0.105	7
Magnetic-field	1	10	1990	2014	0.100	9
Plasma	1	39	1987	2014	0.145	2
Propagation	1	13	1988	2014	0.103	8
Radiation	1	7	1991	2014	0.088	10
Spread-f	5	23	1991	2014	0.068	13
TEC	1	18	1990	2014	0.128	3
Thermosphere	1	13	1991	2014	0.117	5
Waves	1	27	1990	2014	0.147	1
Airglow	2	11	1991	2014	0.076	12
Anomalies	1	7	1990	2014	0.084	11
Bubbles	1	11	1991	2014	0.109	6
Geomagnetic storm	1	12	1992	2014	0.119	4

t_0*: the Initial (first) year (The Year in which no. of keywords occurrence first time;* ***t_n****: the last year (No. of keywords occurrence);* ***V(t_0)****: Initial observed value (no. of keywords occurrence);* ***V(t_n)****: last observed value (no. of keywords occurrence);* ***CAGR:*** *Compound Annual Growth Rate;* ***R:*** *Rank.* ***Source: WoS***

The Compound Annual Growth Rate (CAGR) described in Chapter 1, Section 1.8.5.B), can be used to select quick rising themes of IMG research; this reveals the indicators of future research directions. Table 4.2.a(ix) lists the top 20 keywords according to the CAGR and sorts them by their rank. The ranks in Table 4.2.a(ix) show that ‘Waves’ and ‘Plasma’ and ‘TEC’ are three leading hot issues that continue to attract broad attention. ‘Waves’ keeps its dominance in terms of total quantity and CAGR.

K. Summary

A total of 2748 journal articles were published on IMG, which received total 20705 citations. The average number of publications per year is 119.40 The most active journal revealed is the ‘JGR Space Physics’ published by AGU originating from the USA. The most active author is Rastogi, R. G. with 165 i.e. 6.00% of total publications. A total of 1073 institutions contributed of which IIGM, Mumbai, India is the most productive institution. India has collaborated with 73 Countries/territories with the USA at the top (274). Keyword analysis reveals that ‘Plasma’, ‘waves’, ‘Irregularities’ and ‘F-region’ are the most frequently used keywords.

4.2.2 Meteorology and Atmospheric Science (MAS)

The study of the atmosphere is grounded in observation, theory, and modeling. As a pioneer of weather forecasting, Lewis Fry Richardson knew very well the challenges of atmospheric modeling and he correctly judged the complexity of the atmosphere's behavior, which is result of interactions between the atmosphere and the other climate system components: the hydrosphere, the cryosphere, the biosphere, and the land surface. The traditional division in the atmospheric sciences has been between meteorology and climatology (Schoof, 2013).

There were 5015 articles that met the selection criteria which appeared in the WoS database during 1960-2014 and these were analyzed.

A. Publication Characteristics

Table 4.2.b(i): Bibliographic Records of MAS research in India during 1960-2014

Bibliometric Indicators `	**No.**
Total Number of Articles	5015
Total Number of Contributing Countries	112
Total Number of Contributing Authors	7959
Total Number of Contributing Institutions	2078
Total Number of Journals appeared	162
Total Number of Keywords (raw) appeared	26419

Source: WoS

The Tables 4.2.b(i) and 4.2.b(ii) show the publication charecteristics of the output of 5015 papers, which received a total of 46282 citations during the period of study, with an average of 9.23 citations per paper. The average number of publications per year is 119.40 and Compound Annual Growth rate (CAGR) is 0.09%.

Table 4.2.b(ii): Citation Metrics of MAS research in India during 1960-2014

Citation-based Indicators	No.
Sum of the Times Cited	46282
Sum of Times Cited without self-citations	35223
Citing Articles	25536
Citing Articles without self-citations	22856
Average Citations per paper	9.23
h-index	70

Source: WoS

B. Publication Pattern

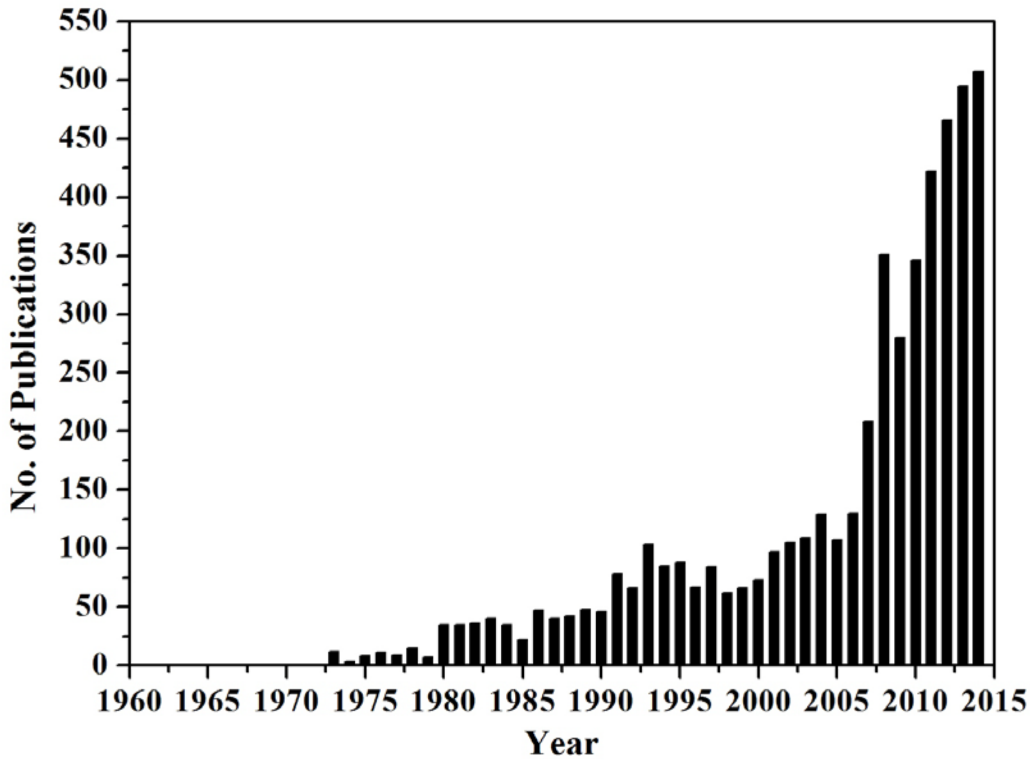

Figure 4.2.b(i): Publications Pattern of MAS research in India during 1960-2014. From the period 1960-1972, no publication appeared in the WoS database.

Publications pattern of MAS research from 1960 to 2014 is presented in Figure 4.2.b(i). The lowest (3) and highest (504) number of publications appear in 1974 and 2014 respectively. It is important to mention that the initial publication appears in the year 1973. A near about 42 times increase is observed over the study period, (from 12 in 1973 to 507 in 2014).

C. Growth Trend

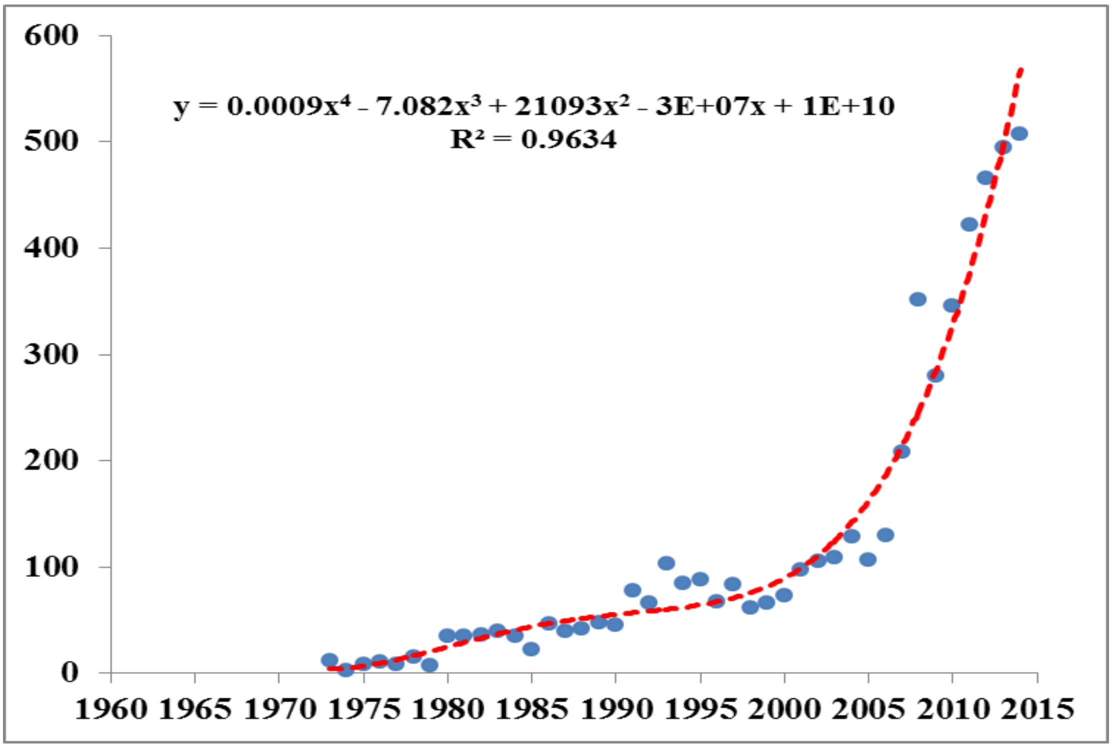

Figure 4.2.b(ii): Growth Trend of MAS research in India during 1960-2014.Blue dot describes the distribution of publications (observed value) and red dashed line describes the correlation of distribution of publications where regression coefficient R^2 = 0.963.

The cumulative progression is represented by a 4th degree power law distribution during 1960-2014 giving an idea of the polynomial growth curve as shown in Figure. 4.2.b(ii). To choose the best fit growth model, various regression types with regression coefficient has been tested as shown in Table 4.2.13. The best fit model is 4th degree polynomial curve to the collected data set where $R^2 = 0.963$. The polynomial best fit for MAS research is found to be: y = 0.0009 x4 - 7.082 x3 + 21093 x2 - 3E+07x + 1E+10, where y is the cumulative number of publications and x is the number of years. The growth of literature shown in Figure 4.2.b(ii) can be divided into two parts, 1st part (1960-1972), there is no literature published by Indian authors and in 2nd part (1973-2014), trend follows a polynomial growth curve.

Table 4.2.b(iii): Different Regression Types with Regression coefficient (R^2) of MAS research

Regression Type	Equation	(R^2)
Exponential	$y = 1E\text{-}80e^{0.0943x}$	0.8902
Linear	y = 9.344x – 18509	0.6577
Logarithmic	y = 18598ln(x) – 14118	0.6556
Polynomial	y = 0.0009x4 - 7.082x3 + 21093x2 - 3E+07x + 1E+10	0.9634
Power	$y = 0x^{188.06}$	0.8904

D. Citation Pattern

Figures 4.2.b(iii) and 4.2.b(iv) represent the year wise growth of citations and citation pattern vs publication pattern, per year during 1960-2014 on MAS research. The total 5015 articles from WoS related to MAS research publication received a total of 46282 citations.

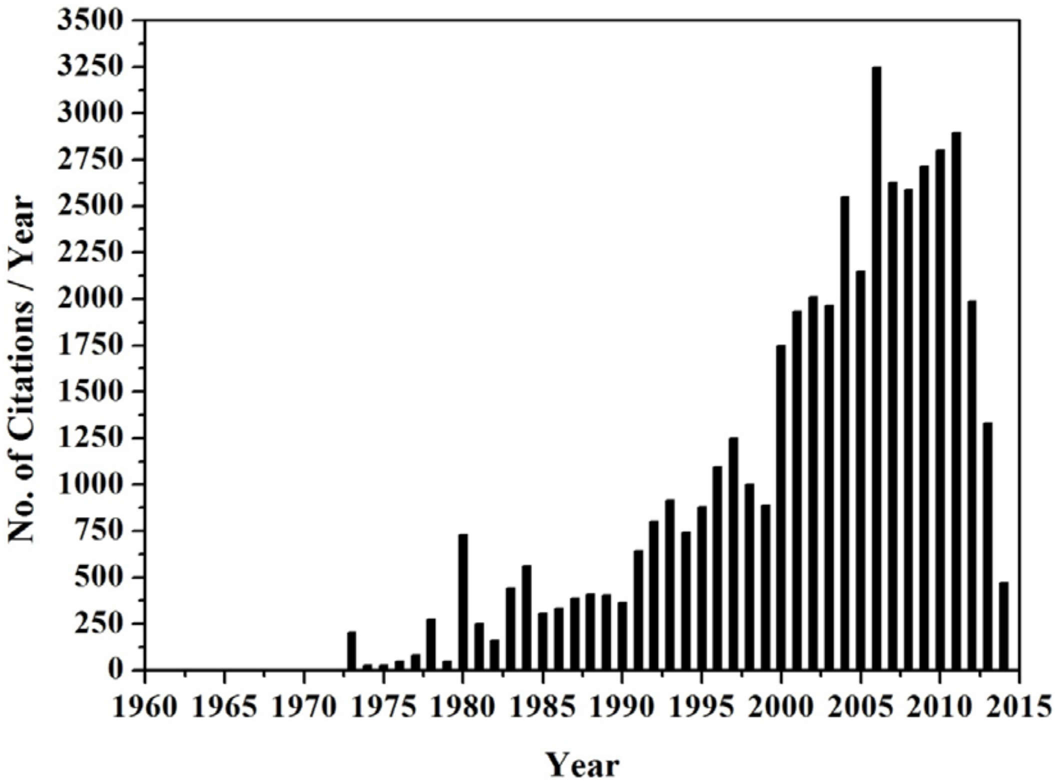

Figure 4.2.b(iii): Citation Pattern of MAS research in India during 1960-2014. From 1960-1972, no citation received as no publication appeared in the WoS database.

The pattern of citations received during the said year is very fluctuating. In the starting year 1973, the total number of citations received is 203 with an average citation of 16.92.The minimum citations received in the year 1974 is twenty six (26) with an average citation of 8.67. The maximum citations received in the year 2006 are 3248 with an average citation of 24.98. It is observed that after the year 2011, citations decrease while publications continue to increase.

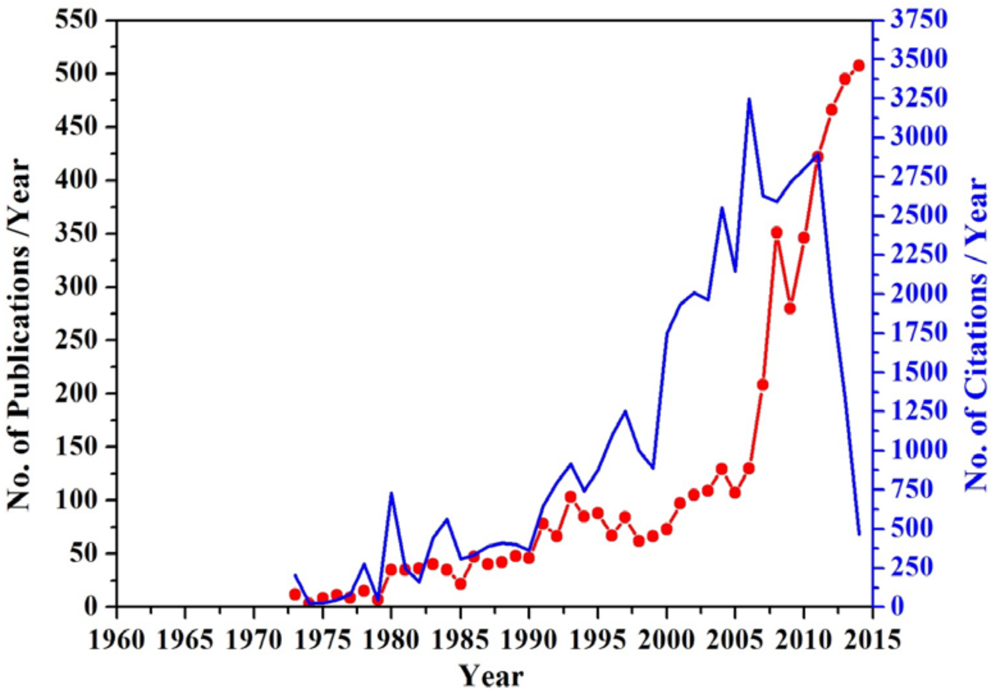

Figure 4.2.b(iv): Citation Pattern Vs Publication Pattern of MAS in India during 1960-2014: Blue line (right Y axis) indicates the citations pattern against red line (left Y axis) that describes the publications pattern.

E. Top Institutions and their research impact

A total of 5015 articles on MAS research appeared from 2078 institutions. Table 4.2.b(iv) shows the top 20 productive institutions during the last 54 years, 1960-2014. Out of these top 20, 18 are Indian. Ministry of Earth Sciences which contributed highest publications has published 1205 papers followed by Indian Institute of Tropical Meteorology (755), Indian Meteorological Department (334), Vikram Sarabhai Space Center (279) and Indian Institute of Technology Delhi (260) publications each. The other two are foreign institutions, among these one is from the USA viz. National Aeronautics Space Administration with 90 publications and another to France i.e. Centre National De La Recherche Scientifique CNRS with 94 publications.

Table 4.2.b(iv): Top institutions on MAS research and their research impact, 1960- 2014

Institution	Region	TP (%)	TC	AvgCPA	h-index
Ministry of Earth Sciences MOES	India	1205(24.028)	12628	10.48	47
Indian Institute of Tropical Meteorology IITM	India	755(15.055)	10231	13.55	45
India Meteorological Department IMD	India	334(6.660)	2034	6.09	22
Vikram Sarabhai Space Center VSSC	India	279(5.563)	3577	12.82	30
Indian Institute of Technology IIT Delhi	India	260(5.184)	2605	10.02	26
Physical Research Laboratory	India	240(4.786)	3214	13.39	30
Indian Institute of Science IISc	India	185(3.689)	3928	21.23	31
National Physics Laboratory	India	176(3.509)	1713	9.73	21
National Atmospheric Research Laboratory	India	109(2.173)	631	5.79	14
Indian Institute of Technology IIT Kanpur	India	105(2.094)	2152	20.50	26
Andhra University	India	105(2.094)	857	8.16	15
Banaras Hindu University	India	104(2.074)	961	9.24	15
Indian Institute of Technology IIT Bombay	India	97(1.934)	1689	17.41	22
Bhabha Atomic Research Center	India	95(1.894)	941	9.91	18
Centre National De La Recherche Scientifique CNRS	France	94(1.874)	1708	18.17	22
University of Calcutta	India	93(1.854)	515	5.54	13
National Aeronautics Space Administration NASA	USA	90(1.795)	2304	25.60	25
National Centre for Medium Range Weather Forecasting	India	88(1.755)	696	7.91	13
Indian Institute of Technology IIT Kharagpur	India	87(1.735)	548	6.30	13
National Institute of Oceanography	India	85(1.695)	776	9.13	13

TP= *Total no. of MAS related articles published by an institution;* ***TC*** *= Total no. of citation received;* ***AvgCPA***= *Average no. of citations per article; h-**index**=defined by the no. of h papers among an institution's no. of publications that have at least h citations each.* ***Source: WoS***

Table 4.2.b(iv) reveals the impact of research in terms of the quality of papers. It is seen from the Table 4.2.b(iv) that MAS research related articles authored by NASA, USA has the highest average impact (AvgCPA = 25.60). Among the Indian institutions, Indian Institute of Science (IISc) has the highest average impact (AvgCPA = 21.23) in AvgCPA index.

F. Top Journals and their research impact

MAS research papers have appeared in 162 journals. Papers have appeared in highest number in the journal "Atmospheric Environment" published by Elsevier from UK. Table 4.2.b(v) shows the top 20 productive journals. These 20 out of the 162 journals have published 3843 of the total 5015 articles. The 'Atmospheric

Environment' ranked first with 469 (9.35%); 'Journal of Agrometeorology 403(8.03%)', 'Journal of Geophysical Research Atmospheres 347 (6.91%)', 'Mausam 318 (6.34%)' and 'Natural Hazards 297 (5.92%)' are ranked at 2nd, 3rd, 4th, and 5th respectively.

Table 4.2.b(v): Top Journals on MAS research and their research impact, 1960-2014

Journal	TP (%)	TC	AvgCPA	Journal Metrics (2013) SJR	IPP	SNIP	Country
Atmospheric Environment	469(9.352)	8709	18.57	1.431	3.406	1.537	UK
Journal of Agrometeorology	403(8.036)	179	0.44	0.103	0.036	0.073	India
Journal of Geophysical Research Atmospheres	347(6.919)	6887	19.85	-	-	-	USA
Mausam	318(6.341)	237	0.75	0.252	0.265	0.686	India
Natural Hazards	297(5.922)	1245	4.91	0.767	1.812	1.193	Netherlands
Indian Journal of Radio Space Physics	280(5.583)	548	1.96	0.408	0.604	0.487	Indian
Advances in Space Research	227(4.526)	895	3.94	0.727	1.506	1.237	UK
Journal of Atmospheric and Solar Terrestrial Physics	176(3.509)	965	5.48	0.890	1.397	0.889	UK
Atmospheric Research	163(3.250)	1464	8.98	1.232	2.905	1.610	Netherlands
International Journal of Climatology	158(3.151)	1710	10.82	1.694	2.906	1.413	UK
Meteorology and Atmospheric Physics	144(2.871)	699	4.85	0.654	1.175	0.702	Austria
Theoretical and Applied Climatology	125(2.493)	978	7.82	-	-	-	Austria
Annales Geophysicae	123(2.453)	1060	8.62	0.996	1.441	0.855	Germany
Atmospheric Chemistry and Physics	76(1.515)	1278	16.82	3.022	5.054	1.574	Germany
Climate Dynamics	68(1.356)	967	14.22	3.036	3.801	1.279	Germany
Boundary Layer Meteorology	67(1.336)	487	7.27	1.517	2.522	1.673	USA
Monthly Weather Review	61(1.216)	1444	23.67	3.081	3.309	1.594	USA
Climatic Change	58(1.157)	1191	20.53	2.116	3.847	1.512	Netherlands
Meteorological Applications	55(1.097)	353	6.42	0.807	1.361	1.022	UK
Agricultural and Forest Meteorology	51(1.017)	1012	19.84	1.828	4.135	1.801	Netherlands

TP= *Total no. of MAS research related articles published by a Journal;* ***TC*** *= Total no. of citation received;* ***AvgCPA****= Average no. of citations that MAS related articles in a journal received;* ***h-index****= no. of h papers among a journal's no. of publications that have at least h citations each.* ***SJR*** *= SCImago Journal Rank;* ***IPP*** *= Impact per Publication;* ***SNIP*** *= Source Normalized Impact per Paper;* ***Source: WoS and SCOPUS***

Table 4.2.b(v) also shows the citation impact of top 20 journals. The AvgCPA and h-index are used to identify which journals have the largest number of high quality articles in the MAS research. It is seen from the Table 4.2.b(v) that the journal "Monthly Weather Review" published by the American Meteorological Society in the USA has the highest average impact (AvgCPA = 23.67) although the journal

'Atmospheric Environment' has the highest number of publications but ranked 5th in the AgvCPA index.

G. Top Authors and their research impact

A total of 5015 articles included the author addresses having India as the country of affilation. Articles on MAS research have been contributed by 7959 authors. Table 4.2.b(vi) shows the top 20 productive authors during the last 54 years, 1960-2014. Top 20 productive authors are ranked based on the decreasing productivity of total publications. Moorthy, K. K. ranked 1st with 96 publications which is 1.91 % of total publications. Mohanty, U. C., Kumar, A., Devara, P. C. S. and Babu, S. S. ranked 2nd, 3rd, 4th and 5th respectively.

Table 4.2.b(vi): Top Authors of MAS research and their research impact, 1960-2014

Author	TP (%)	TC	TC woSC	CI	CIwoSC	AgCPA	h-index
Moorthy, K.K.	96(1.914)	2203	165	872	782	22.95	27
Mohanty, U.C.	87(1.735)	801	712	610	560	9.21	14
Kumar, A.	82(1.635)	396	369	349	330	4.83	11
Devara, P.C.S.	74(1.476)	791	644	480	430	10.69	15
Babu, S.S.	64(1.276)	990	718	478	423	15.47	18
Kamra, A.K.	55(1.097)	436	345	258	220	7.93	12
Rao, D.N.	53(1.057)	540	483	385	354	10.19	14
Tripathi, S.N.	51(1.017)	1371	1163	748	705	26.88	20
Goswami, B.N.	51(1.017)	891	812	683	649	17.47	14
Singh, R.	50(0.997)	344	322	298	281	6.88	9
Parameswaran, K.	49(0.977)	532	449	392	359	10.86	13
Singh, D.	48(0.957)	179	166	162	150	3.73	7
Singh, S.	47(0.937)	454	412	324	311	9.66	13
Lal, S.	47(0.937)	676	578	400	367	14.38	13
Kumar, S.	47(0.937)	252	249	241	238	5.36	8
Pal, P.K.	46(0.917)	234	209	170	152	5.09	8
Satheesh, S.K.	45(0.897)	1362	1243	660	623	30.27	20
Ratnam, M.V.	45(0.897)	288	228	199	169	6.40	11
Ramachandran, S.	45(0.897)	733	622	489	449	16.29	17
Pandithurai, G.	45(0.897)	514	453	365	338	11.42	13

TP: *Total no. of MAS related articles published by a author;* ***TC:*** *Total no. of citation;* ***TC woSc:*** *Sum of Times Cited without self-citations;* ***CI:*** *Citing Articles ;* ***CIwoSC:*** *Citing Articles without self-citations;* ***AvgCPA:*** *Average Citations per Article;* ***h-index :*** *no. of h papers among a author's no. of publications that have at least h citations each.* ***Source: WoS***

Table 4.2.b(vi) reveals the impact of research in terms of quality of papers by means of AvgCPA and the h-index. It is seen from the Table 4.2.b(vi) that MAS research articles authored by Satheesh, S. K. have the highest average impact (AvgCPA = 30.27) followed by Tripathi, S.N. (AvgCPA = 26.88) although Moorthy, K. K.has the maximum number of publications but ranks 3rd in the AvgCPA index.

H. Collaboration Pattern: Continents

Based on the author attributions, world-wide collaboration of MAS research publications can be mapped. As shown in Figure 4.2.b(v), the major spatial clusters of research collaborations are located in Asia, followed by Europe, Africa, South America and North America. Several minor clusters are distributed in other parts of the world.

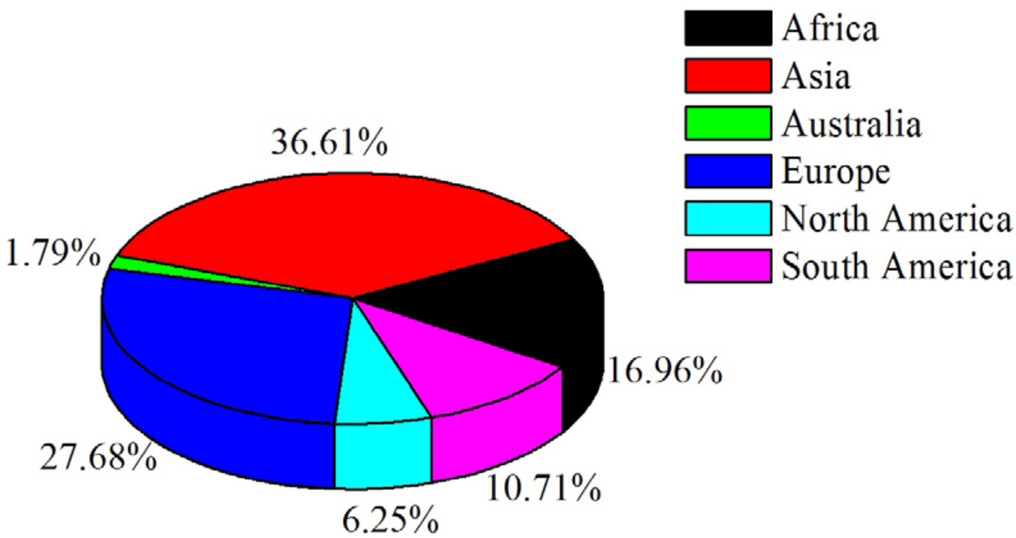

Figure 4.2.b(v): Continent wise Collaboration pattern of MAS research

I. Collaboration Pattern and research impact: Countries

There are 112 collaborating Countries/territories which participated in research on MAS research. Top 20 countries /territories are ranked based on the number of total articles, along with the citations and percentage of international collaboration (Table-4.2.b(vii)). Out of these 20 countries / territories, the USA produced 482 publications which are 9.611% of the total publications with 8234 citations. It is seen from the Table 4.2.b(vii) that MAS research related articles authored in collaboration with Netherlands (Europe) have the highest average impact (AvgCPA=48.41) followed by Peoples R China (Asia) AvgCPA=34.82 although USA ranked 12th in the AgvCPA index.

Table 4.2.b(vii): Country wise Collaboration Pattern and research impact of MAS research

Countries	Continent	TP (%)	TC	AvgCPA	h-index
USA	North America	482(9.611)	8234	17.08	43
Japan	Asia	165(3.290)	2470	14.97	26
Germany	Europe	129(2.572)	2507	19.43	28
France	Europe	121(2.413)	2102	17.37	23
England	Europe	89(1.775)	2906	32.65	27
Canada	North America	73(1.456)	1996	27.34	20
Peoples R China	Asia	56(1.117)	1950	34.82	20
South Korea	Asia	48(0.957)	627	13.06	13
Italy	Europe	44(0.877)	951	21.61	16
Brazil	South America	42(0.837)	675	16.07	13
Taiwan	Asia	37(0.738)	420	11.35	11
Netherlands	Europe	37(0.738)	1791	48.41	15
Sweden	Europe	34(0.678)	546	16.06	13
Australia	Australia	34(0.678)	1408	41.41	16
Finland	Europe	32(0.638)	712	22.25	14
Greece	Europe	30(0.598)	579	19.30	13
South Africa	Africa	28(0.558)	536	19.14	10
Thailand	Asia	25(0.499)	447	17.88	12
Austria	Europe	23(0.459)	672	29.22	10
Russia	Europe	20(0.399)	331	16.55	10

TP*= Total no. ofMAS related articles published by a country;* ***TC*** *= Total no. of citation received;* ***AvgCPA****= Average no. of citations per Article;* ***h-index****= no. of h papers among a country's no. of publications that have at least h citations each.* ***Source: WoS***

J. Keyword Analysis

A total of 26419 different keywords have been identified in the field of MAS research during the period 1960 to 2014. The number of analysed publications during the study period was 5015. Of them only 4146 provided keywords. While the rest (869) did not have any keywords. To obtain the accurate results, the keywords were pre-processed by merging the singular and plural forms of the same terminology, and those keywords with the same meaning while using different expressions. 23747 unique Keywords have been obtained. Among these unique keywords 10274 (43.26 %) appear once or twice at the most.

J.1 Hotspots

Table 4.2.b(viii): Top most frequently used keywords in MAS research

Keywords	NO	%	Ranking
Aerosol	671	2.82	2
Climate	480	2.02	6
Cloud	323	1.36	9
Convection	215	0.90	15
El-nino	1860	7.83	1
Emissions	219	0.92	14
Monsoon	562	2.36	4
Ocean	499	2.10	5
Oscillation	221	0.93	13
Ozone	208	0.87	17
Pollution	237	0.99	12
Prediction	250	1.05	11
Radar	213	0.89	16
Rain	643	2.70	3
Rainfall	417	1.75	7
Simulation	219	0.92	14
Summer	323	1.36	9
Water	384	1.61	8
Weather	155	0.65	18
Wind	262	1.10	10

NO: Number of time occurrences; R : rank ***Source: WoS***

An analysis of the keywords was undertaken to pick out the research hotsopts (Chapter 1, Section 1.8.5.1) that have attracted most research attention and to reveal the research tendencies in the fields of MAS. The top 20 most frequently used keywords for the study period are listed in Table 4.2.b(viii). The four most frequently used keywords were ‘El-nino’, ‘Aerosol’, ‘Rain’ and ‘Monsoon’.

J.2 Quick Rising Themes

Table 4.2.b(ix): Top Quick rising themes in MAS research

Keyword	$V(t_0)$	$V(t_n)$	t_0	t_n	CAGR (%)	R
Absorption	1	22	1993	2014	0.158	15
Aerosol	2	84	1991	2014	0.176	9
Black carbon	1	21	2000	2014	0.242	1
Climate	3	88	1992	2014	0.166	12
Cloud	1	31	1992	2014	0.168	10
Convection	1	42	1991	2014	0.176	9
El-nino	3	280	1990	2014	0.208	2
Emissions	1	36	1993	2014	0.186	7
Monsoon	4	97	1991	2014	0.148	16
Ocean	1	57	1991	2014	0.192	6
Optical-properties	1	30	1995	2014	0.196	5
Prediction	1	39	1990	2014	0.164	13
Radar	1	35	1991	2014	0.167	11
Rain	1	91	1990	2014	0.206	3
Simulation	1	41	1994	2014	0.204	4
Stratosphere	1	11	1995	2014	0.134	18
Summer	2	61	1991	2014	0.160	14
Surface temperature	1	14	1993	2014	0.133	19
Tropical cyclone	1	14	1994	2014	0.141	17
Water	1	53	1990	2014	0.179	8
Weather	2	31	1992	2014	0.132	20

***t_0**: the Initial (first) year (The Year in which no. of keywords occurrence first time; **t_n**: the last year (No. of keywords occurrence); **$V(t_0)$**: Initial observed value (no. of keywords occurrence); **$V(t_n)$**: last observed value (no. of keywords occurrence); **CAGR:** Compound Annual Growth Rate; **R:** Rank.*
Source: WoS

The Compound Annual Growth Rate (CAGR) described in Chapter 1, Section 1.8.5.2, can be used to select quick rising themes of MAS research; this reveals the indicators of future research directions. Table 4.2.b(ix) lists the top 20 keywords according to the CAGR and sorts them by their ranks. The ranks in Table 4.2.b(ix) show that ‘Black carbon’ , ‘El-nino’ and ‘Rain’ are three leading hot issues that continue to attract broad attention. ‘El-nino’ kept its dominance in terms of total quantity and compound annual growth rate.

K. Summary

A total of 5015 literature were published on MAS, which received total 46282 citations. The average number of publications per year was 119.40 and the average number of citations per publication was 9.23. Publications on MAS appeared in 162 journals of which most active journal was ‘Atmospheric Environment’ published by Elsevier from UK and 469 (9.352) of the total publications. A total of 7654 authors contributed to MAS research. The most active author is Moorthy, K. K. who produced maximum number of publications 96 of total publications. A total of 2078 institutions contributed of which Ministry of Earth Sciences, Hyderabad is the most productive institution. For globalization of MAS Research in India, the results show that there are 112 Countries/territories which participated in MAS research. The USA produced maximum publications with 482 i.e. 9.611 % of total publication with 8234 citations. A Keyword analysis reveals that El-nino, Aerosol, Climate, Monson, Rainfall are the most frequently used keywords.

4.3 Astronomy and Astrophysics (A & A)

Astronomy, a natural science, is the study of celestial objects (such as stars, galaxies, planets, moons, asteroids, comets and nebulae) and processes (such as supernovae explosions, gamma ray bursts, and cosmic microwave background radiation), the physics, chemistry, and evolution of such objects and processes, and more generally all phenomena that originate outside the atmosphere of Earth. A related but distinct subject, physical cosmology, is concerned with studying the Universe as a whole. Astronomy is one of the oldest sciences. The early civilizations in recorded history, such as the Babylonians, Greeks, Indians, Egyptians, Nubians, Iranians, Chinese, and Maya performed methodical observations of the night sky. Historically, astronomy has included disciplines as diverse as astrometry, celestial navigation, observational astronomy and the making of calendars, but professional astronomy is nowadays often considered to be synonymous with astrophysics ('Astronomy', n.d.).

Astrophysics is the branch of astronomy that deals with the physics of the universe, including the physical properties (luminosity, density, temperature, chemical composition) of astronomical objects such as stars, galaxies, and the interstellar medium, as well as their interactions. The study of physical cosmology is theoretical astrophysics at its largest scale; conversely, since the energies involved in cosmology, especially the Big Bang, are the largest known, the observations of the cosmos also serve as the laboratory for physics at its smallest scales as well ('Category: Astrophysics', n.d.).

4.3.1 Astrometry and Celestial Mechanics (ACM)

Astronomers use astrometric techniques for the tracking of near-Earth objects. Astrometry is responsible for the detection of many record-breaking Solar System objects. To find such objects astrometrically, astronomers use telescopes to survey the sky and large-area cameras to take pictures at various determined intervals. Once a movement per unit time is observed, astronomers compensate for the parallax caused by Earth's motion during this time and the heliocentric distance to this object is calculated. Using this distance and other photographs, more information about the object, including its orbital elements, can be obtained ('Astrometry', n.d.).

There were 3013 publications that met the selection criteria which appeared in the WoS database during 1960-2014 and these were analyzed.

A. Publication Characteristics

Table 4.3.a(i): Bibliographic Records of ACM research in India during 1960-2014

Bibliometric Indicators `	**No.**
Total Number of Articles	3013
Total Number of Contributing Countries	91
Total Number of Contributing Authors	17475
Total Number of Contributing Institutions	2188
Total Number of Journals appeared	101
Total Number of Keywords (raw) appeared	9506

Source: WoS

From the Tables 4.3.a(i) and 4.3.a(ii), the output of 3013 papers has received a total of 42275 citations during the said period with an average of about 14.03 citations per paper. The average number of publications per year is 70.06 and CAGR is 0.12%.

Table 4.3.a(ii): Citation Metrics of ACM research in India during 1960- 2014

Citation-based Indicators	No.
Sum of the Times Cited	42275
Sum of Times Cited without self-citations	38947
Citing Articles	30217
Citing Articles without self-citations	28762
Average Citations per Item	14.03
h-index	71

Source: WoS

B. Publication Pattern

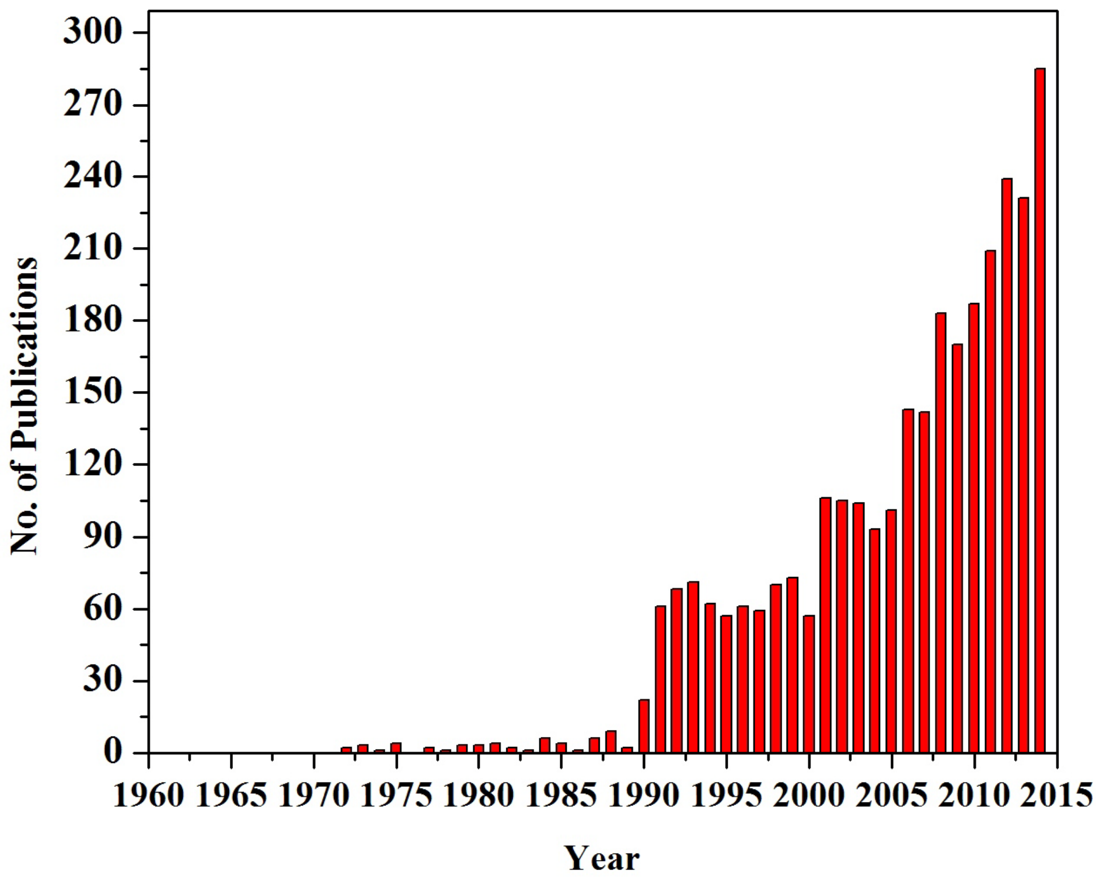

Figure 4.3.a(i): Publication Pattern of ACM research in India during 1960-2014. From the period 1960-1971, no publication appeared in the WoS database.

Publication pattern of ACM research from 1960 to 2014 is presented in Figure 4.3.a(i). The initial publication in the sub-field of ACM research is observed in the year 1972. A near about one hundred fourty times increase is observed over the study period, (from 2 in 1972 to 285 in 2014). The highest number of papers is published in the year 2014, with 285 publications and the lowest in 1976 with no publication.

C. Growth Trend

The cumulative progression is represented by a 4th degree power law distribution during 1960-2014 giving an idea of the polynomial growth curve as shown in Figure. 4.3.a(ii). To choose the best fit growth model, various regression types with regression coefficient has been tested as shown in Table 4.3.a(iii). The best fit model received 4th degree polynomial curve to the collected data set where $R^2 = 0.972$. The polynomial best fit for ACM research is found to be: $y = 0.0004x^4 - 2.9858x^3 + 8914.3x^2 - 1E+07x + 6E+09$, where y is the cumulative number of publications and x is the number of years. The growth of literature shown in Figure 4.3.a(ii) can be divided into two parts, 1st part (1960-1971), there is no literature published by Indian authors and in 2nd part (1972-2014), trend follows a polynomial growth curve.

Table 4.3.a(iii): Different Regression Types with Regression coefficient (R^2) of ACM research

Regression Type	Equation	(R^2)
Linear	$y = 5.6494x – 11189$	0.8254
Logarithmic	$y = 11246\ln(x) – 85371$	0.8235
Polynomial	$y = 0.0004x^4 - 2.9858x^3 + 8914.3x^2 - 1E+07x + 6E+09$	0.972

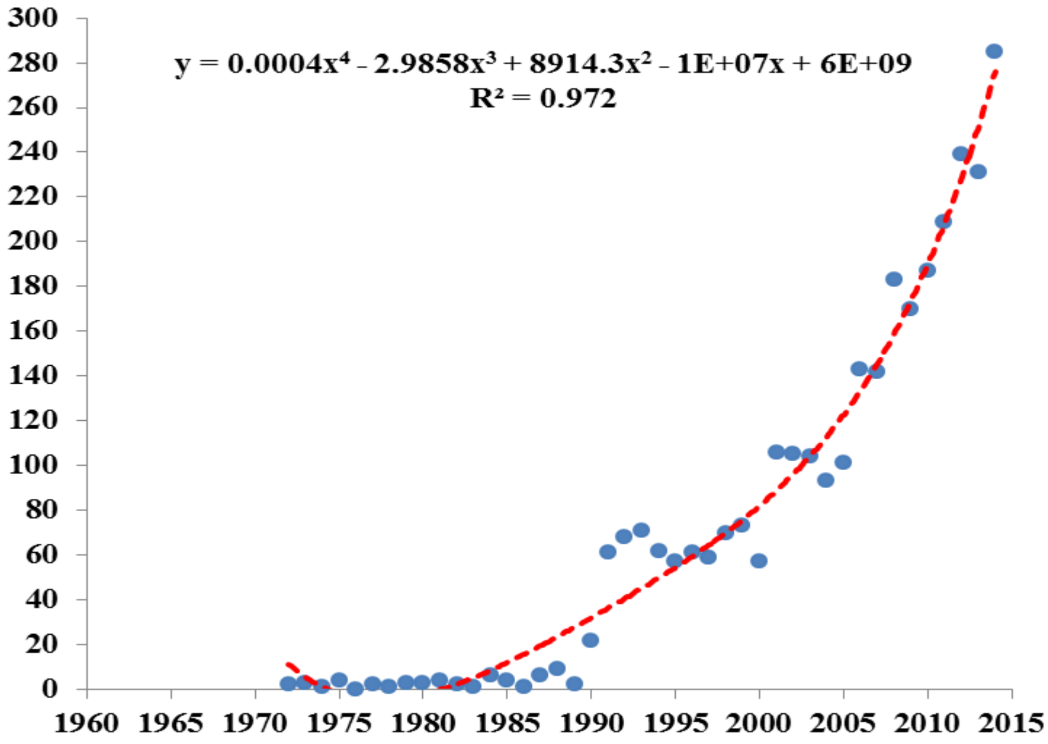

Figure 4.3.a(ii): Growth Trend of ACM research in India during 1960-2014. Blue dot describes the distribution of publications (observed value) and Red dashed line describe the correlation of distribution of publications where regression coefficient R^2 = 0.972

D. Citation Pattern

Figures 4.3.a(iii) and 4.3.a(iv) represent the citation pattern and number of citations vs. number of publications per year of ACM research in India during 1960-2014. A total of 3013 research papers have received 42275 citations. The pattern of citations is very fluctuating. In the initial year 1972, the total number of citations received is 31 with an average citation of 15.5. The minimum citations are received in the year 1986 and 1989 is zero (0) and the maximum citations are received in the year 2009 which are 4096 with an average citation of 24.09. It has been observed from Figure 4.3.a(iv) that after the year 2009, citations decrease while publications continue to increase.

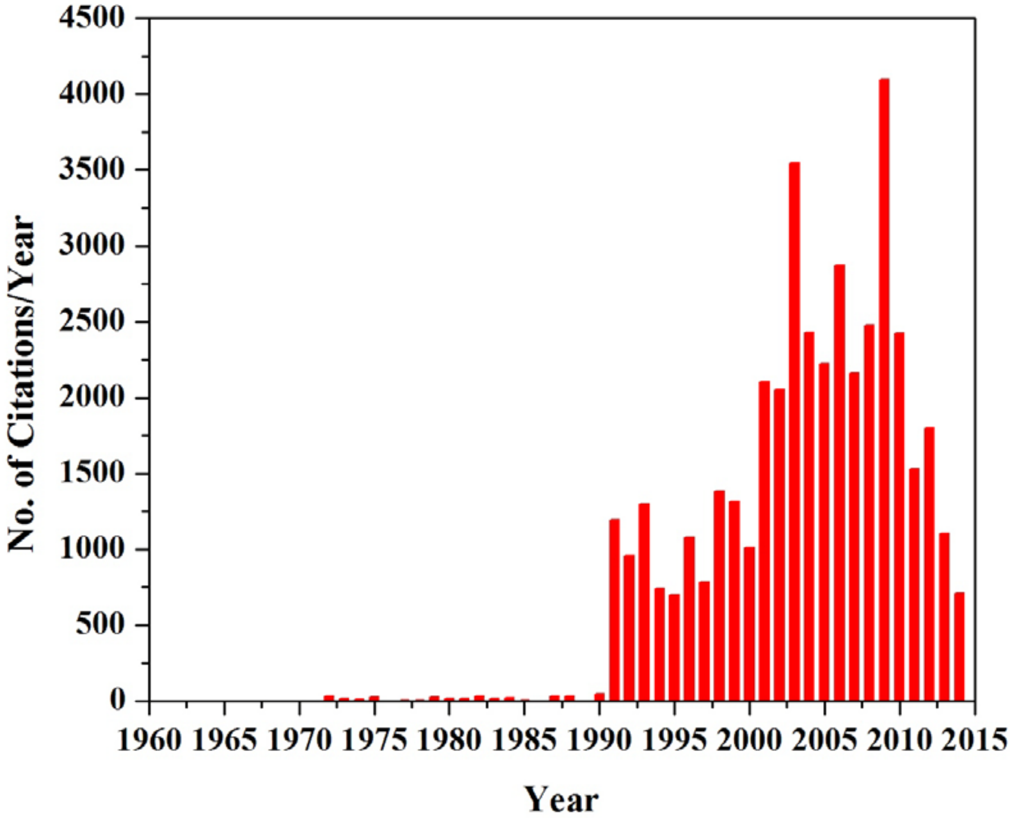

Figure 4.3.a(iii): Citation Pattern of ACM research in India during 1960-2014. From 1960-1971, no citation received as no publication appeared in the WoS database.

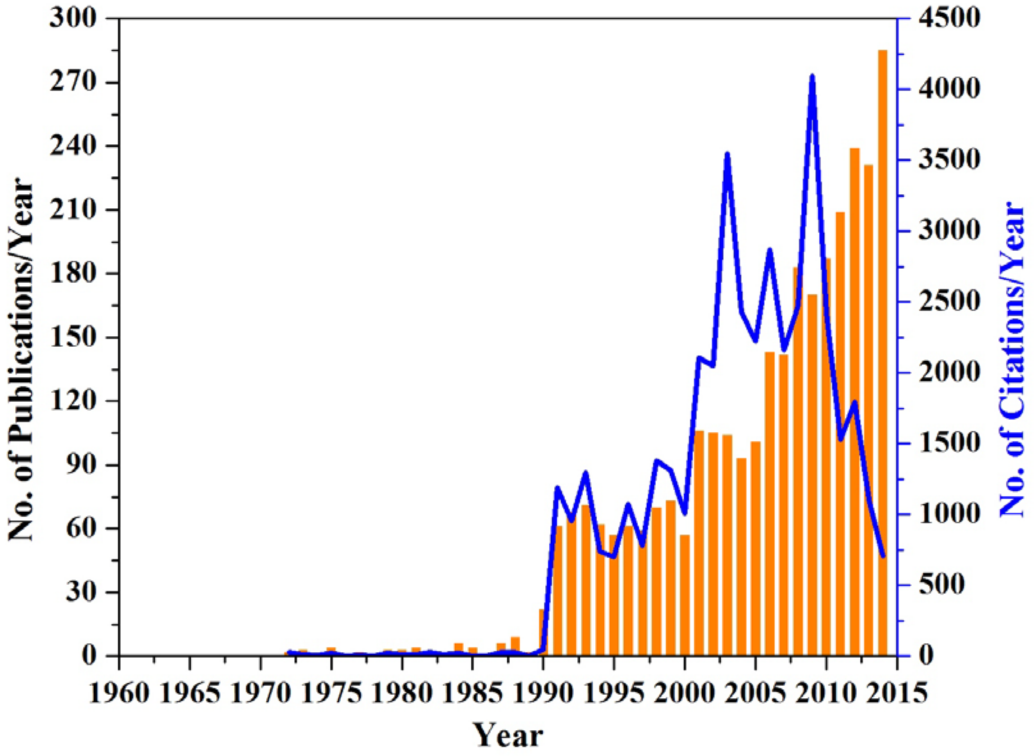

Figure 4.3.a(iv): Citation pattern Vs Publication Pattern of ACM research in India during 1960-2014: Blue line (right Y axis) indicates the citations pattern against orange bar (left Y axis) that describes the publications pattern.

E. Top Institutions and their research impact

A total of 3013 publications on ACM appeared from 2188 institutions. Table 4.3.a(iv) shows that out of the top 20 institutions, only 10 of these are Indian. Tata Institute of Fundamental Research, Mumbai, Physical Research Laboratory (PRL), Ahmadabad and Vikram Sarabhai Space Center (Department of Space). These institutions have published 442, 206 and 94 papers respectively. Indian Institute of Astrophysics (IIA), Raman Research Institute, Bangalore, Aryabhatta Research Institute of Observational Sciences, Nainital and Indian Institute of Geomagnetism, Mumbai, have published 345, 132,110 and 92 papers respectively. Inter University Centre for Astronomy Astrophysics and Jadavpur University have published papers 330 and 106 respectively. Indian Institute of Science (IISc) Banglore has published 82 papers.

Table 4.3.a(iv): Top institutions on ACM research and their research impact, 1960- 2014

Institution	Region	TP (%)	TC	AvgCPA	h-index
Tata Institute of Fundamental Research	India	442(14.670)	11711	26.50	45
Indian Institute of Astrophysics	India	345(11.450)	4760	13.80	34
Inter University Centre for Astronomy Astrophysics	India	330(10.953)	7160	21.70	45
Physical Research Laboratory	India	206(6.837)	1991	9.67	22
Max Planck Society	Germany	186(6.173)	6145	33.04	38
Centre National De La Recherche Scientifique	France	182(6.040)	5054	27.77	39
National Aeronautics Space Administration	USA	164(5.443)	7080	43.17	40
Russian Academy of Sciences	Russia	136(4.514)	3312	24.35	33
Raman Research Institute	India	132(4.381)	2036	15.42	24
California Institute of Technology	USA	116(3.850)	4889	42.15	33
Aryabhatta Research Institute of Observational Sciences	India	110(3.651)	976	8.87	16
University of California System	USA	107(3.551)	4606	43.05	31
Jadavpur University	India	106(3.518)	736	6.94	16
Chinese Academy of Sciences	China	98(3.253)	1936	19.76	25
Vikram Sarabhai Space Center	India	94(3.120)	738	7.85	16
United States Department of Energy	USA	94(3.120)	5788	61.57	30
Indian Institute of Geomagnetism	India	92(3.053)	900	9.78	16
Goddard Space Flight Center	USA	89(2.954)	3049	34.26	33
Observatoire De Paris	France	85(2.821)	3056	35.95	33
Indian Institute of Science	India	82(2.722)	1503	18.33	25

TP**= Total no. of ACM related articles published by an institution; **TC** = Total no. of citation received; **AvgCPA**= Average no. of citations per article; h-**index**=defined by the no. of h papers among an institution's no. of publications that have at least h citations each. **Source: WoS

Out of the 10 foreign collaborative institutions, 5 belong to the USA namely National Aeronautics Space Administration (NASA), California Institute of Technology, USA; University of California System, United States Department of Energy,Goddard Space Flight Center; and 2 belong to France namely Centre National De La Recherche Scientifique CNRS, France; Observatoire De Paris, France; 1 belongs to Germany viz. Max Planck Society; 1 to Russia - Russian Academy of Sciences, and 1 to China - Chinese Academy of Sciences.

Table 4.3.a(iv) reveals the impact of research in terms of quality of papers. It is seen from the Table 4.3.a(iv) that ACM related articles authored in collaboration with United States Department of Energy have the highest average impact (AvgCPA = 61.57) followed by NASA with average impact (AvgCPA = 43.17). Among Indian

institutions, Tata Institute of Fundamental Research has the highest average impact (26.50) in AvgCPA index.

F. Top Journals and their research impact

ACM papers have appeared in 101 journals. Papers have appeared in the highest numbers in the journal 'Physical Review D' published by the American Physical Society originating from the USA.

Table 4.3.a(v): Top Journals on ACM research and their research impact, 1960-2014

Journal	TP (%)	TC	AvgCPA	Journal Metrics (2013)			Country
				SJR	IPP	SNIP	
Physical Review D	415(13.774)	9796	23.60	1.899	3.192	1.136	USA
Astrophysics and Space Science	383(12.712)	2246	5.86	1.081	1.748	1.056	Netherland
Monthly Notices of the Royal Astronomical Society	365(12.114)	5426	14.87	3.196	4.911	1.494	USA
Astrophysical Journal	292(9.691)	6712	22.99	3.159	4.348	1.145	UK
Astronomy Astrophysics	254(8.430)	4583	18.04	1.471	1.932	0.612	France
Journal of Geophysical Research Space Physics	130(4.315)	1328	10.22	2.376	3.286	1.412	USA
Solar Physics	127(4.215)	1737	13.68	2.256	3.184	1.769	Netherland
Advances in Space Research	111(3.684)	454	4.09	0.751	1.416	1.291	Netherland
Annales Geophysicae	101(3.352)	903	8.94	1.176	1.533	1.533	Germany
International Journal of Modern Physics D	96(3.186)	795	8.28	0.733	1.021	0.540	Singapore
General Relativity and Gravitation	87(2.887)	774	8.90	1.109	1.628	1.015	UK
Journal of Astrophysics and Astronomy	77(2.556)	276	3.58	0.477	0.541	0.224	India
Classical and Quantum Gravity	71(2.356)	1196	16.85	1.476	2.192	0.966	UK
Indian Journal of Radio Space Physics	49(1.626)	86	1.76	0.347	0.514	0.621	India
Journal of Cosmology and Astroparticle Physics	36(1.195)	482	13.39	0.615	2.374	0.465	UK
Astrophysical Journal Letters	35(1.162)	503	14.37	3.914	4.852	1.487	UK
Radio Science	33(1.095)	282	8.55	0.994	1.265	1.078	USA
Planetary and Space Science	31(1.029)	384	12.39	0.925	1.560	0.800	Netherlands
Astronomical Journal	30(0.996)	304	10.13	2.795	3.282	1.092	UK
Annales Geophysicae Atmospheres Hydrospheres and Space Sciences	30(0.996)	390	13.00	-	-	-	Germany

TP**= Total no. of ACM research related articles published by a Journal; **TC** = Total no. of citation received; **AvgCPA**= Average no. of citations that ACM related articles in a journal received; **h-index**= no. of h papers among a journal's no. of publications that have at least h citations each. **SJR** = SCImago Journal Rank; **IPP** = Impact per Publication; **SNIP** = Source Normalized Impact per Paper; **Source: WoS and SCOPUS

Table 4.3.a(v) shows the top 20 productive journals. These 20 out of the 101 journals have published 1724 (73.20%) of the total 3013 articles. The 'Physical

Review D' ranked 1st with 415 (13.77%) publications ; 'Astrophysics and Space Science 383 (12.71%)', 'Monthly Notices of the Royal Astronomical Society 365 (12.11%)', 'Astrophysical Journal 292 (9.69%)', and 'Astronomy Astrophysics 254 (8.43%)' ranked at 2nd , 3rd , 4th and 5th respectively.

Table 4.3.a(v) also shows the citation impact on top 20 journals. It is seen from the Table 4.3.a(v) that the journal 'Physical Review D' published by IOP Publishing for the American Physical Society in USA has the highest number of publications as well as highest average impact (AvgCPA = 23.60) followed by the journal 'Astrophysical Journal' which has the second highest average impact (AvgCPA = 22.99).

G. Top Authors and their research impact

A total of 3013 articles included the author addresses having India as the country of affilation. Articles on ACM research have been contributed by 17475 authors. Table 4.3.a(vi) showed the top 20 productive authors during the period 1960-2014. Top 20 productive authors are ranked based on the decreasing productivity of total publications. Sagar, R. produced maximum number of publications - 51 i.e. 1.69% of total publications and ranked first followed by Chakraborty, S., Chakrabarti, S. K., Padmanabhan, T. and Choi, Y. at 2nd, 3rd and 4th ranks respectively.

Table 4.3.a(vi) reveals the impact of research in terms of quality of papers. It is seen from the Table 4.3.a(vi) that ACM related articles authored by Padmanabhan, T. have the highest average impact (AvgCPA = 26.64) followed by Yamashita, Y. (AvgCPA = 25.26) although Sagar, R having the maximum number of publications but ranks 18th in the AvgCPA index.

Table 4.3.a(vi): Top Authors of ACM research and their research impact, 1960-2014

Author	TP(%)	TC	TC woSC	CI	CIwoSC	AvgCPA	h-index
Sagar, R.	51(1.693)	940	904	773	751	18.43	19
Chakraborty, S.	50(1.659)	241	216	197	183	4.82	9
Chakrabarti, S.K.	48(1.593)	766	694	447	417	15.96	16
Padmanabhan, T.	45(1.494)	1199	1144	899	876	26.64	18
Choi, Y.	45(1.494)	1079	1022	830	803	23.98	16
Sakai, Y.	44(1.460)	1072	1015	821	794	24.36	16
Schneider, O.	43(1.427)	1061	1004	812	785	24.67	16
Piilonen, Le.	43(1.427)	1061	1004	812	785	24.67	16
Nishida, S.	43(1.427)	1061	1004	812	785	24.67	16
Li, J.	43(1.427)	1151	1113	948	927	26.77	20
Eidelman, S.	43(1.427)	1061	1004	812	785	24.67	16
Cheon, B.G.	43(1.427)	1061	1004	812	785	24.67	16
Zhang, Z.P.	42(1.394)	983	942	785	761	23.40	16
Yamashita, Y.	42(1.394)	1061	1004	812	785	25.26	16
Wang, Ch.	42(1.394)	1060	1005	812	786	25.24	16
Uno, S.	42(1.394)	1058	1001	810	783	25.19	16
Unno, Y.	42(1.394)	853	825	695	676	20.31	14
Uehara, S.	42(1.394)	1060	1005	812	786	25.24	16
Teramoto, Y.	42(1.394)	1058	1004	811	785	25.19	16
Miyata, H.	42(1.394)	845	796	667	641	20.12	16

TP: *Total no. of ACM related articles published by a author;* ***TC:*** *Total no. of citation****; TC woSc:*** *Sum of Times Cited without self-citations****; CI:*** *Citing Articles* ***; CIwoSC:*** *Citing Articles without self-citations****; AvgCPA:*** *Average Citations per Article****; h-index :*** *no. of h papers among a author's no. of publications that have at least h citations each.* ***Source: WoS***

H. Collaboration Pattern: Continents

Based on the author attributions, world-wide geographic collaboration of ACM research publications can be mapped. As shown in Figure 4.3.a(v), the major spatial clusters of research collaborations are located in Europe, followed by Asia and Africa. Several minor clusters distributed in other parts of the world like South America, North America and Australia.

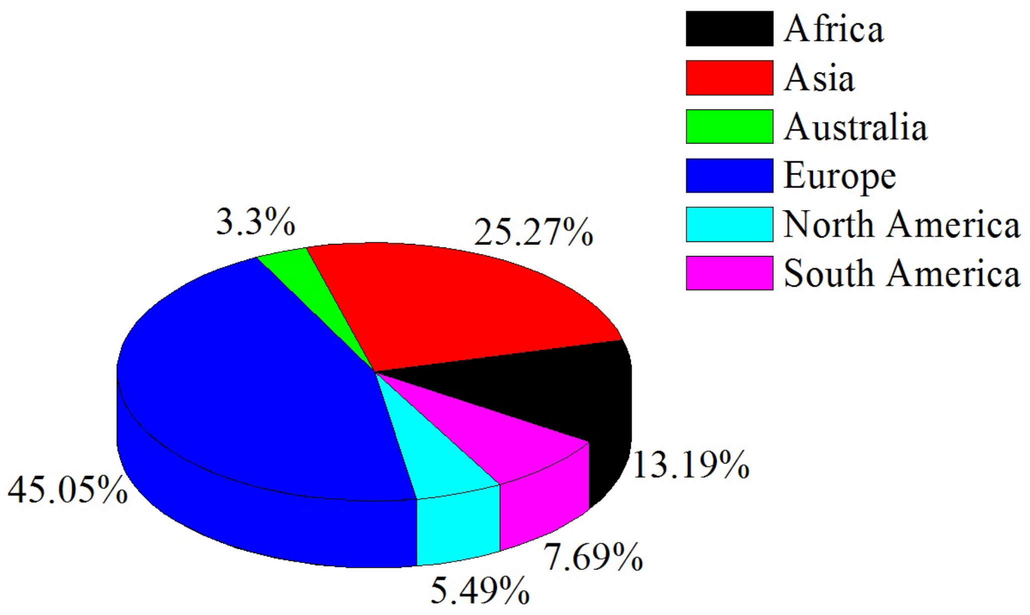

Figure 4.3.a(v): Continent wise Collaboration pattern of ACM research

I. Collaboration Pattern and research impact: Countries

Table 4.3.a(vii): Country wise Collaboration Pattern and research impact of ACM research

Country	Continent	TP (%)	TC	AvgCPA	h-index
USA	North America	665(22.071)	19054	28.65	61
Germany	Europe	323(10.720)	9941	30.78	48
France	Europe	223(7.401)	6377	28.60	42
Japan	Asia	212(7.036)	6417	30.27	40
England	Europe	200(6.638)	7431	37.15	41
Italy	Europe	193(6.406)	5258	27.24	41
Russia	Europe	179(5.941)	4548	25.41	39
Australia	Australia	163(5.410)	6614	40.58	40
Spain	Europe	145(4.812)	5444	37.54	37
Peoples R China	Asia	129(4.281)	2596	20.12	30
South Korea	Asia	125(4.149)	4132	33.06	26
Poland	Europe	119(3.950)	4550	38.24	31
Taiwan	Asia	110(3.651)	1946	17.69	26
Canada	North America	102(3.385)	4608	45.18	32
Switzerland	Europe	87(2.887)	3933	45.21	27
Netherlands	Europe	85(2.821)	3802	44.73	29
Brazil	South America	84(2.788)	1609	19.15	24
Austria	Europe	79(2.622)	1745	22.09	22
Chile	South America	68(2.257)	3610	53.09	24
South Africa	Africa	65(2.157)	3467	53.34	23

TP*= Total no. of ACM related articles published by a country;* ***TC*** *= Total no. of citation received;* ***AvgCPA****= Average no. of citations per Article;* ***h-index****= no. of h papers among a country's no. of publications that have at least h citations each.* ***Source: WoS***

The 3013 articles retrieved from the WoS included author address, source country and research institute. Table 4.3.a(vii) shows that the USA has produced maximum publications viz. 665 which is 22.07% of total publications with high citations (19054). It is seen from the said Table 4.3.a(vii) that ACM related articles authored in collaboration with South Africa (Africa) have the highest average impact (AvgCPA = 53.34) followed by Chile (South America) AvgCPA = 53.09, while the USA ranks 13th in the AgvCPA index.

J. Keyword Analysis

This work has revealed 9506 different keywords, during the period of study. The number of analysed publications during the study period is 2656. Of these only 2483 provide keywords.While the rest (173) did not have any keywords. To obtain the accurate results, the keywords were pre-processed by merging the singular and plural forms of the same terminology, and those keywords with the same meaning while using different expressions. 8746 unique Keywords have been obtained. Among these unique keywords 2886 (32.99%) appear once or twice at the most. Table 4.3.a(viii) shows the most used keywords during the considered period.

J.1 Hotspots

An analysis of the keywords was undertaken to pick out the hotsopts that have attracted most research attention and to reveal the research tendencies in the fields of ACM. The top 20 most frequently used keywords for the study period are listed in Table 4.3.a(viii). The four most frequently used keywords were ‘Model’, ‘stars’, ‘time’ and ‘Universe’.

Table 4.3.a(viii): Top most frequently used keywords in ACM research

Keyword	NO	%	R
Model	495	5.65	1
Stars	463	5.29	2
Time	443	5.06	3
Universe	300	3.43	4
Region	292	3.33	5
Dynamics	274	3.13	6
Emission	270	3.08	7
Evolution	267	3.05	8
Sun	262	2.99	9
Radiation	246	2.81	10
Cosmology	203	2.32	11
Gravity	190	2.17	12
Oscillations	168	1.92	13
Ionosphere	166	1.89	14
Variability	158	1.80	15
Supernovae	155	1.77	16
Dark energy	126	1.44	17
Space-time	118	1.34	18
General-relativity	95	1.08	19
Cosmological constant	81	0.92	20

NO: Number of time occurrences; R : rank ***Source: WoS***

J.2 Quick rising themes

To identify the top quick rising themes, the Compound Annual Growth Rate (CAGR) has been put to use. The quick rising theme can symbolise the future research trends. Table 4.3.a(ix) lists the top 20 keywords according to the CAGR and sorted them by their rank. The ranks in Table 4.3.a(ix) show that ‘Dark energy’ and ‘Stars’ and ‘Sun’ are three leading hot issues that continue to attract broad attention. ‘stars’ kept its dominance in terms of total quantity and CAGR.

Table 4.3.a(ix): Top Quick rising themes in ACM research

Keyword	V (t_0)	V (t_n)	t_0	t_n	CAGR (%)	R
Model	4	55	1991	2014	0.120	9
Stars	1	35	1990	2014	0.159	2
Time	3	53	1991	2014	0.132	6
Universe	4	33	1991	2014	0.096	13
Region	1	31	1990	2014	0.153	4
Dynamics	4	32	1992	2014	0.099	12
Emission	7	29	1991	2014	0.063	17
Evolution	5	25	1991	2014	0.072	15
Sun	1	33	1990	2014	0.156	3
Radiation	3	34	1991	2014	0.111	10
Cosmology	3	19	1991	2014	0.083	14
Gravity	1	21	1991	2014	0.141	5
Oscillations	1	14	1991	2014	0.121	8
Ionosphere	3	19	1991	2014	0.083	14
Variability	4	18	1991	2014	0.067	16
Supernovae	1	21	1993	2014	0.156	3
Dark energy	1	25	2003	2014	0.339	1
Space-time	1	13	1992	2014	0.123	7
General-relativity	1	10	1992	2014	0.110	11
Cosmological constant	2	10	2000	2014	0.121	8

t_0**: the Initial (first) year (The Year in which no. of keywords occurrence first time; **t_n**: the last year (No. of keywords occurrence); **V(t_0)**: Initial observed value (no. of keywords occurrence); **V(t_n)**: last observed value (no. of keywords occurrence); **CAGR:** Compound Annual Growth Rate; **R:** Rank. **Source: WoS

K. Summary

A total of 3013 literature were published on ACM which received 42275 citations. The average number of publications per year is 70.06 and average number of citations per publication was 14.03. Publications on ACM appeared in 101 journals of which most active journal was ‘Physical Review D’ published by American Physical Society originating from USA and 415 (13.77%) of the total 3013 publications. A total of 17475 authors contributed on ACM research. The most active author was Sagar, R who produced maximum number of publications 51 (1.69%) of total publications. A total of 2188 institutions contributed of which Tata Institute of Fundamental Research, Mumbai, is the most productive institution. For globalization of ACM Research in India, the results show that there are 91 Countries/territories which participated in ACM research. The USA produced maximum publications - 665 i.e. 22.07% of total publication with 19054 citations. A Keyword analysis reveals that ‘Model’, ‘stars’, ‘time’, ‘Universe’ and ‘region’ are the most frequently used keywords.

4.3.2 Astronomical Instrumentation, Methods and Technique (AIMT)

Scientific instruments are a source for the development of science and technology and their importance cannot be underestimated. In India, various kinds of astronomical and time-measuring instruments have been in use since time immemorial. Their construction and use are even discussed in a number of Sanskrit texts (Sarma, 1994). The field of astronomical instrumentation involves development of various instruments and telescopes for the detection of the photons.

There were 2296 publications that met the selection criteria which appeared in the WoS database during 1960-2014 and these were analyzed.

A. Publication Characteristics

Table 4.3.b(i): Bibliographic Records of AIMT research in India during 1960-2014

Bibliometric Indicators `	No.
Total Article found:	2296
Total Number of Countries contribution	86
Total Number of Author's contribution	905
Total Number of Institution's contribution	1883
Total Number of Journal appeared	85
Total Number of Keywords (raw) appeared	2514

Source: WoS

The total 2296 articles of Indian scientists during 1960-2014 were abstracted from WoS related to AIMT publications. From the Tables 4.3.b(i) and 4.3.b(ii), the output of 2296 papers has received a total of 36316 citations during the said period with an average of about 15.82 citations per paper. The average number of publications per year is 72.86 and Compound Annual Growth Rate (CAGR) is 0.15%.

Table 4.3.b(ii): Citation Metrics of AIMT research in India during 1960-2014

Citation-based Indicators	No.
Sum of the Times Cited	36316
Sum of Times Cited without self-citations	32426
Citing Articles	23394
Citing Articles without self-citations	22114
Average Citations per Item	15.82
h-index	75

Source: WoS

B. Publication Pattern

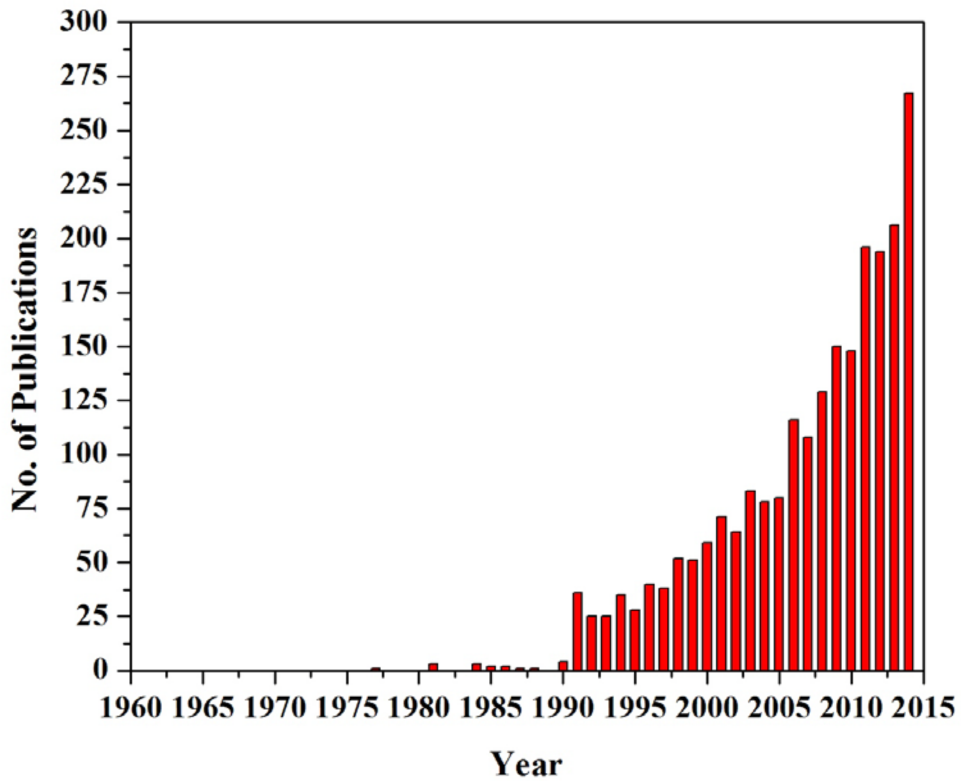

Figure 4.3.b(i): Publication Pattern of AIMT research in India during 1960-2014. From the period 1960-1976, no publication appeared in the WoS database.

Publication pattern of AIMT research from 1960 to 2014 is presented in Figure 4.3.b(i). The initial publication in the sub-field of AIMT research is observed in the year 1977. A near about two hundred sixty (260) times increase was observed over the study period, (from 1 in 1977 to 267 in 2014). The highest number of papers is published in the year 2014, with 267 publications and the lowest in 1978 with no publication.

C. Growth Trend

The cumulative progression is represented by a 4th degree power law distribution during 1960-2014 giving an idea of the polynomial growth curve as shown in Figure 4.3.b(ii). To choose the best fit growth model, various regression types with regression coefficients have been tested as shown in Table 4.3.b(iii). The best fit model is 4th degree polynomial curve, where $R^2 = 0.985$. The polynomial best fit for AIMT research is found to be: $y = 0.0005x^4 - 4.237x^3 + 12660x^2 - 2E{+}07x + 8E{+}09$, where y is the cumulative number of publications and x is the number of years. The growth of literature shown in Figure 4.3.b(ii) can be divided into two parts. In 1st part (1960-1976), there is no literature published by Indian authors and the 2nd part (1977-2014), follows a polynomial growth curve.

Table 4.3.b(iii): Different Regression Types with Regression coefficient (R^2) of AIMT research

Regression Type	Equation	(R^2)
Linear	$y = 5.6849x - 11284$	0.810
Logarithmic	$y = 11332\ln(x) - 86045$	0.809
Polynomial	$y = 0.0005x^4 - 4.237x^3 + 12660x^2 - 2E{+}07x + 8E{+}09$	0.985

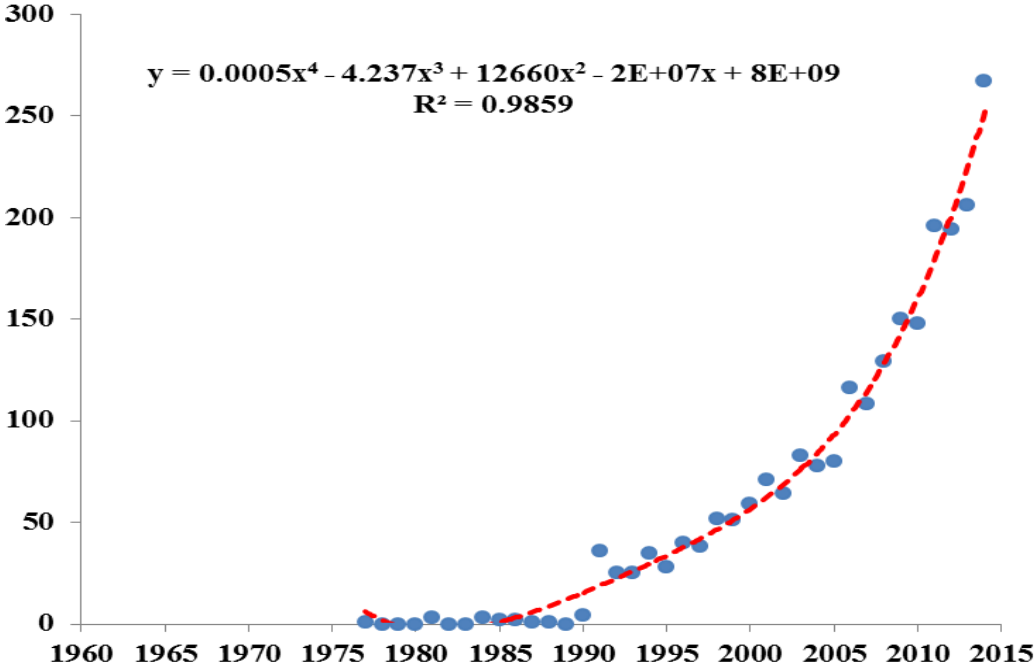

Figure 4.3.b(ii): Growth Pattern of AIMT research in India during 1960-2014.Blue dot describes the distribution of publications (observed value) and red dashed line describe the correlation of distribution of publications where regression coefficient R^2 = 0.985

D. Citation Pattern

Figures 4.3.b(iii) and 4.3.b(iv) represent the citation pattern and number of citations vs. number of publications per year during 1960-2014 on AIMT. A total of 2656 research papers have received 44732 citations. The pattern of citations is very fluctuating. In the initial year 1977, the total number of citations received is 5 with an average citation of 5. The minimum citation received in the year 1997 is zero (0) and the maximum citations received in the year 2011 are 3287 with an average citation of 16.77. It is observed from Figure 4.3.b(iv) that after the year 2011, the number of citations drop sharply and rise back considerably in the year 2013, while the publications increase all along.

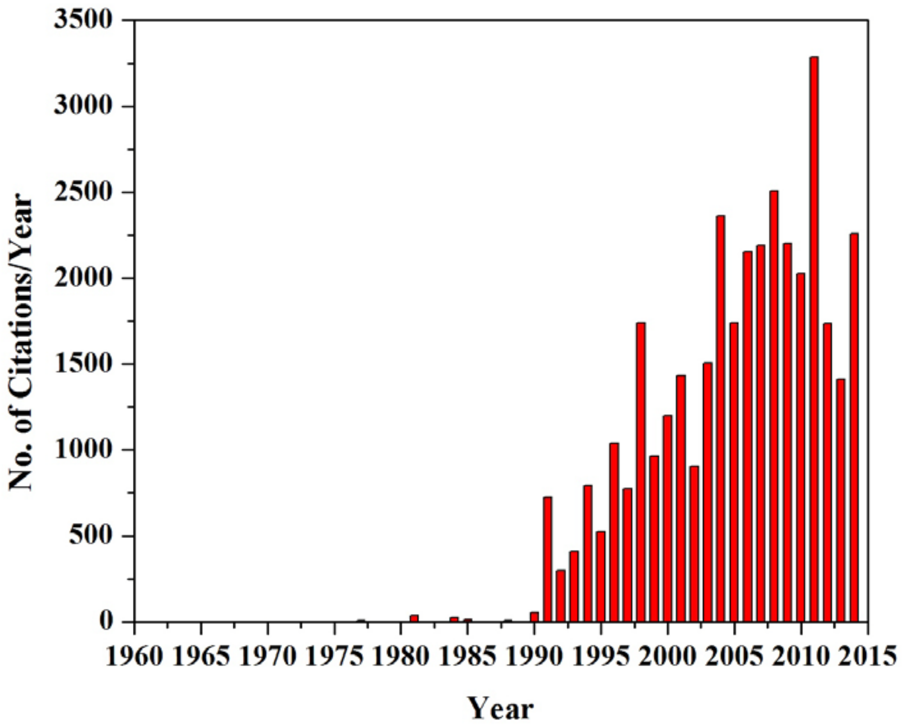

Figure 4.3.b(iii): Citation Pattern of AIMT research in India during 1960-2014. From 1960-1976, no citation received as no publication appeared in the WoS database.

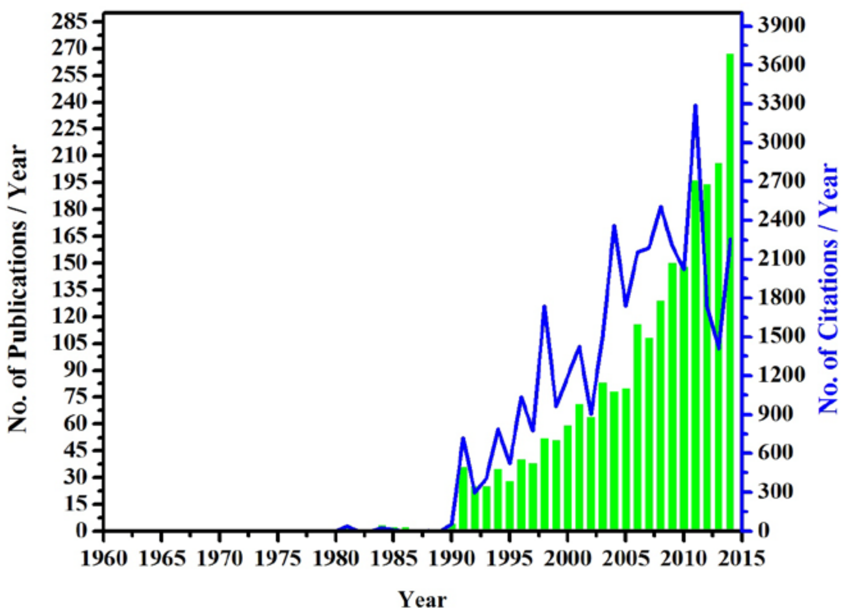

Figure 4.3.b(iv): Citation Pattern Vs Publication Pattern of AIMT research in India during 1960-2014: Blue line (right Y axis) indicates the citation pattern against green bar line (left Y axis) that describes the publications pattern

E. Top Institutions and their research impact

In the AIMT research, a total of 2296 articles appeared from 1883 institutions. Table 4.3.b(iv) shows that out of these top 20 institutions only 6 are Indian. Tata Institute of Fundamental Research contributed highest number of publications (584), followed by Inter University Centre for Astronomy Astrophysics which contributed 396 publications, Indian Institute of Astrophysics had a share of 339 publications, Raman Research Institute and Physical Research Laboratory (PRL) with 219, and Aryabhatta Research Institute of Observational Sciences with 109, publications respectively. The other 14 are foreign institutions, among these 7 belong to the USA namely National Aeronautics Space Administration (NASA), USA; California Institute of Technology, University of California System, Goddard Space Flight Center, United States Department of Energy, Harvard University, Florida State University System ; 3 are from France namely Centre National De La Recherche Scientifique CNRS; Observatoire De Paris, Pierre Marie Curie University; 1 each from Australia, Russia and Germany.

Table 4.3.b(iv): Top institutions on AIMT research and their research impact, 1960- 2014

Institution	Region	TP (%)	TC	AvgCPA	h-index
Tata Institute of Fundamental Research	India	584(25.436)	7764	13.29	41
Inter University Centre for Astronomy Astrophysics	India	396(17.247)	11056	27.92	52
Indian Institute of Astrophysics	India	339(14.765)	4497	13.27	33
Centre National De La Recherche Scientifique	France	319(13.894)	9746	30.55	48
Max Planck Society	Germany	273(11.890)	9020	33.04	49
National Aeronautics Space Administration	USA	242(10.540)	9773	40.38	52
Raman Research Institute	India	219(9.538)	3334	15.22	32
Physical Research Laboratory India	India	219(9.538)	1693	7.73	21
California Institute of Technology	USA	195(8.493)	7469	38.30	45
Observatoire De Paris	France	167(7.274)	6427	38.49	42
University of California System	USA	144(6.272)	5510	38.26	38
Goddard Space Flight Center	USA	143(6.228)	5745	40.17	44
Russian Academy of Sciences	Russia	132(5.749)	3992	30.24	35
United States Department of Energy	USA	124(5.401)	5214	42.05	37
Centre for Extragalactic Astronomy	South Africa	117(5.096)	5211	44.54	39
Pierre Marie Curie University Paris	France	114(4.965)	4149	36.39	35
Florida State University System	USA	113(4.922)	5031	44.52	40
Harvard University	USA	112(4.878)	2917	26.04	23
Australian National University	Australia	110(4.791)	3576	32.51	37
Aryabhatta Research Institute of Observational Sciences	India	109(4.747)	1035	9.50	18

TP= *Total no. of AIMT related articles published by an institution;* ***TC*** *= Total no. of citation received;* ***AvgCPA***= *Average no. of citations per article; h-**index**=defined by the no. of h papers among an institution's no. of publications that have at least h citations each.* ***Source: WoS***

Table 4.3.b(iv) reveals the impact of research in terms of quality of papers. It is seen from this Table [4.3.b(iv)] that AIMT related articles authored in collaboration with Centre for Extragalactic Astronomy have the highest average impact (AvgCPA = 44.54) followed by Florida State University System (AvgCPA = 44.52). Among the Indian institutions, Inter University Centre for Astronomy Astrophysics has the highest average impact (27.92) in the AgvCPA index.

F. Top Journals and their research impact

AIMT research papers have appeared in 85 journals. Papers have appeared in highest numbers in the journal 'Monthly Notices of the Royal Astronomical Society' published by Oxford University Press on behalf of the Royal Astronomical Society originating from the United Kingdom. Table 4.3.b(v) shows the top 20 productive journals. These 20 out of the 85 journals have published 1593 (69.38 %) of the total 2296 articles. The 'Monthly Notices of the Royal Astronomical Society' ranked first with 489 papers (21.29%) followed by 'Astrophysical Journal with 391 papers (17.03%)', 'Astronomy Astrophysics with 350 pubications (15.24%)', 'Physical Review D with 161 (7.01%)' and 'Journal of Astrophysics and Astronomy with 102 (4.44%)' papers, these journals ranked 2^{nd} , 3^{rd} , 4^{th} and 5^{th} respectively.

Table 4.3.b(v) also shows the citation impact of top 20 journals. The journal 'Astroparticle Physics' published by Elsevier and the journal 'Astrophysical Journal Supplement Series' published by IOP Publishing, both have the highest average impact (AvgCPA = 69.84), it is seen that though the journal 'Monthly Notices of the

Royal Astronomical Society' has the highest number of publications but ranked 8th in the AgvCPA index.

Table 4.3.b(v): Top Journals on AIMT research and their research impact, 1960-2014

				Journal Metrics (2013)			
Journal	**TP (%)**	**TC**	**AvgCPA**	**SJR**	**IPP**	**SNIP**	**Country**
Monthly Notices of the Royal Astronomical Society	489(21.298)	6767	13.84	3.196	4.911	1.494	UK
Astrophysical Journal	391(17.030)	8626	22.06	3.159	4.348	1.145	UK
Astronomy Astrophysics	350(15.244)	7315	20.90	1.471	1.932	0.612	France
Physical Review D	161(7.012)	5130	31.86	1.899	3.192	1.136	USA
Journal of Astrophysics and Astronomy	102(4.443)	433	4.25	0.477	0.541	0.224	India
Astrophysics and Space Science	82(3.571)	478	5.83	1.081	1.748	1.056	Netherland
Solar Physics	78(3.397)	845	10.83	2.256	3.184	1.769	Netherland
Advances in Space Research	58(2.526)	198	3.41	0.751	1.416	1.291	Netherland
Astrophysical Journal Letters	50(2.178)	596	11.92	3.914	4.852	1.487	UK
Astronomical Journal	42(.829)	605	14.40	2.795	3.282	1.092	UK
Bulletin of the Astronomical Society of India	38(1.655)	90	2.37	1.091	1.068	0.516	India
Indian Journal of Radio Space Physics	31(1.350)	51	1.65	0.347	0.514	0.621	India
Experimental Astronomy	31(1.350)	114	3.68	1.072	2.146	1.882	Netherlands
Classical and Quantum Gravity	30(1.307)	784	26.13	1.476	2.192	0.966	UK
Journal of Geophysical Research Space Physics	26(1.132)	259	9.96	2.376	3.286	1.412	USA
Astroparticle Physics	26(1.132)	1746	69.84	3.012	3.828	2.776	Netherlands
Research in Astronomy and Astrophysics	25(1.089)	76	3.04	0.953	1.331	0.768	UK
Astrophysical Journal Supplement Series	25(1.089)	1746	69.84	6.857	9.687	3.125	USA
Annales Geophysicae	25(1.089)	204	8.16	1.176	1.533	1.533	Germany
Journal of Cosmology and Astroparticle Physics	22(0.958)	299	13.59	0.615	2.374	0.465	UK

TP*= Total no. of AIMT research related articles published by a Journal;* ***TC*** *= Total no. of citation received;* ***AvgCPA****= Average no. of citations that AIMT related articles in a journal received;* ***h-index****= no. of h papers among a journal's no. of publications that have at least h citations each.* ***SJR*** *= SCImago Journal Rank;* ***IPP*** *= Impact per Publication;* ***SNIP*** *= Source Normalized Impact per Paper;* ***Source: WoS and SCOPUS***

G. Top authors and their research impact

A total of 2296 articles included the author addresses having India as the country of affilation. Articles on AIMT have been contributed by 905 authors. Table 4.3.b(vi) shows the top 20 productive authors during the last 54 years, 1960-2014. Top 20 productive authors are ranked based on the decreasing productivity of total publications. Mitra, S. produced maximum number of publications i.e. 66 which is 2.875 % of total publications and ranked 1st followed by Dhurandhar, S., Bose, S. and Sathyaprakash, B. S. at 2nd, 3rd and 4th ranks respectively.

Table 4.3.b(vi): Top Authors of AIMT research and their research impact, 1960-2014

Author	TP (%)	TC	TC woSC	CI	CIwoSC	AvgCPA	h-index
Mitra, S.	66(2.875)	2996	2315	1440	1387	45.39	35
Dhurandhar, S.	65(2.831)	2426	2229	1034	980	37.32	31
Bose, S.	63(2.744)	2467	2285	1074	1023	39.16	32
Sathyaprakash, B.S.	62(2.700)	2562	2404	1270	1223	41.32	32
Saikia, D.J.	59(2.570)	788	666	522	478	13.36	17
Chengalur, J.N.	59(2.570)	1068	972	661	619	18.10	20
Mccarthy, R.	58(2.526)	2355	2186	1038	990	40.60	31
Yoshida, S.	57(2.483)	2451	2282	1120	1073	43.00	32
Whelan, J.T.	57(2.483)	2360	2179	1013	963	40.69	31
Vecchio, A.	57(2.483)	2397	2227	1050	1002	42.05	32
Lazzarini, A.	57(2.483)	2329	2165	999	951	40.86	31
Zhang, L.	56(2.439)	2310	2142	996	949	41.25	31
Mukherjee S	56(2.439)	2460	2292	1143	1096	43.93	31
Grote H	56(2.439)	2357	2188	1025	977	42.09	31
Gonzalez G	56(2.439)	2356	2174	1015	967	42.07	31
Danzmann K	56(2.439)	2357	2188	1025	977	42.09	31
Buonanno A	56(2.439)	2444	2272	1062	1015	43.64	32
Babak S	56(2.439)	2365	2183	1011	963	42.23	32
Woan G	55(2.395)	2341	2172	1017	969	42.56	31
Willke B	55(2.395)	2322	2158	1020	973	42.22	31

TP: *Total no. of AIMT related articles published by a author;* ***TC:*** *Total no. of citation;* ***TC woSc:*** *Sum of Times Cited without self-citations;* ***CI:*** *Citing Articles;* ***CIwoSC:*** *Citing Articles without self-citations;* ***AvgCPA:*** *Average Citations per Article;* ***h-index:*** *no. of h papers among a author's no. of publications that have at least h citations each.* ***Source: WoS***

Table 4.3.b(vi) reveals the impact of research in terms of quality of papers by means of AvgCPA and the h-index. AIMT articles authored by Mitra, S. have the highest number of publications as well as the highest average impact (AvgCPA = 45.39) followed by Mukherjee, S. (AvgCPA = 43.93) who ranked 2nd in the AgvCPA index.

H. Collaboration pattern: Continents

Based on the author attributions, world-wide collaboration of AIMT research publications can be mapped. As shown in Figure 4.3.b(v), the major spatial clusters of research publications are located in Europe, followed by Asia and Africa. Several minor clusters are distributed in other parts of the world. North America and South America have equal contributions.

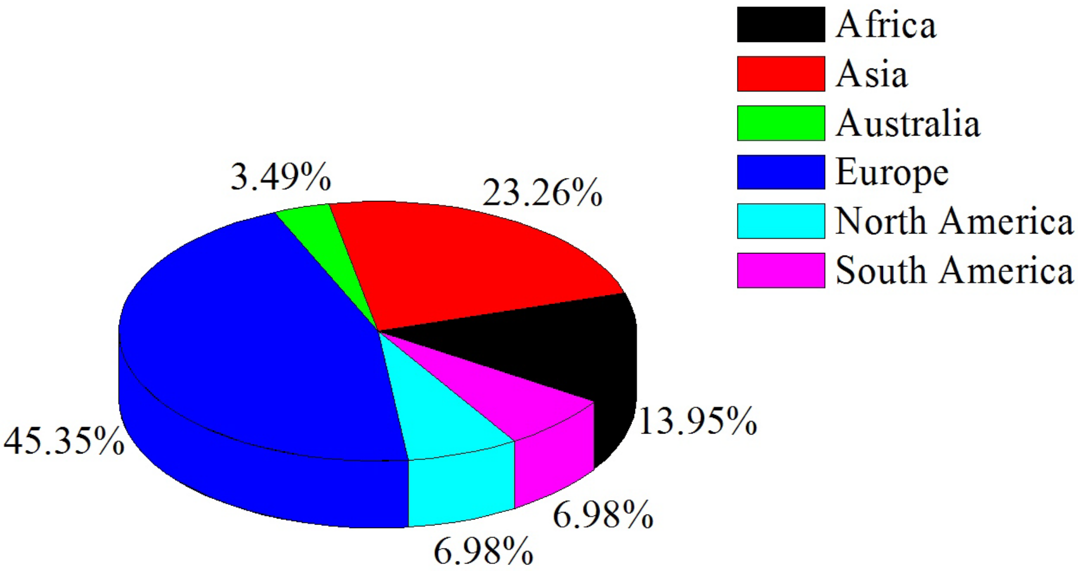

Figure 4.3.b(v): Continent wise Collaboration pattern of AIMT research

I. Collaboration Pattern and research impact: Countries

Table 4.3.b(vii): Country wise Collaboration Pattern and research impact of AIMT research

Country	Continent	TP(%)	TC	AvgCPA	h-index
USA	North America	789(34.364)	20661	26.19	66
Germany	Europe	412(17.944)	11723	28.45	54
France	Europe	381(16.594)	12221	32.08	52
England	Europe	331(14.416)	10861	32.81	52
Italy	Europe	263(11.455)	9691	36.85	49
Australia	Australia	242(10.540)	7331	30.29	46
Spain	Europe	228(9.930)	8250	36.18	48
Japan	Asia	199(8.667)	5199	26.13	42
Russia	Europe	183(7.970)	6372	34.82	44
Canada	North America	164(7.143)	6489	39.57	41
Netherlands	Europe	161(7.012)	4658	28.93	37
Poland	Europe	125(5.444)	3871	30.97	35
Wales	Europe	115(5.009)	5007	43.54	41
Peoples R China	Asia	115(5.009)	2363	20.55	29
Chile	South America	109(4.747)	4113	37.73	34
Taiwan	Asia	96(4.181)	3196	33.29	33
South Africa	Africa	95(4.138)	3305	34.79	34
Brazil	South America	93(4.051)	2583	27.77	28
South Korea	Asia	90(3.920)	1971	21.90	23
Switzerland	Europe	82(3.571)	2664	32.49	33

TP= *Total no. of AIMT related articles published by a country;* ***TC*** *= Total no. of citation received;* ***AvgCPA***= *Average no. of citations per Article;* ***h-index***= *no. of h papers among a country's no. of publications that have at least h citations each.* ***Source: WoS***

A total of 2296 articles included author address, source country and research institute. 86 collaborating Countries/territories participated in collaborative research with Indian institutions in AIMT research. As shown in the Table 4.3.b(vii), Top 20 countries / territories were ranked based on the number of total articles, along with the citations and percentage of international collaboration. Out of these 20 countries / territories, The USA produced maximum publications i.e. 789 which accounts for 34.36% of total publications with 20661 citations. It is seen from the Table 4.3.b(vii) that AIMT related articles authored in collaboration with in the Wales (Europe) have the highest average impact (AvgCPA = 43.54) followed by Canada (North America) AvgCPA = 39.57 while the USA ranked 16th in the AgvCPA index.

J. Keyword Analysis

A total of 2514 different keywords, from 1960 to 2014 in the AIMT research have been identified. The no. of analysed publications during the study period was 2656. To obtain accurate results, keywords were pre-processed by merging the singular and plural forms of the same terminology, and those keywords with the same meaning while using different expressions. A total 2313 unique Keywords are obtained. Among these unique keywords 721 (31.17 %) appear once or twice at the most, it can be deduced that this can be a sign of lack of research continuity or of a wide range of research focus. Table 4.3.b(viii) shows the most used keywords during the considered period.

J.1 Hotspots

An analysis of the keywords was undertaken to pick out the hotsopts that have attracted most research attention and to reveal the research tendencies in the sub-field of AIMT. The top 20 most frequently used keywords for the study period are listed in

Table 4.3.b(viii). The four most frequently used keywords were ‘Telescopes’, ‘Methods: Data analysis’, ‘Instrumentation: Detectors’ and ‘Techniques: Image processing’.

Table 4.3.b(viii): Top most frequently used keywords in AIMT research

Keywords	**Forms of measurement**	**NO**	**%**	**R**
Analytical	Methods	39	1.68	12
Data analysis		139	6.00	2
Laboratory		5	0.21	18
Numerical		106	4.58	3
Observational		56	2.42	9
Statistical		79	3.41	6
Adaptive optics	Instrumentation	14	0.60	16
Detectors		100	4.32	4
Interferometers		57	2.46	8
Photometers		7	0.30	17
Polarimeters		21	0.90	14

Spectrographs		42	1.81	11
Image processing	Techniques	79	3.41	6
Interferometric		55	2.37	10
Photometric		76	3.28	7
Polarimetric		32	1.38	13
Radar astronomy		18	0.77	15
Spectroscopic		91	3.93	5
Telescopes	Miscellaneous	484	20.92	1
Site testing		5	0.21	18

NO: Number of time occurrences; R : rank Source: WoS

J.2 Quick Rising Themes

The Compound Annual Growth Rate (CAGR) described in Chapter 1, Section 1.8.5.B, can be used to select quick rising themes of AIMT research, this reveals the indicators of future research directions. Table 4.3.b(ix) lists the top 20 keywords according to the CAGR and sorts them by their rank. The ranks in Table 4.3.b(ix) show that Telescopes, Method: Data analysis, Method: Statistical, Technique: Interferometric are four leading hot issues that continue to attract broad attention. 'Telescopes' kept its dominance in terms of total quantity and CAGR.

Table 4.3.b(ix): Top Quick rising themes in AIMT research

Keyword		**V (t_0)**	**V (t_n)**	**t_0**	**t_n**	**CAGR (%)**	**R**
Analytical	Methods	1	3	1993	2014	0.05	17
Data analysis		1	22	1994	2014	0.16	2
Laboratory		1	1	2010	2013	0.00	18
Numerical		1	16	1992	2014	0.13	6
Observational		1	13	1994	2014	0.13	5
Statistical		1	16	1995	2014	0.15	3
Adaptive optics	Instrumentation	1	3	2000	2014	0.08	13
Detectors		2	19	1994	2014	0.11	9
Interferometers		3	9	1994	2014	0.05	16
Photometers		1	3	2005	2014	0.12	8

Polarimeters		2	5	1998	2014	0.05	15
Spectrographs		1	4	1994	2014	0.07	14
Image processing	Techniques	1	15	1992	2014	0.13	7
Interferometric		1	12	1995	2014	0.13	4
Photometric		1	9	1991	2014	0.10	11
Polarimetric		1	5	1997	2014	0.09	12
Radar astronomy		1	1	1998	2014	0.00	18
Spectroscopic		1	9	1993	2014	0.11	10
Telescopes	Miscellaneous	2	79	1991	2014	0.17	1
Site testing		1	1	1999	2014	0.00	18

***t_0**: the Initial (first) year (The Year in which no. of keywords occurrence first time; **t_n**: the last year (No. of keywords occurrence); **$V(t_0)$**: Initial observed value (no. of keywords occurrence); **$V(t_n)$**: last observed value (no. of keywords occurrence); **CAGR:** Compound Annual Growth Rate; **R:** Rank.*
Source: WoS

K. Summary

A total of 2296 journal articles were published on AIMT, which received total 36316 citations. The average number of publications per year is 72.86 and average number of citations per publication was 15.82. Publications on AIMT appeared in 85 journals of which most active journal was Monthly Notices of the Royal Astronomical Society which published 489 (21.298 %) of the total 2296 publications. A total of 905 authors contributed on AIMT research. The most active author was Mitra, S. who produced maximum number of publications 66 (2.875%) of total publications. 1883 institutions contributed of which Tata Institute of Fundamental Research, India is the most productive institution which produced 584 (25.436%) of total publications. For globalisation of AIMT research in India, the results show there were 86 Countries/territories which participated in AIMT research. The USA produced maximum publications i.e. 789 which are 34.364% of total publication with higher citations (20661). A Keyword analysis reveals that 'Telescopes', 'Methods: Data analysis', 'Instrumentation: Detectors' and 'Techniques: Image processing' are the most frequently used keywords.

4.3.3 Cosmology

After the demise of the Aristotelian world picture, it took hundreds years of astronomical observations and physical theories to reach a level at which a satisfactory modern scientific picture of the physical universe could be formed. The decisive steps in the development were the clarification of the nature of the galaxies in the 1920's and the general theory of relativity developed by Einstein in the 1910's.

Cosmology is the study of the structure, origin and the evolution of the universe as a whole. Research in cosmology tries to answer questions such as: How large and how old is the universe? How is matter distributed? How were the elements formed? What will be the future of the Universe? The central tenet of modern cosmology is the model of the expanding universe (Karttunen, 2007).

There were 2423 articles that met the selection criteria which appeared in the WoS database during 1960-2014 and these were analyzed.

A. Publication Characteristics

Table 4.3.c(i): Bibliographic Record of Cosmology research in India during 1960-2014

Bibliometric indicators `	**No.**
Total Article found:	2423
Total Number of Contributing Countries	70
Total Number of Contributing Authors	12599
Total Number of Contributing Institutions	1605
Total Number of Journals appeared	54
Total Number of Keywords (raw) appeared	6172

Source: WoS

A total of 2423 articles of Indian scientists during 1960-2014 were abstracted from WoS related to Cosmology publications. From the Tables 4.3.c(i) and 4.3.c(ii), the output of 2423 papers has received a total of 40944 citations during the said period with an average of about 16.90 citations per paper. The average number of publications per year is 59.09 and CAGR is 0.14%.

Table 4.3.c(ii): Citation Metrics of Cosmology research in India during 1960-2014

Citation-based Indicators	No.
Sum of the Times Cited	40944
Sum of Times Cited without self-citations	34945
Citing Articles	22473
Citing Articles without self-citations	20912
Average Citations per Item	16.90
h-index	74

Source: WoS

B. Publications Pattern

Publication pattern of Cosmology research from 1960 to 2014 is presented in Figure 4.3.c(i). The initial publication in the sub-field of Cosmology research is observed in the year 1974. A near about two hundred thirty five time's increase was observed over the study period, (from 1 in 1974 to 235 in 2014). The highest number of papers is published in the year 2014, with 235 publications and the lowest in 1974 with 1 publication.

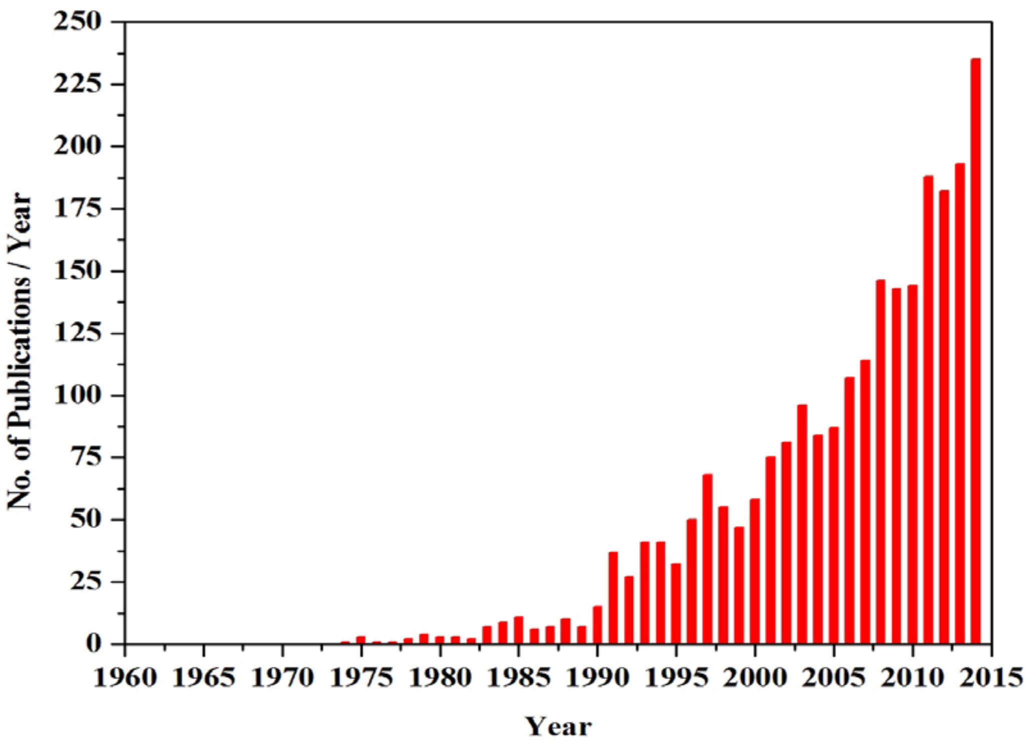

Figure 4.3.c(i): Publication Pattern of Cosmology research in India during 1960-2014. From the period 1960-1973, no publication appeared in the WoS database.

C. Growth Trend

The cumulative progression is represented by a 4th degree power law distribution during 1960-2014 giving an idea of the polynomial growth curve as shown in Figure 4.3.c(ii). To choose the best fit growth model, various regression types with regression coefficient has been tested as shown in Table 4.3.c(iii). The best fit model is 4th degree polynomial curve, where $R^2 = 0.959$. The polynomial best fit for Cosmology research is found to be: $y = 0.0002x^4 - 1.9259x^3 + 5748.3x^2 - 8E+06x + 4E+09$, where y is the cumulative number of publications and x is the number of years. The growth of literature shown in Figure 4.3.c(ii) can be divided into two parts, In the 1st part (1960-1973), there is no literature published by Indian scientists and in 2nd part (1974-2014), the trend follows a polynomial growth curve.

Table 4.3.c(iii): Different Regression Types with Regression coefficient (R^2) of Cosmology research

Regression Type	Equation	(R^2)
Exponential	$y = 1E\text{-}116e^{0.1355x}$	0.9375
Linear	$y = 4.8847x – 9680.9$	0.8367
Logarithmic	$y = 9729.3\ln(x) – 73863$	0.8349
Polynomial	$y = 0.0002x^4 - 1.9259x^3 + 5748.3x^2 - 8E{+}06x + 4E{+}09$	0.9837
Power	$y = 0x^{270.21}$	0.9383

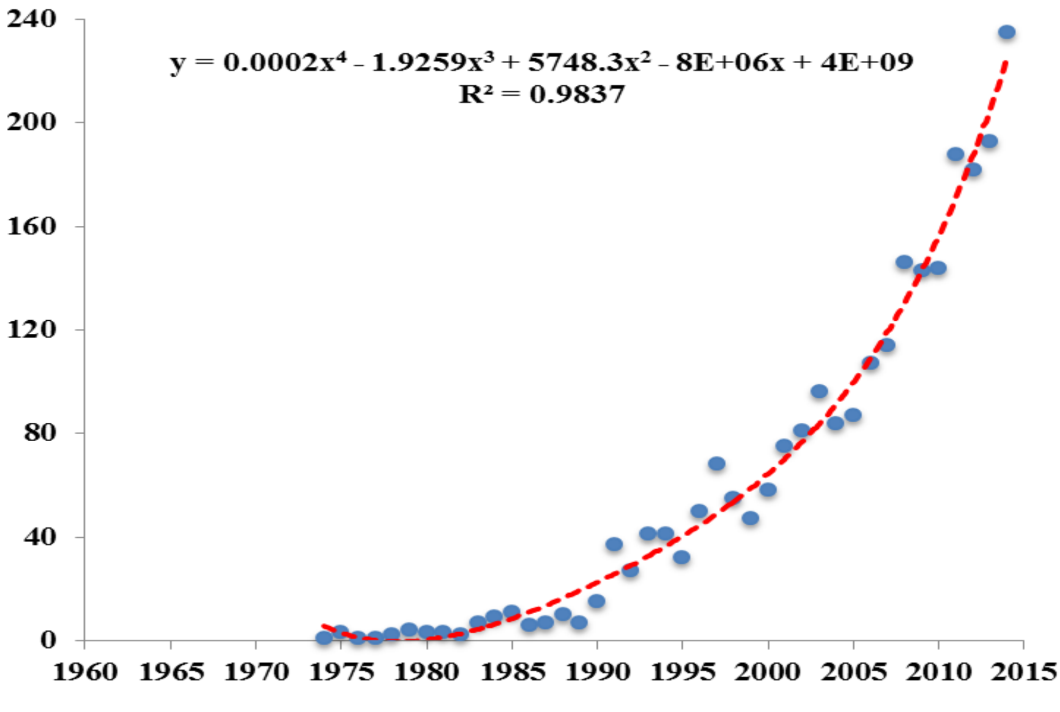

Figure 4.3.c(ii): Growth Pattern of Cosmology research in India during 1960-2014. Blue dot describes the distribution of publications (observed value) and red dashed line describe the correlation of distribution of publications where regression coefficient $R^2 = 0.983$

D. Citation Pattern

Figures 4.3.c(iii) and 4.3.c(iv) represent the citation pattern and number of citations vs. number of publications per year of Cosmology research in India during 1960-2014. A total of 2423 research papers have received 40944 citations. The pattern of citations is very fluctuating. In the initial year 1974, the total number of citations received is 18 with an average citation of 18. The minimum citation received in the year 1978 is three (3) and the maximum citations received in the year 2004 are 3053 with an average citation of 36.35. It has been observed from Figure 4.3.c(iv) that after the year 2006, citations decrease while publications continue to increase.

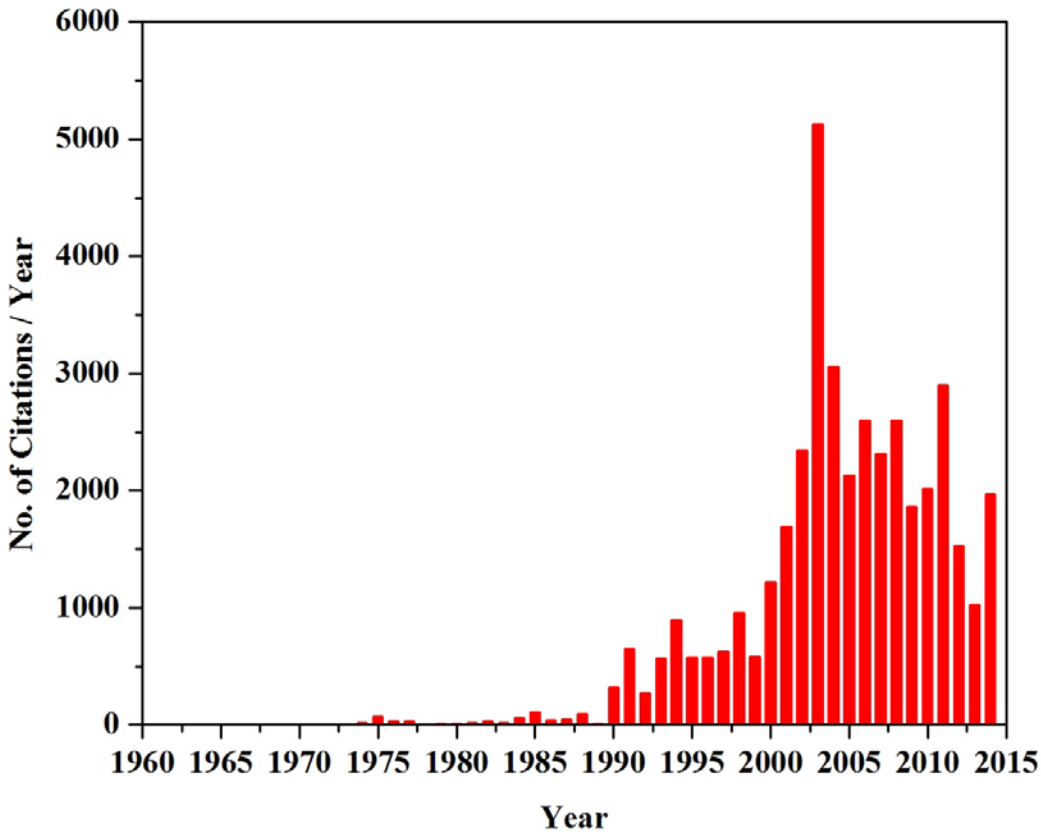

Figure 4.3.c(iii): Citation Pattern of Cosmology research in India during 1960-2014. From 1960-1973, no citation received as no publication appeared in the WoS database.

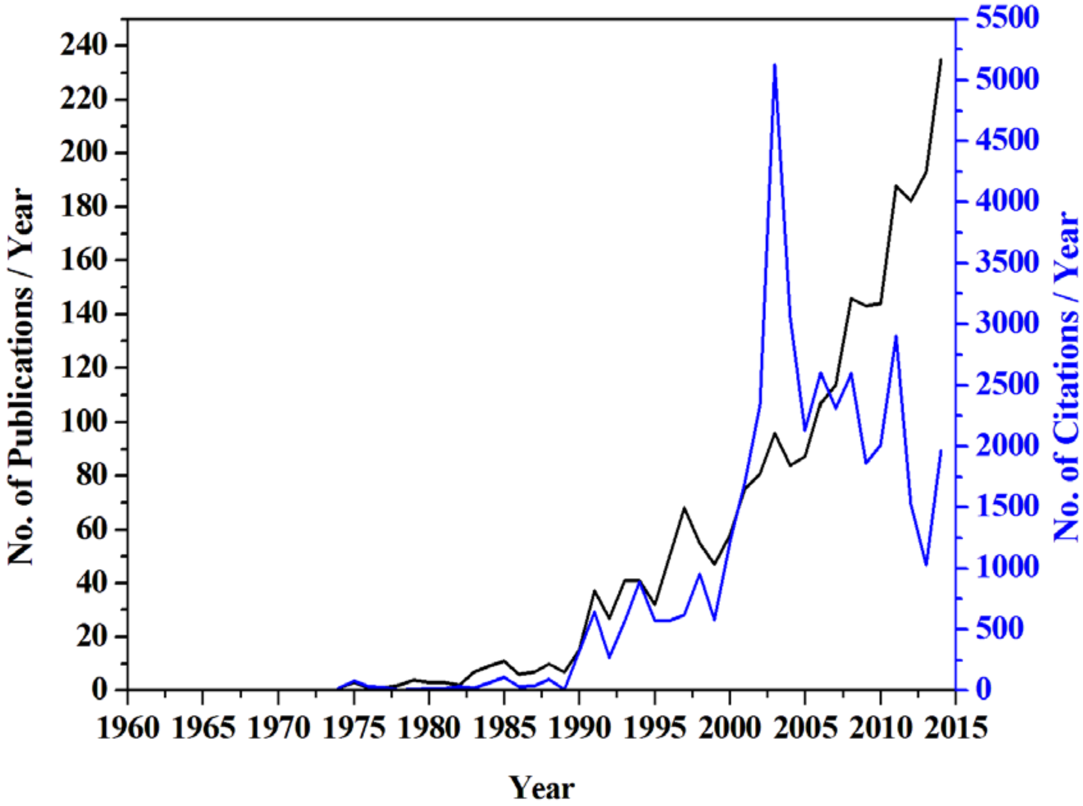

Figure 4.3.c(iv): Citation Pattern Vs Publication Pattern of Cosmology research in India during 1960-2014: Blue line (right Y axis) indicates the citations pattern against black line (left Y axis) that describes the publications pattern.

E. Top Institutions and their research impact

Table 4.3.c(iv) show the top 20 productive Institution during the last 54 years, 1960-2014. A total of 2423 Articles on Cosmology research have appeared from 1605 institutions. Out of the top 20 institutions only 8 are Indian. Inter University Centre for Astronomy Astrophysics contributed highest number of publications (531), followed by Tata Institute of Fundamental Research, Mumbai , Indian Institute of Astrophysics with 279 and 196 papers respectively.

The remaining 12 institutions are foreign. Among these 6 belong to the USA namely National Aeronautics Space Administration (NASA), USA; California Institute of Technology, USA; University of Texas , Austin, USA; Goddard Space Flight Center, USA; University of California System, USA; Pennsylvania Commonwealth System of

Higher Education,USA; 3 to France namely Centre National De La Recherche Scientifique CNRS, France; Observatoire De Paris, France; Institut De Recherche Pour Le Developpement (IRD), France; 2 are from Japan namely National Institutes of Natural Sciences (NINS), Japan; National Astronomical Observatory of Japan; and 1 to Germany the Max Planck Society..

Table 4.3.c(iv): Top institutions on Cosmology research and their research impact, 1960- 2014

Institution	Region	TP (%)	TC	AvgCPA	h-index
Inter University Centre for Astronomy Astrophysics	India	531(21.915)	16132	30.38	60
Tata Institute of Fundamental Research	India	279(11.515)	6563	23.52	36
Centre National De La Recherche Scientifique	France	246(10.153)	7779	31.63	45
Indian Institute of Astrophysics	India	196(8.089)	2433	12.41	23
Jadavpur University	India	147(6.067)	1349	9.18	18
Max Planck Society	Germany	145(5.984)	5269	36.34	39
Observatoire De Paris	India	130(5.365)	4963	38.18	40
Raman Research Institute	India	127(5.241)	1930	15.20	25
National Aeronautics Space Administration	USA	123(5.076)	5036	40.94	38
University of California System	USA	119(4.911)	4719	39.66	36
Pierre Marie Curie University Paris	France	113(4.664)	3895	34.47	35
California Institute of Technology	USA	110(4.540)	3946	35.87	36
European Southern Observatory	Germany	107(4.416)	4648	43.44	38
United States Department of Energy	USA	91(3.756)	5834	64.11	35
Paris Diderot University	France	84(3.467)	3726	44.36	35
Paris-Sorbonne University	France	84(3.467)	3726	44.36	35
Centre for Extragalactic Astronomy	South Africa	83(3.426)	4070	49.04	35
University of Cambridge	USA	81(3.343)	3703	45.72	34
Russian Academy of Sciences	Russia	81(3.343)	2900	35.80	34
Physical Research Laboratory	India	81(3.343)	846	35.80	34

TP= *Total no. of Cosmology related articles published by an institution;* ***TC*** = *Total no. of citation received;* ***AvgCPA***= *Average no. of citations per article; h-**index**=defined by the no. of h papers among an institution's no. of publications that have at least h citations each.* ***Source: WoS***

Table 4.3.c(iv) reveals the impact of research in terms of quality of papers. The Cosmology related articles authored in collaboration with foreign institutions (United States Department of Energy) have the highest average impact (AvgCPA = 64.11). Among the Indian institutions, Inter University Centre for Astronomy Astrophysics ranks 15th in the AvgCPA (30.38) index.

F. Top Journals and their research impact

Cosmology papers have appeared in 54 journals. Papers have appeared in highest number in the journal ‘Astrophysics and Space Science’ published by Springer from Netherlands. Table 4.3.c(v) shows the top 20 productive journals. These 20 out of the 54 journals have published 2363 (97.52 %) of the total 2423 articles. The ‘Astrophysics and Space Science’ ranked first with 434 (17.91%) publications; ‘Physical Review D with 420 (17.33%) publications’, ‘Monthly Notices of the Royal Astronomical Society with 356 (14.69%) papers’,‘Astrophysical Journal had 231 (9.53%) publications ’ and ‘Astronomy Astrophysics with 226 (9.32%) papers. These journals ranked 2^{nd} , 3^{rd} , 4^{th} and 5^{th} respectively.

Table 4.3.c(v): Top Journals on Cosmology research and their research impact, 1960-2014

				Journal Metrics (2013)			
Journal	**TP (%)**	**TC**	**AvgCPA**	**SJR**	**IPP**	**SNIP**	**Country**
Astrophysics and Space Science	434(17.912)	2771	6.38	1.081	1.748	1.056	Netherlands
Physical Review D	420(17.334)	10554	25.13	1.899	3.192	1.136	USA
Monthly Notices of the Royal Astronomical Society	356(14.693)	6823	19.17	3.196	4.911	1.494	USA
Astrophysical Journal	231(9.534)	4141	17.93	3.159	4.348	1.145	UK
Astronomy Astrophysics	226(9.327)	6113	27.07	1.471	1.932	0.612	France
International Journal of Modern Physics D	138(5.695)	1257	9.11	0.733	1.021	0.540	Singapore
General Relativity and Gravitation	123(5.076)	1293	10.51	1.109	1.628	1.015	UK
Classical and Quantum Gravity	112(4.622)	2428	21.68	1.476	2.192	0.966	UK
Journal of Cosmology and Astroparticle Physics	103(4.251)	1651	16.03	0.615	2.374	0.465	UK
Journal of Astrophysics and Astronomy	64(2.641)	343	5.36	0.477	0.541	0.224	India
Astrophysical Journal Letters	33(1.362)	650	19.70	3.914	4.852	1.487	UK
Astronomical Journal	23(0.949)	763	33.17	3.159	4.348	1.145	UK
Research in Astronomy and Astrophysics	20(0.825)	84	4.20	0.953	1.331	0.768	UK
Gravitation Cosmology	17(0.702)	49	2.88	0.395	0.486	0.478	Russia
New Astronomy	13(0.537)	126	9.69	0.734	1.053	0.523	Netherlands
Astroparticle Physics	13(0.537)	173	13.31	3.012	3.828	2.776	Netherlands
Advances in Space Research	12(0.495)	34	2.83	0.751	1.416	1.291	Netherland
Astrophysical Journal Supplement Series	10(0.413)	902	90.20	6.857	9.687	3.125	USA
IAU Symposia	8(0.330)	5	0.62	-	-	-	Puerto Rico
Publications of the Astronomical Society of Japan	7(0.289)	88	12.57	1.521	1.626	0.750	Japan

TP= *Total no. of Cosmology research related articles published by a Journal;* ***TC*** *= Total no. of citation received;* ***AvgCPA***= *Average no. of citations that Cosmology related articles in a journal received;* ***h-index***= *no. of h papers among a journal’s no. of publications that have at least h citations each.* ***SJR*** *= SCImago Journal Rank;* ***IPP*** *= Impact per Publication;* ***SNIP*** *= Source Normalized Impact per Paper;* ***Source: WoS and SCOPUS***

Table 4.3.c(v) also shows the citation impact of top 20 journals. The AvgCPA and h-index are used to identify which journals have the largest number of high quality articles in the Cosmology research. It is seen from the Table 4.3.c(v) that the journal 'Astrophysical Journal Supplement Series' published by IOP Publishing for the American Astronomical Society in the USA has the highest average impact (AvgCPA = 90.20) although the journal 'Astrophysics and Space Science' has the highest number of publications but ranked 15th in the AvgCPA index.

G. Top Authors and their research impact

A total of 2423 articles included the author addresses having India as the county of affilation. Articles on Cosmology have been contributed by 12599 authors. Table 4.3.c(vi) showed the top 20 productive authors during the last 54 years, 1960-2014. Top 20 productive authors are ranked based on the decreasing productivity of total publications. Srianand, R. produced maximum number of publications -101 i.e. 4.16% of total publications and ranked 1st followed by Chakraborty, S., Petitjean, P., Padmanabhan, T. and Mitra, S. ranked at 2nd , 3rd, 4th and 5th places respectively.

Table 4.3.c(vi) reveals the impact of research in terms of quality of papers. The AvgCPA and h-index are used to identify which author has the largest number of high quality articles in the Cosmology research. It is seen from the Table 4.3.c(vi) that Cosmology related articles authored by Gorski, K.M. have the highest average impact (AvgCPA = 45.12) followed by De Zotti, G. (AvgCPA = 44.88) while Sagar, R. have published the maximum number of publications but ranks 13th in the AvgCPA index.

Table 4.3.c(vi): Top Authors of Cosmology research and their research impact, 1960-2014

Author	TP (%)	TC	TC woSC	CI	CIwoSC	AvgCPA	h-index
Srianand, R.	101(4.168)	2800	2276	1281	1193	27.72	30
Chakraborty, S.	79(3.260)	505	458	412	381	6.39	10
Petitjean, P.	73(3.013)	2907	2486	1459	1395	39.82	30
Padmanabhan, T.	61(2.518)	2399	2298	1678	1640	39.33	22
Mitra, S.	58(2.394)	2025	1265	873	831	34.91	30
Sahni, V.	51(2.105)	2875	2740	2026	1984	56.37	28
Souradeep, T.	46(1.898)	1088	971	687	654	23.65	19
Bharadwaj, S.	46(1.898)	740	562	387	349	16.09	16
Pradhan, A.	45(1.857)	882	773	404	367	19.60	20
Munshi, D.	44(1.816)	1903	1102	775	740	43.25	31
Nagendra, K.N.	43(1.775)	339	199	146	111	7.88	11
Ledoux, C.	43(1.775)	1800	1535	705	666	41.86	26
Debnath, U.	43(1.775)	482	445	382	360	11.21	10
Ensslin, T.A.	42(1.733)	1849	1050	715	682	44.02	31
Banday, A.J.	42(1.733)	1826	1020	695	661	43.48	30
Narlikar, J.V.	41(1.692)	619	526	409	382	15.10	15
De Zotti, G.	41(1.692)	1840	1042	697	663	44.88	32
Bouchet, F.R.	41(1.692)	1782	984	660	628	43.46	29
Hildebrandt, S.R.	40(1.651)	1758	959	635	603	43.95	29
Gorski, K.M.	40(1.651)	1805	1004	680	648	45.12	30

TP: *Total no. of Cosmology related articles published by a author;* ***TC:*** *Total no. of citation****; TC woSc:*** *Sum of Times Cited without self-citations****; CI:*** *Citing Articles* ***; CIwoSC:*** *Citing Articles without self-citations****; AvgCPA:*** *Average Citations per Article****; h-index :*** *no. of h papers among a author's no. of publications that have at least h citations each.* ***Source: WoS***

H. Collaboration Pattern: Continents

Based on the author attributions, world-wide collaboration of Cosmology research publications can be mapped. As shown in Figure 4.3.c(v), the major spatial clusters of research institutes are located in Europe, followed by Asia and Africa. Several minor clusters are distributed in other parts of the world. North America and South America have equal contributions.

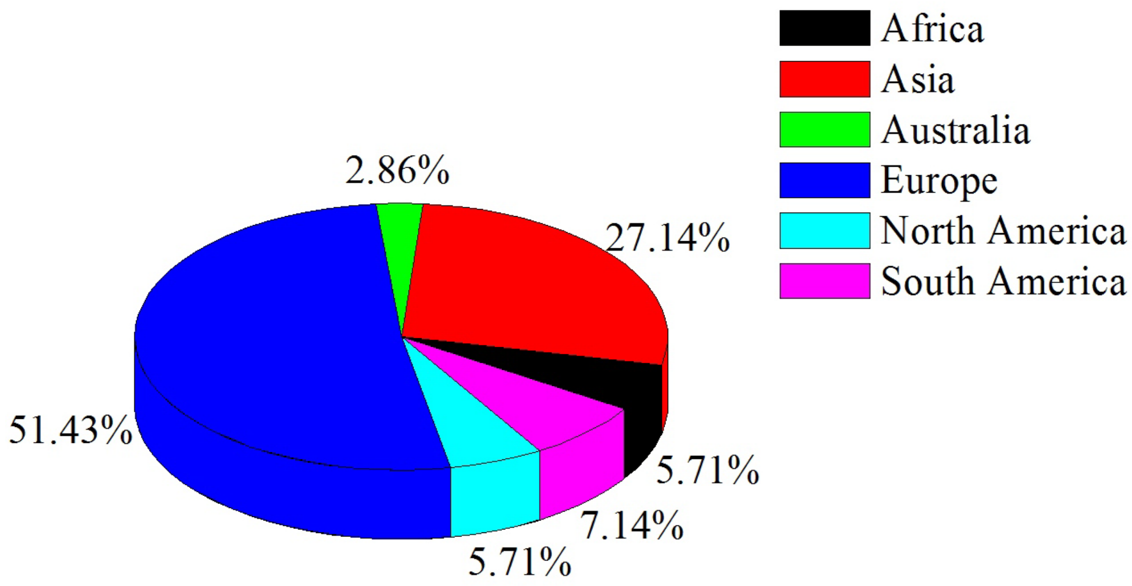

Figure 4.3.c(v): Continent wise Collaboration pattern of Cosmology research

I. Collaboration Pattern and research impact: Countries

A total of 2423 articles were retrived from WoS on the Cosmology research, these articles included author address, source country and research institute. There are 72 collaborating Countries/territories which participated in collaborative research with Indian institutions. Out of the top 20 countries / territories, the USA produced maximum publications i.e. 464 which accounts for 19.15% of total publications with high citations (14425). It is seen from the Table 4.3.c(vii) that Cosmology related articles authored in Spain (Europe) have the highest average impact (AvgCPA = 44.05) followed by Taiwan (Asia) AvgCPA = 42.18 although USA ranked 14th in the AvgCPA index.

Table 4.3.c(vii): Country wise Collaboration Pattern and research impact of Cosmology research

Country	Continent	TP(%)	TC	AvgCPA	h-index
USA	North America	464(19.150)	14425	31.09	53
France	Europe	276(11.391)	8854	32.08	46
Germany	Europe	239(9.864)	7247	30.32	45
England	Europe	205(8.461)	7316	35.69	42
Italy	Europe	183(7.553)	6014	32.86	40
Russia	Europe	124(5.118)	5127	41.35	37
Spain	Europe	113(4.664)	4978	44.05	36
Netherlands	Europe	111(4.581)	3214	28.95	35
Canada	North America	109(4.499)	4305	39.50	35
Chile	South America	108(4.457)	3999	37.03	35
Australia	Australia	96(3.962)	2651	27.61	27
Japan	Asia	92(3.797)	3031	32.95	28
Switzerland	Europe	76(3.137)	2239	29.46	33
South Africa	Africa	75(3.095)	2413	32.17	33
Denmark	Europe	74(3.054)	2666	36.03	34
Poland	Europe	71(2.930)	2444	34.42	33
Wales	Europe	62(2.559)	2535	40.89	34
Taiwan	Asia	56(2.311)	2362	42.18	31
Norway	Europe	53(2.187)	2083	39.30	33
Peoples R China	Asia	51(2.105)	1538	30.16	20

TP= *Total no. of Cosmology related articles published by a country;* ***TC*** = *Total no. of citation received;* ***AvgCPA***= *Average no. of citations per Article;* ***h-index***= *no. of h papers among a country's no. of publications that have at least h citations each.* ***Source: WoS***

J. Keyword Analysis

A total of 6172 different keywords, from 1960 to 2014 in the Cosmology research have been identified. The number of analysed publications during the study period is 2423. To obtain accurate results, the keywords were pre-processed by merging the singular and plural forms of the same terminology, and those keywords with the same meaning while using different expressions. A total of 5617 unique Keywords are obtained. Among these unique keywords 2078 (36.99%) appear once or twice at the most. Table 4.3.c(viii) shows the most used keywords during the considered period.

J.1 Hotspots

An analysis of the keywords was undertaken to pick out the research hotsopts (Chapter 1, Section 1.8.5.A) that have attracted most research attention and to reveal the research tendencies in the fields of Cosmology. The top 20 most frequently used keywords for the study period are listed in Table 4.3.c(viii). The five most frequently used keywords were 'Theory', 'Redshift', 'Observations', 'Dark Energy' and 'Cosmological constant'.

Table 4.3.c(viii): Top most frequently used keywords in Cosmology research

Keywords	Total	%	R
Cosmic Background Radiation	44	0.78	13
Cosmic strings	49	0.87	12
Cosmological constant	218	3.88	5
Cosmological models	101	1.79	8
Cosmological Parameters	79	1.40	9
Dark Ages	16	0.28	17
Dark Energy	305	5.42	4
Dark Matter	59	1.05	11
Diffuse Radiation	33	0.58	14
Distance Scale	15	0.26	18
Early Universe	102	1.81	7
First Stars	13	0.23	19
Inflation	214	3.80	6
Large-Scale Structure of Universe	79	1.40	9
Observations	370	6.58	3
Quantum cosmology	32	0.56	15
Redshift	397	7.06	2
Reionization	60	1.06	10
Supersymmetry	21	0.37	16
Theory	447	7.95	1

NO: Number of time occurrences; R : rank Source: WoS

J.2 Quick Rising Themes

The Compound Annual Growth Rate (CAGR) described in Chapter 1, Section 1.8.5.B, can be used to select quick rising themes of Cosmology research, this reveals the indicators of future research directions. Table 4.3.c(ix) lists the top 20 keywords according to the CAGR and sorts them by their rank. The ranks in Table 4.3.c(ix) show that 'Cosmic Background Radiation', 'Reionization' and 'Dark Energy' are three leading hot issues that continue to attract broad attention. 'Dark Energy' kept its dominance in terms of total quantity and CAGR.

Table 4.3.c(ix): Top Quick rising keywords in Cosmology research

Keyword	V (t_0)	V (t_n)	t_0	t_n	CAGR (%)	R
Cosmic Background Radiation	1	28	2010	2014	1.300	1
Cosmic strings	1	2	1992	2014	0.032	17
Cosmological constant	2	22	1991	2014	0.109	11
Cosmological models	1	11	1991	2014	0.109	11
Cosmological Parameters	1	13	2000	2014	0.201	4
Dark Ages	4	5	2011	2014	0.077	12
Dark Energy	6	57	2003	2014	0.227	3
Dark Matter	1	4	1991	2014	0.062	15
Diffuse Radiation	1	4	1993	2014	0.068	14
Distance Scale	1	1	1992	2014	0.000	0
Early Universe	1	13	1991	2014	0.118	10
Inflation	2	24	1992	2014	0.119	9
Large-Scale Structure of Universe	5	11	1993	2014	0.038	16
Observations	2	64	1991	2014	0.162	6
Quantum cosmology	1	5	1991	2014	0.072	13
Redshift	2	39	1991	2014	0.137	8
Reionization	1	5	1997	2014	0.258	2
Supersymmetry	1	2	1999	2014	0.148	7
Theory	1	47	1991	2014	0.182	5

t_0: *the Initial (first) year (The Year in which no. of keywords occurrence first time;* ***t_n***: *the last year (No. of keywords occurrence);* ***V(t_0)***: *Initial observed value (no. of keywords occurrence);* ***V(t_n)***: *last observed value (no. of keywords occurrence);* ***CAGR:*** *Compound Annual Growth Rate;* ***R:*** *Rank.* ***Source: WoS***

K. Summary

A total of 2423 literature were published on Cosmology, which received 40944 citations. The average number of publications per year was 59.09; Compound Annual Growth Rate (CAGR) is 14.62% and the average number of citations per publication was 16.90. Publications on Cosmology appeared in 54 journals of which most active journal was 'Astrophysics and Space Science' published by Springer from Netherlands with 434 (17.91%) of the total 2423 publications. A total of 12599 authors contributed to the Cosmology research. The most active author was Srianand, R who produced the maximum number of publications i.e. 101 which is 4.16% of total publications. 1605 institutions contributed of which Inter University Centre for Astronomy Astrophysics; Pune, India is the most productive institution. For globalization of Cosmology Research in India, the results show there were 70 Countries/territories which participated in the Cosmology research. The USA produced maximum publications i.e. 464 which accounts for 19.15% of total publications with 8234 citations. A Keyword analysis reveals that ‘Theory’, ‘Redshift’, ‘Observations’, ‘Dark Energy’ and ‘Cosmological constant’ are the most frequently used keywords.

4.3.4 Galaxies

The Galaxies are the fundamental building blocks of the universe. Some of them are very simple in structure, containing only normal stars and showing no particular individual features. There are other galaxies that are almost entirely made of neutral gas. On the other hand, others are complex systems, built up from many separate components – stars, neutral and ionized gas, dust, molecular clouds, magnetic fields, cosmic ray….. The galaxies may form small groups or large clusters in space (Karttunen, 2007).

There were 1554 articles that met the selection criteria which appeared in the WoS database during 1960-2014 and these were analyzed.

A. Publication Characteristics

A total of 1554 articles of Indian scientists during 1960-2014 were abstracted from WoS related to Galaxies publications. From the Tables 4.3.d(i) and 4.3.d(ii), the output of 1554 papers has received a total of 27403 citations during the said period with an average of about 17.63 citations per paper. The average number of publications per year is 37.00 and CAGR is 0.09%.

Table 4.3.d(i): Bibliographic Records of Galaxies research in India during 1960-2014

Bibliometric Indicators `	**No.**
Total Number of Articles	1554
Total Number of Contributing Countries	61
Total Number of Contributing Authors	477
Total Number of Contributing Institutions	1110
Total Number of Journals appeared	47
Total Number of Keywords (raw) appeared	5128

Source: WoS

Table 4.3.d(ii): Citation Metrics of Galaxies research in India during 1960-2014

Citation-based Indicators	No.
Sum of the Times Cited	27403
Sum of Times Cited without self-citations	23707
Citing Articles	16736
Citing Articles without self-citations	15686
Average Citations per Item	17.63
h-index	62

Source: WoS

B. Publications Pattern

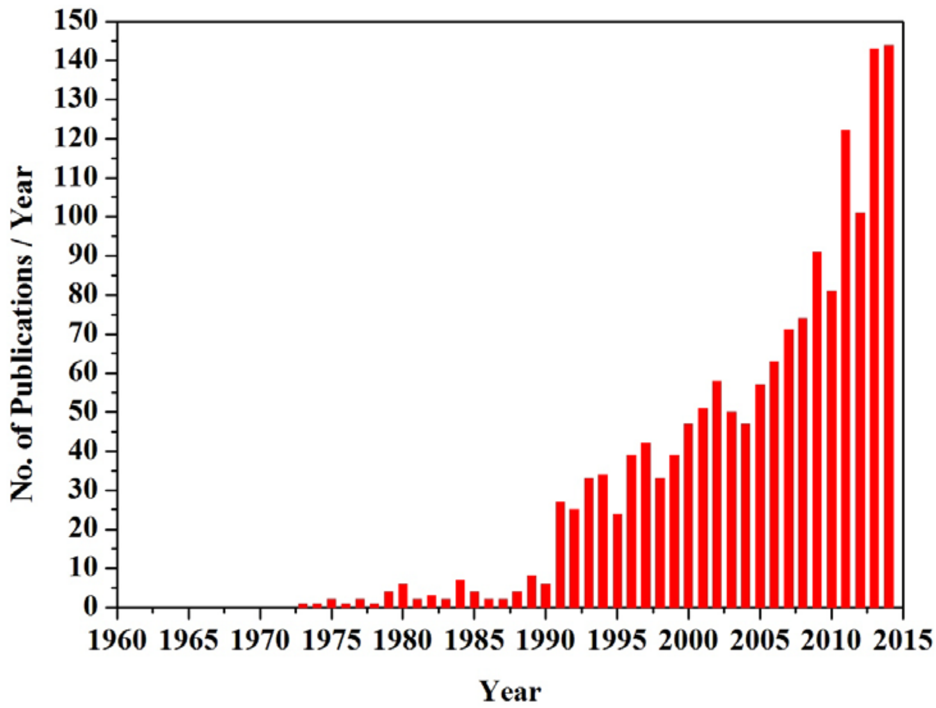

Figure 4.3.d(i): Publication Pattern of Galaxies research in India during 1960-2014. From the period 1960-1972, no publication appeared in the WoS database.

Publication pattern of Galaxies research from 1960 to 2014 is presented in Figure 4.3.d(i). The initial publication in the field of Galaxies research is observed in the year 1972. A near about one hundred fourty four times increase was observed over the study period, (from 1 in 1973 to 144 in 2014). The highest number of papers is published in the year 2014, with 144 publications and the lowest in 1976 with 1 publication.

C. Growth Trend

The cumulative progression is represented by a 4th degree power law distribution during 1960-2014 giving an idea of the polynomial growth curve as shown in Figure 4.3.d(ii). To choose the best fit growth model, various regression types with regression coefficients have been tested as shown in Table 4.3.d(iii). The best fit model is 4th degree polynomial, where $R^2 = 0.966$. The polynomial best fit for Galaxies research is found to be: $y = 0.0003x^4 - 2.2189x^3 + 6627.4x^2 - 9E{+}06x + 4E{+}09$, where y is the cumulative number of publications and x is the number of years. The growth of literature shown in Figure 4.3.d(ii) can be divided into two parts, in the 1st part (1960-1972), no literature is published by Indian scientists and in 2nd part (1973-2014), growth trend follows a polynomial growth curve.

Table 4.3.d(iii): Different Regression Types with Regression coefficient (R^2) of Galaxies research

Regression Type	Equation	(R^2)
Exponential	$y = 1E{-}11e^{0.135x}$	0.937
Linear	$y = 4.884x – 9680$	0.836
Logarithmic	$y = 9729.\ln(x) – 73863$	0.834
Polynomial	$y = 0.0003x^4 - 2.2189x^3 + 6627.4x^2 - 9E{+}06x + 4E{+}09$	0.9665
Power	$y = 0x^{270.2}$	0.938

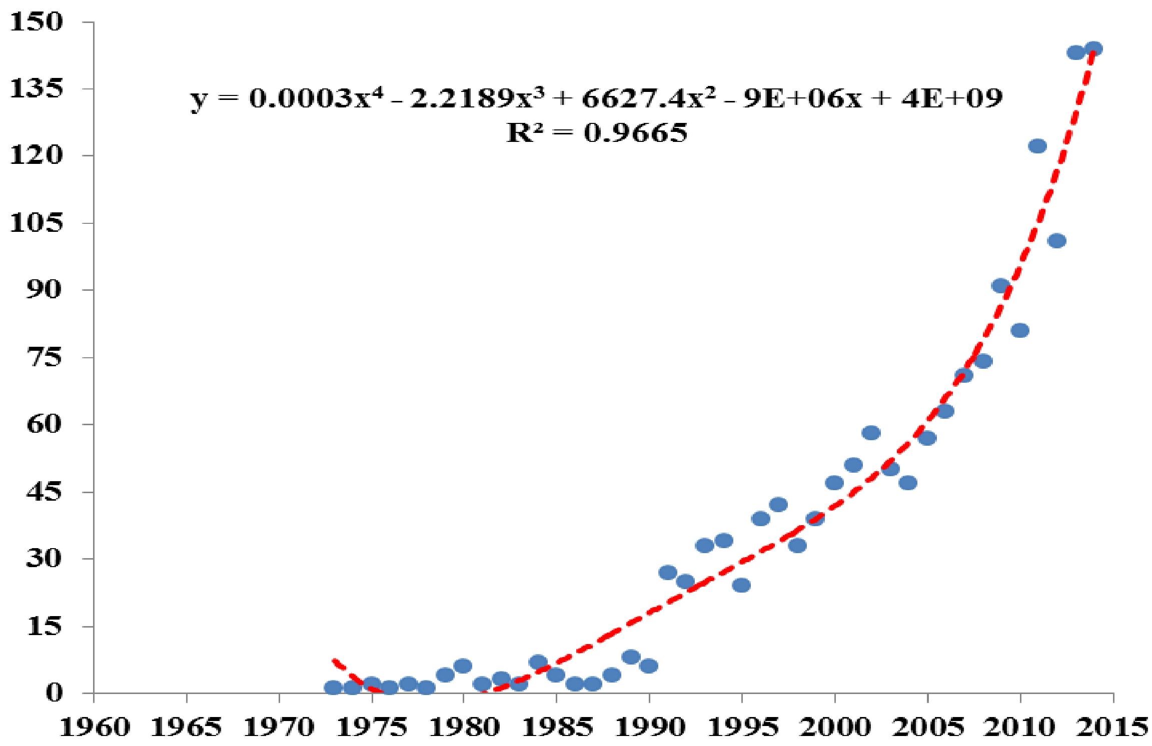

Figure 4.3.d(ii): Growth Trend of Galaxies research in India during 1960-2014. Blue dot describes the distribution of publications (observed value) and red dashed line describes the correlation of distribution of publications where regression coefficient R^2 = 0.966

D. Citation Pattern

Figures 4.3.d(iii) and 4.3.d(iv) represent the citation pattern and number of citations vs. number of publications per year of Galaxies research in India during 1960-2014. A total of 1554 research papers have received 27403 citations. The pattern of citations is very fluctuating. In the initial year 1973, the total number of citations received is 18 with an average citation of 18. The minimum citation received in the year 1978 is zero (0) and the maximum citations received in the year 2009 are 3342 with an average citation of 36.73. It has been observed from Figure 4.3.d(iv) that after the year 2011, citations decrease while publications continue to increase

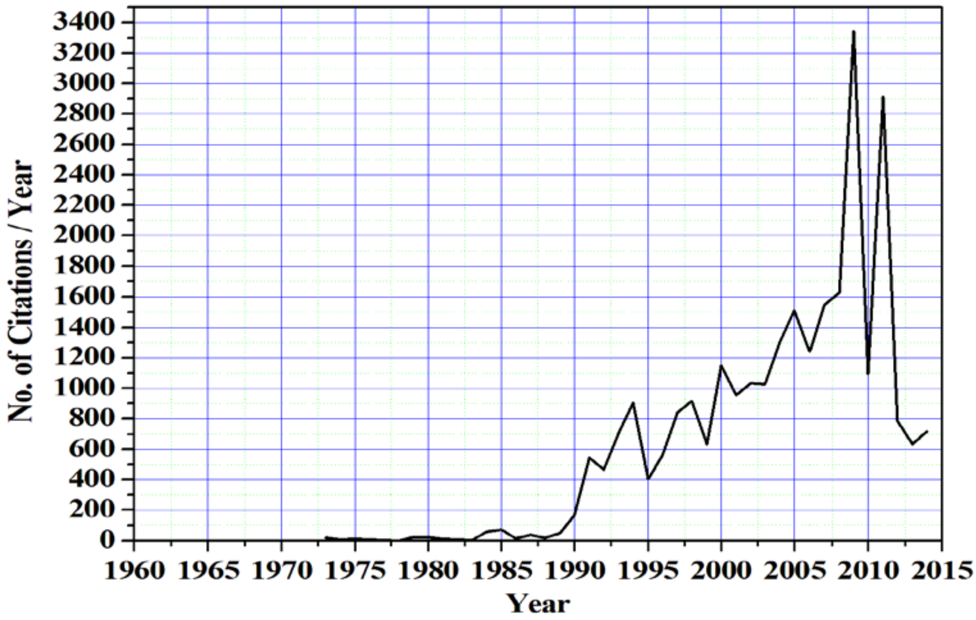

Figure 4.3.d(iii): Citation Pattern of Galaxies research in India during 1960-2014. From 1960-1972, no citation received as no publication appeared in the WoS database.

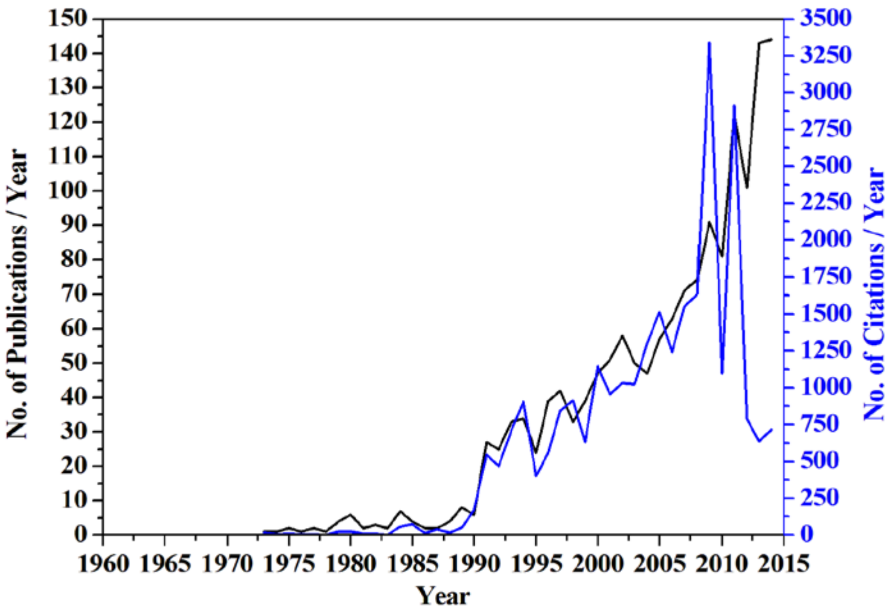

Figure 4.3.d(iv): Citation Pattern Vs Publication Pattern of Galaxies research in India during 1960-2014: Blue line (right Y axis) indicates the citation pattern against black line (left Y axis) that describes the publications pattern.

E. Top Institutions and their research impact

A total of 1554 articles on Galaxies appeared from 1110 institutions. Table 4.3.d(iv) shows out of these top 20 institutions only 8 are Indian. Tata Institute of Fundamental Research contributed highest number of publications (450), followed by Inter University Centre for Astronomy Astrophysics which accounts for 394 publications, Indian Institute of Astrophysics contributed 216 papers , Raman Research Institute with 160, Indian Institute of Science (IISc) with 109, University of Pune with 93, Aryabhatta Research Institute of Observational Sciences with 88 and National Centre for Radio Astrophys with 67 publications respectively.

Table 4.3.d(iv): Top institutions on Galaxies research and their research impact, 1960- 2014

Institution	Region	TP (%)	TC	AvgCPA	h-index
Tata Institute of Fundamental Research	India	450(28.958)	8208	18.24	39
Inter University Centre for Astronomy Astrophysics	India	394(25.354)	8572	21.76	46
Indian Institute of Astrophysics	India	216(13.900)	3238	14.99	26
Centre National De La Recherche Scientifique	France	178(11.454)	6347	35.66	42
Raman Research Institute	India	160(10.296)	2497	15.61	28
Max Planck Society	Germany	137(8.816)	6370	46.50	35
Indian Institute of Science	India	109(7.014)	1991	18.27	24
Observatoire De Paris	France	98(6.306)	4097	41.81	36
European Southern Observatory	Germany	97(6.242)	5725	59.02	35
University of Pune	India	93(5.985)	1402	15.08	21
Aryabhatta Research Institute of Observational Sciences	India	88(5.663)	669	7.60	14
Harvard University	USA	82(5.277)	2874	35.05	23
University of California System	USA	77(4.955)	5515	71.62	30
Russian Academy of Sciences	Russia	75(4.826)	1702	22.69	26
National Radio Astronomy Observatory	USA	74(4.762)	1246	16.84	23
Smithsonian Institution	USA	70(4.505)	1455	20.79	21
National Aeronautics Space Administration	USA	68(4.376)	5447	80.10	29
National Centre for Radio Astrophys	India	67(4.311)	1529	15.60	23
Pierre Marie Curie University	France	66(4.247)	2793	42.32	29
University of Cambridge	USA	65(4.183)	4523	69.58	29

TP*= Total no. of Galaxies related articles published by an institution;* ***TC*** *= Total no. of citation received;* ***AvgCPA****= Average no. of citations per article; h-****index****=defined by the no. of h papers among an institution's no. of publications that have at least h citations each.* ***Source: WoS***

Out of the 12 foreign institutions, 6 belong to the USA namely Harvard University, University of California System, National Radio Astronomy Observatory, Smithsonian Institution, National Aeronautics Space Administration (NASA), University of Cambridge USA; 3 belong to France namely Centre National De La Recherche Scientifique CNRS, France; Observatoire De Paris, France; Pierre Marie Curie University Paris, France; 2 belong to Germany namely Max Planck Society and European Southern Observatory, Germany; and 1 is from Russia - the Russian Academy of Sciences.

Table 4.3.d(iv) reveals the impact of research in terms of quality of papers. Galaxies related articles authored in collaboration with NASA have the highest average impact (AvgCPA = 80.10) followed by University of Cambridge (AvgCPA = 69.58). Among the Indian institutions, Inter University Centre for Astronomy Astrophysics ranks 1st (21.76) in the AgvCPA index.

F. Top Journals and their research impact

Papers on Galaxies have appeared in 47 journals. Papers have appeared in highest number in the journal 'Monthly Notices of the Royal Astronomical Society' published by Oxford University Press on behalf of the Royal Astronomical Society originating from United Kingdom. Table 4.3.d(v) shows the top 20 productive journals. These 20 out of the 47 journals have published 1593 (69.38 %) of the total 1554 articles. The 'Monthly Notices of the Royal Astronomical Society' ranked first with 508 (32.69%) papers; 'Astrophysical Journal published 303 (19.49%) papers ', 'Astronomy Astrophysics has 292 (17.79%) papers', 'Astrophysics and Space Science with 83 (5.34%) papers' and 'Journal of Astrophysics and Astronomy with 65 (4.18%) publications' these journals ranked at 2nd , 3rd , 4th and 5th respectively.

Table 4.3.d(v) also shows the citation impact of top 20 journals. The AvgCPA and h-index are used to identify which journals have the largest number of high quality articles in the Galaxies research. It is seen from the Table 4.3.d(v) that the

journal ‘Astrophysical Journal Supplement Series’ published by IOP Publishing for the American Astronomical Society in USA has the highest average impact (AvgCPA = 203.16) although the journal ‘Monthly Notices of the Royal Astronomical Society’ has the highest number of publications but it ranks 9^{th} in the AgvCPA index.

Table 4.3.d(v): Top Journals on Galaxies research and their research impact, 1960-2014

				Journal Metrics (2013)			
Journal	**TP (%)**	**TC**	**AvgCPA**	**SJR**	**IPP**	**SNIP**	**Country**
Monthly Notices of the Royal Astronomical Society	508(32.690)	7524	14.81	3.196	4.911	1.494	UK
Astrophysical Journal	303(19.498)	5210	17.19	3.159	4.348	1.145	UK
Astronomy Astrophysics	292(18.790)	7041	24.11	1.471	1.932	0.612	France
Astrophysics and Space Science	83(5.341)	240	2.89	1.081	1.748	1.056	Netherland
Journal of Astrophysics and Astronomy	65(4.183)	230	3.54	0.477	0.541	0.224	India
Astronomical Journal	45(2.896)	1117	24.82	2.795	3.282	1.092	UK
Astrophysical Journal Letters	41(2.638)	516	12.59	3.914	4.852	1.487	UK
Physical Review D	27(1.737)	459	17.00	1.899	3.192	1.136	USA
New Astronomy	25(1.609)	239	9.56	0.734	1.053	0.523	Netherlands
IAU Symposia	22(1.416)	6	0.27	-	-	-	Puerto Rico
International Journal of Modern Physics D	19(1.223)	183	9.63	0.733	1.021	0.540	Singapore
Bulletin of the Astronomical Society of India	19(1.223)	29	1.53	1.091	1.068	0.516	India
Astrophysical Journal Supplement Series	19(1.223)	3860	203.16	6.857	9.687	3.125	USA
Research in Astronomy and Astrophysics	11(0.708)	44	4.00	0.953	1.331	0.768	UK
Publications of the Astronomical Society of Australia	9(0.579)	150	16.67	1.869	2.543	0.910	Australia
New Astronomy Reviews	7(0.450)	9	1.29	4.143	6.462	1.973	Netherlands
Astronomy Astrophysics Supplement Series	7(0.450)	136	19.43	-	-	-	France
Journal of Cosmology and Astroparticle Physics	6(0.386)	44	7.33	0.615	2.374	0.465	UK
Classical and Quantum Gravity	6(0.386)	142	23.67	1.476	2.192	0.966	UK
Astronomische Nachrichten	5(0.322)	25	5.00	0.775	1.042	0.576	Germany

TP**= Total no. of Galaxies research related articles published by a Journal; **TC** = Total no. of citation received; **AvgCPA**= Average no. of citations that Galaxies related articles in a journal received; **h-index**= no. of h papers among a journal’s no. of publications that have at least h citations each. **SJR** = SCImago Journal Rank; **IPP** = Impact per Publication; **SNIP** = Source Normalized Impact per Paper; **Source: WoS and SCOPUS

G. Top Authors and their research impact

A total of 1554 articles included the author addresses having India as the county of affilation. Articles on Galaxies have been contributed by 5477 authors. Table 4.3.d(iv) shows the top 20 productive authors during the last 54 years, 1960-2014. Top 20 productive authors were ranked based on the decreasing productivity of total publications. Saikia, D. J. produced maximum number of publications i.e.109 which is 7.01% of total publications and ranked 1^{st} followed by Srianand, R., Chengalur, J. N., Wiita, P. J. and Petitjean, P. who ranked 2nd , 3rd , 4th and 5th respectively.

Table 4.3.d(iv) also reveals the impact of research in terms of quality of papers by means of AvgCPA and h-index to identify which author has the largest no. of high quality articles in the Galaxies research. It is seen from the Table 4.3.d(iv) that Galaxies related articles authored by Petitjean, P. have the highest average impact (AvgCPA = 51.05) followed by Ledoux, C. (AvgCPA = 43.34) while Saikia, D. J. having the maximum number of publications but ranked 14th in the AgvCPA index.

Table 4.3.d(iv): Top Authors of Galaxies research and their research impact, 1960-2014

Author	TP (%)	TC	TC woSC	CI	CIwoSC	AvgCPA	h-index
Saikia, D.J.	109(7.014)	1517	1166	911	825	13.92	24
Srianand, R.	92(5.920)	2555	2132	1205	1129	27.77	30
Chengalur, J.N.	67(4.311)	1278	1087	724	668	19.07	22
Wiita, P.J.	65(4.183)	956	805	546	497	14.71	18
Petitjean, P.	62(3.990)	3165	2845	1786	1732	51.05	30
Jog, C.J.	51(3.282)	1193	1019	815	772	23.39	18
Gopal-Krishna	45(2.896)	561	489	385	362	12.47	12
Sagar, R.	42(2.703)	738	670	518	495	17.57	16
Nath, B.B.	42(2.703)	572	505	470	442	13.62	14
Subramanian, K.	38(2.445)	644	580	502	476	16.95	14
Gupta, A.C.	38(2.445)	507	411	287	259	13.34	14
Ledoux, C.	35(2.252)	1592	1376	600	568	45.49	24
Singh, K.P.	34(2.188)	291	272	265	252	8.56	9
Khare, P.	32(2.059)	496	402	221	194	15.50	15
Kanekar, N.	31(1.995)	569	471	311	286	18.35	15
Bharadwaj, S.	30(1.931)	381	311	232	210	12.70	13
Noterdaeme, P.	28(1.802)	867	735	380	358	30.96	16
Dwarakanath, K.S.	28(1.802)	219	204	192	183	7.82	9
Begum, A.	26(1.673)	564	481	357	333	21.69	14
Subramaniam, A.	25(1.609)	384	336	293	276	15.36	12

TP: *Total no. of Galaxies related articles published by a author;* ***TC:*** *Total no. of citation;* ***TC woSc:*** *Sum of Times Cited without self-citations;* ***CI:*** *Citing Articles;* ***CIwoSC:*** *Citing Articles without self-citations;* ***AvgCPA:*** *Average Citations per Article;* ***h-index:*** *no. of h papers among a author's no. of publications that have at least h citations each.* ***Source: WoS***

H. Collaboration Pattern: Continents

Based on the author attributions, world-wide collaboration of Galaxies research publications has been mapped. Figure 4.3.d(v) shows the major spatial clusters of research institutes are located in Europe, followed by Asia and Africa. Several minor clusters are distributed in other parts of the world. North America and South America have equal contribution.

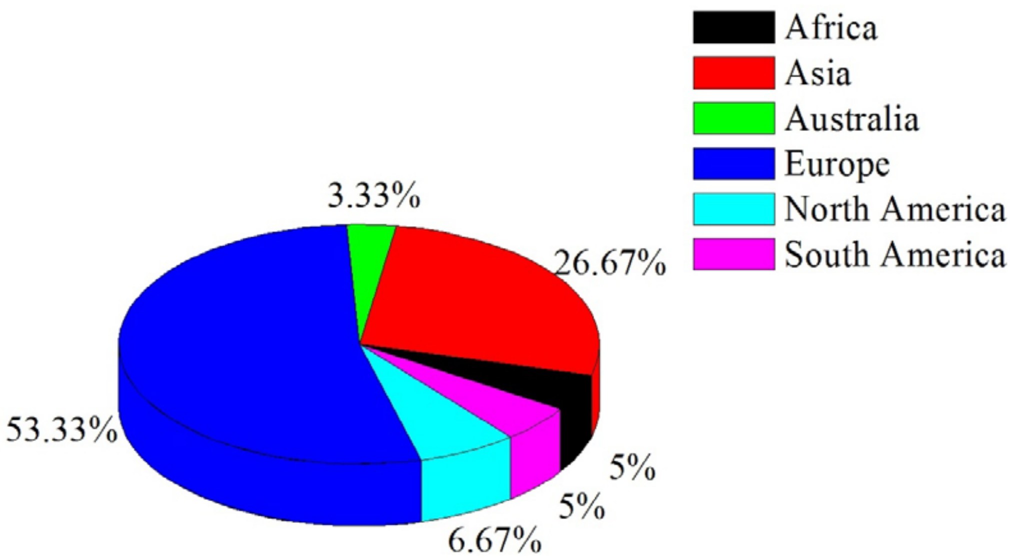

Figure 4.3.d(v): Continent wise Collaboration pattern of Galaxies research

I. Collaboration Pattern and research impact: Countries

A total of 1554 articles included author address, source country and research institute. There are 61 collaborating Countries/territories which participated in Indian institution in Galaxies research. Top 20 countries / territories are ranked based on the number of total articles, along with the citations and percentage of international collaborations (Table 4.3.d(vii)). Out of these 20 countries / territories, The USA produced maximum publication viz. 529 which accounts for 34.041% of total publications with high citations (14414). It is seen from the Table 4.3.d(vii) that galaxies research related articles authored in collaboration with Japan (Asia) have the highest average impact (AvgCPA = 86.36) followed by South Africa (Africa) AvgCPA = 67.86 while the USA ranked 18th in the AgvCPA index.

Table 4.3.d(vii): Country wise Collaboration Pattern and research impact of Galaxies research

Country	Continent	TP (%)	TC	AvgCPA	h-index
USA	North America	529(34.041)	14414	27.25	51
Germany	Europe	219(14.093)	8658	39.53	44
France	Europe	215(13.835)	7714	35.88	43
England	Europe	189(12.162)	7427	39.30	37
Italy	Europe	150(9.653)	5106	34.04	37
Australia	Australia	113(7.272)	4880	43.19	28
Netherlands	Europe	103(6.628)	4294	41.69	32
Chile	South America	97(6.242)	5053	52.09	33
Russia	Europe	96(6.178)	1985	20.68	27
Canada	North America	93(5.985)	5645	60.70	31
Spain	Europe	87(5.598)	5532	63.59	31
Poland	Europe	52(3.346)	2941	56.56	20
Japan	Asia	44(2.831)	3800	86.36	19
Taiwan	Asia	43(2.767)	1773	41.23	18
South Africa	Africa	42(2.703)	2850	67.86	16
Denmark	Europe	39(2.510)	1233	31.62	22
Peoples R China	Asia	37(2.381)	1323	35.76	17
Finland	Europe	37(2.381)	972	26.27	17
Sweden	Europe	35(2.252)	1033	29.51	22
Wales	Europe	34(2.188)	1173	34.50	22

TP= *Total no. of Galaxies related articles published by a country;* ***TC*** = *Total no. of citation received;* ***AvgCPA***= *Average no. of citations per Article;* ***h-index***= *no. of h papers among a country's no. of publications that have at least h citations each.* ***Source: WoS***

J. Keyword Analysis

A total of 5128 different keywords, from 1960 to 2014 in the Galaxies research have been identified. The number of analysed publications during the study period is 1554. To obtain accurate results, the keywords are pre-processed by merging the singular and plural forms of the same terminology, and those keywords with the same meaning while using different expressions. A total 4923 unique Keywords are obtained. Among these unique keywords 441 (8.95 %) appear once or twice at the most, it can be deduced that this can be a sign of lack of research continuity or of a wide range of research focus. Table 4.3.d(viii) shows the most used keywords during the considered period.

J.1 Hotspots

An analysis of the keywords was undertaken to pick out the research hotsopts (Chapter 1, Section 1.8.5.A) that have attracted most research attention and to reveal the research tendencies in the fields of Galaxies. The top 20 most frequently used keywords for the study period are listed in Table 4.3.d(viii). The five most frequently used keywords are ‘Individual’, ‘Clusters’, ‘Active’, ‘Evolution’ and ‘Quasars’.

Table 4.3.d(viii): Top most frequently used keywords in Galaxies research

Keywords	NO	%	R
Abundances	100	2.03	15
Active	419	8.51	2
BL Lacertae objects	79	1.60	19
Clusters	358	7.27	3
Dwarf	85	1.72	17
Evolution	356	7.23	4
Formation	316	6.41	7
Halos	119	2.41	14
High-redshift	154	3.12	11
Individual	464	9.42	1
Intergalactic medium	88	1.78	16
Jets	203	4.12	9
Kinematics	151	3.06	12
Nuclei	338	6.86	6
Photometry	137	2.78	13
Quasars	349	7.08	5
Seyfert	84	1.70	18
Spiral	173	3.51	10
Starburst	79	1.60	19
Structure	278	5.64	8

NO: Number of time occurrences; R : rank Source: WoS

J.2 Quick Rising Themes

The Compound Annual Growth Rate (CAGR) described in Chapter 1, Section 1.8.5.B, can be used to select quick rising themes of Galaxies research; this reveals the indicators of future research directions. Table 4.3.d(ix) lists the top 20 keywords according to the CAGR and sorts them by their rank. The ranks in Table 4.3.d(ix) show that 'Formation', 'High-redshift', 'Clusters' and 'Halos' are four leading hot issues that continue to attract broad attention. 'Clusters' kept its dominance in terms of total quantity and CAGR

Table 4.3.d(ix): Top Quick rising themes in Galaxies research

Keyword	$V(t_0)$	$V(t_n)$	t_0	t_n	CAGR (%)	R
Abundances	1	10	1992	2014	0.110	6
Active	4	43	1991	2014	0.108	7
BL Lacertae objects	1	11	1992	2014	0.115	4
Clusters	2	32	1991	2014	0.128	3
Dwarf	2	11	1997	2014	0.105	8
Evolution	4	31	1991	2014	0.093	12
Formation	2	39	1991	2014	0.137	1
Halos	1	16	1991	2014	0.128	3
High-redshift	1	17	1991	2014	0.131	2
Individual	5	57	1991	2014	0.111	5
Intergalactic medium	1	6	1991	2014	0.081	14
Jets	7	19	1991	2014	0.044	18
Kinematics	1	9	1992	2014	0.105	9
Nuclei	5	37	1991	2014	0.090	13
Photometry	3	10	1993	2014	0.059	15
Quasars	10	28	1991	2014	0.045	17
Seyfert	6	12	1991	2014	0.030	19
Spiral	2	16	1991	2014	0.094	11
Starburst	2	7	1992	2014	0.058	16
Structure	3	27	1991	2014	0.100	10

t_0*: the Initial (first) year (The Year in which no. of keywords occurrence first time;* ***t_n****: the last year (No. of keywords occurrence);* ***$V(t_0)$****: Initial observed value (no. of keywords occurrence);* ***$V(t_n)$****: last observed value (no. of keywords occurrence);* ***CAGR:*** *Compound Annual Growth Rate;* ***R:*** *Rank.* ***Source: WoS***

K. Summary

A total of 1554 literature were published on Galaxies, which received total 27403 citations. The average number of publications per year was 37.00 and the average number of citations per publication was 17.63. Publications on Galaxies appeared in 47 journals of which most productive journal was 'Monthly Notices of the Royal Astronomical Society' published by Oxford University Press on behalf of the Royal Astronomical Society originating from United Kingdom and 489 (21.29%) of the total 1554 publications. A total of 5477 authors contributed on galaxies research. The most active author was Saikia, D.J. produced maximum no. of publications 109 i.e.7.014 % of total publications. 1110 institutions contributed of which TIFR, Mumbai is the most productive institution. For globalization of Galaxies Research in India, the results show there were 61 Countries/territories which participated in Galaxies research. USA produced maximum publications 529 that are 34.04% of total publication with 14414 citations. A Keyword analysis reveals that 'Individual', 'Clusters', 'Active', 'Evolution' and 'Quasars' are the most used keywords.

4.3.5 Interstellar Medium (ISM)

In astronomy, the interstellar medium (ISM) is the matter that exists in the space between the star systems in a galaxy. This matter includes gas in ionic, atomic, and molecular form, as well as dust and cosmic rays. It fills interstellar space and blends smoothly into the surrounding intergalactic space. The energy that occupies the same volume, in the form of electromagnetic radiation, is the interstellar radiation field (Murdin, 2001; 'Interstellar medium', n.d.).

There were 797 articles that met the selection criteria which appeared in the WoS database during 1960-2014 and these were analyzed.

A. Publication Characteristics

A total of 797 articles of Indian scientists during 1960-2014 were abstracted from WoS related to ISM publications. From the Tables 4.3.e (i) and 4.3.e (ii), the output of 797 papers has received a total of 11952 citations during the said period with an average of about 15.00 citations per paper. The average number of publications per year is 19.92 and CAGR is 0.14%.

Table 4.3.e(i): Bibliographic Records of ISM research in India during 1960-2014

Bibliometric Indicators `	No.
Total Number of Articles	797
Total Number of Contributing Countries	49
Total Number of Contributing Authors	2783
Total Number of Contributing Institutions	696
Total Number of Journals appeared	35
Total Number of Keywords (raw) appeared	3553

Source: WoS

Table 4.3.e(ii): Citation Metrics of ISM research in India during 1960-2014

Citation-based Indicators	No.
Sum of the Times Cited	11952
Sum of Times Cited without self-citations	10373
Citing Articles	7771
Citing Articles without self-citations	7289
Average Citations per Item	15.00
h-index	47

Source: WoS

B. Publications Pattern

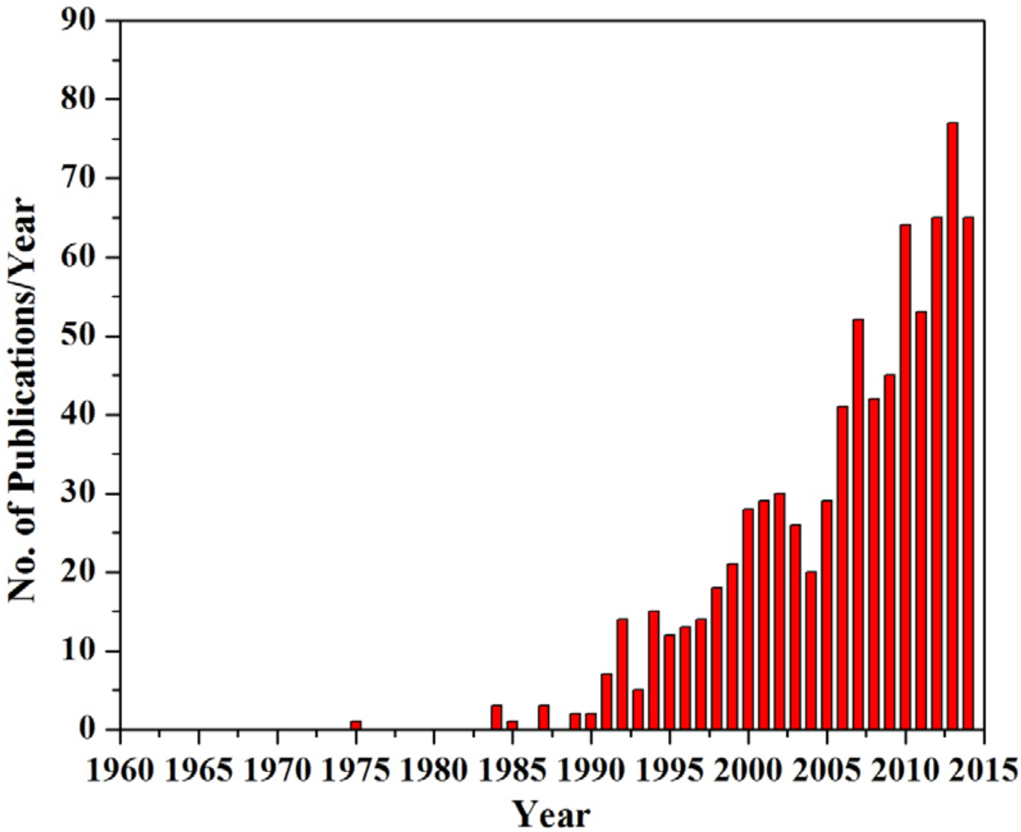

Figure 4.3.e(i): Publication Pattern of ISM research in India during 1960-2014. From the period 1960-1974, no publication appeared in the WoS database.

Publication pattern of ISM research from 1960 to 2014 is presented in Figure 4.3.e(i). The initial publication in the sub-field of ISM research is observed in the year 1975. A near about sixty five times increase is observed over the study period, (from 1 in 1975 to 65 in 2014). The highest number of papers is published in the year 2013, with 77 publications and the lowest in 1976 with no publication.

C. Growth Trend

The cumulative progression is represented by a 3rd degree power law distribution during 1960-2014 giving an idea of the polynomial growth curve as shown in Figure 4.3.e(ii). To choose the best fit growth model, various regression types with regression coefficient has been tested as shown in Table 4.3.e(iii). The best fit model is 3rd degree polynomial curve, where $R^2 = 0.972$. The polynomial best fit for ISM research is found to be: $y = 0.0006x^3 - 3.68x^2 + 7208x - 5E+06$, where y is the cumulative number of publications and x is the number of years. The growth of literature shown in Figure 4.3.e(ii) can be divided into two parts, in the 1st part (1960-1974), no literature is published by Indian scientists and in 2nd part (1975-2014), trend follows a polynomial growth curve.

Table 4.3.e(iii): Different Regression Types with Regression Coefficient (R^2) of ISM research

Regression Type	**Equation**	**(R^2)**
Linear	$y = 1.7562x - 3482.8$	0.8295
Logarithmic	$y = 3499.1\ln(x) – 26567$	0.8279
Polynomial	$y = 0.0006x^3 - 3.68x^2 + 7208x - 5E+06$	0.9586

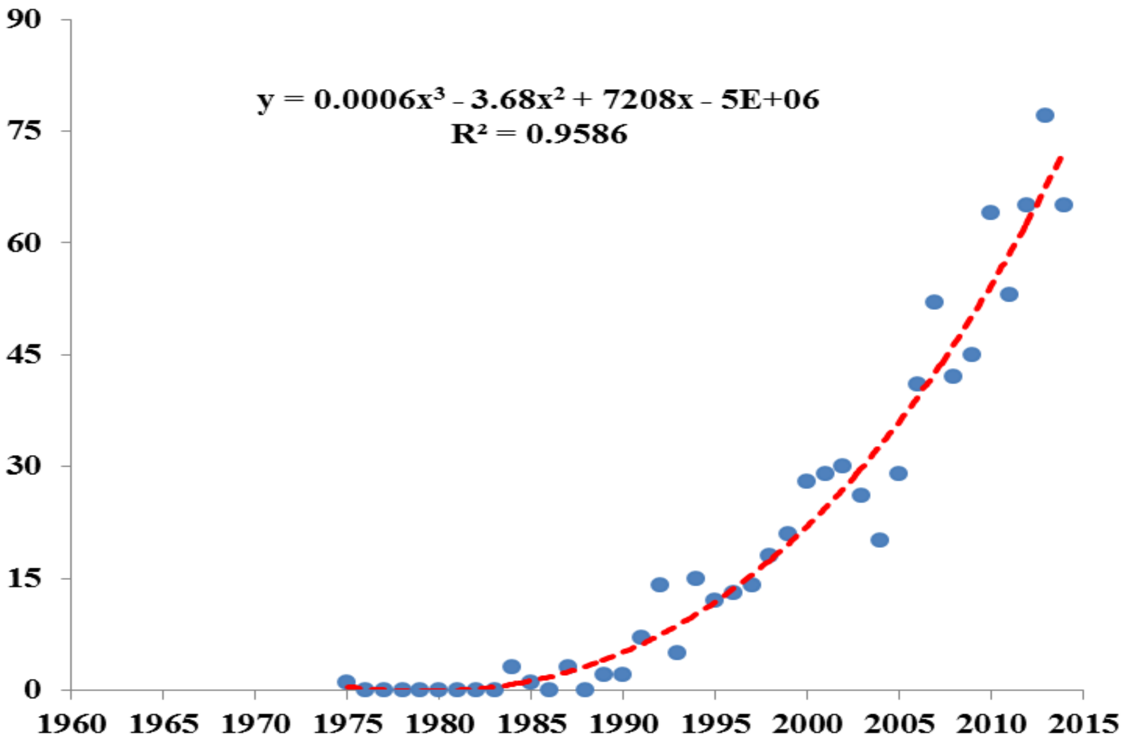

Figure 4.3.e(ii): Growth Trend of ISM research in India during 1960-2014.Blue dot describes the distribution of publications (observed value) and red dashed line describes the correlation of distribution of publications where regression coefficient R^2 = 0.958

D. Citations Pattern

Figures 4.3.e (iii) and 4.3.e (iv) represent the citation pattern and number of citations vs. number of publications per year of ISM research in India during 1960-2014. A total of 797 research papers have received 11952 citations. The pattern of citations is very fluctuating. In the initial year 1975, the total number of citations received is 1 with an average citation of 1. The minimum citation received in the year 1975 is one (1) and the maximum citations received in the year 2011 are 1145 with an average citation of 17.89. It has been observed from Figure 4.3.e (iv) that after the year 2011, citations decrease while publications continue to increase.

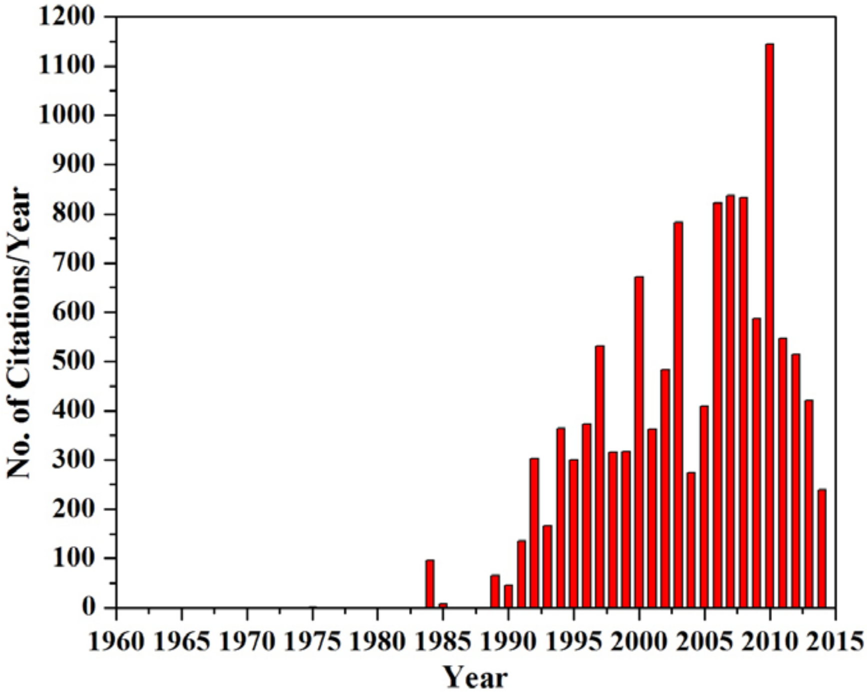

Figure 4.3.e(iii): Citation Pattern of ISM research in India during 1960-2014. From 1960-1974, no citation received as no publication appeared in the WoS database.

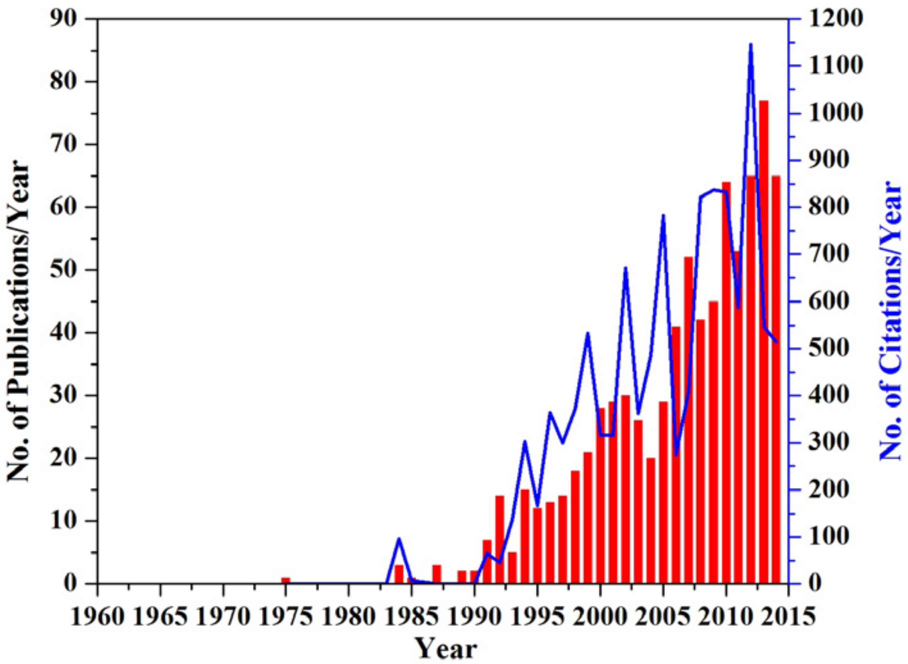

Figure 4.3.e(iv): Citation Pattern Vs Publication Pattern of ISM research in India during 1960-2014: Blue line (right Y axis) indicates the citation pattern against red bar (left Y axis) that describes the publications pattern.

E. Top Institutions and their research impact

A total of 797 articles on ISM appeared from 696 institutions. Table 4.3.e(iv) shows that out of these top 20 institutions only 7 are Indian. Tata Institute of Fundamental Research contributed highest number of publications (264), followed by Indian Institute of Astrophysics which contributed 128 papers, Inter University Centre for Astronomy Astrophysics contributed 119 publications, Raman Research Institute contributed 115, National Centre for Radio Astrophysics - 51, Indian Institute of Science - 50 and Aryabhatta Research Institute of Observational Sciences contributed 43 papers respectively..

Table 4.3.e(iv): Top institutions on ISM research and their research impact, 1960- 2014

Institution	Region	TP (%)	TC	AvgCPA	h-index
Tata Institute of Fundamental Research	India	264(33.124)	3596	13.62	33
Indian Institute of Astrophysics	India	128(16.060)	1254	9.80	17
Centre National De La Recherche Scientifique CNRS	France	122(15.307)	3109	25.48	34
Inter University Centre for Astronomy Astrophysics	India	119(14.931)	2851	23.96	30
Raman Research Institute	India	115(14.429)	1560	13.57	22
Observatoire De Paris	France	70(8.783)	2040	29.14	30
Max Planck Society	Germany	69(8.657)	1192	17.28	20
National Radio Astronomy Observatory	USA	62(7.779)	836	13.48	18
National Aeronautics Space Administration NASA	USA	53(6.650)	1272	24.00	20
National Centre for Radio Astrophysics	India	51(6.399)	1146	18.48	20
California Institute of Technology	USA	51(6.399)	1614	31.65	23
Indian Institute of Science IISc	India	50(6.274)	836	16.72	17
European Southern Observatory	Germany	49(6.148)	1715	35.00	27
Commonwealth Scientific Industrial Research Organisation	Australia	47(5.897)	1187	25.26	22
Aryabhatta Research Institute of Observational Sciences	India	43(5.395)	319	7.42	10
University of Groningen	Netherlands	42(5.270)	737	17.55	15
Pierre Marie Curie University Paris	France	38(4.768)	1006	26.47	20
Jet Propulsion Laboratory	USA	36(4.517)	998	27.72	17
Consejo Superior De Investigaciones Cientificas CSIC	Spain	34(4.266)	753	22.15	16
University of Manchester	USA	33(4.141)	748	22.67	15

TP**= Total no. of ISM related articles published by an institution; **TC** = Total no. of citation received; **AvgCPA**= Average no. of citations per article; h-**index**=defined by the no. of h papers among an institution's no. of publications that have at least h citations each.* ***Source: WoS

Out of the 13 foreign institutions, 5 belong to the USA namely National Radio Astronomy Observatory, National Aeronautics Space Administration (NASA), USA; California Institute of Technology, USA; Jet Propulsion Laboratory and University of Manchester USA; 3 are from France namely Centre National De La Recherche Scientifique CNRS, France; Observatoire De Paris and Pierre Marie Curie University Paris, France; 2 belong to Germany viz. Max Planck Society and European Southern Observatory, Germany; The Commonwealth Scientific Industrial Research Organisation, Australia; University of Groningen, Netherlands and Consejo Superior De Investigaciones Cientificas,Spain are the remaining three from their respective countries.

Table 4.3.e(iv) reveals the impact of research in terms of quality of papers. It is seen from the Table 4.3.e(iv) that ISM research articles authored in coolaboration with European Southern Observatory have the highest average impact (AvgCPA = 35.00). Among Indian institutions, Inter University Centre for Astronomy Astrophysics has the highest impact (23.96) in the AvgCPA index.

F. Top Journals and their research impact

ISM papers have appeared in 35 journals. Papers have appeared in highest number in the journal ‘Monthly Notices of the Royal Astronomical Society’ published by Oxford University Press on behalf of the Royal Astronomical Society originating from United Kingdom. Table 4.3.e(v) shows the top 20 productive journals. These 20 out of the 35 journals have published 786 (98.61 %) of the total 797 articles. The ‘Monthly Notices of the Royal Astronomical Society’ ranked first with 247 (30.99%); ‘Astronomy Astrophysics 209 (26.22%)’, ‘Astrophysical Journal 158 (19.82%)’ and ‘Journal of Astrophysics and Astronomy 30 (3.76%)’ ranked at 2nd, 3rd and 4th respectively.

Table 4.3.e(v) also shows the citation impact on top 20 journals. The AvgCPA and h-index are used to identify which journals have the largest number of high quality articles in the ISM research. It is seen from the Table 4.3.e(v) that the journal 'Astrophysical Journal' published by IOP Publishing for the American Astronomical Society in USA has the highest average impact (AvgCPA = 19.87) followed by 'Astronomy Astrophysics Supplement Series' with average impact (AvgCPA = 19.50) although the journal 'Monthly Notices of the Royal Astronomical Society' has the highest number of publications but ranked 4th in the AvgCPA index.

Table 4.3.e(v): Top Journals on ISM research and their research impact, 1960-2014

Journal	TP (%)	TC	AvgCPA	Journal Metrics (2013) SJR	IPP	SNIP	Country
Monthly Notices of the Royal Astronomical Society	247(30.991)	3782	15.31	3.196	4.911	1.494	UK
Astronomy Astrophysics	209(26.223)	3728	17.84	1.471	1.932	0.612	France
Astrophysical Journal	158(19.824)	3139	19.87	3.159	4.348	1.145	UK
Journal of Astrophysics and Astronomy	30(3.764)	230	7.67	0.477	0.541	0.224	India
Astrophysics and Space Science	25(3.137)	56	2.24	1.081	1.748	1.056	Netherland
Astronomical Journal	25(3.137)	240	9.60	2.795	3.282	1.092	UK
New Astronomy	22(2.760)	171	7.77	0.734	1.053	0.523	Netherlands
Astrophysical Journal Letters	16(2.008)	173	10.81	3.914	4.852	1.487	UK
Bulletin of the Astronomical Society of India	10(1.255)	10	1.00	1.091	1.068	0.516	India
IAU Symposia	7(0.878)	0	0.00	-	-	-	Puerto Rico
Astrophysical Journal Supplement Series	7(0.878)	80	11.43	6.857	9.687	3.125	USA
Advances in Space Research	7(0.878)	7	1.00	0.727	1.506	1.237	UK
Research in Astronomy and Astrophysics	5(0.627)	24	4.80	0.953	1.331	0.768	UK
Publications of the Astronomical Society of Japan	4(0.502)	42	10.50	1.521	1.626	0.750	Japan
Astronomy Astrophysics Supplement Series	4(0.502)	78	19.50	-	-	-	France
Publications of the Astronomical Society of the Pacific	2(0.251)	26	13.00	2.990	3.147	1.266	USA
Publications of the Astronomical Society of Australia	2(0.251)	26	13.00	1.869	2.543	0.910	Australia
Experimental Astronomy	2(0.251)	3	1.50	1.072	2.146	1.882	Netherlands
Astronomische Nachrichten	2(0.251)	18	9.00	0.775	1.042	0.576	Germany
Annales Geophysicae	2(0.251)	19	9.50	1.176	1.533	1.533	Germany

TP= *Total no. of ISM research related articles published by a Journal;* ***TC*** *= Total no. of citation received;* ***AvgCPA***= *Average no. of citations that ISM related articles in a journal received;* ***h-index***= *no. of h papers among a journal's no. of publications that have at least h citations each.* ***SJR*** *= SCImago Journal Rank;* ***IPP*** *= Impact per Publication;* ***SNIP*** *= Source Normalized Impact per Paper;* ***Source: WoS and SCOPUS***

G. Top Authors and their research impact

A total of 797 articles included the author addresses having India as the county of affilation. Articles on ISM have been contributed by 2783 authors. Table 4.3.e(vi) showed the top 20 productive authors during the last 54 years, 1960-2014. Top 20 productive authors are ranked based on the decreasing productivity of total publications. Chengalur, J. N. has produced maximum number of publications -57 i.e. 7.15% of total publications and ranked 1st followed by Srianand, R., Ojha, D. K., Mookerjea, B. and Petitjean, P. who ranked at 2nd , 3rd , 4th and 5th respectively.

Table 4.3.e(vi): Top Authors of ISM research and their research impact, 1960-2014

Author	TP (%)	TC	TC woSC	CI	CIwoSC	AvgCPA	h-index
Chengalur, J.N.	57(7.152)	984	859	589	548	17.26	20
Srianand, R.	47(5.897)	1599	1322	671	630	34.02	24
Ojha, D.K.	41(5.144)	336	252	225	196	8.20	11
Mookerjea, B.	41(5.144)	786	707	453	423	19.17	16
Petitjean, P.	39(4.893)	1480	1250	596	561	37.95	23
Ghosh, S.K.	36(4.517)	323	238	223	195	8.97	11
Murthy, J.	29(3.639)	171	120	112	91	5.90	8
Ledoux, C.	29(3.639)	1342	1160	502	474	46.28	22
Jog, C.J.	27(3.388)	591	526	423	403	21.89	14
Saikia, D.J.	26(3.262)	356	331	304	289	13.69	11
Kanekar, N.	26(3.262)	518	437	274	253	19.92	15
Bhatt, H.C.	24(3.011)	175	147	136	124	7.29	9
Noterdaeme, P.	23(2.886)	684	573	292	270	29.74	16
Pandey, A.K.	22(2.760)	221	163	121	104	10.05	9
Gupta, Y.	22(2.760)	402	364	265	250	18.27	11
Goss, W.M.	22(2.760)	352	337	314	302	16.00	11
Anantharamaiah, K.R.	21(2.635)	317	285	242	226	15.10	11
Verma, R.P.	20(2.509)	157	131	130	118	7.85	8
Chandra, S.	20(2.509)	111	75	78	63	5.55	5
Chakrabarti, S.K.	20(2.509)	226	164	85	70	11.30	11

TP:** Total no. of ISM related articles published by a author; **TC:** Total no. of citation**; TC woSc:** Sum of Times Cited without self-citations**; CI:** Citing Articles**; CIwoSC:** Citing Articles without self-citations**; AvgCPA:** Average Citations per Article**; h-index:** no. of h papers among a author's no. of publications that have at least h citations each. **Source: WoS

Table 4.3.e(vi) also reveals the impact of research in terms of quality of papers. The AvgCPA and h-index are used to identify which author has the largest number of high quality publications in the ISM research. It is seen from the Table 4.3.e(vi) that ISM related articles authored by Ledoux, C. have the highest average impact (AvgCPA =

46.28) followed by Petitjean, P. (AvgCPA = 37.95) and Srianand, R. (AvgCPA = 34.02) while Chengalur, J. N. inspite of having the maximum number of publications but ranked 9th in the AgvCPA index.

H. Collaboration Pattern: Continents

Based on the author attributions, world-wide collaboration of ISM research publications has been mapped. As shown in Figure 4.3.e(v), the major spatial clusters of research institutes are located in Europe, followed by Asia and Africa. Several minor clusters are distributed in other parts of the world. North America and South America have equal contributions.

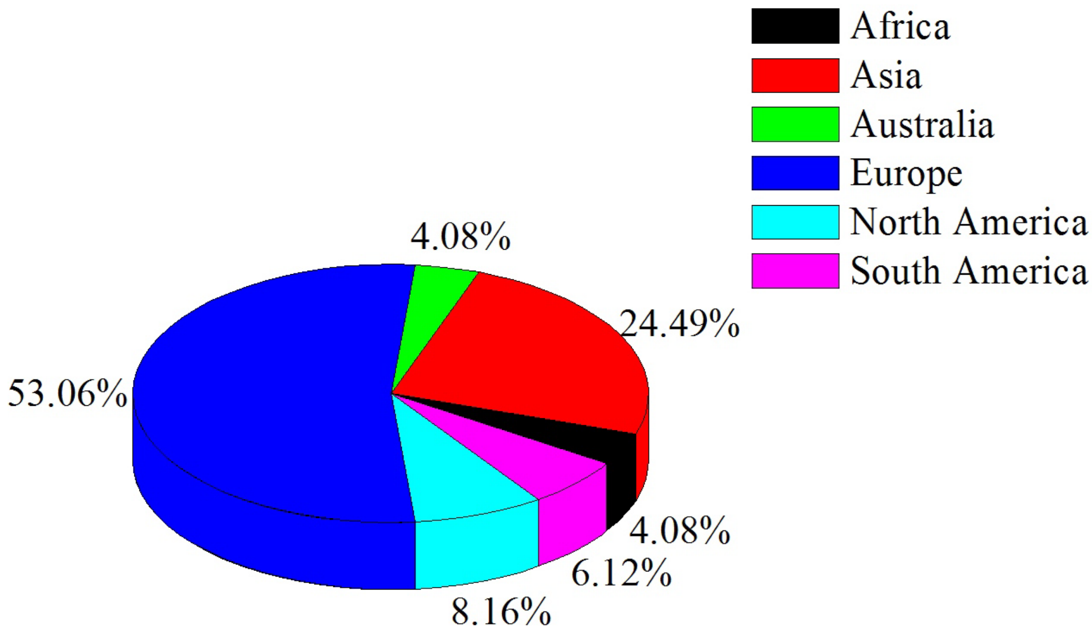

Figure 4.3.e(v): Continent wise Collaboration pattern of ISM research

I. Collaboration Pattern and research impact: Countries

A total of 797 articles included author address, source country and research institute. There are 49 collaborating Countries/territories which participated in collaborative research with Indian institutions in the ISM research. As shown in the Table 4.3.e(vii), top 20 countries / territories are ranked based on the number of total articles, along with the citations and percentage of international collaboration. Out of these 20 countries / territories, The USA has produced maximum publications i.e. 285 which accounts for 35.759% of total publications with high citations (5741). It is seen from the Table 4.3.e(vii) that ISM research articles published in collaboration with Denmark (Europe) have the highest average impact (AvgCPA=36.26) followed by Chile (South America) AvgCPA=35.42 while the USA ranked 10th in the AgvCPA index.

Table 4.3.e(vii): Country wise Collaboration Pattern and research impact of ISM research

Country	Continent	TP (%)	TC	AgCPA	h-index
USA	North America	285(35.759)	5741	20.14	37
France	Europe	138(17.315)	3331	24.14	34
Germany	Europe	114(14.304)	2082	18.26	29
Netherlands	Europe	86(10.790)	1614	18.77	24
England	Europe	85(10.665)	1962	23.08	26
Australia	Australia	64(8.030)	1521	23.77	24
Canada	North America	58(7.277)	1380	23.79	23
Spain	Europe	56(7.026)	1057	18.88	20
Chile	South America	52(6.524)	1842	35.42	26
Japan	Asia	51(6.399)	876	17.18	18
Italy	Europe	49(6.148)	1184	24.16	19
Russia	Europe	36(4.517)	557	16.19	14
Sweden	Europe	34(4.266)	809	23.79	18
Taiwan	Asia	28(3.513)	333	11.89	10
Poland	Europe	23(2.886)	570	24.78	12
Denmark	Europe	19(2.384)	689	36.26	12
Ireland	Europe	17(2.133)	296	17.41	10
Wales	Europe	15(1.882)	248	16.53	8
Switzerland	Europe	14(1.757)	232	16.57	7
South Africa	Africa	14(1.757)	237	16.93	8

TP**= Total no. of ISM related articles published by a country; **TC** = Total no. of citation received; **AvgCPA**= Average no. of citations per Article; **h-index**= no. of h papers among a country's no. of publications that have at least h citations each. **Source: WoS

J. Keyword Analysis

A total of 3553 different keywords, from 1960 to 2014 in the Interstellar medium have been identified. The number of analysed publications during the study period is 797. To obtain accurate results, the keywords have been pre-processed by merging the singular and plural forms of the same terminology, and those keywords with the same meaning while using different expressions. A total 3375 unique Keywords are obtained. Among these unique keywords 1314 (36.98 %) appear once or twice. Table 4.3.e(viii) shows the most used keywords during the considered period.

J.1 Hotspots

Table 4.3.e(viii): Top most frequently used keywords in ISM research

Keywords	Total	%	R
Abundances	100	2.81	9
Atom	34	0.95	17
Bands	25	0.70	19
Bubble	22	0.61	20
Clouds	294	8.27	1
Cosmic rays	22	0.61	20
Dust	165	4.64	3
Dynamics	95	2.67	10
Evolution	143	4.02	4
Extinction	117	3.29	7
General	134	3.77	5
HII regions	42	1.82	12
Individual objects	36	1.01	15
Jets	47	1.32	13
Kinematics	90	2.53	11
Lines	267	7.51	2
Magnetic fields	33	0.92	18
Molecules	118	3.32	6
Outflows	40	1.25	14
Structure	103	2.89	8
Supernova remnants	35	0.98	16

NO: Number of time occurrences; R : rank Source: WoS

An analysis of the keywords was undertaken to pick out the research hotsopts (Chapter 1, Section 1.8.5.A) that have attracted most research attention and to reveal the research tendencies in the fields of ISM. The top 20 most frequently used keywords for the study period are listed in Table 4.3.e(viii). The four most frequently used keywords were ‘Clouds’, ‘Lines’, ‘Dust’ and ‘Evolution’.

J.2 Quick rising themes

Table 4.3.e(ix): Top Quick rising themes in ISM research

Keyword	V (t_0)	V (t_n)	t_0	t_n	CAGR (%)	R
Abundances	2	11	1992	2044	0.080	12
Atom	1	6	1992	2014	0.084	10
Bands	1	7	2000	2014	0.149	2
Bubble	1	3	1993	2014	0.053	16
Clouds	1	25	1991	2014	0.150	1
Cosmic rays	1	1	1991	2014	0.000	19
Dust	1	14	1992	2014	0.127	3
Dynamics	1	6	1991	2014	0.081	11
Evolution	3	16	1991	2014	0.075	13
Extinction	1	8	1992	2014	0.099	7
General	1	10	1992	2014	0.110	4
HII regions	2	4	1999	2014	0.047	18
Individual objects	1	6	1994	2014	0.093	9
Jets	2	7	1991	2014	0.056	15
Kinematics	1	3	1992	2014	0.051	17
Lines	2	19	1991	2014	0.102	5
Magnetic fields	1	3	1992	2014	0.051	17
Molecules	2	17	1991	2014	0.097	8
Outflows	1	5	1997	2014	0.099	6
Structure	3	10	1991	2014	0.053	16
Supernova remnants	1	3	1994	2014	0.056	14

t_0**: the Initial (first) year (The Year in which no. of keywords occurrence first time; **t_n**: the last year (No. of keywords occurrence); **$V(t_0)$**: Initial observed value (no. of keywords occurrence); **$V(t_n)$**: last observed value (no. of keywords occurrence); **CAGR:** Compound Annual Growth Rate; **R:** Rank. **Source: WoS

The Compound Annual Growth Rate (CAGR) described in Chapter 1, Section 1.8.5.B, can be used to select quick rising themes of ISM research, this reveals the indicators of future research directions. Table 4.3.e(ix) lists the top 20 keywords according to the CAGR and sorts them by their rank. The ranks in Table 4.3.e(ix) show that ‘Clouds’, ‘Bands’ and ‘Dust’ are three leading hot issues that continue to attract broad attention. ‘Clouds’ kept its dominance in terms of total quantity and CAGR.

K. Summary

A total of 797 journal articles were published on ISM, which received total 11952 citations. The average number of publications per year is 19.92 and the average number of citations per publication was 15.00. Publications on ISM appeared in 35 journals of which most active journal was Monthly Notices of the Royal Astronomical Society” published by Oxford University Press on behalf of the Royal Astronomical Society originating from United Kingdom and 247 (30.99%) of the total 797 publications. A total of 2783 authors contributed on ISM research. The most active author was Chengalur, J.N. produced maximum number of publications 57 (7.15%) of total publications. 696 institutions contributed of which Tata Institute of Fundamental Research, India is the most productive institution. For globalization of ISM Research in India, the results show there were 49 Countries/territories which participated in collaborative ISM research. USA produced maximum publications 285 that is 35.75% of total publication with higher citations (5741). A Keyword analysis reveals that ‘Clouds’, ‘Bands’ and ‘Dust’ are the most frequently used keywords.

4.3.6 Physical Data and Processes (PDP)

Astrophysical systems present us with vast laboratories in the universe giving us unique opportunities to study the enormous kinds of physical processes comprised within. 'Physical data and processes' is the field that lists the physical phenomenon and the relevant data compilation responsible for the formation, evolution, interaction and demise of any astrophysical system at all length scales and distances in the cosmos.

There are 5487 articles that met the selection criteria which appeared in the WoS database during 1960-2014 and these have been analyzed.

A. Publication Characteristics

The total 5487 articles of Indian scientists during 1960-2014 have been abstracted from WoS related to PDP publication. From Tables4.3.f(i) and 4.3.f(ii), it is seen that the output of 5487 paper has received a total of 74841 citations during the said period with an average of about 13.64 citations per paper. The average number of publications per year is 127.60 andCAGR is 0.15%.

Table4.3.f(i): Bibliographic Records ofPDP research in India during 1960-2014

Bibliometric Indicators `	**No.**
Total Number of Articles	5487
Total Number of ContributingCountries	95
Total Number of Contributing Authors	20522
Total Number of Contributing Institutions	2450
Total Number of Journals appeared	105
Total Number ofKeywords (raw) appeared	13798

Source: WoS

Table4.3.f(ii): Citation Metrics of PDP research in India during 1960-2014

Citation-based Indicators	No.
Sum of the Times Cited	74841
Sum of Times Cited without self-citations	64403
Citing Articles	44648
Citing Articles without self-citations	41291
Average Citations per Item	13.64
h-index	91

Source: WoS

B. Publication Pattern

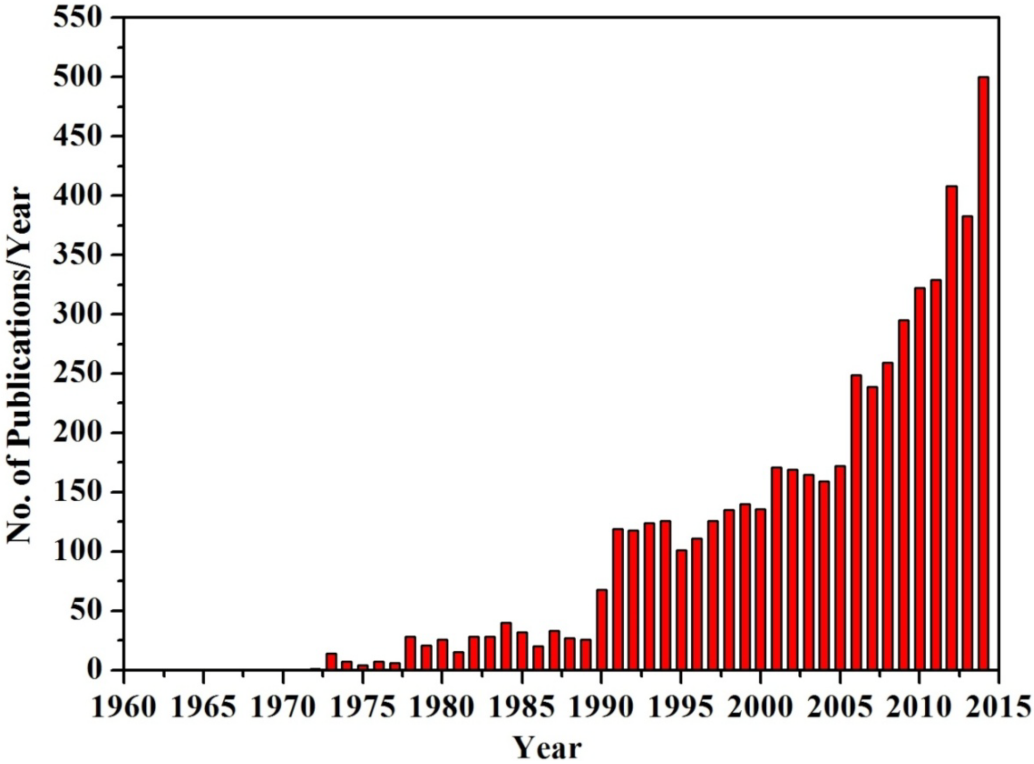

Figure4.3.f(i): Publication Pattern of PDP research in India during 1960-2014. From the period 1960-1972, no publication appeared in the WoS database.

Publication pattern of PDP research from 1960 to 2014 has been presented in Figure 4.3.f(i). The initial publication in the sub-field of PDP research is observed in the year 1972. A near about five hundred times increase is observed over the study period, (from 1 in 1972 to 500 in 2014). The highest number of papers is published in the year 2014, with 500publications and the lowest in 1972 with 1 publication.

C. Growth Trend

The cumulative progression is represented by a 4th degree power law distribution during 1960-2014 giving an idea of the polynomial growth curve as shown in Figure4.3.f(ii).

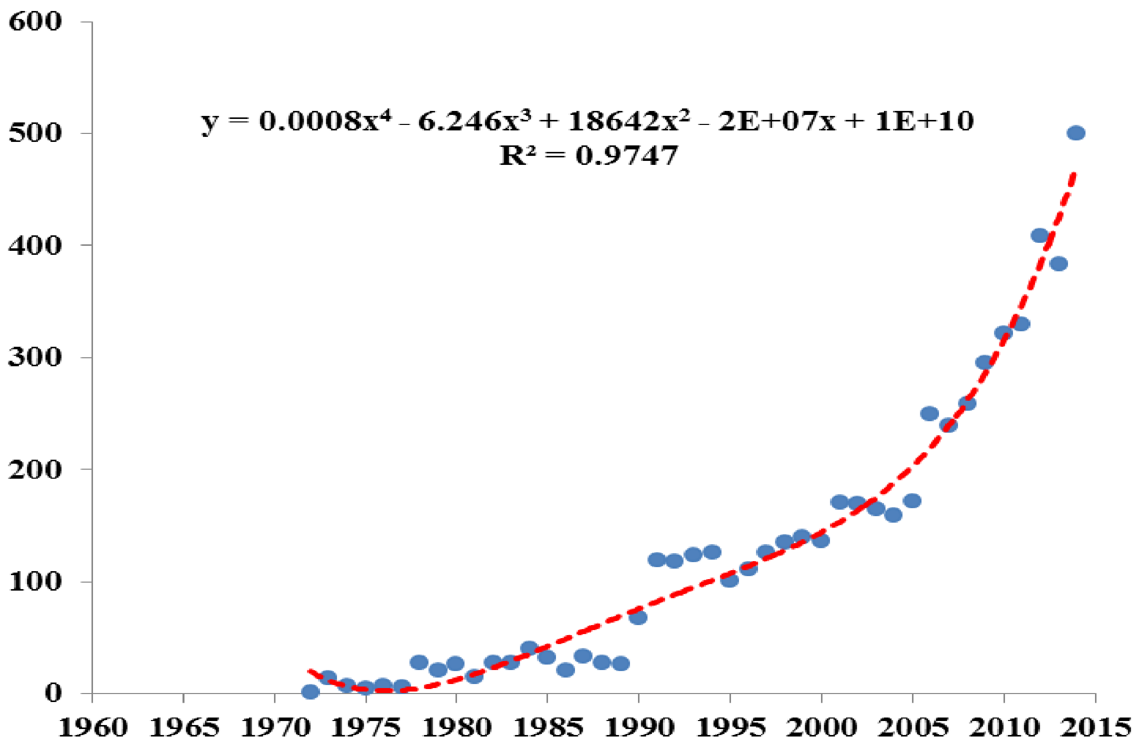

Figure4.3.f(ii): Growth Trend of PDP research in India during 1960-2014.Blue dot descries the distribution of publications (observed value) and red dashed line describes the correlation of distribution of publications where regression coefficient R^2 = 0.974

To choose the best fit growth model, various regression types with regression coefficient has been tested as shown in Table 4.3.f(iii). The best fit model is 4th degree polynomial curve, where R^2 = 0.974. The polynomial best fit for PDP research is found to be: $y = 0.0008x^4 - 6.246x^3 + 18642x^2 - 2E{+}07x + 1E{+}10$, where y is the cumulative number of publications and x is the number of years. The growth of literature shown in Figure 4.3.f(ii) can be divided into two parts, in the 1st part (1960-1972), no literature is published by Indian scientists and in 2nd part (1973-2014), growth trend follows a polynomial growth curve.

Table4.3.f(iii): Different Regression Types with Regression coefficient (R^2) of PDP research

Regression Type	**Equation**	**(R^2)**
Exponential	$y = 2E\text{-}91e^{0.106x}$	0.879
Linear	y = 9.088x - 17986	0.833
Logarithmic	y = 18095ln(x) – 13734	0.831
Polynomial	$y = 0.0008x^4 - 6.246x^3 + 18642x^2 - 2E{+}07x + 1E{+}10$	0.974
Power	$y = 0x^{213.0}$	0.880

D. Citations Pattern

Figures4.3.f(iii) and 4.3.f(iv) represent the citation pattern andnumber of citations vs. number of publications per yearof PDP research in India during 1960-2014. A total of 5487 research papers have received 46282 citations. The pattern of citations is very fluctuating. In the initial year1972, the total number of citations received is 3 with an average citation of 3 which is also the minimum. The maximum citations received in the year 2004 are 4526 with an average citation of 28.47.It has been observed from Figure 4.3.f(iv)that after the year 2010,citations decrease while publicationscontinue to increase.

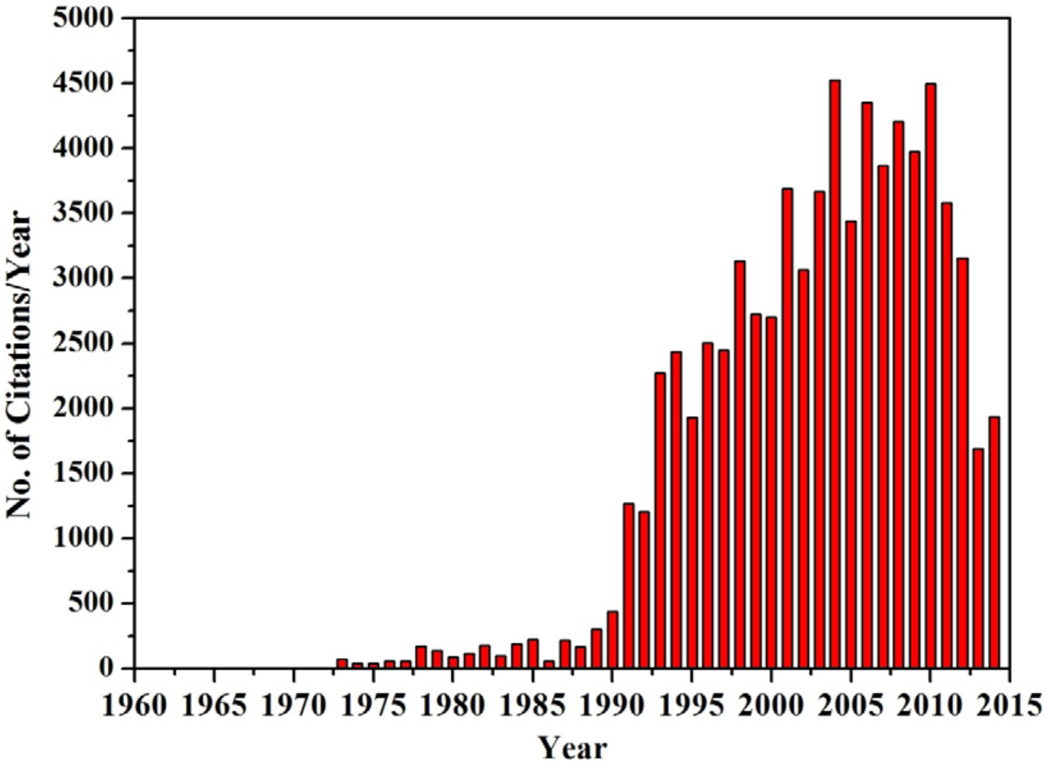

Figure4.3.f(iii): Citation Pattern of PDP research in India during 1960-2014. From 1960-1972, no citation received as no publication appeared in the WoS database.

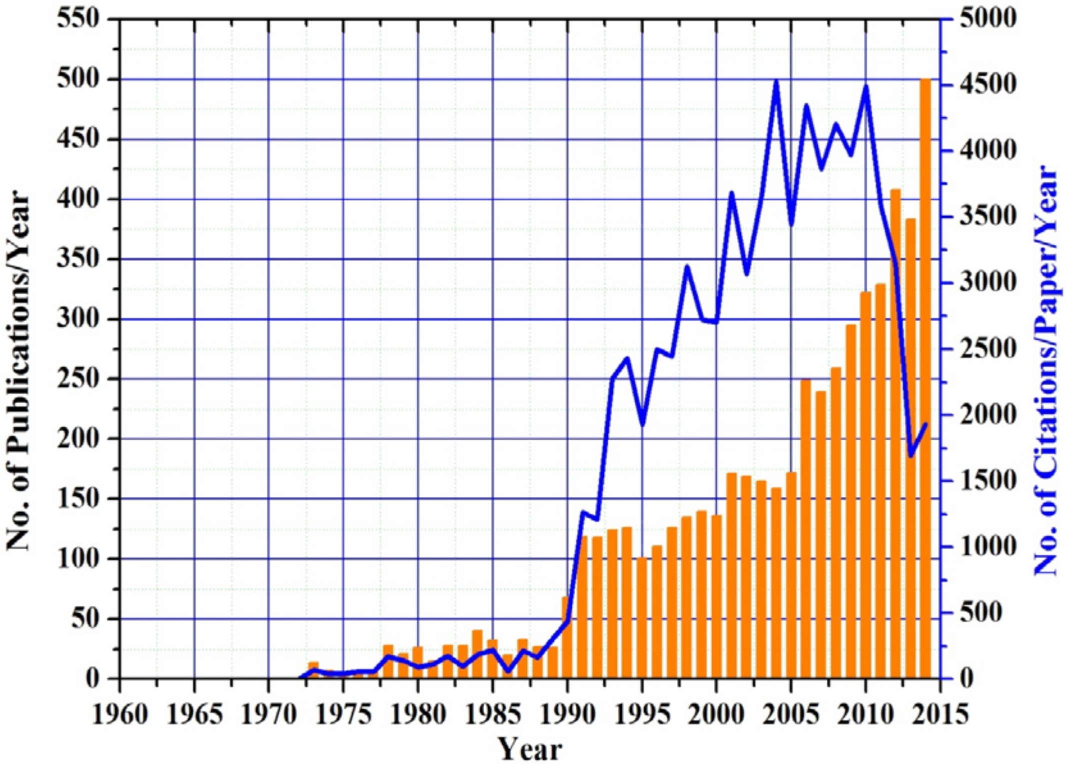

Figure4.3.f(iv): Citation Pattern Vs Publication Pattern of PDP research in India during 1960-2014:Blue line (right Y axis) indicates the citation pattern against red line (left Y axis) that describes the publications pattern

E. Top 20 Institutions and their research impact

In the sub-field of PDP a total of 5487 articles have appeared from 2450 institutions. Out of 2450 institution, 972 institutions appeared once and 321 institutions appeared twice. Table4.3.f(iv) shows the top 20 productive institutions, out of these10 are Indian. Tata Institute of Fundamental Research has contributed highest publicationsviz. 858 papers followed by Indian Institute of Astrophysics (768) , Inter University Centre for Astronomy Astrophysics (589), Physical Research Laboratory(405). The other 10 are foreign institutions. Among these, 5 belong to the USA namely National Radio Astronomy Observatory, National Aeronautics Space Administration (NASA), USA; California Institute of Technology, University of California System, Goddard Space Flight Center and United States Department of

Energy, USA; 2 are from France namely Centre National De La RechercheScientifique CNRS and Observatoire De Paris, France; Max Planck Society, Germany; Centre for Extragalactic Astronomy CEA, UK; and Russian Academy of Sciences, Russia.are the other three from their respective countries.

Table4.3.f(iv): Top institutions on PDP research and their research impact, 1960-2014

Institution	Region	TP (%)	TC	AvgCPA	h-index
Tata Institute of Fundamental Research	India	858(15.637)	14986	17.47	56
Indian Institute of Astrophysics	India	768(13.997)	9804	12.77	42
Inter University Centre for Astronomy Astrophysics	India	589(10.734)	14563	24.72	60
Physical Research Laboratory India	India	405(7.381)	4138	10.22	29
Centre National De La Recherche Scientifique	France	378(6.889)	11297	29.89	53
Max Planck Society	Germany	322(5.868)	9025	28.03	51
National Aeronautics Space Administration	USA	301(5.486)	10469	34.78	59
Raman Research Institute	India	272(4.957)	5596	20.57	36
Indian Institute of Science Iisc Banglore	India	242(4.410)	2336	9.16	24
California Institute of Technology	USA	219(3.991)	6976	31.85	46
Banaras Hindu University	India	206(3.754)	1707	8.29	19
University of California System	USA	182(3.317)	5137	28.23	37
Observatoire De Paris	France	175(3.189)	7201	41.15	47
Goddard Space Flight Center	USA	168(3.062)	6080	36.19	48
United States Department of Energy	USA	167(3.044)	5556	33.27	37
Russian Academy of Sciences	Russia	167(3.044)	4207	25.19	35
Centre for Extragalactic Astronomy	UK	150(2.734)	4592	30.61	6
University of Delhi	India	148(2.697)	1652	11.16	22
Aryabhatta Research Institute of Observational Sciences	India	145(2.643)	1388	9.57	20
Indian Institute of Geomagnetism	India	140(2.551)	1571	11.22	20

TP *= Total no. of PDP related articles published by an institution;* ***TC*** *= Total no. of citation received;* ***AvgCPA****= Average no. of citations per article; h-****index****=defined by the no. of h papers among an institution's no. of publications that have at least h citations each.* ***Source: WoS***

Table4.3.f(iv) reveals the impact of research in terms of quality of papers. It is seen from thisTable4.3.f(iv) that PDP research publications authored in collaboration with Observatoire De Paris have the highest average impact (AvgCPA=41.15).Among Indian institutions, Inter University Centre for Astronomy Astrophysics has the highest average impact (AvgCPA=24.72) in the AvgCPA index.

F. Top Journals and their research impact

PDP research papers have appeared in 105 journals. Papers have appeared in highest number in the journal ‘Physical Review D’ published by American Physical Society (APS) in the USA. Table4.3.f (v) shows the top 20 productive journals. These 20 out of the 105 journals have published 5047 of the total 5487 articles. The ‘Physical Review D’ ranked first with 854(15.56%); ‘Astrophysical Journal739(13.46%)’, ‘Astrophysics and Space Science 708(12.90%)’, ‘Monthly Notices of the Royal Astronomical Society691(12.59%)’ and ‘Astronomy Astrophysics 531(9.67%)’ ranked 2nd, 3rd, 4thand 5threspectively.

Table4.3.f(v): Top Journals on PDP research and their research impact, 1960-2014

				Journal Metrics (2013)			
Journal	**TP (%)**	**TC**	**AvgCPA**	**SJR**	**IPP**	**SNIP**	**Country**
Physical Review D	854(15.564)	16152	18.91	1.899	3.192	1.136	USA
Astrophysical Journal	739(13.468)	14832	20.07	3.159	4.348	1.145	UK
Astrophysics and Space Science	708(12.903)	3477	4.91	1.081	1.748	1.056	Netherland
Monthly Notices of the Royal Astronomical Society	691(12.593)	11069	16.02	3.196	4.911	1.494	UK
Astronomy Astrophysics	531(9.677)	10886	20.50	1.471	1.932	0.612	France
Solar Physics	212(3.864)	2414	11.39	2.256	3.184	1.769	Netherland
Journal of Geophysical Research Space Physics	206(3.754)	2190	10.63	2.376	3.286	1.412	USA
Journal of Astrophysics and Astronomy	143(2.606)	659	4.61	0.477	0.541	0.224	India
Annales Geophysicae	142(2.588)	1207	8.50	1.176	1.533	1.533	Germany
International Journal of Modern Physics D	118(2.151)	770	6.53	0.733	1.021	0.540	Singapore
Advances in Space Research	114(2.078)	367	3.22	0.751	1.416	1.291	Netherland
Planetary and Space Science	91(1.658)	987	10.85	0.925	1.560	0.800	Netherlands
Classical and Quantum Gravity	83(1.513)	2058	24.80	1.517	2.308	0.995	UK
Astrophysical Journal Letters	82(1.494)	1154	14.07	3.914	4.852	1.487	UK
Indian Journal of Radio Space Physics	75(1.367)	84	1.12	0.347	0.514	0.621	India
General Relativity and Gravitation	55(1.002)	497	9.04	1.109	1.628	1.015	UK
Journal of Cosmology and Astroparticle Physics	53(0.966)	822	15.51	0.615	2.374	0.465	UK
IAU Symposia	53(0.966)	8	0.15	-	-	-	Puerto Rico
New Astronomy	52(0.948)	378	7.27	0.734	1.053	0.523	Netherlands
Radio Science	45(0.820)	548	12.18	0.994	1.265	1.078	USA

T

P*= Total no. of PDP research related articles published by a Journal;* ***TC*** *= Total no. of citation received;* ***AvgCPA****= Average no. of citations that PDP related articles in a journal received;* ***h-index****= no. of h papers among a journal’s no. of publications that have at least h citations each.* ***SJR*** *= SCImago Journal Rank;* ***IPP*** *= Impact per Publication;* ***SNIP*** *= Source Normalized Impact per Paper;* ***Source: WoS and SCOPUS***

Table4.3.f (v)also shows the citation impact on top 20 journals. The AvgCPAand h-index are used to identify which journals have the largest number of high quality

articles in the PDP research. It is seen from the Table 4.3.f (v) that the journal 'Classical and Quantum Gravity' published by IOP Publishing in UK has the highest average impact (AvgCPA=24.80) followed by 'Astronomy Astrophysics' (AvgCPA= 20.50) although the journal 'Physical Review D' has the highest number of publications but ranked 4th in the AvgCPA index.

G. Top Authors and their research impact

A total of 5487 articles included the author addresses having India as the country of affilation. Articles on PDP research have been contributed by 20522 authors. Table4.3.f(vi) showed the top 20 productive authors during the last 54 years, 1960-2014.

Table4.3.f(vi): Top Authors of PDP research and their research impact, 1960-2014

Author	TP (%)	TC	TC woSC	CI	CIwoSC	AvgCPA	h-index
Chakrabarti, S.K.	143(2.606)	2308	1571	857	732	16.14	25
Antia, H.M.	81(1.476)	2374	2113	1345	1276	29.31	30
Mccarthy, R.	80(1.458)	3241	2956	1413	1347	40.51	36
Bose, S.	78(1.422)	3011	2713	1149	1085	38.60	35
Mukherjee, S.	77(1.403)	2938	2660	1149	1088	38.16	35
Gonzalez, G.	77(1.403)	3245	2931	1318	1248	42.14	37
Frey, R.	77(1.403)	2829	2552	1084	1022	36.74	34
Pan, Y.	75(1.367)	2639	2387	1031	970	35.19	33
Dhurandhar, S.	73(1.330)	2910	2601	1061	995	39.86	35
Zhang, L.	72(1.312)	2880	2602	1092	1031	40.00	35
Chen, Y.	71(1.294)	2878	2600	1090	1029	40.54	35
Yoshida, S.	70(1.276)	3005	2724	1193	1131	42.93	35
Lakhina, G.S.	70(1.276)	924	823	664	617	13.20	18
Sathyaprakash, B.S.	69(1.258)	3108	2851	1294	1234	45.04	35
Ivanov, A.	69(1.258)	2877	2599	1089	1028	41.70	35
Mitselmakher, G.	68(1.239)	2842	2570	1084	1024	41.79	34
Brau, J.E.	67(1.221)	2836	2558	1048	987	42.33	35
Babak, S.	67(1.221)	2927	2635	1106	1044	43.69	35
Yamamoto, H.	66(1.203)	2842	2564	1054	993	43.06	35
Whelan, J.T.	66(1.203)	2831	2548	1047	984	42.25	35

TP *: Total no. of PDP related articles published by a author;* ***TC:*** *Total no. of citation;* ***TC woSc:*** *Sum of Times Cited without self-citations;* ***CI:*** *Citing Articles ;****CIwoSC:*** *Citing Articles without self-citations;* ***AvgCPA:*** *Average Citations per Article;* ***h-index :*** *no. of h papers among a author's no. of publications that have at least h citations each.* ***Source: WoS***

Top 20 productive authors were ranked based on the decreasing productivity of total publications.Chakrabarti, S.K. produced maximum number of publications 143 i.e. 2.606 % of total publications and ranked 1stfollowed by Antia, H. M ,Mccarthy, R., Bose, S.and Mukherjee, S. who ranked 2nd , 3rd , 4th and 5th respectively.

Table4.3.f(vi) reveals the impact of research in terms of quality of papers. The AvgCPA and h-index are used to identify which author has the largest number of high quality articles in the PDP research. It is seen from the Table4.3.f(vi) that PDP research related articles authored by Sathyaprakash, B. S. have the highest average impact (AvgCPA=45.04) followed by Babak, S. (AvgCPA=43.69) although Chakrabarti, S. K.in spite of having the maximum number of publications, ranked 19th in the AvgCPA index.

H. Collaboration Pattern: Continents

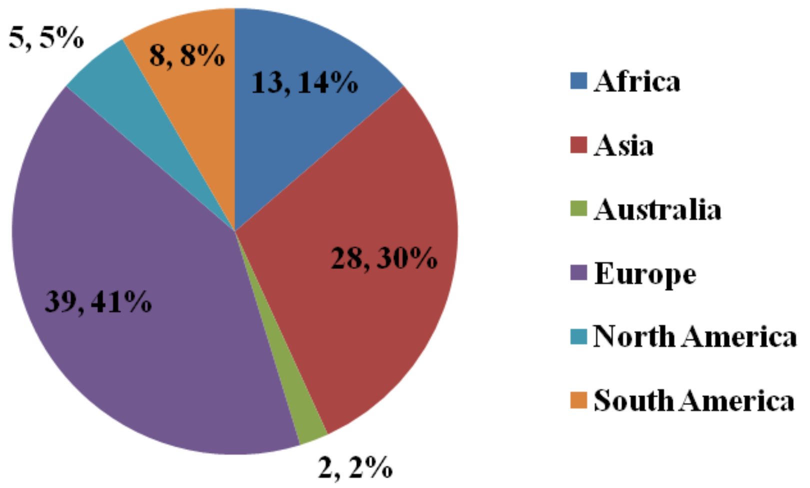

Figure4.3.f(v): Continent wise Collaboration pattern of PDP research

Based on the author attributions, world-wide collaboration of PDP research publications has been mapped. As shown in Figure4.3.f(v), the major spatial clusters of research institutes are located in Europe, followed by Asia, Africa, South America and North America. Several minor clusters are distributed in other parts of the world.

I. Collaboration Pattern and research impact:Countries

A total of 5487 articles are retrieved which included author address, source country and research institute. There are 95 collaborating Countries/territories which participated in collaborative research with Indian institutions in the sub-field of PDP.

Table4.3.f(vii): Country wise Collaboration Pattern and research impact of PDP research

Country	Continent	TP (%)	TC	AvgCPA	h-index
USA	North America	1253(22.836)	29892	23.86	78
Germany	Europe	558(10.169)	14188	25.43	60
France	Europe	447(8.147)	13743	30.74	59
England	Europe	415(7.563)	12195	29.39	57
Italy	Europe	344(6.269)	10376	30.16	53
Japan	Asia	302(5.504)	7582	25.11	46
Russia	Europe	262(4.775)	7952	30.35	46
Spain	Europe	248(4.520)	7819	31.53	48
Australia	Australia	214(3.900)	6619	30.93	45
Canada	North America	188(3.426)	5423	28.85	37
Netherlands	Europe	184(3.353)	4280	23.26	36
South Korea	Asia	177(3.226)	2749	15.53	28
Peoples R China	Asia	169(3.080)	4102	24.27	35
Poland	Europe	165(3.007)	4100	24.85	36
Brazil	South America	133(2.424)	3088	23.22	29
Sweden	Europe	120(2.187)	3134	26.12	32
Taiwan	Asia	117(2.132)	2825	24.15	26
Scotland	Europe	117(2.132)	3708	31.69	38
Switzerland	Europe	114(2.078)	2576	22.60	28
Wales	Europe	112(2.041)	5111	45.63	41

TP= *Total no. of PDP related articles published by a country;* ***TC*** *= Total no. of citation received;* ***AvgCPA***= *Average no. of citations per Article;****h-index***= *no. of h papers among a country's no. of publications that have at least h citations each.* ***Source: WoS***

As shown in the Table 4.3.f(vii), top 20 countries / territories were ranked based on the number of total articles, along with the citations and percentage of international collaborations. Out of these 20 countries / territories, the USA has produced maximum publications i.e. 1253 which is 22.863% of total publications with high citations (29892).

It is seen from the Table4.3.f(vii) that PDP research related articles authored in collaboration with the Wales (Europe) have the highest average impact (AvgCPA=45.63) followed by Scotland (Europe) AvgCPA=31.69 while the USA ranks 16th in the AvgCPA index.

J. Keyword Analysis

A total of 13798 different keywords, from 1960 to 2014 in the PDP research have been identified. The number of analysed publications during the study period is 5487. Of these only 4893 provide key words. While the rest (594) do not provide any keywords.To obtain accurate results, the keywords were pre-processed by merging the singular and plural forms of the same terminology, and those keywords with the same meaning while using different expressions. A total 12557 unique Keywords are obtained. Among these unique keywords 4895 (38.98 %) appear once or twice at the most. Table4.3.f(viii) shows the most used keywords during the considered period.

J.1 Hotspots

An analysis of the keywords was undertaken to pick out the research hotsopts (Chapter 1, Section 1.8.5.A) that have attracted most research attention and to reveal the research tendencies in the fields of PDP. The top 20 most frequently used keywords for the study period are listed in Table4.3.f(viii).The four most frequently used keywords were ‘Waves’, ‘Polarization’, ‘Radiation’ and ‘Scattering’.

Table4.3.f(viii): Top most frequently used keywords in PDP research

Keywords	NO	%	R
Waves	694	5.52	1
Radiation	536	4.26	2
Polarization	389	3.09	3
Scattering	357	2.84	4
Magnetic fields	328	2.61	5
Gravitation	324	2.58	6
Abundances	314	2.50	7
Accretion	242	1.92	8
Turbulence	227	1.80	9
Black hole physics	215	1.71	10
Hydrodynamics	203	1.61	11
Convection	165	1.31	12
Dynamo	132	1.05	13
Instabilities	116	0.92	14
Plasmas	115	0.91	15
Neutrinos	113	0.89	16
Nucleosynthesis	102	0.81	17
Shock waves	93	0.74	18
Radiative transfer	89	0.70	19
Diffusion	77	0.61	20

NO: Number of time occurrences; R : rank Source: WoS

J.2 Quick rising themes

The Compound Annual Growth Rate (CAGR) described in Chapter 1, Section 1.8.5.B, has been used to select quick rising themes of PDP research, which reveals the indicators of future research directions. Table4.3.f(ix) lists the top 20 keywords according to the CAGR and sorts them by their rank.The ranks in Table4.3.f(ix)show that ‘line- formation’, ‘Polarization’ and ‘Scattering’ are three leading hot issues that continue to attract broad attention. ‘Polarization’ kept its dominance in terms of total quantity and CAGR.

Table4.3.f(ix): Top Quick rising themes in PDP research

Keyword	V (t_0)	V (t_n)	t_0	t_n	CAGR (%)	R
Waves	4	79	1990	2014	0.132	7
Radiation	7	66	1991	2014	0.102	11
Polarization	1	38	1990	2014	0.163	2
Scattering	1	34	1990	2014	0.158	3
Magnetic fields	2	44	1991	2014	0.143	5
Gravitation	4	37	1991	2014	0.101	12
Abundances	3	27	1991	2014	0.100	14
Accretion	2	10	1991	2014	0.072	17
Turbulence	1	30	1990	2014	0.152	4
Black hole physics	3	14	1992	2014	0.072	17
Hydrodynamics	1	24	1990	2014	0.141	6
Dynamo	1	17	1991	2014	0.131	8
Instabilities	1	10	1991	2014	0.105	10
Plasmas	1	13	1990	2014	0.112	9
Neutrinos	2	10	1991	2014	0.072	17
Nucleosynthesis	2	6	1992	2014	0.051	20
Shock waves	3	13	1992	2014	0.068	19
Radiative transfer	1	5	1990	2014	0.069	18
Astrochemistry	2	5	2002	2014	0.079	16
Atomic data	2	6	1992	2014	0.051	20
Line- formation	1	4	2008	2014	0.259	1
Magnetic reconnection	1	6	1992	2014	0.084	15
Magnetohydrodynamics	1	10	1990	2014	0.100	13
Radiative transfer	1	5	1990	2014	0.069	18

t_0: *the Initial (first) year (The Year in which no. of keywords occurrence first time;* ***t_n***: *the last year (No. of keywords occurrence);* ***V(t_0)***: *Initial observed value (no. of keywords occurrence);* ***V(t_n)***: *last observed value (no. of keywords occurrence);* ***CAGR:*** *Compound Annual Growth Rate;* ***R:*** *Rank.* ***Source: WoS***

K. Summary

A total of 5487 literature were published on PDP, which received total 74841 citations. The average number of publications per year was 127.60and the average number of citations per publication was 13.64. Publications on PDP appeared in 105 journals of which most active journal was 'Physical Review D' published by American Physical Society (APS) in USA and 854 (15.56%) of the total 5487 publications. A total of 20522authors contributed on PDP research. The most active author was Chakrabarti, S.K.who produced maximum number of publications i.e. 143 which accounts for 2.60 % of total publications. 2450 institutions contributed of which TIFR, Mumbai, India was the most productive institution. For globalization of

PDP Research in India, the results show there were 95 Countries/territories which participated in PDP research. The USA produced maximum publications 1253that is 22.836% of total publication with higher citations (29892). A Keyword analysis reveals that ‘Waves’, ‘Polarization’, ‘Radiation’ and ‘Scattering’ are the most used keywords.

4.3.7 Planetary Systems (PS)

A planetary system is a set of gravitationally bound non-stellar objects in orbit around a star or star system. Generally speaking, systems with one or more planets constitute a planetary system, although such systems may also consist of bodies such as dwarf planets, asteroids, natural satellites, meteoroids, comets, planetesimals and circumstellar disks. The Sun together with its planetary system, which includes Earth, is known as the Solar System. The term exoplanetary system is sometimes used in reference to other planetary system. There are at least 2,597 known planetary systems, including 589 systems consisting of multiple planets as of 15 July 2016. These systems contain more than 3,472 known exoplanets (‘Planetary System’, n.d.).

There were 1914 articles that met the selection criteria which appeared in the WoS database during 1960-2014 and these were analyzed.

A. Publication characteristics

A total of 1914 articles of Indian scientists during 1960-2014 were abstracted from WoS related to PS publications. From Table 4.3.g (i) and 4.3.g(ii), the output of 1914 papers received 20373 citations during the said period with an average of about 10.64 citations per paper. The average number of publications per year is 45.57 and CAGR is 0.10%.

B. Publication Pattern

Publication pattern of PS research from 1960 to 2014 is presented in Figure 4.3.g (i). The initial publication in the sub-field of PS research is observed in the year 1973. A near about 70 time’s increase is observed over the study period, (from 3 in

1973 to 223 in 2014). The highest number of papers is published in the year 2014, with 223 publications and the lowest in 1973 and 1975 with 1 publication.

Table 4.3.g(i): Bibliographic Records of Planetary Systems (PS) in India during 1960-2014

Bibliometric Indicators `	No.
Total Number of Articles	1914
Total Number of Contributing Countries	76
Total Number of Contributing Authors	9051
Total Number of Contributing Institutions	1813
Total Number of Journals appeared	422
Total Number of Keywords (raw) appeared	8761

Source: WoS

Table 4.3.g(ii): Citation Metrics of Planetary Systems (PS) research in India during 1960-2014

Citation-based Indicators	No.
Sum of the Times Cited	20373
Sum of Times Cited without self-citations	18424
Citing Articles	15769
Citing Articles without self-citations	14869
Average Citations per Item	10.64
h-index	54

Source: WoS

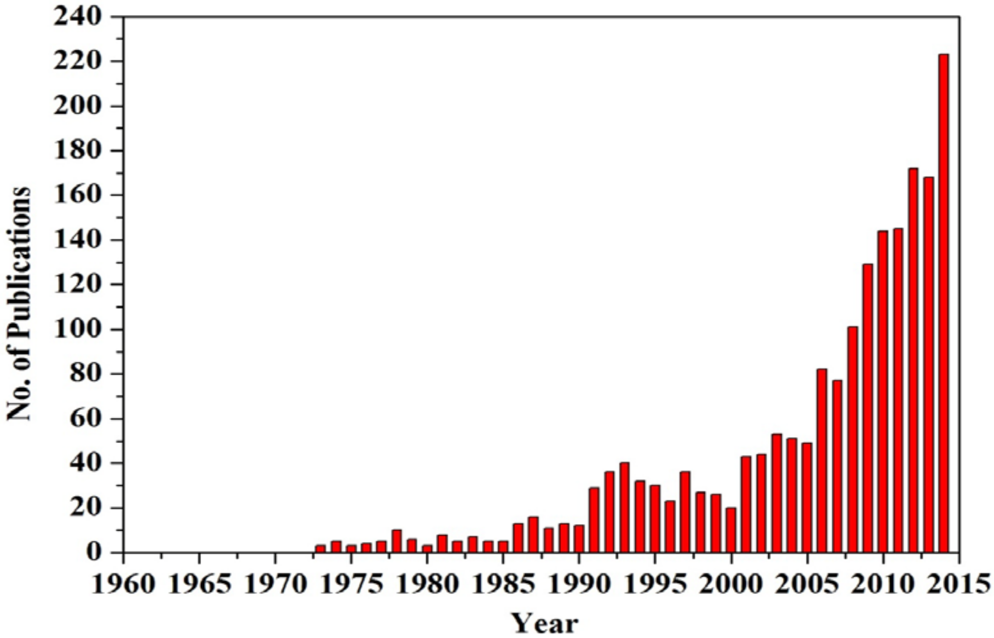

Figure 4.3.g(i): Publication Pattern of PS research in India during 1960-2014. From the period 1960-1972, no publication appeared in the WoS database.

C. Growth Trend

The cumulative progression is represented by a 4th degree power law distribution during 1960-2014 giving an idea of the polynomial growth curve as shown in Figure 4.3.g(ii). To choose the best fit growth model, various regression types with regression coefficient has been tested as shown in Table 4.3.g (iii). The best fit model is 4th degree polynomial curve, where $R^2 = 0.975$. The polynomial best fit for PS research is found to be: $y = 0.0004x^4 - 3.1295x^3 + 9330.4x^2 - 1E+07x + 6E+09$, where y is the cumulative number of publications and x is the number of years. The growth of literature shown in Figure 4.3.g(ii) can be divided into two parts, in the 1st part (1960-1972), no literature is published by Indian scientists and in the 2nd part (1973-2014), growth trend follows a polynomial growth curve.

Table 4.3.g (iii): Different Regression Types with Regression coefficient (R^2) of PS research

Regression Type	Equation	(R^2)
Exponential	$y = 2E\text{-}85e^{0.0993x}$	0.925
Linear	$y = 3.7161x - 7362.4$	0.688
Logarithmic	$y = 7396.4\ln(x) – 56150$	0.686
Polynomial	$y = 0.0004x^4 - 3.1295x^3 + 9330.4x^2 - 1E{+}07x + 6E{+}09$	0.975
Power	$y = 0x^{197.96}$	0.925

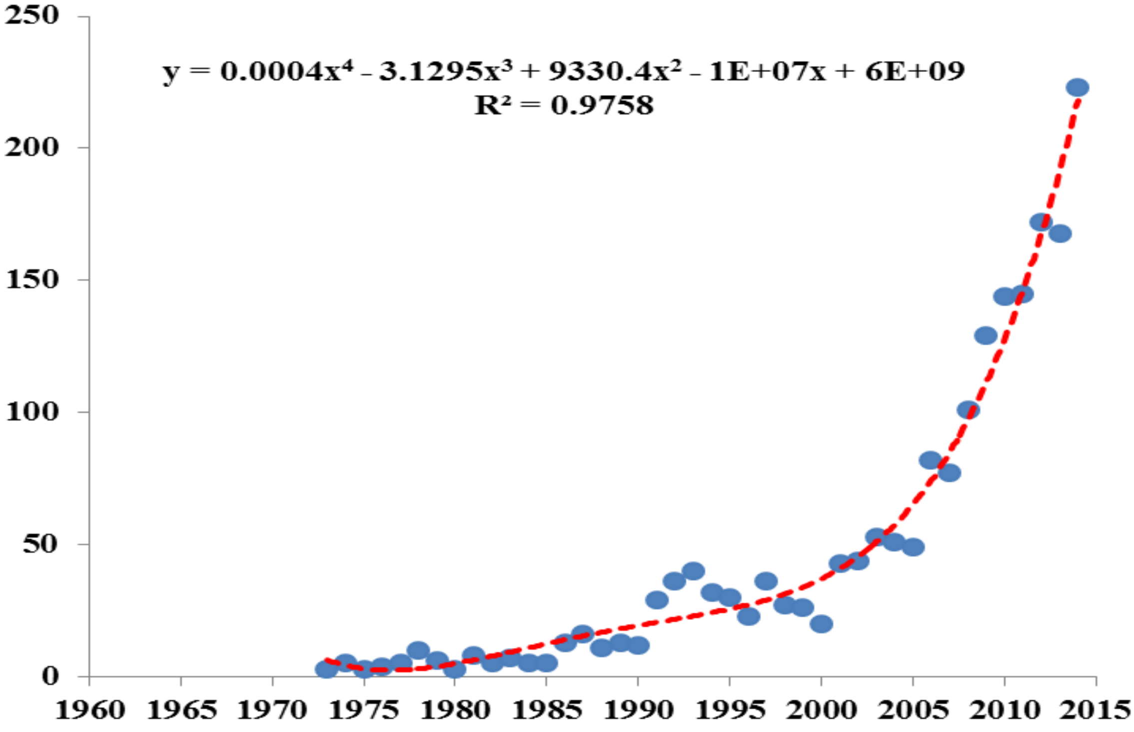

Figure 4.3.g(ii): Growth Trend of PS research in India during 1960-2014.Blue dot describes the distribution of publications (observed value) and red dashed line describes the correlation of distribution of publications where regression coefficient R^2 = 0.975

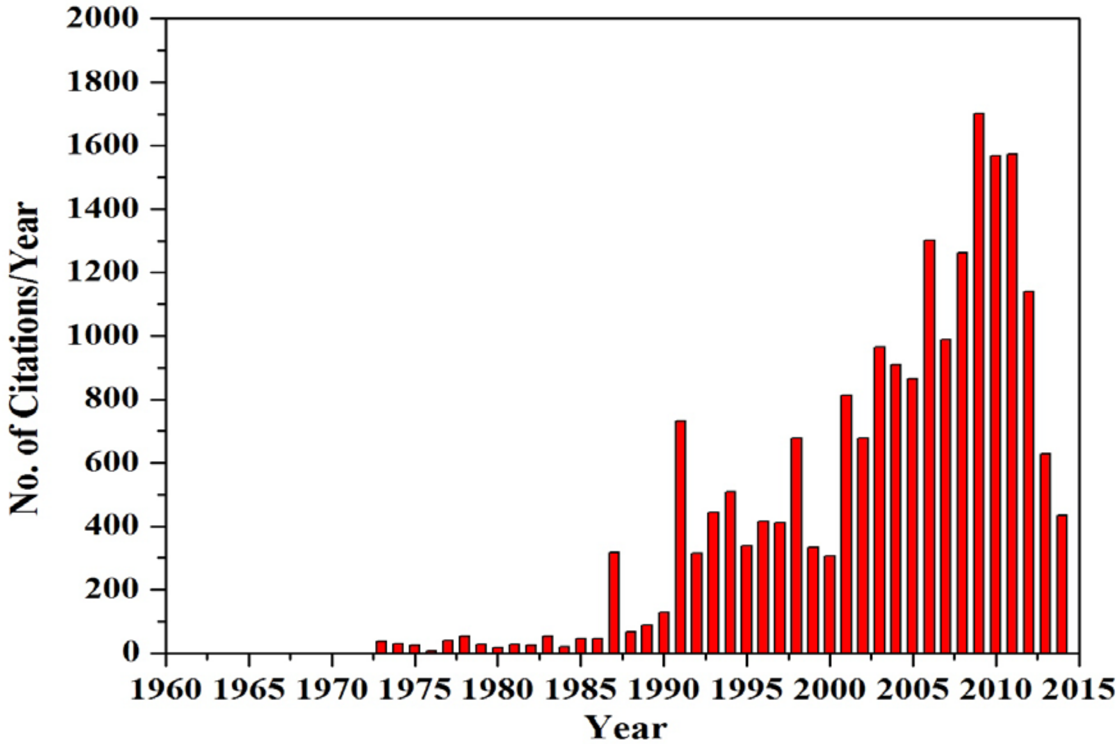

Figure 4.3.g(iii): Citation Pattern of PS research in India during 1960-2014. From 1960-1972, no citation received as no publication appeared in the WoS database.

D. Citation Pattern

Figures 4.3.g (iii) and 4.3.g (iv) represent the citation pattern and number of citations vs. number of publications per year of PS research in India during 1960-2014. A total of 1914 research papers have received 20373 citations. The pattern of citations is very fluctuating. In the initial year 1973, the total number of citations received is 37 with an average citation of 12.33. The minimum citation received in the year 1976 is six (6) and the maximum citations received in the year 2009 are 1703 with an average citation of 13.20. From Figure 4.3.g (iv), it has been observed that after the year 2010, citations decrease while publications continue to increase.

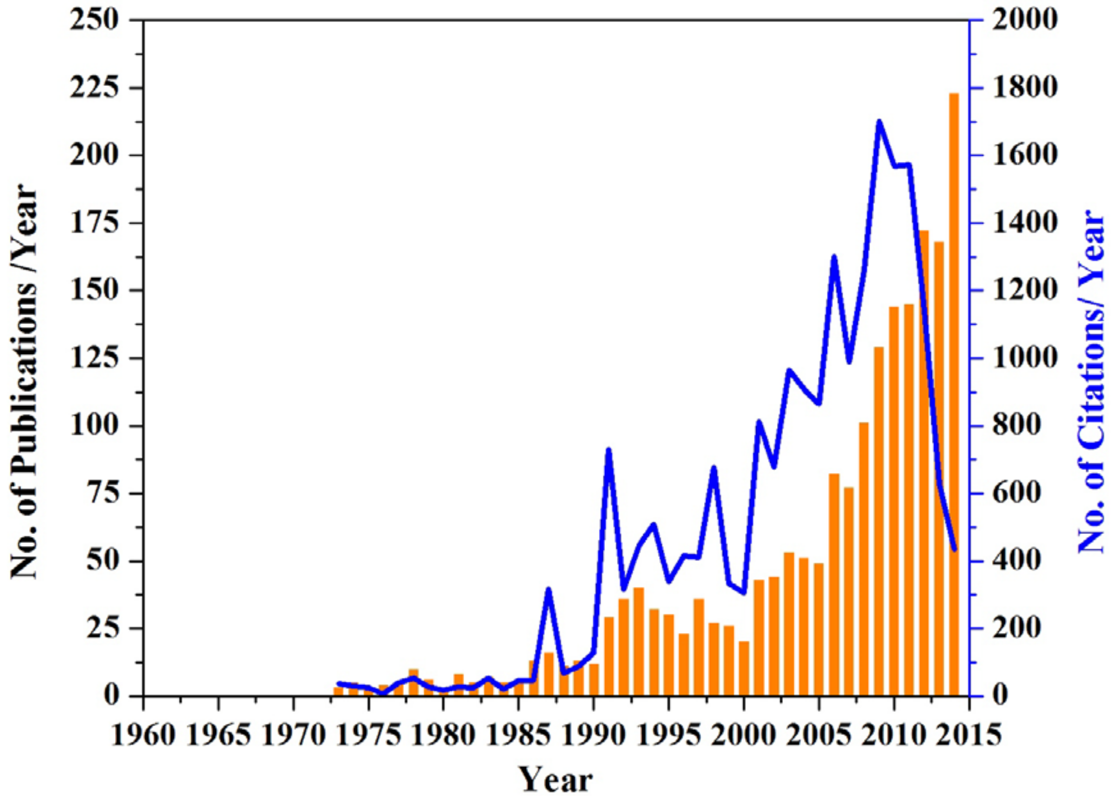

Figure 4.3.g(iv): Citation Pattern Vs Publication Patteern of PS research in India during 1960-2014: Blue line (right Y axis) indicates the citation pattern against orange bar (left Y axis) that describes the publications pattern

E. Top Institutions and their research impact

The contribution of different institutions was estimated by affiliated institution of at least one author. A total of 1914 articles on Planetary Systems appeared from 1813 institutions. Table 4.3.g(iv) shows the top 20 productive institutions during the last 54 years, 1960-2014. Out of these top 20 institutions, 10 are Indian. Physical Research Laboratory which contributed highest publication had published 253 papers followed by Tata Institute of Fundamental Research (125) and Indian Institute of Astrophysics (117).

There are 10 foreign institutions. Among these 6 belong to the USA namely National Aeronautics Space Administration (NASA),California Institute of Technology, University of California System, Jet Propulsion Laboratory, University of Texas Austin and United States Department of Energy, USA; 2 are from France namely Centre National De La Recherche Scientifique CNRS and Observatoire De Paris, France; 1 from Germany namely Max Planck Society; and 1 from Russia i.e. the Russian Academy of Sciences.

Table 4.3.g(iv) reveals the impact of research in terms of quality of papers. The AvgCPA and h-index are used to identify which institution has the largest number of high quality articles in the PS. It is seen from the above Table 4.3.g(iv) that PS related articles authored in collaboration with University of Texas, Austin have the highest average impact (AvgCPA = 55.69). Among the Indian institutions, Indian Institute of Astrophysics has the highest impact (21.02) in the AvgCPA index.

Table 4.3.g(iv): Top institutions on PS research and their research impact, 1960-2014

Institution	Region	TP (%)	TC	AvgCPA	h-index
Physical Research Laboratory	India	253(13.218)	3413	13.49	30
Tata Institute of Fundamental Research	India	125(6.531)	1613	12.90	23
Indian Institute of Astrophysics	India	117(6.113)	2459	21.02	21
Vikram Sarabhai Space Center VSSC	India	108(5.643)	988	9.15	17
National Aeronautics Space Administration NASA	USA	108(5.643)	3337	30.90	33
Centre National De La Recherche Scientifique CNRS	France	95(4.963)	2301	24.22	28
California Institute of Technology	USA	74(3.866)	1790	24.19	24
Max Planck Society	Germany	71(3.7102)	225	31.34	29
Indian Institute of Geomagnetism	India	71(3.710)	638	8.99	16
Observatoire De Paris	France	65(3.396)	2081	32.02	29
Inter University Centre for Astronomy Astrophysics	India	65(3.396)	1184	18.22	21
Aligarh Muslim University	India	61(3.187)	645	10.57	14
Bhabha Atomic Research Center	India	59(3.083)	637	10.80	16
University of California System	USA	57(2.978)	1735	30.44	22
University of Calcutta	India	54(2.821)	527	9.76	15
Jet Propulsion Laboratory	USA	46(2.403)	952	20.70	18
University of Texas Austin	USA	45(2.351)	2506	55.69	27
United States Department of Energy	USA	43(2.247)	1428	33.21	21
Russian Academy of Sciences	Russia	43(2.247)	1053	24.49	22
Indian Institute of Technology IIT Kanpur	India	40(2.09)	422	10.55	13

TP*= Total no. of PS related articles published by an institution;* ***TC*** *= Total no. of citation received;* ***AvgCPA****= Average no. of citations per article; h-****index****=defined by the no. of h papers among an institution's no. of publications that have at least h citations each.* ***Source: WoS***

F. Top Journals and their research impact

PS papers have appeared in 422 journals. Papers have appeared in highest number in the journal 'Astronomy Astrophysics' published by Oxford University Press from the United Kingdom. Table 4.3.g (v) shows the top 20 productive journals. The 'Astronomy Astrophysics' journal ranks first with 111 (5.79%) publications; 'Astrophysical Journal with 91 (4.75%) publications', 'Astrophysics and Space Science with 90 (4.70%) publications', 'Advances in Space Research' with 79 (4.12%) publications and 'Monthly Notices of the Royal Astronomical Society' with 75 (3.91%) publications. These journals ranked at 2nd, 3rd, 4th and 5th places respectively.

Table 4.3.g(v): Top Journals on PS research and their research impact, 1960-2014

Journal	TP (%)	TC	AvgCPA	Journal Metrics (2013) SJR	IPP	SNIP	Country
Astronomy Astrophysics	111(5.799)	2168	19.53	1.471	1.932	0.612	France
Astrophysical Journal	91(4.754)	2464	27.08	3.159	4.348	1.145	UK
Astrophysics and Space Science	90(4.702)	311	3.46	1.081	1.748	1.056	Netherlands
Advances in Space Research	79(4.127)	376	4.76	0.751	1.416	1.291	Netherlands
Monthly Notices of the Royal Astronomical Society	75(3.918)	1144	15.25	3.196	4.911	1.494	UK
Journal of Geophysical Research Space Physics	74(3.866)	804	10.86	2.376	3.286	1.412	USA
Planetary and Space Science	62(3.239)	476	7.68	0.925	1.560	0.800	Netherlands
Earth Moon and Planets	61(3.187)	103	1.69	0.254	0.660	0.600	Netherlands
Current Science	39(2.038)	80	2.05	0.293	0.841	0.771	India
Physical Review D	36(1.881)	548	15.22	1.899	3.192	1.136	USA
Annales Geophysicae	33(1.724)	275	8.33	1.176	1.533	1.533	Germany
Journal of Astrophysics and Astronomy	31(1.620)	72	2.32	0.477	0.541	0.224	India
Meteoritics Planetary Science	30(1.567)	382	12.73	1.551	2.115	0.857	USA
Solar Physics	26(1.358)	382	14.69	2.256	3.184	1.769	Netherlands
Icarus	25(1.306)	233	9.32	1.966	2.967	1.198	USA
Indian Journal of Radio Space Physics	23(1.202)	51	2.22	0.347	0.514	0.621	India
Geochimica Et Cosmochimica Acta	17(0.888)	844	49.6	-	-	-	UK
Radio Science	16(0.836)	91	5.69	0.994	1.265	1.078	USA
Proceedings of the Indian Academy of Sciences Earth and Planetary Sciences	15(0.784)	75	5.00	0.467	1.152	0.939	India
Astronomical Journal	15(0.784)	464	30.93	2.795	3.282	1.092	UK

TP= *Total no. of PS research related articles published by a Journal;* ***TC*** *= Total no. of citation received;* ***AvgCPA****= Average no. of citations that PS related articles in a journal received;* ***h-index****= no. of h papers among a journal's no. of publications that have at least h citations each.* ***SJR*** *= SCImago Journal Rank;* ***IPP*** *= Impact per Publication;* ***SNIP*** *= Source Normalized Impact per Paper;* ***Source: WoS and SCOPUS***

Table 4.3.g(v) also shows the citation impact on top 20 journals. The AvgCPA and h-index are used to identify which journals have the largest number of high quality articles in the PS. It is seen from the Table 4.3.g(v) that the journal 'Geochimica Et Cosmochimica Acta' published by Elsevier from North-Holland has the highest average impact (AvgCPA = 49.60) and the journal 'Astronomical Journal' published by IOP Publishing for the American Astronomical Society in USA has the highest average impact (AvgCPA = 30.93). It is seen that though the journal 'Astronomy Astrophysics' has the highest number of publications, still it ranks 4th in the AvgCPA index.

G. Top Authors and their research impact

Table 4.3.g(vi): Top Authors of PS research and their research impact, 1960-2014

Author	TP (%)	TC	TC woSC	CI	CIwoSC	AvgCPA	h-index
Goswami, J.N.	48(2.508)	1427	1331	1018	987	29.73	18
Bhandari, N.	42(2.194)	685	606	494	467	16.31	14
Bhardwaj, A.	40(2.090)	556	443	334	305	13.90	15
Lakhina, G.S.	35(1.829)	490	449	395	371	14.00	15
Murty, S.V.S.	34(1.776)	355	306	277	253	10.44	12
Nair, C.K.K.	30(1.567)	389	324	294	268	12.97	13
Ramkumar, G.	29(1.515)	226	172	162	139	7.79	9
Kumar, R.	29(1.515)	550	522	430	419	18.97	12
Jena, G.B	28(1.463)	314	254	256	232	11.21	12
Sen, A.K.	26(1.358)	207	154	135	116	7.96	9
Mukherjee, A.	26(1.358)	327	299	291	275	12.58	10
Kumar, K.K.	26(1.358)	187	132	121	102	7.19	9
Ashoka, B.N.	26(1.358)	1123	1079	729	711	43.19	20
Vauclair, G.	25(1.306)	1063	1019	677	659	42.52	19
Kepler, S.O.	25(1.306)	1063	1026	689	672	42.52	19
Kanaan, A.	25(1.306)	1049	1007	682	665	41.96	19
Kumar, S.	24(1.254)	238	236	221	219	9.92	7
Winget, D.E.	23(1.202)	1012	979	657	642	44.00	18
Nather, R.E.	23(1.202)	1005	968	645	630	43.70	18
Wood, M.A.	22(1.149)	1011	969	660	644	45.95	17

TP: *Total no. of PS related articles published by a author;* ***TC:*** *Total no. of citation****;*** ***TC woSc:*** *Sum of Times Cited without self-citations;* ***CI:*** *Citing Articles ;* ***CIwoSC:*** *Citing Articles without self-citations;* ***AvgCPA:*** *Average Citations per Article;* ***h-index :*** *no. of h papers among a author's no. of publications that have at least h citations each.* ***Source: WoS***

A total of 1914 articles included the author addresses having India as the country of affiliation. Articles on PS have been contributed by 9051 authors. Table 4.3.g(vi) shows the top 20 productive authors during the last 54 years, 1960-2014. Top 20 productive authors are ranked based on the decreasing productivity of total publications. Goswami, J. N. has produced 48 publications, which is the maximum and accounts for 2.50% of total publications. He is followed by Bhandari, N., Bhardwaj, A. and Lakhina, G. S. who rank 2^{nd}, 3^{rd} and 4^{th} respectively.

Table 4.3.g(vi) also reveals the impact of research in terms of quality of papers. The AvgCPA and h-index are used to identify which author has the largest number of high quality publications in the PS research. It is seen from the Table 4 that PS related articles authored by Wood, M. A. have the highest average impact (AvgCPA = 45.95) followed by Winget, D. E. (AvgCPA = 44.00) who ranked 2^{nd} in the AvgCPA index. It is observed that Goswami, J. N. ranks 1^{st} in the number of publications and ranks 7^{th} in the AvgCPA index.

H. Collaboration Pattern: Continents

Based on the author attributions, world-wide collaboration of PS research publications has been mapped. From Figure 4.3.g(v), it is seen that the major spatial clusters of research institutes are located in Europe, followed by Asia and Africa. Several minor clusters are distributed in other parts of the world. North America and South America have equal contribution.

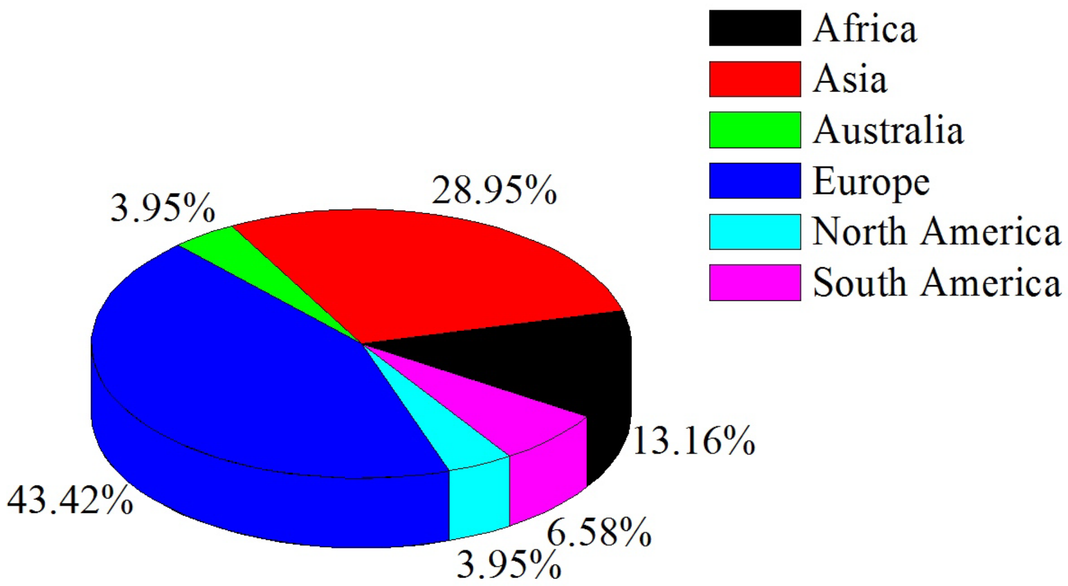

Figure 4.3.g(v): Continent wise Collaboration pattern of PS research

I. Collaboration Pattern and research impact: Countries

Table 4.3.g(vii): Country wise Collaboration Pattern and research impact of PS research

Country	Continent	TP (%)	TC	AvgCPA	h-index
USA	North America	331(17.294)	7866	23.76	44
Germany	Europe	140(7.315)	3340	23.86	34
France	Europe	136(7.106)	3657	26.89	34
England	Eurpope	109(5.695)	3409	31.28	34
Italy	Europe	106(5.538)	2583	24.37	30
Japan	Asia	104(5.434)	2048	19.69	23
Spain	Eurpe	91(4.754)	2678	29.43	32
Brazil	South America	58(3.030)	1898	32.72	23
Australia	Australia	57(2.978)	2004	35.16	27
Russia	Europe	56(2.926)	1343	23.98	23
Peoples R China	Asia	54(2.821)	1415	26.20	20
Canada	South America	45(2.351)	1911	42.47	24
Poland	Europe	41(2.142)	1022	24.93	22
Taiwan	Asia	40(2.090)	1170	29.25	17
Netherlands	Europe	39(2.038)	1112	28.51	21
South Africa	Africa	38(1.985)	1303	34.29	22
Chile	South America	37(1.933)	1096	29.62	17
Switzerland	Europe	34(1.776)	674	19.82	15
Norway	Europe	33(1.724)	1124	34.06	22
South Korea	Asia	32(1.672)	385	12.03	12

TP**= Total no. of PS related articles published by a country; **TC** = Total no. of citation received; **AvgCPA**= Average no. of citations per Article; **h-index**= no. of h papers among a country's no. of publications that have at least h citations each. **Source: WoS

There are 1914 articles which included author addresses, source country and research institutes. 76 collaborating Countries/territories have participated in collaborative research with the Indian institutions in the PS sub-field. As shown in the Table 4.3.g (vii), top 20 countries / territories are ranked based on the number of total articles, along with the citations and percentage of international collaborations. Out of these 20 countries / territories, The USA has produced 331 publications which is the maximum, with high citations as well (7866). The AvgCPA and h-index are used to identify which country has the largest number of high quality articles in the PS research. It is seen from the Table 4.3.68 that PS related articles authored in collaboration with Canada (North America) have the highest average impact (AvgCPA = 42.47) followed by Australia (AvgCPA = 35.16). It is also seen that the USA ranks 15th in the AvgCPA index.

J. Keyword Analysis

A total of 8761 different keywords, from 1960 to 2014 in the PS have been identified. To obtain accurate results, the keywords have been pre-processed by merging the singular and plural forms of the same terminology, and those keywords with the same meaning while using different expressions. A total 7623 unique Keywords are obtained. Among these unique keywords 4653 (61.03%) appear once or twice at the most. Table 4.3.g (viii) shows the most used keywords during the considered period.

J.1 Hotspots

An analysis of the keywords was undertaken to pick out the research hotsopts (Chapter 1, Section 1.8.5.A) that have attracted most research attention and to reveal the research tendencies in the fields of PS. The top 20 most frequently used keywords for the study period are listed in Table 4.3.g(viii). The five most frequently used keywords were ‘Comets’, ‘Meteorites’, ‘Earth’, ‘Moon’ and ‘Formation’

Table 4.3.g(viii): Top most frequently used keywords in PS research

Keyword	NO	%	R
Asteroids	13	0.17	12
Atmospheres	13	0.17	12
Comets	502	6.58	1
Composition	39	0.51	6
Detection	13	0.17	12
Earth	118	1.54	2
Formation	64	0.83	4
Interiors	10	0.13	13
Interplanetary medium	20	0.26	9
Magnetic fields	21	0.27	8
Meteorites	109	1.42	3
Meteoroids	16	0.20	10
Moon	54	0.70	5
Oceans	15	0.19	11
Planets and satellites	24	0.31	7

NO: Number of time occurrences; R: rank; ***Source: WoS***

J.2 Quick rising themes

The Compound Annual Growth Rate (CAGR) described in Chapter 1, Section 1.8.5.2, can be used to select quick rising themes of PS research, this reveals the indicators of future research directions. Table 4.3.g(ix) lists the top 20 keywords according to the CAGR and sorts them by their ranks. The ranks in Table 4.3.g(ix) show that ‘Comets’, ‘Moon’ and ‘Formation’ are three leading hot issues that continue to attract broad attention. ‘Comets’ keeps its dominance in terms of total quantity and CAGR.

Table 4.3.g(ix): Top Quick rising themes in PS research

Keyword	V (t_0)	V (t_n)	t_0	t_n	CAGR (%)	R
Asteroids	1	1	1999	2014	0.000	14
Atmospheres	1	3	1996	2013	0.062	7
Comets	4	59	1991	2014	0.124	1
Composition	1	5	1991	2014	0.072	5
Detection	1	4	1993	2014	0.068	6
Earth	2	14	1993	2014	0.097	4
Formation	1	8	1992	2014	0.099	3
Interiors	1	1	1998	2014	0.000	14
Interplanetary medium	2	3	1995	2014	0.021	12
Magnetic fields	1	3	1995	2014	0.059	8
Meteorites	4	6	1991	2014	0.017	13
Meteoroids	1	2	1996	2012	0.039	10
Moon	1	11	1992	2014	0.115	2
Oceans	1	2	1993	2014	0.033	11
Planets and satellites	1	3	1994	2014	0.056	9

t_0**: the Initial (first) year (The Year in which no. of keywords occurrence first time; **t_n**: the last year (No. of keywords occurrence); **V(t_0)**: Initial observed value (no. of keywords occurrence); **V(t_n)**: last observed value (no. of keywords occurrence); **CAGR:** Compound Annual Growth Rate; **R:** Rank. **Source: WoS

K. Summary

A total of 1914 literature were published on PS, which received total 20373 citations and the average number of citations per publication was 10.64. Publications on PS appeared in 422 journals of which most active journal was “Astronomy Astrophysics” published by Oxford University Press from the United Kingdom with 111 (5.79%) publications. A total of 9051 authors contributed to the PS research. The most active author was Goswami, J.N. who produced maximum number of publications (48) i.e. 2.50% of total publications. 1813 institutions contributed of which Physical Research Laboratory; Ahmedabad, India turns out to be the most productive institution. For globalization of PS research in India, the results show there were 76 Countries/territories which participated in PS research. The USA has produced maximum publications in collaboration i.e. 331 which accounts for 17.294% of the total publications with high citations (7866). A Keyword analysis reveals that ‘Comets’, ‘Meteorites’, ‘Earth’, ‘Moon’ and ‘Formation’ are the most used keywords.

4.3.8 Resolved and Unresolved Sources as a Function of Wavelength (RUSFW)

Astrophysical systems have different morphology as seen from different wavelength bands ranging from gamma rays, X rays, UV, optical, infrared and radio wavelengths. Different emission mechanism originating from different regions of the sourcs are responsible for radiation in each wavelength band. Thus, each wavelength band is responsible for resolving different regions of the source. A combination of multi-wavelength studies are performed to get a complete picture of such sources. Such studies are listed under the field 'Resolved and unresolved sources as a function of wavelength.

There were 1079 articles that met the selection criteria which appeared in the WoS database during 1960-2014 and these were analyzed.

A. Publication characteristics

A total of 1079 articles of Indian scientists during 1960-2014 were abstracted from WoS related to RUSFW. From Table 4.3.h (i) and 4.3.h (ii), the output of 1079 paper received a total of 14439 citations during the said period with an average of about 13.38 citations per paper. The average number of publications per year is 43.16 and CAGR is 0.19%.

B. Publication Pattern

Publication pattern of RUSFW research from 1960 to 2014 is presented in Figure 4.3.h(i). The initial publication in the sub-field of RUSFW research is observed in the year 1990. A near about ninety one times increase was observed over the study period, (from 1 in 1990 to 91 in 2014). The highest number of papers is published in the year 2013, with 90 publications and the lowest in 1990 with 1 publication.

Table 4.3.h (i): Bibliographic Records of RUSFW research in India during 1960-2014

Bibliometric Indicators `	**No.**
Total Number of Articles	1079
Total Number of Contributing Countries	50
Total Number of Contributing Authors	4110
Total Number of Contributing Institutions	855
Total Number of Journals appeared	21
Total Number of Keywords (raw) appeared	4534

Source: WoS

Table 4.3.h(ii): Citation Metrics of RUSFW research in India during 1960-2014

Citation-based indicators	**No.**
Sum of the Times Cited	14439
Sum of Times Cited without self-citations	12487
Citing Articles	9988
Citing Articles without self-citations	9319
Average Citations per Item	13.38
h-index	49

Source: WoS

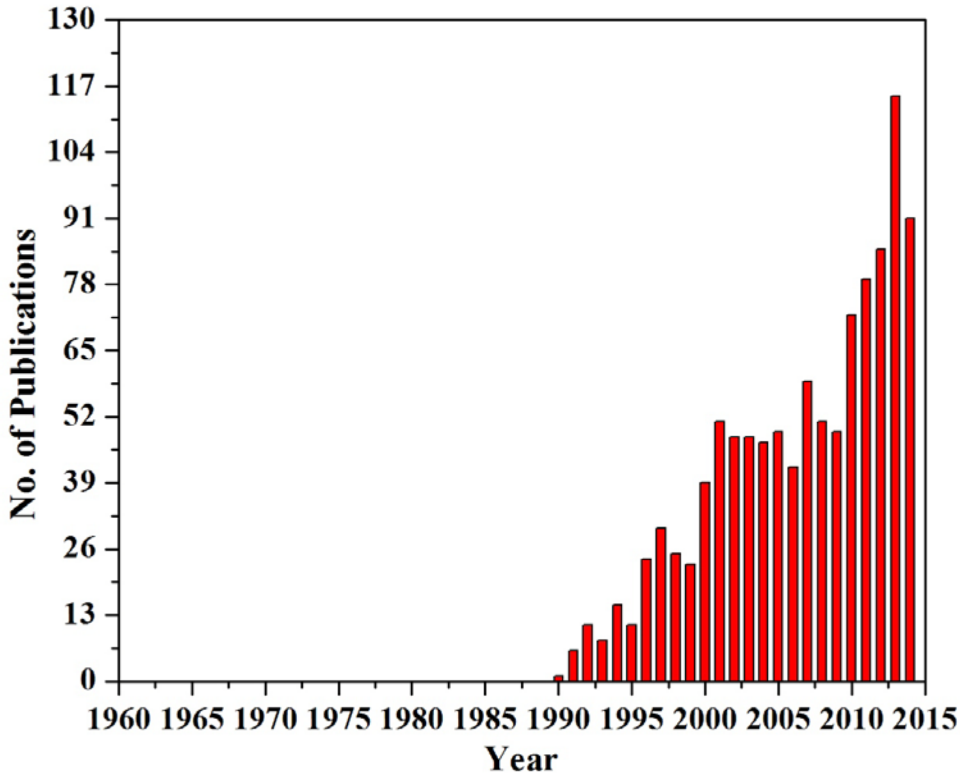

Figure 4.3.h(i): Publications Pattern of RUSFW research in India during 1960-2014. From the period 1960-1989, no publication appeared in the WoS database.

C. Growth Trend

The cumulative progression is represented by a 5th degree power law distribution during 1960-2014 giving an idea of the polynomial growth curve as shown in Figure 4.3.h(ii). To choose the best fit growth model, various regression types with regression coefficient has been tested as shown in Table 4.3.h (iii). The best fit model is 5th degree polynomial curve, where $R^2 = 0.930$. The polynomial best fit for RUSFW research is found to be: $y = -0.0002x^5 + 1.6917x^4 - 6778.9x^3 + 1E{+}07x^2 - 1E{+}10x + 5E{+}12$, where y is the cumulative number of publications and x is the number of year. The growth of literature shown in Figure 4.3.h (ii) can be divided into two parts, in the 1st part (1960-1989), no literature is published by Indian scientists, the 2nd part (1990-2014), follows a polynomial growth curve.

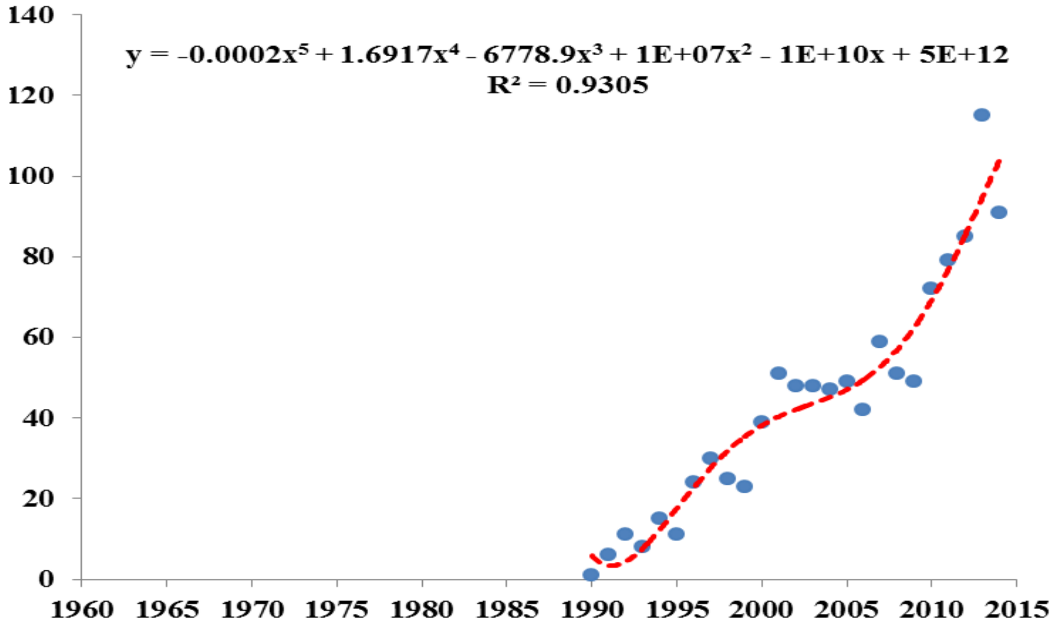

Figure 4.3.h(ii): Growth Trend of RUSFW research in India during 1960-2014. Blue dot describes the distribution of publications (observed value) and red dashed line describe the correlation of distribution of publications where regression coefficient R^2 = 0.930

Table 4.3.h(iii): Different Regression Types with Regression coefficient (R^2) of RUSFW research

Regression Type	**Equation**	**(R^2)**
Exponential	$y = 2E\text{-}108e^{0.1256x}$	0.767
Linear	$y = 3.7277x - 7419.7$	0.886
Logarithmic	$y = 7461.2\ln(x) - 56676$	0.886
Polynomial	$y = -0.0002x^5 + 1.6917x^4 - 6778.9x^3 + 1E{+}07x^2 - 1E{+}10x + 5E{+}12$	0.930
Power	$y = 0x^{251.53}$	0.768

D. Citation Pattern

Figures 4.3.h(iii) and 4.3.h(iv) represent the citation pattern and number of citations vs. number of publications per year of RUSFW research in India during 1960-2014. A total of 1079 research papers have received 14439 citations.

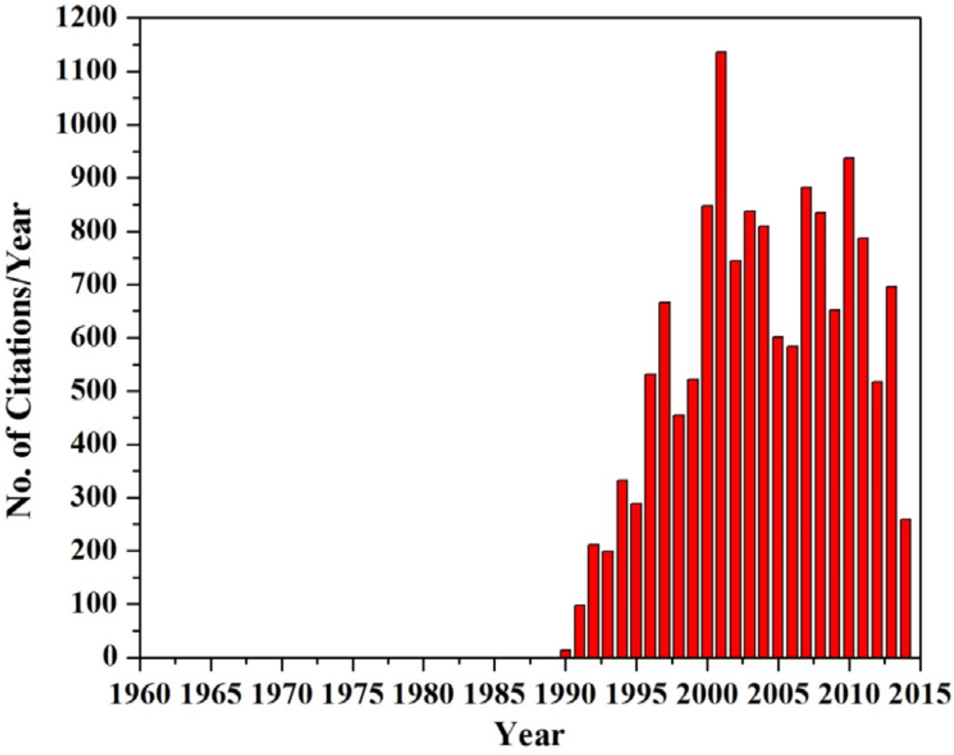

Figure 4.3.h(iii): Citation Pattern of RUSFW research in India during 1960-2014. From 1960-1989, no citation received as no publication appeared in the WoS database.

The pattern of citations is very fluctuating. In the initial year 1990, the total number of citations received is 14 with an average citation of 14 which is the minimum citation received during the said period. The maximum citations received in the year 2001 are 1136 with an average citation of 22.27. It has been observed from Figure 4.3.h(iv) that after the year 2010, citations decrease while publications continue to increase.

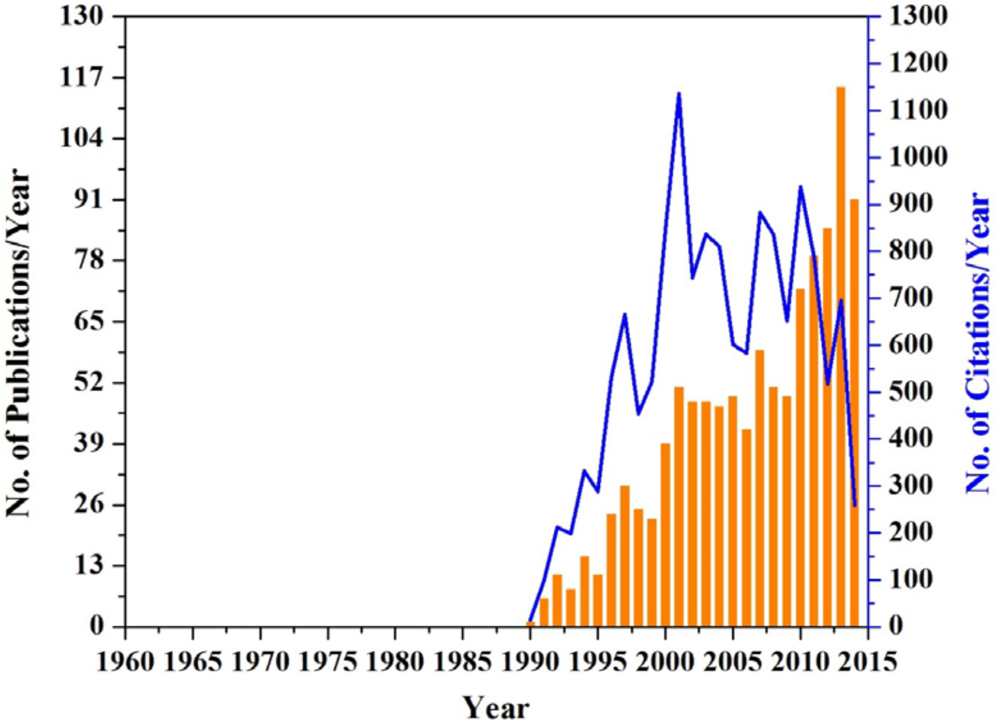

Figure 4.3.h(iv): Citation Pattern Vs Publication Pattern of RUSFW research in India during 1960-2014: Blue line (right Y axis) indicates the citations pattern against orange bar line (left Y axis) that describes the publications pattern

E. Top Institutions and their research impact

The contribution of different institutions was estimated by affiliated institution of at least one author. A total of 1079 articles on RUSFW research appeared from 855 institutions. Table 4.3.h(iv) shows the top 20 productive institutions during the last 54 years, 1960-2014. Out of these top 20 institutions, 8 are Indian. Tata Institute of Fundamental Research contributed highest publications with 508 papers followed by Raman Research Institute: 177, Inter University Centre for Astronomy Astrophysics: 151 and Indian Institute of Astrophysics: 132. The other 12 are foreign institutions. Among these 8 belong to the USA namely NASA, National Radio Astronomy Observatory, Harvard University, Smithsonian Institution, California Institute of Technology, University of California System, Goddard Space Flight Center and

United States Department of Energy, USA; 2 are from France namely Centre National De La Recherche Scientifique CNRS and Observatoire De Paris, France; 1 each from Max Planck Society, Germany; and Commonwealth Scientific Industrial Research Organisation, Australia.

Table 4.3.h(iv): Top institutions on RUSFW research and their research impact, 1960- 2014

Institution	Region	TP (%)	TC	AvgCPA	h-index
Tata Institute of Fundamental Research	India	508(47.081)	6708	13.20	37
Raman Research Institute	India	177(16.404)	2353	13.29	26
Inter University Centre for Astronomy Astrophysics	India	151(13.994)	2084	13.80	23
Indian Institute of Astrophysics	India	132(12.234)	1328	10.06	19
Max Planck Society	Germany	102(9.453)	2087	20.46	29
Centre National De La Recherche Scientifique CNRS	France	99(9.175)	2032	20.53	26
National Aeronautics Space Administration NASA	USA	96(8.897)	2333	24.30	30
Physical Research Laboratory	India	90(8.341)	959	10.66	17
National Radio Astronomy Observatory	USA	86(7.970)	1123	13.06	21
Harvard University	USA	78(7.229)	1189	15.24	19
University of Pune	India	65(6.024)	775	11.92	16
Smithsonian Institution	USA	65(6.024)	1053	16.20	18
National Centre for Radio Astrophys	India	62(5.746)	1316	14.15	21
California Institute of Technology	USA	57(5.283)	1451	25.46	23
University of California System	USA	56(5.190)	1234	22.04	21
Indian Institute of Science Iisc Banglore	India	56(5.190)	926	16.54	16
Commonwealth Scientific Industrial Research Organisation	Australia	56(5.190)	1195	21.34	21
Goddard Space Flight Center	USA	54(5.005	1274	23.59	19
Observatoire De Paris	France	53(4.912	1408	26.57	25
United States Department of Energy	USA	46(4.263	1111	24.15	20

TP= *Total no. of RUSFW related articles published by an institution;* ***TC*** *= Total no. of citation received;* ***AvgCPA****= Average no. of citations per article; h-****index****=defined by the no. of h papers among an institution's no. of publications that have at least h citations each.* ***Source: WoS***

Table 4.3.h(iv) reveals the impact of research in terms of quality of papers. It is seen that RUSFW research related articles authored in collaboration with Observatoire De Paris, France have the highest average impact (AvgCPA = 26.57) followed by California Institute of Technology, USA (AvgCPA = 25.46). Among Indian institutions, Indian Institution of Science (IISc), Bangalore has the highest average impact (AvgCPA=16.54) in AvgCPA index.

F. Top Journals and their research impact

RUSFW research papers have appeared in 21 journals. Papers have appeared in highest number in the journal 'Monthly Notices of the Royal Astronomical Society' published by Oxford University Press from the United Kingdom.

Table 4.3.h(v): Top Journals on RUSFW research and their research impact, 1960-2014

				Journal Metrics (2013)			
Journal	**TP (%)**	**TC**	**AvgCPA**	**SJR**	**IPP**	**SNIP**	**Country**
Monthly Notices of the Royal Astronomical Society	344(31.881)	4181	12.15	3.196	4.911	1.494	UK
Astrophysical Journal	306(28.360)	5009	16.37	3.159	4.348	1.145	UK
Astronomy Astrophysics	238(22.057)	3936	16.54	1.471	1.932	0.612	France
Journal of Astrophysics and Astronomy	36(3.336)	112	3.11	0.477	0.541	0.224	India
Astrophysical Journal Letters	29(2.688)	321	11.07	3.914	4.852	1.487	UK
Bulletin of the Astronomical Society of India	24(2.224)	47	1.96	1.091	1.068	0.516	India
Astronomical Journal	20(1.854)	108	5.40	2.795	3.282	1.092	USA
Astrophysical Journal Supplement Series	13(1.205)	258	19.85	5.524	8.853	2.789	USA
Research in Astronomy and Astrophysics	12(1.112)	21	1.75	0.953	1.331	0.768	UK
Publications of the Astronomical Society of Australia	9(0.834)	117	13.00	1.869	2.543	0.910	Australia
Astronomy Astrophysics Supplement Series	9(0.834)	93	10.33	-	-	-	France
New Astronomy	8(0.741)	78	9.75	1.074	1.332	0.726	Netherlands
Astrophysics and Space Science	7(0.649)	19	2.71	1.081	1.748	1.056	Netherlands
Publications of the Astronomical Society of Japan	5(0.463)	105	21.00	1.521	1.626	0.750	Japan
Chinese Journal of Astronomy and Astrophysics	5(0.463)	7	1.40	-	-	-	Chaina
Astronomische Nachrichten	4(0.371)	5	1.25	0.775	1.042	0.576	Germany
Advances in Space Research	4(0.371)	10	2.50	0.727	1.506	1.237	UK
New Astronomy Reviews	3(0.278)	4	1.33	4.143	6.462	1.973	Netherlands
Experimental Astronomy	1(0.093)	3	3.00	1.072	2.146	1.882	Netherlands
Baltic Astronomy	1(0.093)	0	0.00	0.501	0.669	0.444	Lithuania

TP*= Total no. of RUSFW research related articles published by a Journal;* ***TC*** *= Total no. of citation received;* ***AvgCPA****= Average no. of citations that RUSFW related articles in a journal received;* ***h-index****= no. of h papers among a journal's no. of publications that have at least h citations each.* ***SJR*** *= SCImago Journal Rank;* ***IPP*** *= Impact per Publication;* ***SNIP*** *= Source Normalized Impact per Paper;* ***Source: WoS and SCOPUS***

Table 4.3.h(v) shows the top 20 productive journals. These 20 out of the 21 journals have published 1078 of the total 1079 articles. The 'Monthly Notices of the Royal Astronomical Society' ranked first with 344 (31.88%) papers; 'Astrophysical Journal with 306 (28.36%) papers and 'Astronomy Astrophysics' with 238 (22.05%) papers' ranked 2nd and 3rd respectively.

Table 4.3.h(v) also shows the citation impact of top 20 journals. The AvgCPA and h-index are used to identify which journals have the largest number of high quality articles in the RUSFW research. It is seen from the Table 4.3.h(v) that the journal 'Publications of the Astronomical Society of Japan' published by the Astronomical Society of Japan has the highest average impact (AvgCPA = 21.00). It is observed that though the journal 'Monthly Notices of the Royal Astronomical Society' has the highest number of publications, still it ranks 6^{th} in the AvgCPA index.

G. Top Authors and their research impact

A total of 1079 articles included the author addresses having India as the country of affiliation. Articles on RUSFW research have been contributed by 4110 authors. Table 4.3.h (vi) showed the top 20 productive authors during the last 54 years, 1960-2014. Top 20 productive authors were ranked based on the decreasing productivity of total publications. Saikia, D. J. has produced maximum number of publications (88) i.e. 8.156 % of total publications and ranked 1^{st} followed by Paul, B. , Chengalur, J. N., Rao, A. R., Singh, K. P. who ranked 2^{nd} , 3^{rd} , 4^{th} and 5^{th} respectively.

Table 4.3.h (vi) reveals the impact of research in terms of quality of papers. The AvgCPA and h-index are used to identify which author has the largest number of high quality articles in the RUSFW research. It is seen from the Table 4.3.h(vi) that RUSFW research related articles authored by Goss, W.M. have the highest average impact (AvgCPA = 19.79) followed by Subrahmanyan, R. (AvgCPA = 19.74). It is observed that though Saikia, D. J. has the maximum number of publications, but he ranks 7^{th} in the AvgCPA index.

Table 4.3.h(vi): Top Authors of RUSFW research and their research impact, 1960-2014

Author	TP (%)	TC	TC woSC	CI	CIwoSC	AvgCPA	h-index
Saikia, D.J.	88(8.156)	1184	916	725	656	13.45	21
Paul, B.	67(6.209)	700	486	388	336	10.45	16
Chengalur, J.N.	55(5.097)	942	843	592	551	17.13	19
Rao, A.R.	52(4.819)	794	660	537	496	15.27	17
Singh, K.P.	45(4.171)	441	423	409	395	9.80	12
Subrahmanyan, R.	38(3.522)	750	703	607	588	19.74	16
Misra, R.	38(3.522)	247	205	195	172	6.50	8
Naik, S.	34(3.151)	397	334	286	263	11.68	14
Ashok, N.M	34(3.151)	349	293	269	247	10.26	11
Ishwara-Chandra,CH.	33(3.058)	386	371	341	331	11.70	11
Bhattacharyya, S.	33(3.058)	212	186	164	148	6.42	8
Ojha, D.K.	32(2.966)	325	282	251	234	10.16	10
Ghosh, S.K.	29(2.688)	255	203	193	174	8.79	10
Goss, W.M.	28(2.595)	554	500	417	398	19.79	14
Banerjee, D.P.K.	28(2.595)	299	241	219	197	10.68	10
Ananthramaiah,K.R.	28(2.595)	525	460	356	333	18.75	14
Kantharia, N.G.	26(2.410)	193	171	166	152	7.42	10
Kanekar, N.	26(2.410)	480	423	286	268	18.46	15
Murthy, J.	24(2.224)	133	85	74	57	5.54	7
Gopal-Krishna	24(2.224)	263	257	241	236	10.96	8

TP: *Total no. of RUSFW related articles published by a author;* ***TC:*** *Total no. of citation****; TC woSc:*** *Sum of Times Cited without self-citations****; CI:*** *Citing Articles* ***; CIwoSC:*** *Citing Articles without self-citations****; AvgCPA:*** *Average Citations per Article****; h-index :*** *no. of h papers among a author's no. of publications that have at least h citations each.* ***Source: WoS***

H. Collaboration Pattern: Continents

Based on the author attributions, world-wide collaboration of RUSFW research publications has been mapped. As shown in Figure 4.3.h(v), the major spatial clusters of research institutes are located in Asia, followed by Europe, Africa, South America and North America. Several minor clusters are distributed in other parts of the world.

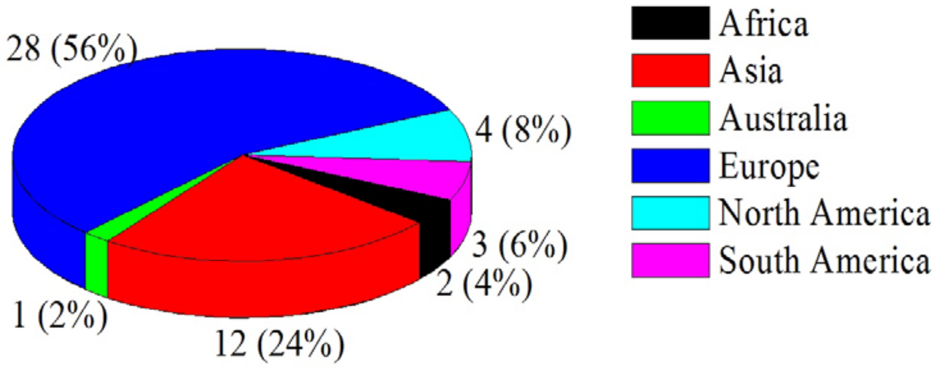

Figure 4.3.h(v): Continent wise Collaboration pattern of RUSFW research

I. Collaboration Pattern and research impact: Countries

There are 1079 articles which included author addresses, source country and research institutes. There are 50 collaborating Countries/territories which participated in collaborative research with India in the RUSFW research. Top 20 countries / territories are ranked on the basis of number of total articles, along with the citations and percentage of international collaborations (Table 4.3.h(vii)). Out of these 20 countries / territories, The USA produced maximum publication 414 that is 38.369% of total publications with high citations (7255). It is seen from the Table 4.3.h(vii) that RUSFW research related articles authored in collaboration with Sweden (Europe) have the highest average impact (AvgCPA = 27.96) followed by Denmark (Europe) AvgCPA = 24.42 while the USA ranked 16th in the AvgCPA index.

Table 4.3.h(vii): Country wise Collaboration Pattern and research impact of RUSFW research

Country	Continent	TP (%)	TC	AvgCPA	h-index
USA	North America	414(38.369)	7255	17.52	41
Germany	Europe	145(13.438)	2865	19.76	34
England	Europe	122(11.307)	2169	17.78	27
France	Europe	117(10.843)	2436	20.82	30
Italy	Europe	105(9.731)	2323	22.12	27
Australia	Australia	95(8.804)	1738	18.29	24
Netherlands	Europe	88(8.156)	1684	19.14	25
Canada	North America	79(7.322)	1790	22.66	26
Spain	Europe	75(6.951)	1186	15.81	19
Japan	Asia	51(4.727)	963	18.88	19
Poland	Europe	43(3.985)	960	22.33	19
Chile	South America	41(3.800)	954	23.27	17
Russia	Europe	39(3.614)	586	15.03	14
South Africa	Africa	33(3.058)	542	16.42	11
Ireland	Europe	33(3.058)	458	13.88	13
Taiwan	Asia	29(2.688)	526	18.14	15
Sweden	Europe	27(2.502)	755	27.96	15
Switzerland	Europe	22(2.039)	403	18.32	11
Peoples R China	Asia	19(1.761)	385	20.26	10
Denmark	Europe	19(1.761)	464	24.42	10

TP*= Total no. of RUSFW related articles published by a country;* ***TC*** *= Total no. of citation received;* ***AvgCPA****= Average no. of citations per Article;* ***h-index****= no. of h papers among a country's no. of publications that have at least h citations each.* ***Source: WoS***

J. Keyword Analysis

A total of 4534 different keywords, from 1960 to 2014 in the RUSFW sub-field have been identified. The number of analysed publications during the study period was 1079. To obtain accurate results, the keywords have been pre-processed by merging the singular and plural forms of the same terminology, and those keywords with the same meaning while using different expressions. A total 4030 unique Keywords are obtained. Among these unique keywords 2939 (72.92%) appear once or twice at the most. Table 4.3.h(viii) shows the most used keywords during the considered period.

J.1 Hotspots

An analysis of the keywords was undertaken to pick out the research hotsopts (Chapter 1, Section 1.8.5.A) that have attracted most research attention and to reveal the research tendencies in the fields of RUSWF. The top 20 most frequently used keywords for the study period are listed in Table 4.3.h(viii). The four most frequently used keywords revealed are 'X-rays : stars', 'radio continuum : galaxies', 'X-rays : binaries' and 'X-rays : galaxies'.

Table 4.3.h(viii): Top most frequently used keywords in RUSFW research

Keyword	NO	%	R
gamma rays: galaxies	7	0.17	17
infrared: galaxies	45	1.11	8
infrared: ISM	40	0.99	9
infrared: stars	83	2.05	5
radio continuum : galaxies	137	3.39	2
radio continuum : general	45	1.11	8
radio continuum : ISM	31	0.76	10
radio continuum : stars	25	0.62	11
radio lines : galaxies	70	1.73	6
radio lines : general	10	0.24	15
radio lines : ISM	50	1.24	7
submillimeter: ISM	13	0.32	13
ultraviolet: galaxies	8	0.19	16
Ultraviolet: general	11	0.27	14
ultraviolet: ISM	21	0.52	12
X-rays : binaries	124	3.07	3
X-rays : bursts	13	0.32	13
X-rays : galaxies	118	2.92	4
X-rays : general	25	0.62	11
X-rays : stars	140	3.47	1

NO: Number of time occurrences; R : rank Source: WoS

J.2 Quick rising themes

The Compound Annual Growth Rate (CAGR) described in Chapter 1, Section 1.8.5.B, can be used to select quick rising themes of RUSFW research; this reveals the indicators of future research directions. Table 4.3.h(ix) lists the top 20 keywords according to the CAGR and sorts them by their rank. The ranks in Table 4.3.h(ix) show that 'gamma rays: galaxies' and 'X-rays : binaries' and 'X-rays : galaxies' are three leading hot issues that continue to attract broad attention. 'X-rays : binaries' keeps its dominance in terms of total quantity and CAGR.

Table 4.3.h(ix): Quick rising themes in RUSFW research

Keyword	$V(t_0)$	$V(t_n)$	t_0	t_n	CAGR (%)	R
gamma rays: galaxies	1	2	2011	2014	0.259	1
infrared: galaxies	3	4	1992	2014	0.013	13
infrared: ISM	1	4	1999	2014	0.096	6
infrared: stars	2	9	1997	2014	0.092	7
radio continuum : galaxies	1	8	1993	2014	0.104	5
radio continuum : general	2	9	2000	2014	0.113	4
radio continuum : ISM	1	2	2000	2014	0.050	10
radio continuum : stars	1	1	1999	2013	0.000	14
radio lines : galaxies	1	2	1993	2014	0.033	11
radio lines : general	1	1	2001	2014	0.000	14
radio lines : ISM	2	3	1998	2014	0.025	12
submillimeter: ISM	8	4	2010	2014	-0.159	16
ultraviolet: galaxies	1	1	2009	2014	0.000	14
Ultraviolet: general	1	2	2003	2014	0.065	8
ultraviolet: ISM	2	1	2004	2014	-0.067	15
X-rays : binaries	2	12	2001	2014	0.147	2
X-rays : bursts	1	1	1999	2014	0.000	14
X-rays : galaxies	1	15	1992	2014	0.131	3
X-rays : general	1	2	1993	2014	0.033	11
X-rays : stars	2	6	1992	2014	0.051	9

***t_0**: the Initial (first) year (The Year in which no. of keywords occurrence first time; **t_n**: the last year (No. of keywords occurrence); **$V(t_0)$**: Initial observed value (no. of keywords occurrence); **$V(t_n)$**: last observed value (no. of keywords occurrence); **CAGR:** Compound Annual Growth Rate; **R:** Rank.*

Source: WoS

K. Summary

A total of 1079 papers were published on RUSFW, which received 14439 citations. The average number of publications per year was found to be 43.16; Compound Annual Growth Rate (CAGR) was 20.68% and the average number of citations per publication was 13.38. Publications on RUSFW appeared in 21 journals of which most active journal was "Monthly Notices of the Royal Astronomical Society" published by Oxford University Press from the United Kingdom and published 344 (31.88%) of the total 1079 publications. A total of 4110 authors contributed to RUSFW research. The most active author was Saikia, D. J. who produced maximum number of publications (88) i.e. 8.156 % of total publications. 855 institutions contributed of which TIFR; Mumbai, India is the most productive institution. For globalization of RUSFW Research in India, the results show that there were 50 Countries/territories which participated in RUSFW research. The USA produced maximum publications - 414 which is 38.369% of total publications with high citations (7255). A Keyword analysis reveals that ‘X-rays: stars’, ‘radio continuum: galaxies’, ‘X-rays: binaries’ and ‘X-rays: galaxies’ are the most frequently used keywords.

4.3.9 Stars

A star is a luminous sphere of plasma held together by its own gravity. The nearest star to Earth is the Sun. Many other stars are visible to the naked eye from Earth during the night, appearing as a multitude of fixed luminous points in the sky due to their immense distance from Earth ('Stars', n.d.). The understanding of the birth and death of stars requires the application of almost all branches of modern physics. These areas include; gravitation, hydrodynamics, atomic physics, liquid-solid state theory, superconductivity and superfluidity ('Stellar Physica', n.d.).

There were 2656 publications that met the selection criteria which appeared in the WoS database during 1960-2014 and these were analyzed.

A. Publication characteristics

Table 4.3.j(i): Bibliographic Records of Stars research in India during 1960-2014

Bibliometric Indicators `	**No.**
Total Number of Articles	2656
Total Number of Contributing Countries	72
Total Number of Contributing Authors	8617
Total Number of Contributing Institutions	1573
Total Number of Journals appeared	75
Total Number of Keywords (raw) appeared	8469

Source: WoS

A total of 2656 articles of Indian scientists during 1960-2014 were abstracted from WoS related to Stars publication. From Table 4.3.j (i) and 4.3.j (ii), the output of 2656 paper received a total of 44732 citations during the said period with an average

16.84 citations per paper. The average number of publications per year is 63.23 and CAGR is 0.10%.

Table 4.3.j(ii): Citation Metrics of Stars research in India during 1960-2014

Citation-based Indicators	No.
Sum of the Times Cited	44732
Sum of Times Cited without self-citations	39629
Citing Publications	28800
Citing Publications without self-citations	27115
Average Citations per Item	16.84
h-index	77

Source: WoS

B. Publication Pattern

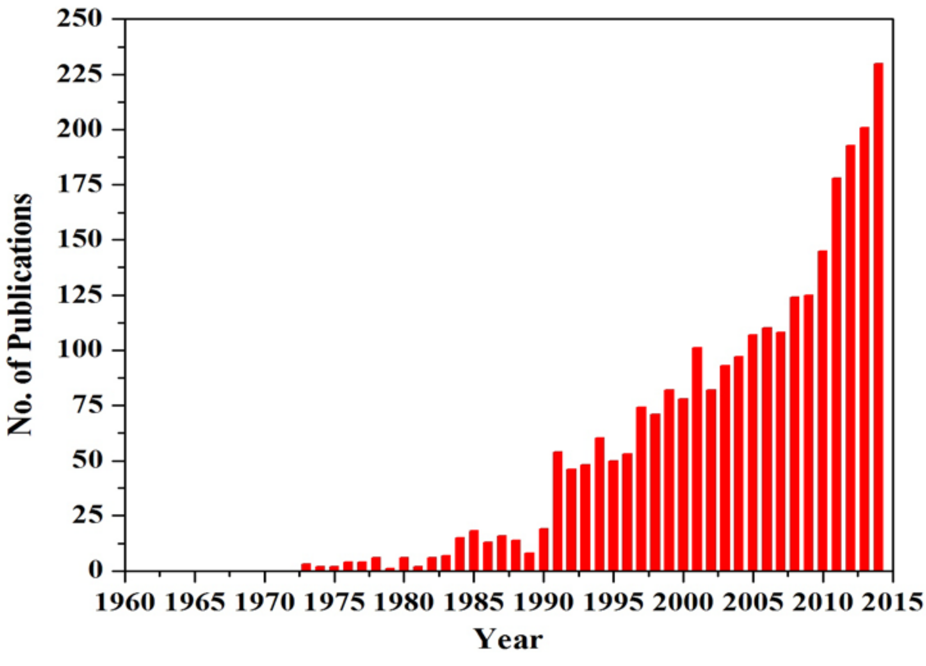

Figure 4.3.j(i): Publication Pattern of Stars research in India during 1960-2014. From the period 1960-1972, no publication appeared in the WoS database.

Publication pattern of Stars research from 1960 to 2014 is presented in Figure 4.3.j(i). The initial publication in the sub-field of Stars research is observed in the year 1973. A near about seventy three time's increase was observed over the study period, (from 3 in 1973 to 230 in 2014). The highest number of papers is published in the year 2014, with 230 publications and the lowest in 1979 with 1 publication.

C. Growth Trend

The cumulative progression is represented by a 4th degree power law distribution during 1960-2014 giving an idea of the polynomial growth curve as shown in Figure 4.3.j(ii). To choose the best fit growth model, various regression types with regression coefficient has been tested as shown in Table 4.3.j (iii). The best fit model is 4th degree polynomial curve, where $R^2 = 0.979$. The polynomial best fit for Stars research is found to be: $y = 0.0004x^4 - 3.459x^3 + 10335x^2 - 1E{+}07x + 7E{+}09$, where y is the cumulative number of publications and x is the number of years. The growth of literature shown in Figure 4.3.j (ii) can be divided into two parts, in the1st part (1960-1972), no literature is published by Indian scientists and in the 2nd part (1973-2014), growth trend follows a polynomial growth curve.

Table 4.3.j(iii): Different Regression Types with Regression coefficient (R^2) of Stars research

Regression Type	**Equation**	**(R^2)**
Exponential	$y = 1E\text{-}10e^{0.119x}$	0.901
Linear	$y = 4.717x – 9340$	0.869
Logarithmic	$y = 9395.\ln(x) – 71318$	0.868
Polynomial	$y = 0.0004x^4 - 3.459x^3 + 10335x^2 - 1E{+}07x + 7E{+}09$	0.979
Power	$y = 0x^{237.9}$	0.902

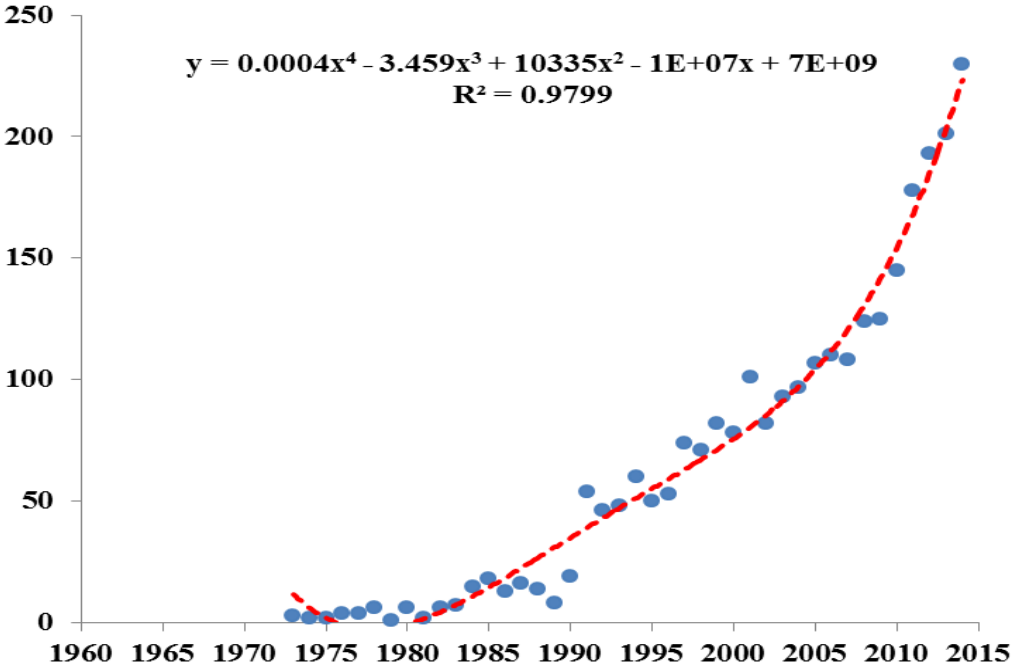

Figure 4.3.j(ii): Growth Trend of Stars research in India during 1960-2014.Blue dot describes the distribution of publications (observed value) and Red dashed line describes the correlation of distribution of publications where regression coefficient $R^2 = 0.979$

D. Citation Pattern

Figures 4.3.j (iii) and 4.3.j (iv) represent the citation pattern and number of citations vs. number of publications per year of Stars research in India during 1960-2014. A total of 2656 research papers have received 44732 citations. The pattern of citations is very fluctuating. In the initial year 1973, the total number of citations received is 15 with an average citation of 5. The minimum citation received in the year 1979 is one (1) and the maximum citations received in the year 2003 are 4347 with an average citation of 46.74. It has been observed from Figure 4.3.j(iv) that after the year 2011, citations decrease while publications continue to increase.

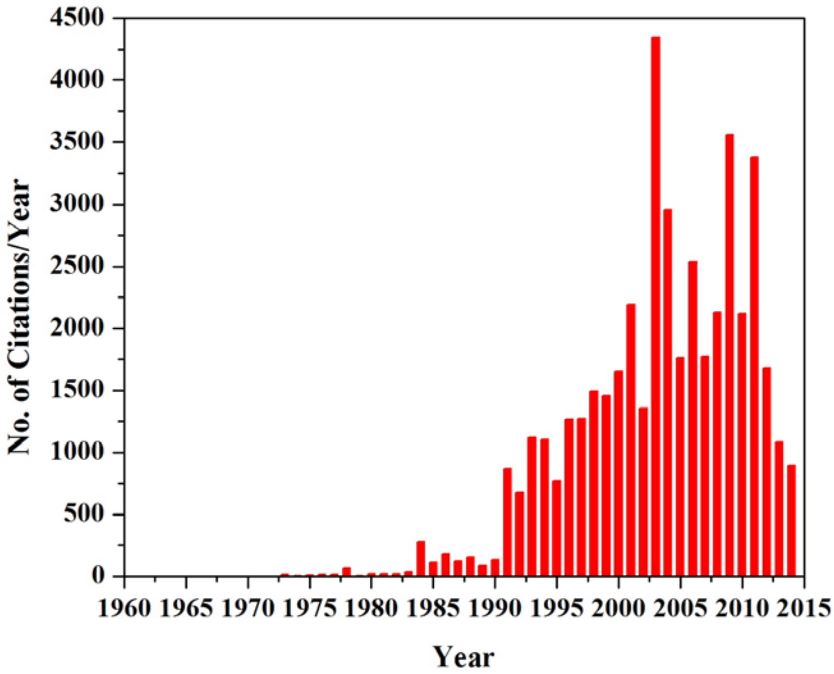

Figure 4.3.j(iii): Citation Pattern of Stars research in India during 1960-2014. From 1960-1972, no citation received as no publication appeared in the WoS database.

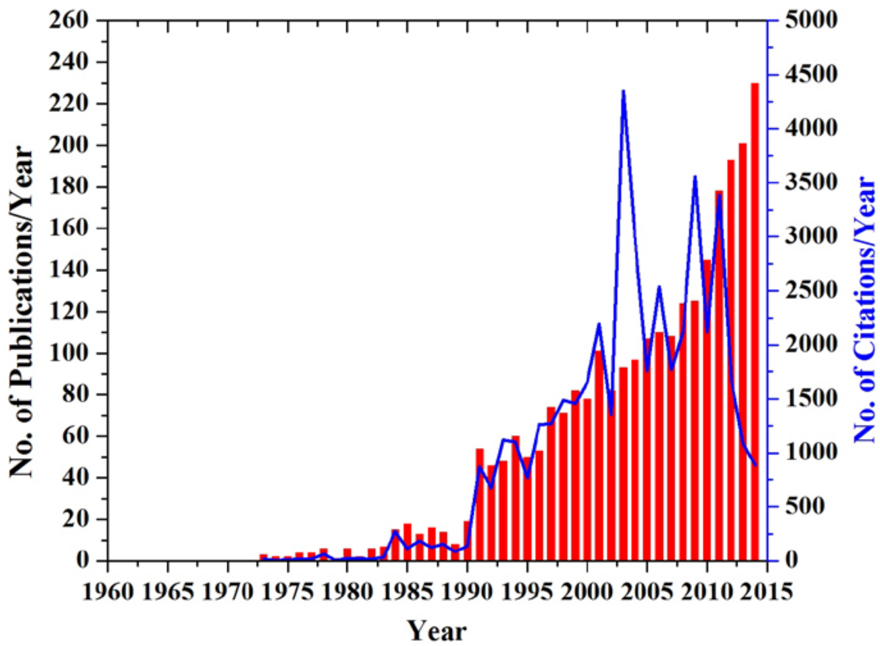

Figure 4.3.j(iv): Citation Pattern Vs Publication Pattern of Stars research in in India during 1960-2014: Blue line (right Y axis) indicates the citation pattern against red bar (left Y axis) that describes the publications pattern.

E. Top Institutions and their research impact

A total of 2656 publications on Stars appeared from 1573 institutions. Out of the top 20 institutions only 8 are Indian. Tata Institute of Fundamental Research, Mumbai and Physical Research Laboratory (PRL), Ahmadabad had published 582 and 184 papers respectively. Indian Institute of Astrophysics (IIA), Raman Research Institute, Bangalore, and Aryabhatta Research Institute of Observational Sciences, Nainital come under the Department of Science and Technology and have published papers 612, 211 and 148 respectively.

Table 4.3.j(iv): Top institutions on Stars research and their research impact, 1960- 2014

Institution	Region	TP (%)	TC	AvgCPA	h-index
Indian Institute of Astrophysics	India	612(23.042)	9368	15.31	42
Tata Institute of Fundamental Research	India	582(21.913)	11132	19.13	40
Inter University Centre for Astronomy Astrophysics	India	366(13.780)	10156	27.75	49
Centre National De La Recherche Scientifique (CNRS)	France	217(8.170)	6659	30.69	42
Raman Research Institute	India	211(7.944)	3416	16.19	29
Physical Research Laboratory	India	184(6.928)	1963	10.67	23
National Aeronautics Space Administration (NASA)	USA	177(6.664)	9177	51.85	47
Max Planck Society	Germany	176(6.627)	8428	47.89	44
Aryabhatta Research Institute of Observational Sciences	India	148(5.572)	1313	8.20	19
California Institute of Technology	USA	127(4.782)	7173	56.48	40
University of Texas Austin	USA	126(4.744)	6558	50.05	36
Observatoire De Paris	France	125(4.706)	4730	37.84	40
Goddard Space Flight Center	USA	111(4.179)	4146	37.35	36
Indian Institute of Science Iisc Banglore	India	110(4.142)	1068	14.62	22
National Institutes of Natural Sciences Nins Japan	Japan	102(3.840)	4902	48.06	32
National Astronomical Observatory of Japan	Japan	102(3.840)	4705	49.53	31
University of Delhi	India	94(3.539)	1044	11.11	15
University of California System	USA	92(3.464)	624	67.89	33
Institut De Recherche Pour Le Developpement (IRD)	France	85(3.200)	3896	45.84	33
Pennsylvania Commonwealth System of Higher Education	USA	82(3.087)	6199	75.06	34

TP*= Total no. of Stars related publications published by an institution;* ***TC*** *= Total no. of citation received;* ***AvgCPA****= Average no. of citations per article; h-****index****=defined by the no. of h papers among an institution's no. of publications that have at least h citations each.* ***Source: WoS***

Inter University Centre for Astronomy Astrophysics and University of Delhi have published papers 366 and 94 respectively. Indian Institute of Science (IISc) Banglore had published 110 papers. The other 12 are foreign institutions, among these 6 belong to the USA viz. (NASA), USA; California Institute of Technology, USA;

University of Texas , Austin, USA; Goddard Space Flight Center, USA; University of California System, USA; Pennsylvania Commonwealth System of Higher Education,USA; 3 belong to France namely Centre National De La Recherche Scientifique CNRS, France; Observatoire De Paris, France; Institut De Recherche Pour Le Developpement (IRD), France; 2 belong to Japan i.e. National Institutes of Natural Sciences (NINS), Japan; and National Astronomical Observatory of Japan; and 1 to Germany – the Max Planck Society.

Table 4.3.j(iv) reveals the impact of research in terms of quality of papers. The AvgCPA and the h- index are used to identify which institution has the largest number of high quality publications in the field of Stars research. It is seen from the Table 4.3.j(iv) that Stars related publications authored in collaboration with the foreign institutions have the highest average impact (AvgCPA=75.06). Among Indian institutions, Inter University Centre for Astronomy Astrophysics has the highest impact (27.75) in AvgCPA index.

F. Journals and their research impact

Papers on Stellar research have appeared in 75 journals. The highest number of papers have appeared in the Journal 'Monthly Notices of the Royal Astronomical Society' published by Oxford University Press from the United Kingdom. Table 4.3.j (v) shows the top 20 productive journals. These 20 out of the 75 journals have published 1724 (73.20%) of the total 2656 publications. The 'Monthly Notices of the Royal Astronomical Society' ranks 1st with 547 (20.59%) papers; 'Astrophysical Journal' with 462 (17.39%) papers, 'Astronomy Astrophysics' with 433 (16.30%) papers, 'Astrophysics and Space Science' with 277 (10.42%) papers and 'Physical

Review D 153 (5.76%)', these journals ranked at 2nd , 3rd , 4th and 5th positions respectively.

Table 4.3.j (v) also shows the citation impact of top 20 journals. The AvgCPA and the h-index are used to identify which journals have the largest number of high quality publications in the Stars research. It is seen from the Table 4.3.j(v) that the journal 'Astrophysical Journal Supplement Series' published by IOP Publishing for the American Astronomical Society in USA has the highest average impact (AvgCPA = 159.83). It is seen that though the journal 'Monthly Notices of the Royal Astronomical Society' has the highest number of publications but ranked 7th in the AvgCPA index.

Table 4.3.j (v): Top Journals on Stars research and their research impact, 1960-2014

				Journal Metrics (2013)			
Journal	**TP (%)**	**TC**	**AvgCPA**	**SJR**	**IPP**	**SNIP**	**Country**
Monthly Notices of the Royal Astronomical Society	547(20.595)	8498	15.54	3.196	4.911	1.494	UK
Astrophysical Journal	462(17.395)	9593	20.76	3.159	4.348	1.145	UK
Astronomy Astrophysics	433(16.303)	7365	17.01	1.471	1.932	0.612	France
Astrophysics and Space Science	277(10.429)	1395	5.04	1.081	1.748	1.056	Netherland
Physical Review D	153(5.761)	6744	44.08	1.899	3.192	1.136	USA
Journal of Astrophysics and Astronomy	126(4.744)	778	6.17	0.477	0.541	0.224	India
International Journal of Modern Physics D	75(2.824)	643	8.57	0.733	1.021	0.540	Singapore
Astronomical Journal	66(2.485)	1311	19.86	2.795	3.282	1.092	UK
Astrophysical Journal Letters	52(1.958)	781	15.02	3.914	4.852	1.487	UK
Bulletin of the Astronomical Society of India	43(1.619)	125	2.91	1.091	1.068	0.516	India
Astronomy Astrophysics Supplement Series	39(1.468)	486	12.46	-	-	-	France
Research in Astronomy and Astrophysics	36(1.355)	135	3.75	0.953	1.331	0.768	UK
IAU Symposia	35(1.318)	8	0.23	-	-	-	Puerto Rico
New Astronomy	34(1.280)	156	4.59	1.074	1.332	0.726	Netherlands
Classical and Quantum Gravity	33(1.242)	799	24.21	1.476	2.192	0.966	UK
Journal of Cosmology and Astroparticle Physics	29(1.092)	623	21.48	0.615	2.374	0.465	UK
General Relativity and Gravitation	26(0.979)	296	11.38	1.109	1.628	1.015	UK
Astrophysical Journal Supplement Series	24(0.904)	3836	159.83	6.857	9.687	3.125	USA
Publications of the Astronomical Society of Japan	22(0.828)	243	11.05	1.521	1.626	0.750	Japan
Publications of the Astronomical Society of the Pacific	21(0.791)	211	10.05	2.990	3.147	1.266	USA

TP= *Total no. of Stars research related articles published by a Journal;* ***TC*** *= Total no. of citation received;* ***AvgCPA***= *Average no. of citations that Stars related articles in a journal received;* ***h-index***= *no. of h papers among a journal's no. of publications that have at least h citations each.* ***SJR*** *= SCImago Journal Rank;* ***IPP*** *= Impact per Publication;* ***SNIP*** *= Source Normalized Impact per Paper;* ***Source: WoS and SCOPUS***

G. Top Authors and their research impact

A total of 2656 publications included the author addresses having India as the country of affilation. Publications on Stars have been contributed by 8617 authors. Table 4.3.j (vi) shows the top 20 productive authors during the last 54 years, 1960-2014. Top 20 productive authors are ranked based on the decreasing productivity of total publications. Sagar, R. has produced maximum number of publications i.e. 93 which accounts for 3.50% of total publications and ranks 1st followed by Paul, B. , Ashok, N. M., Lambert, D. L., Ojha, D. K. who ranked 2nd , 3rd, 4th and 5th respectively.

Table 4.3.j(vi): Top Authors of Stars research and their research impact, 1960-2014

Author	TP (%)	TC	TC woSC	CI	CIwoSC	AgCPA	h-index
Sagar, R.	93(3.502)	1203	1070	913	860	12.94	19
Paul, B.	79(2.974)	721	475	394	333	9.13	16
Ashok, N.M.	66(2.485)	692	557	495	450	10.48	15
Lambert, D.L.	61(2.297)	1524	1305	919	869	24.98	20
Ojha, D.K.	60(2.259)	724	582	474	434	12.07	15
Pandey, A.K.	58(2.184)	734	514	427	381	12.66	16
Rao, A.R.	57(2.146)	812	673	556	513	14.25	17
Parthasarathy, M.	56(2.108)	810	694	606	572	14.46	17
Gonzalez, G.	56(2.108)	2355	2168	1121	1073	42.05	31
Anupama, G.C.	55(2.071)	820	763	644	619	14.91	16
Rao, N.K.	51(1.920)	849	695	464	427	16.65	16
Gupta, Y.	50(1.883)	858	759	535	500	17.16	17
Bose, S.	48(1.807)	1978	1803	859	817	41.21	26
Banerjee, D.P.K.	48(1.807)	486	343	297	256	10.12	13
Yoshida, S.	47(1.770)	2037	1870	904	864	43.34	27
Mukherjee, S.	47(1.770)	2049	1884	919	879	43.60	28
Bhatt, H.C.	47(1.770)	476	439	413	395	10.13	12
Singh, K.P.	45(1.694)	577	551	531	519	12.82	13
Giridhar, S.	45(1.694)	623	493	345	312	13.84	15
Chakrabarti, S.K.	45(1.694)	956	852	474	439	21.24	16

TP:** Total no. of Stars related articles published by a author; **TC:** Total no. of citation**; TC woSc:** Sum of Times Cited without self-citations**; CI:** Citing Articles **; CIwoSC:** Citing Articles without self-citations**; AvgCPA:** Average Citations per Article**; h-index :** no. of h papers among a author's no. of publications that have at least h citations each. **Source: WoS

Table 4.3.j(vi) reveals the impact of research in terms of quality of papers. The AvgCPA and the h-index are used to identify which author has the largest number of high quality publications in the Stars research. It is seen from the Table 4.3.j(vi) that Stars related publications authored by Mukherjee, S. have the highest average impact (AvgCPA = 43.60) followed by Yoshida, S. (AvgCPA = 43.34). It is seen that though Sagar, R. has the maximum number of publications, but he ranks 12th in the AvgCPA index.

H. Collaboration Pattern: Continents

Based on the author attributions, world-wide collaboration of Stars research publications has been mapped. As shown in Figure 4.3.j (v), the major spatial clusters of research institutes are located in Europe, followed by Asia and Africa. Several minor clusters are distributed in other parts of the world. North America and South America have equal contribution.

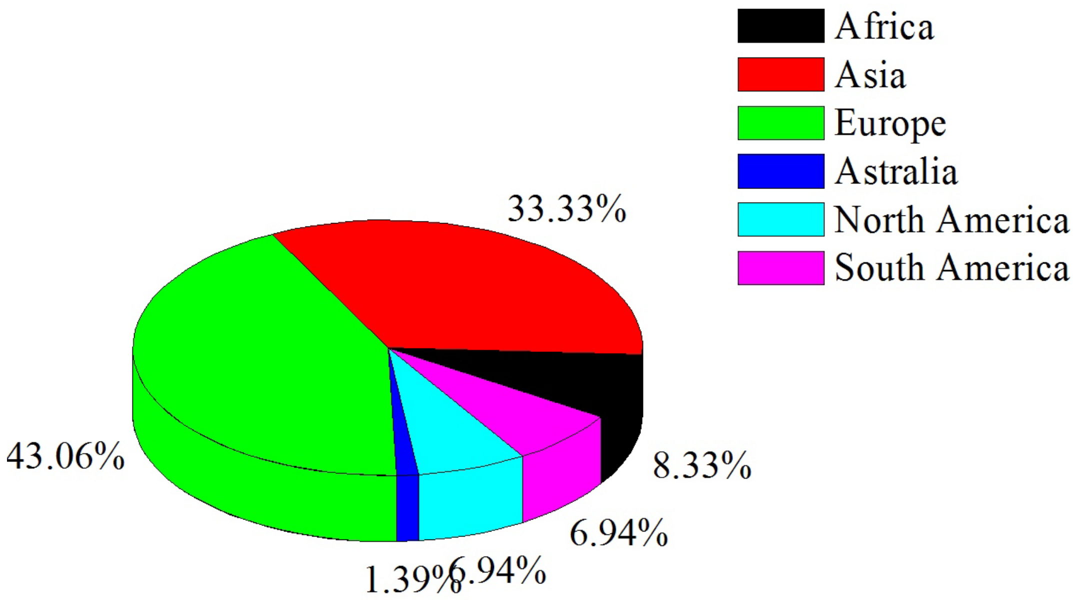

Figure 4.3.j(v): Continent wise Collaboration pattern of Stars research

I. Collaboration Pattern and research impact: Countries

A total of 2656 publications included author address, source country and research institutes. There were 72 collaborating Countries/territories which collaborated with Indian institutions involved in the stellar research. Out of the 2656 papers, 113 (4.8%) papers appeared in India's own publications without international collaboration and the remaining 2242 (95.20%) appeared with international collaboration.

Table 4.3.j(vii): Country wise Collaboration Pattern and research impact of Stars research

Country	Continent	TP (%)	TC	AgCPA	h-index
USA	North America	660(24.849)	21946	33.25	66
Germany	Europe	292(10.994)	10303	35.28	49
France	Europe	271(10.203)	8492	31.34	48
England	Europe	250(9.413)	11684	46.74	52
Italy	Europe	211(7.944)	8216	38.94	49
Australia	Australia	193(7.267)	8752	45.35	47
Japan	Asia	189(7.116)	7587	40.14	40
Spain	Europe	181(6.815)	9150	50.55	45
Russia	Asia	124(4.669)	4804	38.74	36
Netherlands	Europe	124(4.669)	5047	40.70	33
Canada	North America	113(4.255)	6943	61.44	34
Poland	Europe	92(3.464)	4337	47.14	30
Peoples R China	Asia	92(3.464)	2488	27.04	29
Brazil	South America	78(2.937)	2612	33.49	25
South Africa	Africa	77(2.899)	4394	57.06	27
Chile	South America	74(2.786)	4250	57.43	24
Scotland	Europe	66(2.485)	5046	76.45	31
Taiwan	Asia	65(2.447)	1926	29.63	15
South Korea	Asia	64(2.410)	3234	50.53	15
Wales	Europe	53(1.995)	2500	47.17	30

TP= *Total no. of Stars related articles published by a country;* ***TC*** = *Total no. of citation received;* ***AvgCPA***= *Average no. of citations per Article;* ***h-index***= *no. of h papers among a country's no. of publications that have at least h citations each.* ***Source: WoS***

As shown in the Table 4.3.j(vii), top 20 countries / territories are ranked based on the number of total publications, along with the citations and percentage of international collaborations. Out of the 20 countries / territories, the USA has produced maximum publications in collaboration i.e. 660 which accounts for 21.614% of total publications with highest citations (21946). It is seen from the Table

4.3.j(vii) that Stars related publications authored in collaboration with Scotland (Europe) have the highest average impact (AvgCPA = 76.45) followed by Canada (North America) AvgCPA = 61.44 while the USA ranked 17th in the AvgCPA index.

J. Keyword Analysis

A total of 28632 different keywords, from 1960 to 2014 in the Stars have been identified. The number of analysed publications during the study period is 2656. Of these only 2483 provides key words, while the rest (173) do not provide any keywords. To obtain accurate results, the keywords have been pre-processed by merging the singular and plural forms of the same terminology, and those keywords with the same meaning while using different expressions (for example, ‘‘Neutron star”, “neutron stars” and “neutron-star”; “late-type stars’’ and “late-type star”) . A total of 11772 unique Keywords have been obtained. Among these unique keywords 5069 (43.05%) appear once or twice at the most. Table 4.3.j (viii) shows the most used keywords during the considered period.

J.1 Hotspots

An analysis of the keywords was undertaken to pick out the research hotspots (Chapter 1, Section 1.8.5.A) that have attracted most research attention and to reveal the research tendencies in the fields of Stars. The top 20 most frequently used keywords for the study period are listed in Table 4.3.j (viii). The five most frequently used keywords were ‘Emission’, ‘Evolution’, ‘Supernovae’, ‘Binaries’ and ‘Neutron’.

Table 4.3.j(viii): Top most frequently used keywords in Stars research

Keyword	NO	%	R
Emission	404	3.43	1
Evolution	401	3.40	2
Supernovae	395	3.35	3
Binaries	371	3.15	4
Neutron	354	3.00	5
Pulsars	344	2.92	6
Formation	271	2.30	7
Variables	202	1.71	8
Abundances	128	1.08	9
Rotation	124	1.05	10
Luminosity	112	0.95	11
Magnetic field	108	0.91	12
Binary	105	0.89	13
Circumstellar matter	98	0.83	14
AGB and post-AGB	94	0.79	15
Atmospheres	94	0.79	16
Novae	80	0.67	17
Late-type	66	0.56	18
Gamma-ray burst	59	0.50	19
Chemically peculiar	36	0.30	20

NO: Number of time occurrences; R : rank Source: WoS

J.2 Quick Rising Themes

Table 4.3.j(ix): Top Quick rising themes in Stars research

Keyword	V (t_0)	V (t_n)	t_0	t_n	CAGR (%)	R
Emission	1	27	1990	2014	0.147	2
Evolution	8	38	1991	2014	0.070	12
Supernovae	2	59	1991	2014	0.158	1
Binaries	2	26	1990	2014	0.112	7
Neutron	1	27	1990	2014	0.147	2
Pulsars	1	23	1990	2014	0.139	3
Formation	4	34	1991	2014	0.097	9
Variables	3	10	1991	2014	0.053	15
Abundances	1	12	1991	2014	0.114	6
Rotation	2	10	1991	2014	0.072	11
Luminosity	1	15	1991	2014	0.125	4
Magnetic field	1	10	1991	2014	0.105	7
Binary	1	10	1990	2014	0.100	8
Circumstellar matter	2	7	1991	2014	0.056	13
AGB and post-AGB	2	6	1993	2014	0.053	15
Atmospheres	1	6	1991	2014	0.081	10
Novae	2	5	1993	2014	0.044	16
Late-type	2	4	1991	2014	0.030	18
Gamma-ray burst	1	12	1992	2014	0.119	5
Chemically peculiar	1	2	1992	2014	0.032	17
Brown dwarfs	1	2	2001	2014	0.054	14

t_0**: the Initial (first) year (The Year in which no. of keywords occurrence first time; **t_n**: the last year (No. of keywords occurrence); **V(t_0)**: Initial observed value (no. of keywords occurrence); **V(t_n)**: last observed value (no. of keywords occurrence); **CAGR:** Compound Annual Growth Rate; **R:** Rank. **Source: WoS

The Compound Annual Growth Rate (CAGR) described in Chapter 1, Section 1.8.5.B, can be used to select quick rising themes of Stars research; this reveals the indicators of future research directions. Table 4.3.j (ix) lists the top 20 keywords according to the CAGR and sorts them by their rank. The ranks in Table 4.3.j(ix) show that 'Supernovae' and 'Emission' and 'Pulsars' are three leading hot issues that continue to attract broad attention. 'Supernovae' kept its dominance in terms of total quantity and CAGR.

K. Summary

A total of 2656 literature were published on Stars, which received total 44732 citations. The average number of publications per year was 63.23 and the average number of citations per publication was 1061.78. Publications on Stars appeared in 75 journals of which most active journal was 'Monthly Notices of the Royal Astronomical Society' published by Oxford University Press on behalf of the Royal Astronomical Society originating from United Kingdom and 547 (20.59%) of the total 2656 publications. 1573 institutions contributed of which Indian Institute of Astrophysics, Bangalore is the most productive institution. For globalization of Stellar Research in India, the results show that there were 72 Countries/territories which participated in Stars research. The USA produced maximum publications: 660 i.e. 24.849 % of total publication with higher citations (21946). A Keyword analysis reveals that 'Emission', 'Evolution', 'Supernovae', 'Binaries' and 'Neutron' are the most frequently used keywords.

4.3.10 The Galaxy

We live on a planet called Earth that is part of our solar system. Our Solar system is a small part of the Milky Way which is a Galaxy. A galaxy is a huge collection of gas, dust, and billions of stars and their solar systems. It is held together by gravity. Our galaxy, the Milky Way, also has a supermassive black hole in the middle (Murdin, 2001; 'NASA Science', n.d.).

There were 1199 articles that met the selection criteria which appeared in the WoS database during 1960-2014 and these were analyzed. The specific characteristics of the publications such as number of publications, the number authors involved in the production of these publication, institutions, journals, etc. were taken into consideration.

A. Publication characteristics

Table 4.3.k(i): Bibliographic Records of 'The Galaxy' research in India during 1960-2014

Bibliometric Indicators `	No.
Total Nunber of Articles	1199
Total Nunber of Contributing Countries	56
Total Nunber of Contributing Authors	5617
Total Nunber of Contributing Institutions	1035
Total Nunber of Journals appeared	91
Total Nunber of Keywords (raw) appeared	5666

Source: WoS

A total of 1199 articles of Indian scientists during 1960-2014 were abstracted from WoS related to 'The Galaxy' publications. From Table 4.3.k(i) and 4.3.k(ii), the output of 1199 paper received a total of 22030 citations during the said period with an average of about 18.37 citations per paper. The average number of publications per year is 27.88 and CAGR is 0.11%.

Table 4.3.k(ii): Citation Metrics of ‘The Galaxy’ research in India during 1960-2014

Citation-based Indicators	No.
Sum of the Times Cited	22030
Sum of Times Cited without self-citations	20246
Citing Articles	15517
Citing Articles without self-citations	14824
Average Citations per Item	18.37
h-index	61

Source: WoS

B. Publication Pattern

Publication pattern of ‘The Galaxy’ research from 1960 to 2014 is presented in Figure 4.3.k(i). The initial publication in the sub-field of ‘The Galaxy’ research is observed in the year 1972. A near about one hundred three times increase was observed over the study period, (from 1 in 1972 to 106 in 2014). The highest number of papers is published in the year 2013, with 120 publications and the lowest in 1979 with 1 publication.

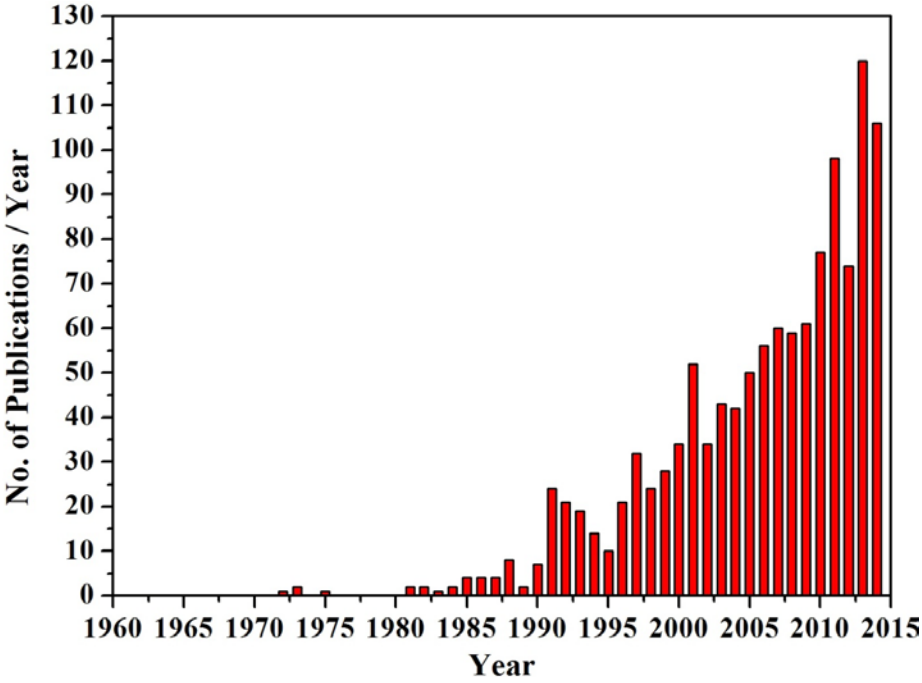

Figure 4.3.k(i): Publications Pattern of 'The Galaxy' research in India during 1960-2014. From the period 1960-1971, no publication appeared in the WoS database.

C. Growth Trend

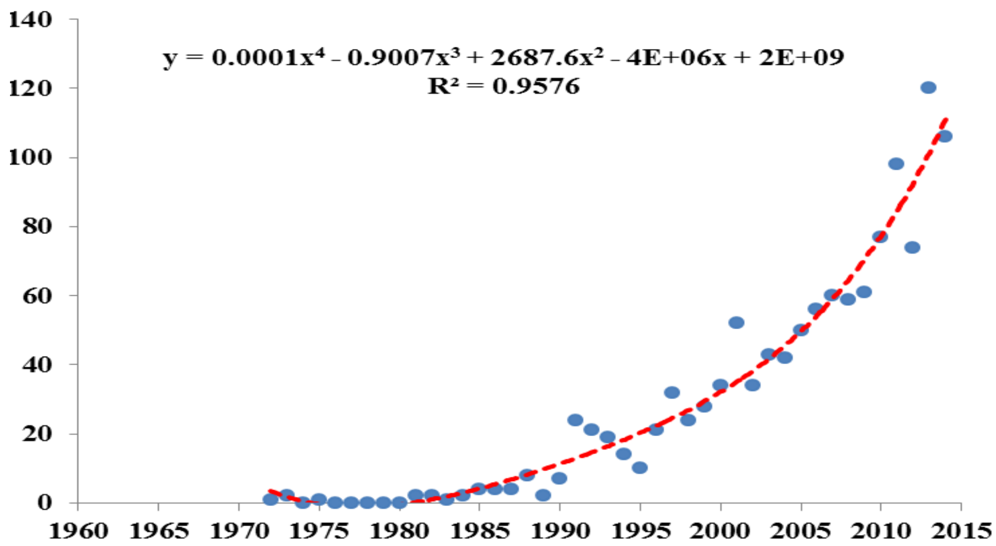

Figure 4.3.k(ii): Growth Trend of 'The 'The Galaxy'' research in India during 1960-2014.Blue dot describes the distribution of publications (observed value) and red dashed line describe the correlation of distribution of publications where regression coefficient R^2 = 0.957

The cumulative progression is represented by a 4th degree power law distribution during 1960-2014 giving an idea of the polynomial growth curve as shown in Figure 4.3.k(ii). To choose the best fit growth model, various regression types with regression coefficient has been tested as shown in Table 4.3.k(iii). The best fit model is 4th degree polynomial curve, where $R^2 = 0.957$. The polynomial best fit for 'The Galaxy' research is found to be: $y = 0.0001x^4 - 0.9007x^3 + 2687.6x^2 - 4E{+}06x + 2E{+}09$, where y is the cumulative number of publications and x is the number of years. The growth of literature shown in Figure 4.3.k(ii) can be divided into two parts, in the 1st part (1960-1971), there is no literature published by Indian scientists and the 2nd part (1972-2014), follows a polynomial growth curve.

Table 4.3.k(iii): Different Regression Types with Regression coefficient (R^2) of 'The Galaxy' research

Regression Type	**Equation**	**(R^2)**
Linear	$y = 2.2839x - 4523.9$	0.804
Logarithmic	$y = 4546.3\ln(x) - 34512$	0.802
Polynomial	$y = 0.0001x^4 - 0.9007x^3 + 2687.6x^2 - 4E{+}06x + 2E{+}09$	0.957

D. Citation Pattern

Figures 4.3.k(iii) and 4.3.k(iv) represent the citation pattern and number of citations vs. number of publications per year of 'The Galaxy' research in India during 1960-2014. A total of 1914 research papers have received 22030 citations. The pattern of citations is very fluctuating. In the initial year 1972, the total number of citations received is 5 with an average citation of 5. The minimum citation received in the year

1982 is two (2) and the maximum citations received in the year 2009 are 2877 with an average citation of 16.83. It has been observed from Figure 4.3.k(iv) that after the year 2009, citations decrease while publications continue to increase.

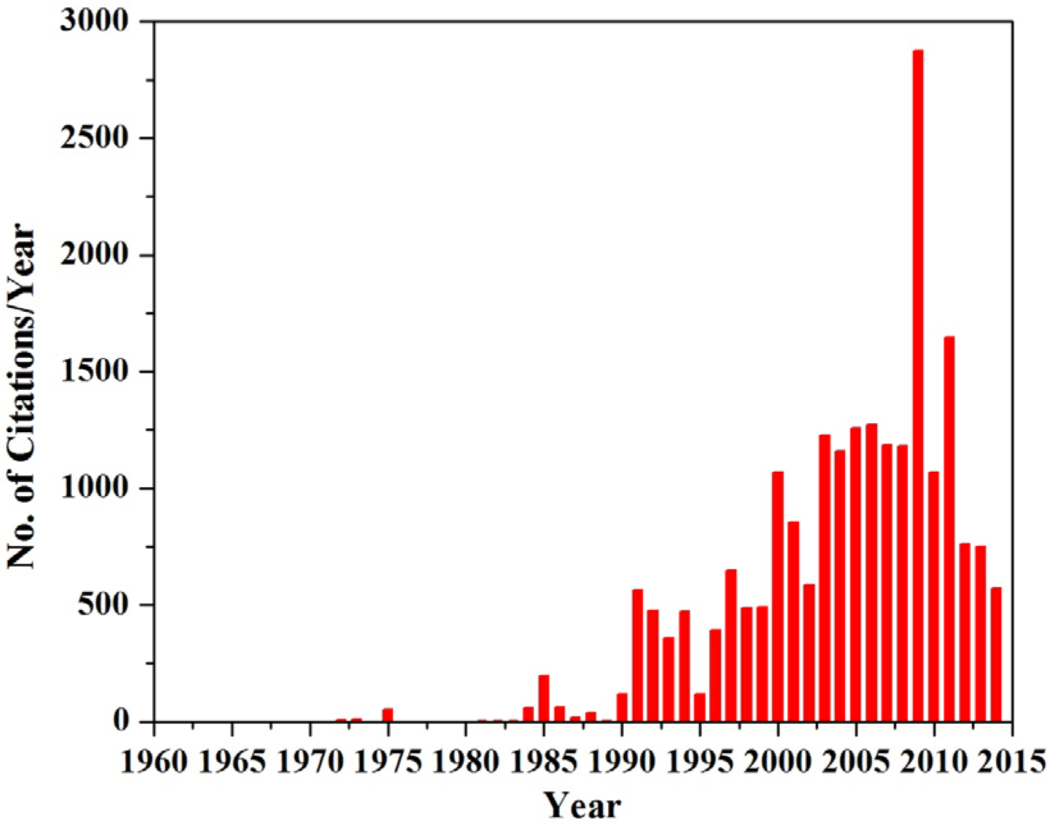

Figure 4.3.k(iii): Citation Pattern of 'The 'The Galaxy' research in India during 1960-2014. From 1960-1971, no citation received as no publication appeared in the WoS database.

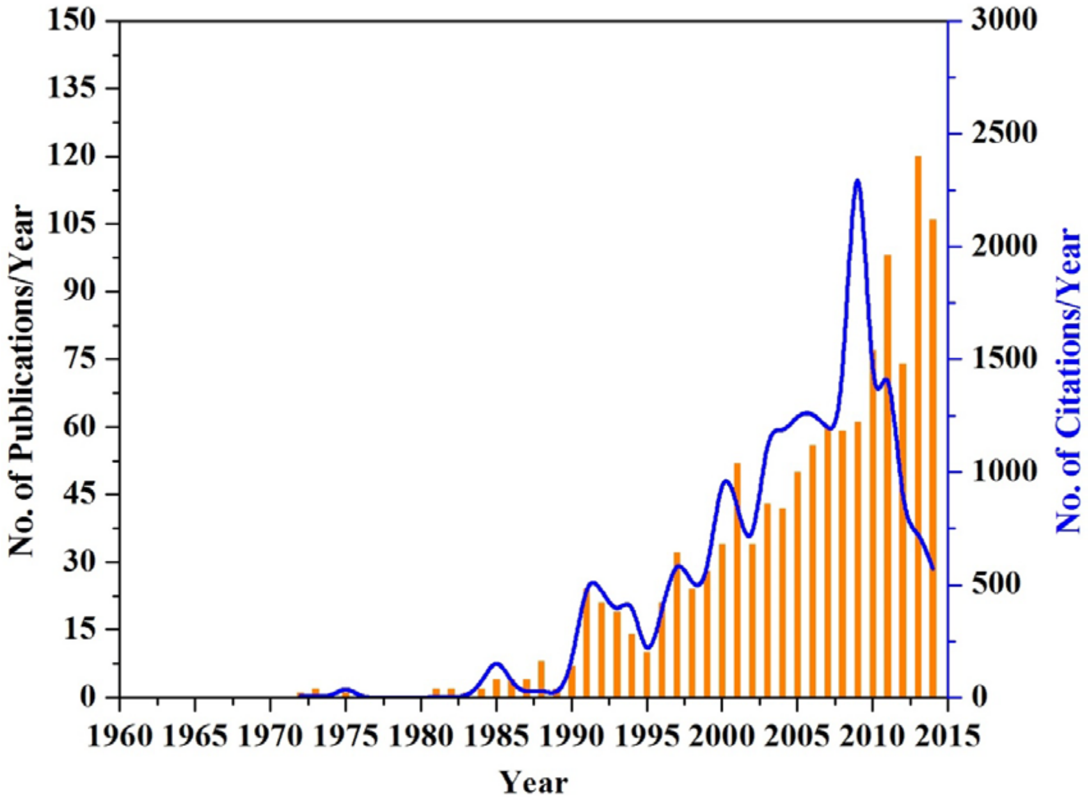

Figure 4.3.k(iv): Citation Pattern Vs Publication Pattern of 'The 'The Galaxy'' research in India during 1960-2014: Blue line (right Y axis) indicates the citations pattern against the orange bar (left Y axis) that describes the publications pattern

E. Top Institutions and their research impact

A total of 1199 articles on 'The Galaxy' research appeared from 1035 institutions. Table 4.3.94 shows the top 20 productive institutions during the last 54 years, 1960-2014. Out of these top 20 institutions, 7 are Indian. Tata Institute of Fundamental Research which contributed highest publication had published 329 (27.44%) papers followed by Inter University Centre for Astronomy Astrophysics with 245 papers, Indian Institute of Astrophysics - 190 and Raman Research Institute – 161 publications respectively.

The other 13 are foreign institutions. Among these 7 belong to the USA namely National Aeronautics Space Administration (NASA), University of California

System, California Institute of Technology, National Radio Astronomy Observatory,Harvard University, United States Department of Energy and Smithsonian Institution; 2 are from France namely Centre National De La Recherche Scientifique and Observatoire De Paris, France; 2 are from Germany namely Max Planck Society and European Southern Observatory, Germany; 1 each from Russian Academy of Sciences, Russia and University of Cambridge, UK.

Table 4.3.k(iv): Top institutions on 'The Galaxy' research and their research impact, 1960- 2014

Institution	Region	TP (%)	TC	AvgCPA	h-index
Tata Institute of Fundamental Research	India	329(27.440)	6720	20.43	36
Inter University Centre for Astronomy Astrophysics	India	245(20.434)	5703	23.28	41
Indian Institute of Astrophysics	India	190(15.847)	2857	15.04	25
Raman Research Institute	India	161(13.428)	420	15.03	26
Centre National De La Recherche Scientifique	France	155(12.927)	4892	31.56	40
Max Planck Society	Germany	121(10.092)	5317	43.94	35
Observatoire De Paris	France	97(8.090)	3347	34.51	36
Indian Institute of Science Iisc Banglore	India	81(6.756)	1716	21.19	21
National Aeronautics Space Administration (NASA)	USA	80(6.672)	4851	60.64	32
European Southern Observatory	Germany	78(6.505)	4540	58.21	32
University of California System	USA	76(6.339)	4562	60.03	29
California Institute of Technology	USA	76(6.339)	3972	52.26	26
National Radio Astronomy Observatory	USA	65(5.421)	1397	16.63	20
University of Cambridge	UK	64(5.338)	4241	66.27	30
National Centre for Radio Astrophysics	India	62(5.171)	1397	16.63	20
Harvard University	USA	57(4.754)	1409	24.72	18
University of Pune	India	53(4.420)	766	14.45	16
Russian Academy of Sciences	Russia	53(4.420)	1167	22.02	22
United States Department of Energy	USA	52(4.337)	4276	82.23	26
Smithsonian Institution	USA	51(4.254)	976	19.14	18

TP**= Total no. of 'The Galaxy' related articles published by an institution; **TC** = Total no. of citation received; **AvgCPA**= Average no. of citations per article; h-**index**=defined by the no. of h papers among an institution's no. of publications that have at least h citations each. **Source: WoS

Table 4.3.k(iv) reveals the impact of research in terms of quality of papers. It is seen from the above Table 4.3.k(iv) that 'The Galaxy' research related articles authored in collaboration with United States Department of Energy have the highest average impact (AvgCPA = 82.23) followed by University of Cambridge (AvgCPA = 66.27). Among the Indian institutions, Inter University Centre for Astronomy Astrophysics has the highest average impact (AvgCPA = 23.28) in AvgCPA index.

F. Top 20 Journals and their research impact

'The Galaxy' research papers have appeared in 51 journals. Papers have appeared in highest number in the journal 'Monthly Notices of the Royal Astronomical Society' published by Oxford University Press on behalf of the Royal Astronomical Society originating from United Kingdom. Table 4.3.k(v) shows the top 20 productive journals. These 20 out of the 51 journals have published 1166 of the total 1199 articles. The 'Monthly Notices of the Royal Astronomical Society' ranked first with 345 (28.77%); 'Astronomy Astrophysics 250 (20.85%)', 'Astrophysical Journal 231 (19.26%)', 'Astrophysics and Space Science 62 (5.17%)' and 'Journal of Astrophysics and Astronomy 53 (4.42%)' ranked at 2^{nd} , 3^{rd} , 4^{th} and 5^{th} respectively.

Table 4.3.k(v): Top Journals on 'The Galaxy' research and their research impact, 1960-2014

				Journal Metrics (2013)			
Journal	**TP (%)**	**TC**	**AvgCPA**	**SJR**	**IPP**	**SNIP**	**Country**
Monthly Notices of the Royal Astronomical Society	345(28.774)	5258	15.24	2.760	4.639	1.325	UK
Astronomy Astrophysics	250 (20.851)	5645	22.58	1.471	1.932	0.612	France
Astrophysical Journal	231(19.266)	4537	19.64	3.159	4.348	1.145	UK
Astrophysics and Space Science	62(5.171)	284	4.58	1.081	1.748	1.056	Netherlands
Journal of Astrophysics and Astronomy	53(4.420)	236	4.45	0.477	0.541	0.224	India
Astronomical Journal	42(3.503)	931	22.17	2.795	3.282	1.092	UK
Physical Review D	34(2.836)	1123	33.03	1.899	3.192	1.136	USA
Astrophysical Journal Letters	25(2.085)	189	7.56	3.914	4.852	1.487	UK
Journal of Cosmology and Astroparticle Physics	19(1.585)	127	6.68	0.615	2.374	0.465	UK
New Astronomy	18(1.501)	129	7.17	1.074	1.332	0.726	Netherlands
IAU Symposia	16(1.334)	3	0.19	-	-	-	Puerto Rico
Bulletin of the Astronomical Society of India	15(1.251)	35	2.33	1.091	1.068	0.516	India
Astrophysical Journal Supplement Series	2(1.001)	2464	205.33	6.857	9.687	3.125	USA
Research in Astronomy and Astrophysics	8(0.667)	22	2.75	0.953	1.331	0.768	UK
International Journal of Modern Physics D	7(0.584)	41	5.86	0.733	1.021	0.540	Singapore
Publications of the Astronomical Society of Japan	6(0.500)	50	8.33	1.521	1.626	0.750	Japan
Classical and Quantum Gravity	6(0.500)	185	30.83	1.476	2.192	0.966	UK
Astronomy Astrophysics Supplement Series	6(0.50)	63	10.50	-	-	-	France
Astronomische Nachrichten	6(0.500)	10	1.67	0.775	1.042	0.576	Germany
Publications of the Astronomical Society of the Pacific	5(0.417)	132	26.40	2.990	3.147	1.266	USA

TP= *Total no. of 'The Galaxy' research related articles published by a Journal;* ***TC*** *= Total no. of citation received;* ***AvgCPA***= *Average no. of citations that 'The Galaxy' related articles in a journal received;* ***h-index***= *no. of h papers among a journal's no. of publications that have at least h citations each.* ***SJR*** *= SCImago Journal Rank;* ***IPP*** *= Impact per Publication;* ***SNIP*** *= Source Normalized Impact per Paper;* ***Source: WoS and SCOPUS***

Table 4.3.k(v) also shows the citation impact of top 20 journals. The AvgCPA and h-index are used to identify which journals have the largest number of high quality articles in the 'The Galaxy' research. It is seen from the Table 4.3.k(v) that the journal 'Astrophysical Journal Supplement Series' published by IOP Publishing for the American Astronomical Society in USA has the highest average impact (AvgCPA = 205.33) although the journal 'Monthly Notices of the Royal Astronomical Society' has the highest number of publications but ranked 7th in the AvgCPA index.

G. Top Authors and their research impact

A total of 1199 articles included the author addresses having India as the county of affilation. Articles on 'The Galaxy' research have been contributed by 5617 authors. Table 4.3.k(vi) showed the top 20 productive authors during the last 54 years, 1960-2014. Top 20 productive authors were ranked based on the decreasing productivity of total publications. Chengalur, J. N. produced maximum number of publications 63 i.e. 5.254 % of total publications with ranked 1st followed by Saikia, D. J., Srianand, R., Jog, C. J. and Dwarakanath, K. S. ranked at 2nd , 3rd , 4th and 5th respectively.

Table 4.3.k(vi) reveals the impact of research in terms of quality of papers. The AvgCPA and h-index are used to identify which author has the largest number of high quality articles in the 'The Galaxy' research. It is seen from the Table 4.3.k(vi) that 'The Galaxy' research related articles authored by Petitjean, P. have the highest average impact (AvgCPA = 54.94) followed by Ledoux, C. (AvgCPA = 53.27) although having the maximum number of publications but Chengalur, J. N. ranked 13th in the AvgCPA index.

Table 4.3.k(vi): Top Authors of 'The Galaxy' research and their research impact, 1960-2014

Author	TP (%)	TC	TC woSC	CI	CIwoSC	AvgCPA	h-index
Chengalur, J.N.	63(5.254)	1036	900	667	617	16.44	20
Saikia, D.J.	57(4.754)	790	704	575	541	13.86	17
Srianand, R.	49(4.087)	1490	1349	792	753	30.41	23
Jog, C.J.	43(3.586)	1093	967	777	742	25.42	17
Dwarakanath, K.S.	34(2.836)	311	300	289	281	9.15	9
Petitjean, P.	31(2.585)	1703	1600	1041	1016	54.94	22
Sagar, R.	30(2.502)	519	500	466	453	17.30	13
Mitra, S.	27(2.252)	755	671	436	421	27.96	15
Bharadwaj, S.	27(2.252)	443	388	316	296	16.41	13
Anantharamaiah, K.R.	27(2.252)	446	400	338	320	16.52	13
Begum, A.	25(2.085)	485	419	323	302	19.40	14
Singh, K.P.	24(2.002)	162	150	142	132	6.75	8
Nath, B.B.	23(1.918)	305	272	247	235	13.26	11
Mazzotta, P.	23(1.918)	581	495	277	261	25.26	14
Kanekar, N.	23(1.918)	435	394	283	267	18.91	13
Ensslin, T.A.	23(1.918)	719	636	401	387	31.26	14
Subramaniam, A.	22(1.835)	259	252	247	240	11.77	10
Ledoux, C.	22(1.835)	1172	1071	515	494	53.27	18
Goss, W.M.	22(1.835)	418	384	340	327	19.00	12
Ganesh, S.	22(1.835)	431	376	287	270	19.59	13

TP: *Total no. of 'The Galaxy' related articles published by a author;* ***TC:*** *Total no. of citation****; TC woSc:*** *Sum of Times Cited without self-citations****; CI:*** *Citing Articles****; CIwoSC:*** *Citing Articles without self-citations****; AvgCPA:*** *Average Citations per Article****; h-index:*** *no. of h papers among a author's no. of publications that have at least h citations each.* ***Source: WoS***

H. Collaboration Pattern: Continents

Based on the author attributions, world-wide collaboration of 'The Galaxy' research publications can be mapped. As shown in Figure 4.3.k(v), the major spatial clusters of research institutes are located in Asia, followed by Europe, Africa, South America and North America. Several minor clusters are distributed in other parts of the world.

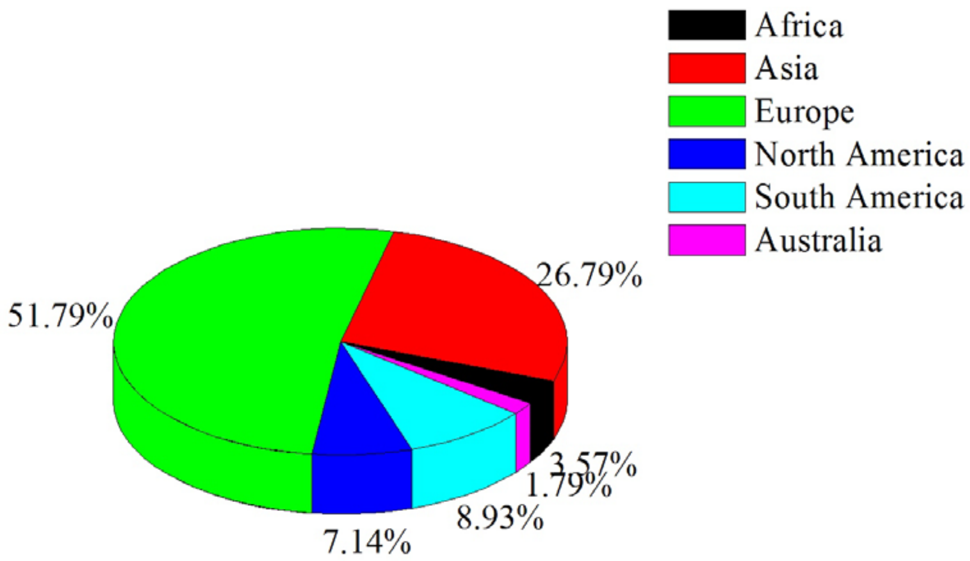

Figure 4.3.k(v): Continent wise Collaboration pattern of 'The Galaxy' research

I. Collaboration Pattern and research impact: Countries

Table 4.3.k(vii): Country wise Collaboration Pattern and research impact of 'The Galaxy' research

Country	Continent	TP (%)	TC	AvgCPA	h-index
USA	North America	421(35.113)	11613	27.58	49
France	Europe	192(16.013)	6040	31.46	44
Germany	Europe	188(15.680)	6990	37.18	41
England	Europe	168(14.012)	6546	38.96	38
Italy	Europe	123(10.259)	3804	30.93	36
Australia	Australia	106(8.841)	4404	41.55	26
Netherlands	Europe	101(8.424)	4319	42.76	33
Chile	South America	89(7.423)	4585	51.52	32
Spain	Europe	88(7.339)	4663	52.99	31
Canada	North America	75(6.255)	4200	56.00	27
Russia	Europe	68(5.671)	1699	24.99	25
Japan	Asia	58(4.837)	3984	68.69	24
Denmark	Europe	47(3.920)	1356	28.85	21
Poland	Europe	40(3.336)	2822	70.55	19
Taiwan	Asia	38(3.169)	1043	27.45	15
South Africa	Africa	36(3.003)	2899	80.53	19
Wales	Europe	34(2.836)	1239	36.44	20
Switzerland	Europe	33(2.752)	2750	83.33	17
Brazil	South America	31(2.585)	889	28.68	12
Sweden	Europe	30(2.502)	866	28.87	19

TP*= Total no. of 'The Galaxy' related articles published by a country;* ***TC*** *= Total no. of citation received;* ***AvgCPA****= Average no. of citations per Article;* ***h-index****= no. of h papers among a country's no. of publications that have at least h citations each.* ***Source: WoS***

A total of 1199 articles included author address, source country and research institute. There are 56 collaborating Countries/territories which participated in collaborative research work with Indian institutions in ‘The Galaxy’ research. Top 20 countries / territories are ranked based on the number of total articles, along with the citations and percentage of international collaborations (Table 4.3.k(vii)). Out of these 20 countries / territories, the USA has produced maximum publications i.e. 421 which is 35.113% of the total publications with high citations (11613). It is seen from the below Table 4.3.k(vii) that ‘The Galaxy’ research related articles authored in South Africa (Africa) have the highest average impact (AvgCPA=80.53) followed by Poland (Europe) AvgCPA=70.55 although USA ranked 17th in the AgvCPA index.

J. Keyword Analysis

A total of 4748 different keywords, from 1960 to 2014 in the ‘The Galaxy’ have been identified. The no. of analysed publications during the study period was 1199. To obtain accurate results, the keywords were pre-processed by merging the singular and plural forms of the same terminology, and those keywords with the same meaning while using different expressions.A total 4276 unique Keywords are obtained. Among these unique keywords 1881 (43.98%) appear once or twice at the most. Table 4.3.k(viii) shows the most used keywords during the considered period.

J.1 Hotspots

An analysis of the keywords was undertaken to pick out the research hotsopts (Chapter 1, Section 1.8.5.A) that have attracted most research attention and to reveal the research tendencies in the fields of ‘The Galaxy’. The top 20 most frequently used keywords for the study period are listed in Table 4.3.k(viii). The five most frequently used keywords were 'Formation', 'Evolution', 'Structure', 'Dynamics' and 'Disk'.

Table 4.3.k(viii): Top most frequently used keywords in 'The Galaxy' research

Keywords	NO	%	R
Abundances	96	2.24	8
Associations	30	0.70	12
Bulge	29	0.67	13
Center	43	1.00	9
Disk	141	3.29	5
Dynamics	151	3.53	4
Evolution	266	6.22	1
Formation	251	5.86	2
Fundamental parameters	33	0.77	11
Halo	127	2.97	7
Kinematics	136	3.18	6
Nucleus	17	0.39	15
Open clusters	35	0.81	10
Stellar content	27	0.63	14
Structure	233	5.44	3

NO: Number of time occurrences; R : rank Source: WoS

J.2 Quick Rising Themes

Table 4.3.k(ix): Top Quick rising themes in 'The Galaxy' research

Keyword	V (t_0)	V (t_n)	t_0	t_n	CAGR (%)	R
Abundances	1	11	1991	2014	0.109	3
Associations	1	2	1997	2014	0.041	11
Bulge	2	2	1999	2014	0.000	13
Disk	2	14	1991	2014	0.088	6
Dynamics	1	13	1991	2014	0.118	2
Evolution	4	22	1991	2014	0.076	7
Formation	3	30	1991	2014	0.105	4
Fundamental parameters	1	4	1992	2014	0.065	9
Globular clusters	1	1	1993	2014	0.000	13
Halo	1	17	1991	2014	0.131	1
Kinematics	2	10	1992	2014	0.075	8
Nucleus	1	2	1993	2013	0.033	12
Open clusters	1	3	1991	2014	0.048	10
Stellar content	1	3	1991	2014	0.048	10
Structure	3	23	1991	2014	0.092	5

t_0: ***t_0***: *the Initial (first) year (The Year in which no. of keywords occurrence first time;* ***t_n***: *the last year (No. of keywords occurrence);* ***V(t_0)***: *Initial observed value (no. of keywords occurrence);* ***V(t_n)***: *last observed value (no. of keywords occurrence);* ***CAGR:*** *Compound Annual Growth Rate;* ***R:*** *Rank.* ***Source: WoS***

The Compound Annual Growth Rate (CAGR) described in Chapter 1, Section 1.8.5.B, can be used to select quick rising themes of 'The Galaxy' research; this reveals the indicators of future research directions. Table 4.3.k(ix) lists the top 20 keywords according to the CAGR and sorts them by their rank. The ranks in Table 4.3.k(ix) show that 'Halo', 'Dynamics' and 'Abundances' are three leading hot issues that continue to attract broad attention. 'Dynamics' kept its dominance in terms of total quantity and CAGR.

K. Summary

A total of 1199 literature were published on 'The Galaxy', which received total 22030 citations. The average number of publications per year was 27.88 and the average number of citations per publication was 18.37. Publications on 'The Galaxy' appeared in 51 journals of which most active journal was 'Monthly Notices of the Royal Astronomical Society' published by Oxford University Press on behalf of the Royal Astronomical Society originating from United Kingdom and 345 (28.774%) of the total 1199 publications. A total of 5617 authors contributed on 'The Galaxy' research. The most active author was Chengalur, J.N. produced maximum number of publications i.e. 63 of total publications. 1035 institutions contributed of which Tata Institute of Fundamental Research; Mumbai is the most productive institution. For globalization of 'The Galaxy' research in India, the results show there were 56 Countries/territories which participated in 'The Galaxy' research. USA produced maximum publications 421 that is 35.113 % of total publication with higher citations (11613). A Keyword analysis reveals that Formation, Evolution, Structure, Dynamics and Disk are the most used keywords.

4.3.11 The Sun (Solar Physics)

The study of the Sun, or 'The Sun' is an important area of Astronomy and Astrophysics in India that grew out of an already well established tradition of astronomical observations. 'The Sun' plays a unique role in astronomy which is a major part of space science. It is the field in classical astronomy that claims significant societal relevance, extending from the obvious direct influence of the solar luminosity on planetary habitability, to the more subtle impacts of Space Weather on human civilization and commerce. 'The Sun' also is unique in contemporary stellar astronomy in having a next-door view of it's (albeit singular) subject, even to the extent of directly capturing particulate matter in the extreme outer limits of the solar atmosphere i.e., the coronal wind (Ayres and Longcope, 2012).

There were 2066 articles that met the selection criteria which appeared in the WoS database during 1960-2014 and these were analyzed.

A. Publication Characteristics

Table 4.3.l(i): Bibliographic Records of 'The Sun' research in India during 1960-2014

Bibliometric Indicators `	No.
Total Number of Articles	2066
Total Number of Contributing Countries	65
Total Number of Contributing Authors	4487
Total Number of Contributing Institutions	1109
Total Number of Journals appeared	91
Total Number of Keywords (raw) appeared	5666

Source: WoS

A total of 2066 articles of Indian scientists during 1960-2014 were abstracted from WoS related to ‘The Sun’ publications. From Table 4.3.l(i) and Table 4.3.l(ii), the output of 2066 paper received a total of 22254 citations during the said period with an average of about 10.77 citations per paper. The average number of publications per year is 48.04 and CAGR is 0.09%.

Table 4.3.l(ii): Citation Metrics of ‘The Sun’ research in India during 1960-2014

Citation-based Indicators	No.
Sum of the Times Cited	22254
Sum of Times Cited without self-citations	18385
Citing Articles	13658
Citing Articles without self-citations	12389
Average Citations per Item	10.77
h-index	59

Source: Web of Science (WoS)

B. Publication Pattern

Publication pattern of ‘The Sun’ research from 1960 to 2014 is presented in Figure 4.3.l(i). The initial publication in the sub-field ‘The Sun’ research is observed in the year 1972. A near about one fifty times increase is observed over the study period, (from 3 in 1972 to 168 in 2014). The highest number of papers is published in the year 2014, with 168 publications and the lowest in 1979 with 1 publication.

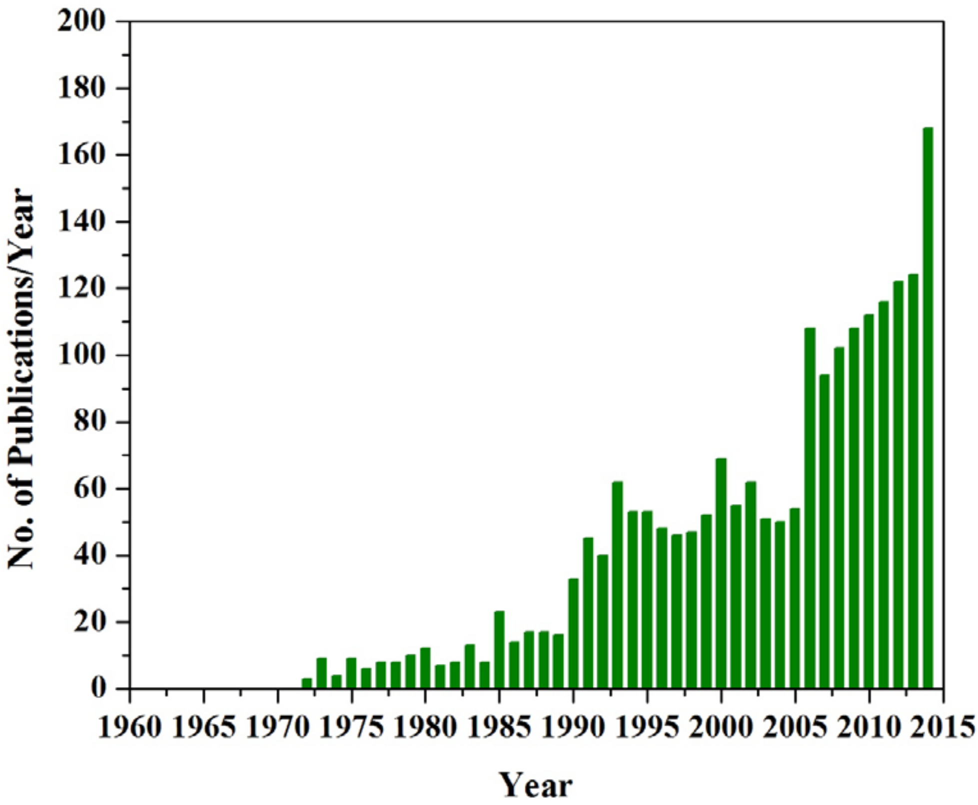

Figure 4.3.l(i): Publication Pattern of 'The Sun' research in India during 1960-2014. From the period 1960-1971, no publication appeared in the WoS database.

C. Growth Trend

The cumulative progression is represented by a 4th degree power law distribution during 1960-2014 giving an idea of the polynomial growth curve as shown in Figure 4.3.l(ii). To choose the best fit growth model, various regression types with regression coefficient has been tested as shown in Table 4.3.l(iii). The best fit model is 4th degree polynomial curve, where $R^2 = 0.941$. The polynomial best fit for 'The Sun' research is found to be: $y = 0.0003x^4 - 2.1734x^3 + 6490.4x^2 - 9E+06x + 4E+09$, where y is the cumulative number of publications and x is the number of years. The growth of literature shown in Figure 4.3.l(ii) can be divided into two parts, in the 1st part (1960-1971), no literature is published by Indian scientists and in 2nd part (1972-2014), growth trend follows a polynomial growth curve.

Table 4.3.l(iii): Different Regression Types with Regression coefficient (R^2) of 'The Sun' research

Regression Types	Equation	(R^2)
Exponential	$y = 4E\text{-}71e^{0.0831x}$	0.917
Linear	$y = 3.058x – 6048$	0.843
Logarithmic	$y = 6091\ln(x) – 46228$	0.842
Polynomial	$y = 0.0003x^4 - 2.1734x^3 + 6490.4x^2 - 9E{+}06x + 4E{+}09$	0.941
Power	$y = 0x165.6$	0.918

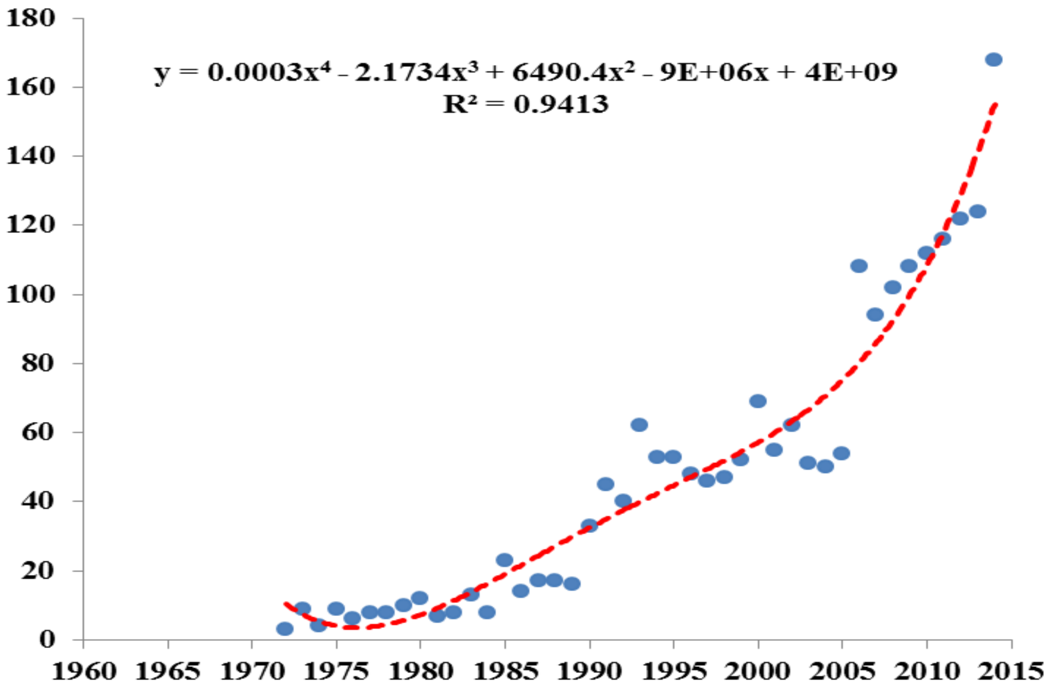

Figure 4.3.l(ii): Growth Trend of 'The Sun' research in India during 1960-2014. Blue dot describes the distribution of publications (observed value) and red dashed line describes the correlation of distribution of publications where regression coefficient R^2 = 0.941.

D. Citation Pattern

Figures 4.3.l(iii) and 4.3.l(iv) represent the citation pattern and number of citations vs. number of publications per year of 'The Sun' research in India during 1960-2014. A total of 2066 research papers have received 22254 citations. The pattern of citations is very fluctuating. In the initial year 1973, the total number of citations received is 6 with an average citation of 2 and which is the minimum citation received during the said period. The maximum citations received in the year 2009 are 1546 with an average citation of 14.31. It has been observed from Figure 4.3.l(iv) that after the year 2009, citations decrease while publications continue to increase.

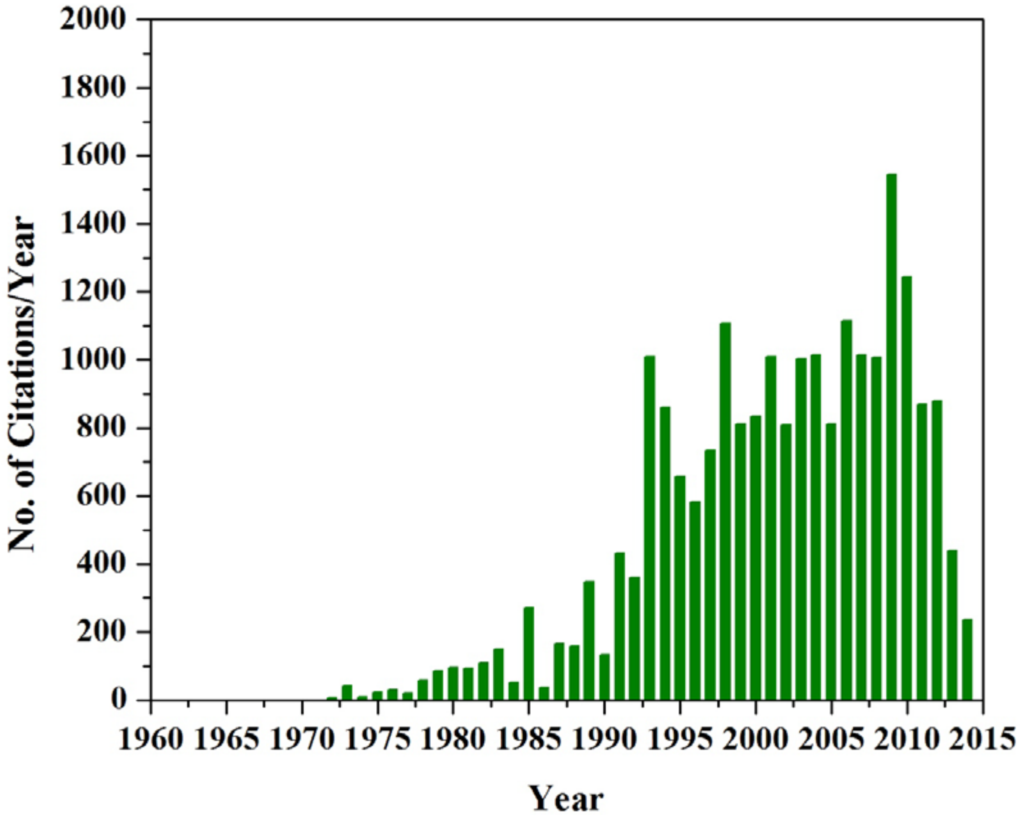

Figure 4.3.l(iii): Citation Pattern of 'The Sun' research in India during 1960-2014. From 1960-1971, no citation received as no publication appeared in the WoS database.

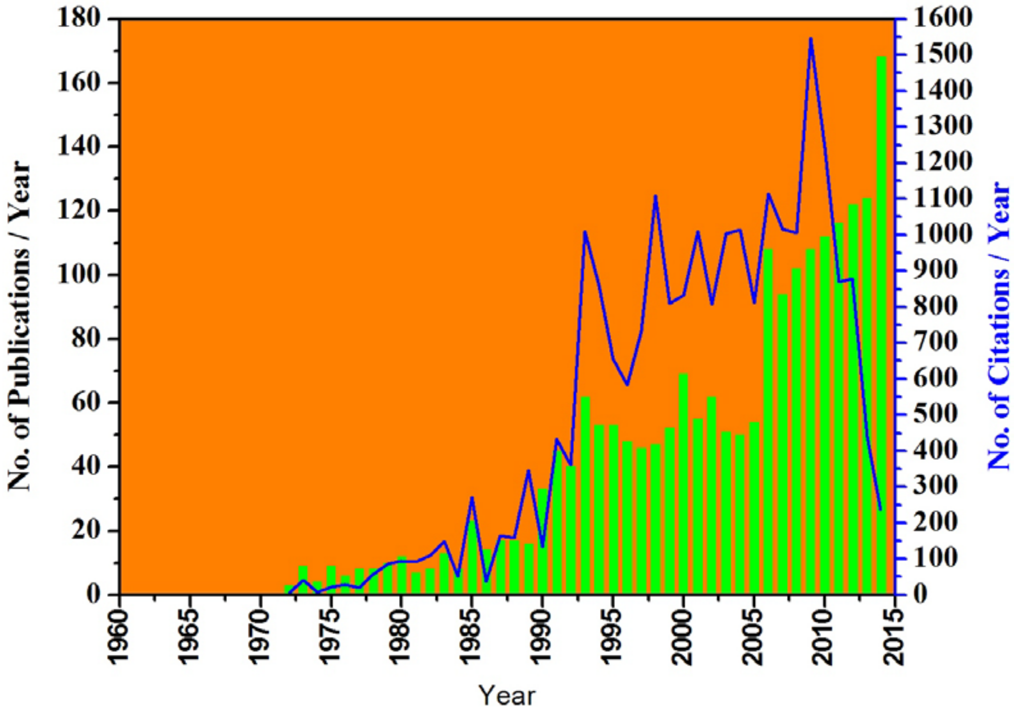

Figure 4.3.l(iv): Citation Pattern Vs Publication Pattern of 'The Sun' research in India during 1960-2014: Blue line (right Y axis) indicates the citation pattern against green bar (left Y axis) that describes the publications pattern.

E. Top Institutions and their research impact

Articles on 'The Sun' appeared from 1109 institutions. Table 4.3.104 shows the top 20 productive institutions during the last 54 years, 1960-2014. Indian Institute of Astrophysics (IIA), Bangalore is the most productive institution with 549 papers, followed by the Physical Research Laboratory (PRL), Ahmadabad with 253 papers and Tata Institute of Fundamental Research, Mumbai with 225 papers. Vikram Sarabhai Space Center (VSSC), Kerala had published 58 papers. Aryabhatta Research Institute of Observational Sciences, Nainital has 110 papers; Indian Institute of Science (IISc) Banglore and Indian Institute of Geomagnetism have published 75 and 87 papers respectively. Banaras Hindu University Uttar Pradesh, Inter University Centre for Astronomy Astrophysics and University of Delhi had published papers 88, 73 and 46 respectively. 56 (2.71%) papers have been published by the National

Physics Laboratory. Among the top 20, 8 are foreign institutions namely National Aeronautics Space Administration, USA with 108 papers; Max Planck Society, Germany with 87 papers; Centre National De La Recherche Scientifique (CNRS), France with 76; Goddard Space Flight Center with 67; Observatoire De Paris, USA with 50 ; University of California System, USA with 47 ; Harvard University, USA with 41 and Russian Academy of Sciences, Russia, 40 publications eachs.

Table 4.3.l(iv): Top institutions on 'The Sun' research and their research impact, 1960- 2014

Institution	Region	TP (%)	TC	AvgCPA	h-index
Indian Institute of Astrophysics	India	549(26.573)	5760	10.49	35
Physical Research Laboratory	India	253(12.246)	2291	9.06	21
Tata Institute of Fundamental Research	India	225(10.891)	4537	20.16	38
Aryabhatta Research Institute of Observational Sciences	India	110(5.324)	1115	10.14	16
National Aeronautics Space Administration (NASA)	USA	108(5.227)	2632	24.37	32
Banaras Hindu University	India	88(4.259)	1034	11.75	13
Max Planck Society	Germany	87(4.211)	1848	21.24	24
Indian Institute of Geomagnetism	India	87(4.211)	696	8.00	14
Centre National De La Recherche Scientifique (CNRS)	France	76(3.679)	2318	30.50	28
Indian Institute of Science (IISc)	India	75(3.630)	1805	24.07	25
Inter University Centre for Astronomy Astrophysics	India	73(3.533)	1356	18.58	22
Goddard Space Flight Center	USA	67(3.243)	1603	23.93	22
Indian Institute of Technology IITs	India	62(3.001)	504	8.13	13
Vikram Sarabhai Space Center (VSSC)	India	58(2.807)	598	10.31	13
National Physics Laboratory	India	56(2.711)	279	4.98	10
Observatoire De Paris	USA	50(2.420)	1504	30.08	25
University of California System	USA	47(2.275)	1230	26.17	22
University of Delhi	India	46(2.227)	205	4.46	7
Harvard University	USA	41(1.985)	787	19.20	17
Russian Academy of Sciences	Russia	40(1.936)	716	17.90	16

TP*= Total no. of 'The Sun' related articles published by an institution;* ***TC*** *= Total no. of citation received;* ***AvgCPA****= Average no. of citations per article; h-****index****=defined by the no. of h papers among an institution's no. of publications that have at least h citations each.* ***Source: WoS***

Table 4.3.l(iv) reveals the impact of research in terms of quality of papers. The AvgCPA and the h-index are used to identify which institution has the largest number of high quality articles in the 'The Sun' research. It is seen from the Table 4.3.l(iv) that 'The Sun' related articles authored in foreign organization (Centre National De La Recherche Scientifique CNRS) have the highest average impact (AvCPA = 30.50)

although Indian institution i,e Indian Institute of Science IISc Banglore ranked 5th in the AgvCPA index.

F. Top Journals and their research impact

'The Sun' papers have appeared in 91 journals. Papers have appeared in highest number in the journal 'Solar Physics' originating from Netherlands published by Springer.

Table 4.3.l(v): Top Journals on 'The Sun' research and their research impact, 1960-2014

Journal	TP (%)	TC	AvgCPA	Journal Metrics (2013) SJR	IPP	SNIP	Country
Solar Physics	460(22.265)	4828	10.50	2.256	3.184	1.769	Netherlands
Astrophysical Journal	273(13.214)	5419	19.85	3.159	4.348	1.145	UK
Astronomy Astrophysics	203(9.826)	1811	12.58	1.471	1.932	0.612	France
Journal of Geophysical Research Space Physics	144(6.970)	383	12.85	2.376	3.286	1.412	USA
Astrophysics and Space Science	135(6.534)	383	2.84	1.081	1.748	1.056	Netherlands
Journal of Astrophysics and Astronomy	117(5.663)	326	2.97	0.477	0.541	0.224	India
Advances in Space Research	116(5.615)	353	3.04	0.751	1.416	1.291	Netherlands
Monthly Notices of the Royal Astronomical Society	109(5.276)	2016	18.50	3.196	4.911	1.494	USA
Indian Journal of Radio Space Physics	57(2.759)	71	1.25	0.347	0.514	0.621	India
Annales Geophysicae	57(2.759)	563	9.88	1.176	1.533	1.533	Germany
Planetary and Space Science	37(1.791)	276	7.46	0.925	1.560	0.800	Netherlands
IAU Symposia	35(1.694)	4	0.11	-	-	-	Puerto Rico
Physical Review D	34(1.646)	616	18.12	1.899	3.192	1.136	USA
Astrophysical Journal Letters	31(1.500)	410	13.23	3.914	4.852	1.487	USA
New Astronomy	27(1.307)	209	7.7	1.074	1.332	0.726	Netherlands
Bulletin of the Astronomical Society of India	27(1.307)	55	2.04	1.091	1.068	0.516	India
Annales Geophysicae Atmospheres Hydrospheres and Space Sciences	22(1.065)	159	7.23	-	-	-	Germany
Earth Moon and Planets	18(0.871)	40	2.22	0.303	0.532	0.399	Netherlands
Research in Astronomy and Astrophysics	15(0.726)	81	5.40	0.953	1.331	0.768	UK
Astroparticle Physics	14(0.678)	70	5	3.012	3.828	2.776	Netherlands

TP**= Total no. of 'The Sun' research related articles published by a Journal; **TC** = Total no. of citation received; **AvgCPA**= Average no. of citations that 'The Sun' related articles in a journal received; **h-index**= no. of h papers among a journal's no. of publications that have at least h citations each. **SJR** = SCImago Journal Rank; **IPP** = Impact per Publication; **SNIP** = Source Normalized Impact per Paper; **Source: WoS and SCOPUS

Table 4.3.l(v) shows the top 20 productive journals. These 20 out of the 91 journals have published 1931 (93.46%) of the total 2066 articles. The journal 'Solar Physics' ranked first with 460 (22.26%); 'Astrophysical Journal 273 (13.21%)',

‘Astronomy Astrophysics 203 (9.82%)’, ‘Journal of Geophysical Research Space Physics 144 (6.97%)’ and ‘Astrophysics and Space Science 135 (6.53%)’ ranked at 2nd , 3rd , 4th and 5th respectively.

Table 4.3.l(v) also shows the citation impact of top 20 journals. The AvCPA and h-index are used to identify which journals have the largest number of high quality articles in the ‘The Sun’ research. It is seen from the Table 4.3.l(v) that the journal ‘Astrophysical Journal’ published by IOP Publishing for the American Astronomical Society in USA has the highest average impact (AvgCPA = 19.85), it is seen that though the journal ‘Solar Physics’ has the highest number of publications but ranked 5th in the AvgCPA index.

G. Top Authors and impact of their research output

A total of 2066 articles included the author addresses having India as the county of affilation. Articles on ‘The Sun’ have been contributed by 4478 authors. Table 4.3.l(vi) showed the top 20 productive authors during the last 54 years, 1960-2014. Top 20 productive authors were ranked based on the decreasing productivity of total publications. Anita, H.M. produced maximum number of publications i.e. 82 and ranked 1st followed by Dwivedi, B. N., Venkatakrishnan, P., Singh, J., Srivastava, A. K. and Basu, S.who ranked 2nd , 3rd , 4th , 5th and 6th respectively.

Table 4.3.l(vi) also reveals the impact of research in terms of quality of papers. The AvgCPA and h-index are used to identify which author has the largest number of high quality articles in the ‘The Sun’ research. It is seen from the Table 4.3.l(vi) that ‘The Sun’ related articles authored by Basu, S. have the highest average impact (AvCPA = 44.73) followed by Choudhuri, A. R. (AvgCPA = 35.53) it is seen that despite of having the maximum number of publications, Antia, H. M. ranked 3rd in the AgvCPA index.

Table 4.3.l(vi): Top Authors of 'The Sun' research and their research impact, 1960-2014

Author	TP (%)	TC	TC woSC	CI	CIwoSC	AvgCPA	h-index
Antia, H.M.	82(3.969)	2551	2276	1415	1343	31.11	30
Dwivedi, B.N.	63(3.049)	880	812	714	677	13.97	13
Venkatakrishnan, P.	62(3.001)	463	388	354	318	7.47	13
Singh, J.	61(2.953)	538	411	337	291	8.82	13
Srivastava, A.K.	51(2.469)	402	274	249	213	7.88	12
Basu, S.	45(2.178)	2013	1877	1179	1141	44.73	28
Ramesh, R.	44(2.130)	332	160	155	118	7.55	10
Manoharan, P.K.	43(2.081)	912	827	663	633	20.73	18
Krishan, V.	41(1.985)	310	253	246	222	7.56	11
Choudhuri , A.R.	40(1.936)	1421	1200	758	723	35.53	22
Hasan, S.S.	39(1.888)	473	422	326	302	12.13	12
Nagendra, K.N.	37(1.791)	261	123	92	59	7.05	10
Lakhina , G.S.	37(1.791)	432	408	368	355	11.68	12
Jain, R.	37(1.791)	207	162	166	142	5.59	8
Banerjee, D.	37(1.791)	525	468	374	353	14.19	13
Chitre, S.M.	34(1.646)	540	497	422	398	15.88	13
Shanmugaraju, A.	33(1.597)	239	176	153	129	7.24	9
Uddin, W.	32(1.549)	347	297	261	238	10.84	11
Sivaraman, K.R.	31(1.500)	582	533	416	393	17.12	15
Srivastava, N.	30(1.452)	353	316	272	258	11.77	10

TP:** Total no. of 'The Sun' related articles published by a author; **TC:** Total no. of citation**; TC woSc:** Sum of Times Cited without self-citations**; CI:** Citing Articles**; CIwoSC:** Citing Articles without self-citations**; AvgCPA:** Average Citations per Article**; h-index:** no. of h papers among a author's no. of publications that have at least h citations each. **Source: WoS

H. Collaboration Pattern: Continents

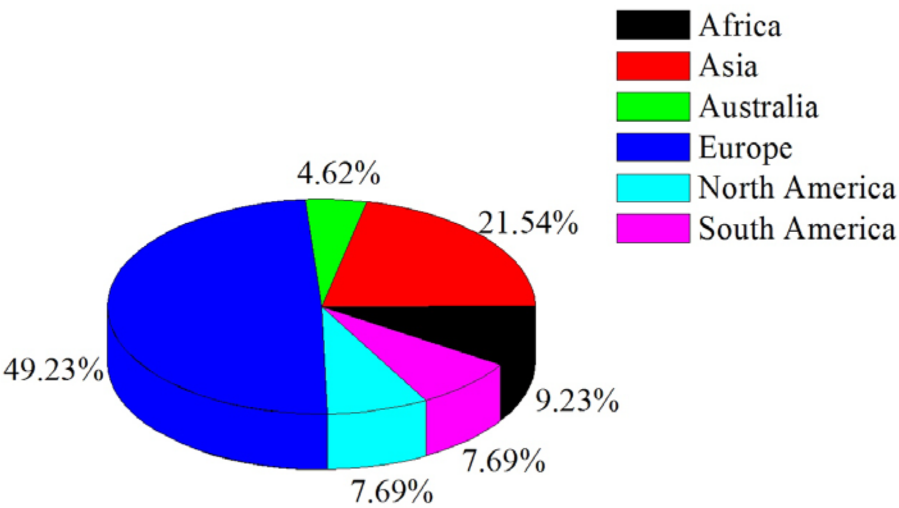

Figure 4.3.l(v): Continent wise Collaboration pattern of 'The Sun' research

Based on the author attributions, world-wide collaboration of 'The Sun' research publications has been mapped. As shown in Figure 4.3.l(v), the major spatial clusters of research institutes are located in Europe followed by Asia, Africa and South and North America. Minor clusters are distributed in Australia.

I. Collaboration Pattern and research impact: Countries

A total of 2066 articles included author address, source country and research institute. There are 65 Countries/territories which participated in 'The Sun' research.

Table 4.3.l(vii): Country wise Collaboration Pattern and research impact of 'The Sun' research

Country	Continent	TP(%)	TC	AvCPA	h-index
USA	North America	420(20.329)	8711	20.74	49
Germany	Europe	137(6.631)	2708	19.77	30
Japan	Asia	103(4.985)	1186	11.51	18
England	Europe	102(4.937)	2611	25.60	32
France	Europe	100(4.840)	2959	29.59	32
South Korea	Asia	57(2.759)	560	9.82	16
Russia	Europe	47(2.275)	669	14.23	16
Spain	Europe	44(2.130)	1116	25.36	19
Switzerland	Europe	43(2.081)	546	12.70	14
North Ireland	Europe	43(2.081)	546	12.70	13
Italy	Europe	42(2.033)	1096	26.10	19
Brazil	South America	42(2.033)	624	14.86	12
Belgium	Europe	31(1.500)	523	16.87	11
Peoples R China	Asia	30(1.452)	469	15.63	11
Australia	Australia	30(1.452)	863	28.77	15
Denmark	Europe	25(1.210)	1129	45.16	17
Austria	Europe	24(1.162)	552	23.00	13
Sweden	Europe	22(1.065)	495	22.50	9
Netherlands	Europe	22(1.065)	800	36.36	14
Canada	North America	22(1.065)	499	22.68	12

TP= *Total no. of 'The Sun' related articles published by a country;* ***TC*** = *Total no. of citation received;* ***AvgCPA***= *Average no. of citations per Article;* ***h-index***= *no. of h papers among a country's no. of publications that have at least h citations each.* ***Source: WoS***

As shown in the Table 4.3.l(vii), top 20 countries / territories are ranked based on the number of total articles, along with the citations and percentage of internationally collaboration publications. Out of these 20 countries / territories, The

USA produced maximum publications - 420 which is 20.32% of total publications with citations (8711). It is seen from the Table 4.3.l(vii) that ‘The Sun’ related articles authored in Denmark have the highest average impact (AvgCPA = 45.16) while USA ranked 10^{th} in the AvCPA index.

J. Keyword Analysis

A total of 5657 different keywords, from 1960 to 2014 in the ‘The Sun’ have been identified. The number of analysed publications during the study period was 2066. Of them only 1775 provides key words. While the rest (291) do not provide the mentioned information. To obtain accurate results, the keywords were pre-processed by merging the singular and plural forms of the same terminology, and those keywords with the same meaning while using different expressions (for example, ‘‘coronal mass ejections’’ ,‘‘Coronal mass ejection’’ “Coronal mass ejections (CMEs), “cme” and “CMEs””, ‘‘magnetic-field’’, ‘‘magnetic fields’’ and “Magnetic field”, ‘‘solar-flare’’ ‘‘Solar flare’’ and ‘‘Solar flares’’). A total 4808 unique Keywords are obtained. Among these unique keywords 3313 (68.91%) appear once or twice at the most. Table 4.3.l(viii) shows the most used keywords during the considered period.

J.1 Hotspots

An analysis of the keywords was undertaken to pick out the research hotspots (Chapter 1, Section 1.8.5.A) that have attracted most research attention and to reveal the research tendencies in the fields of ‘The Sun’. The top 20 most frequently used keywords for the study period are listed in Table 4.3.l(viii). The four most frequently used keywords were 'Corona', 'Flares', 'Magnetic Fields' and 'Coronal Mass Ejections'.

Table 4.3.l(viii): Top most frequently used keywords in 'The Sun' research

Keyword	NO	%	R
Corona	415	8.63	1
Flares	266	5.53	2
Magnetic Fields	260	5.40	3
Coronal Mass Ejections	245	5.09	4
Activity	245	5.09	5
Oscillation	237	4.92	6
Atmosphere	194	4.03	7
Sunspots	182	3.78	8
Evolution	149	3.09	9
Rotation	146	3.03	10
Solar Wind	92	1.91	11
Active region	85	1.76	12
Chromosphere	79	1.64	13
Interior	79	1.64	14
Filaments	73	1.51	15
Photosphere	67	1.39	16
Prominences	58	1.20	17
Abundances	52	1.08	18
Transition region	51	1.06	19
Radio radiation	49	1.01	20

NO: Number of time occurrences; R : rank; ***Source: WoS***

J.2 Quick Rising Theme

The Compound Annual Growth Rate (CAGR) described in Chapter 1, Section 1.8.5.B, can be used to select quick rising themes of 'The Sun' research; this reveals the indicators of future research directions. Table 4.3.l(ix) lists the top 20 keywords according to the CAGR and sorts them by their rank. The ranks in Table 4.3.l(ix) show that 'Coronal Mass Ejections' and 'Activity' and 'Flares' are three leading hot issues that continue to attract broad attention. 'Corronal Mass Ejections' kept its dominance in terms of total quantity and CAGR.

Table 4.3.l(ix): Top Quick rising themes in 'The Sun' research

Keyword	V (t_0)	V (t_n)	t_0	t_n	CAGR (%)	R
Abundances	3	3	1992	2014	0.000	20
Active region	1	7	1991	2014	0.088	12
Activity	1	29	1990	2014	0.150	2
Atmosphere	2	23	1992	2014	0.117	8
Chromosphere	2	7	1990	2014	0.053	18
Corona	3	55	1991	2014	0.134	5
Coronal Mass Ejections	2	39	1996	2014	0.179	1
Evolution	1	16	1991	2014	0.128	7
Filaments	2	10	1991	2014	0.072	13
Flares	1	27	1990	2014	0.147	3
Interior	1	6	1993	2014	0.089	11
Magnetic Fields	2	39	1991	2014	0.137	4
Oscillation	3	16	1990	2014	0.072	14
Photosphere	2	9	1990	2014	0.064	16
Prominences	1	10	1995	2014	0.128	6
Radio radiation	1	4	1991	2014	0.062	17
Rotation	1	8	1990	2014	0.090	10
Solar Wind	1	9	1994	2014	0.116	9
Sunspots	3	14	1991	2014	0.069	15
Transition region	1	3	1991	2014	0.048	19

t_0: *the Initial (first) year (The Year in which no. of keywords occurrence first time;* ***t_n***: *the last year (No. of keywords occurrence);* ***V(t_0)***: *Initial observed value (no. of keywords occurrence);* ***V(t_n)***: *last observed value (no. of keywords occurrence);* ***CAGR:*** *Compound Annual Growth Rate;* ***R:*** *Rank.*
Source: WoS

K. Summary: The Sun

A total of 2066 literature is published on 'The Sun', which received total 22254 citations. The average number of publications per year was 48.04 and the average number of citations per publication was 10.77. Articles on 'The Sun' appeared in 92 journals of which most active journal was 'Solar Physics' published by Elsevier from Netherland and 460 (22.26%) of the total 2066 articles. 1109 institutions contributed of which Indian Institute Astrophysics, Bangalore (549) is the most productive institution. For globalization of 'The Sun' Research in India, there were 65 Countries/territories which participated in collaborative research. The USA produced maximum publications, 420 of total publications with 8711 citations. A Keyword analysis reveals that Corona, Flares, Magnetic Fields, Coronal Mass Ejections, Activity, Oscillation, Atmosphere are the most used keywords.

4.4 Summary

This chapter commences with the data analysis and interpretation of 13 sub-fields of Space Science namely IMG, MAS, ACM, AIMT, Cosmology, Galaxies, ISM, PDP, PS, RUSFW, Stars, 'The Galaxy' and 'The Sun'. The data analysis and interpretation help to address the research questions. This chapter describes a brief description of the sub-fields of space science followed by characteristics of literature of each sub-field which appeared in the WoS database during 1960-2014 and these were analyzed. The specific characteristics of the publications such as number of publications, the number of authors involved in the production of these publication, institutions, journals etc were taken into consideration. Each sub-field of Space Science has been described by the bibliometric indicators like author, title, institution etc. and keyword analysis through Hotspots and Quick rising themes, with the help of suitable statistical Tables, Figures, illustrations, etc. It further discusses the performance indicators like h-index, AvgCPA and IPP.

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Chapter 5

MAPPING THE SPACE SCIENCE LITERATURE, 1960-2014

5.1 Introduction

The process of mapping literature through bibliometric analysis reflects the organisation and structure of the field, improves access to information and provides direction for future growth. Thus, the mapping of space science literature could help to identify the current trends in the field. Findings from Bibliometric and Scientometric methods are reported to be a valid and reliable method of mapping the development and structure of a scientific field (Fayland, 2008; Larsen&von Ins, 2010). This study measures and maps the changes in the corresponding sub-fields of Space Science research over the last 54 years. It presents a practical way to map scientific outputs and to depict how 13 sub-fields have evolved during 1960 to 2014 and how these results help address theresearch questions: Which growth trend is being followed? Has the growth trends changed over time?To describe the nature of research being published in Space Science, taxonomy has been developed. According to taxonomy all the publications arecategorised into one of the thirteen specialties or sub-fields or areas. A total of 32,2,47 of Space Sciencerelated research publicationshave been published in the last 54 years (Eck, 2011).

The following Scientometric and Bibliometric measures have been taken into account to map the growth of Space Science literature:

1. Distribution of publications among sub-fields of Space Science,
2. Citation received across the 13 sub-fields of Space Science which indicate maturity of the field,
3. Citation behavior among sub-fields fields of Space Science,
4. Descriptive statistics of publications and citations,

6. Publication pattern in five decades among 13 fields of Space Science,
7. Percentage growth in sub-fields of Space Scienceover 10 year's period,
8. Average annual growth rates among 13 fields of Space Science,
9. Growth trends of 13 sub-fields of Space Science (Bornmann&Mutz, n.d.).

5.2 Distribution of Publications

To begin with, the themes related to each of the Space Science research areas are described in order to provide a picture of the amount and types of research in Space Science are conducted. Next, the volume and relative proportions of 32,2,47 publications in each of the Space Science research sub-fieldsare examined. Finally, results are provided from an analysis of how these research topics and total Space Science research more generally have grown and evolved over the last 54 years. Figure 5.1 shows the distribution of 32,2,47 research publications across the 13 sub-fields of Space Science. The sub-field with the largest number of research publications is Physical Data and Processes (PDP) of 17.02%, followed by Meteorology and Atmospheric Science (MAS) with 15.55%, Astrometry and Celestial Mechanics (ACM) with 9.34% and Ionosphere, Magnetosphere and Geomagnetism (IMG) with 8.52%. Comparatively less research was published in the sub-field of Interstellar Medium (ISM) with 2.47%, Resolved Unresolved Source as a Function of Wavelength (RUSFW) 3.35%, The Galaxy 3.72%, and Galaxies 4.82%.

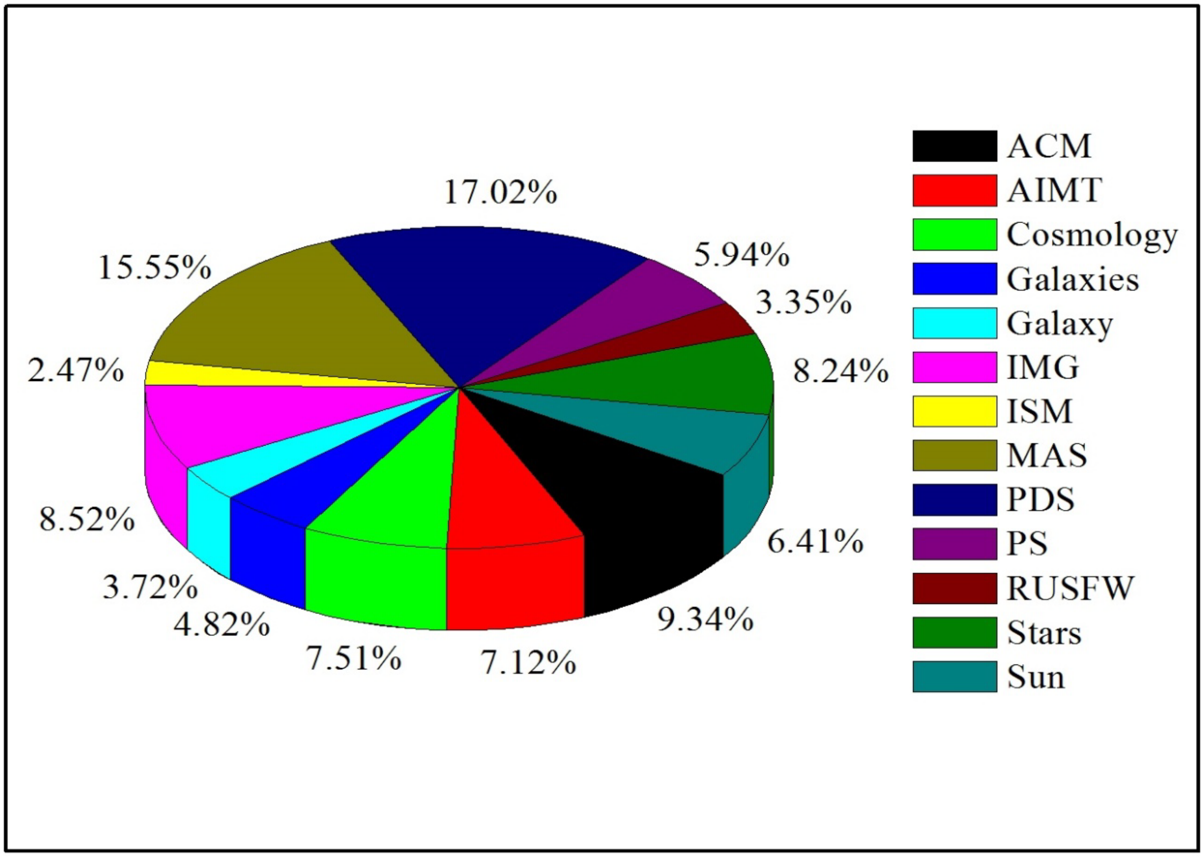

Figure 5.1: Distribution of Space Science research publications within the 13 sub-fields

***ACM**: Astrometry and Celestial Mechanics; **AIMT**: Astronomical Instrumentation, Methods and Techniques; **IMG**: Ionosphere, Magnetosphere and Geomagnetism; **ISM**: Interstellar Medium; **MAS**: Meteorology & Atmospheric Science; **PDS**: Physical Data and Processes; **PS**: Planetary Systems; **RUSFW**: Resolved and Unresolved Sources as a Function of Wavelength*

5.3 Distribution of Citations

Over the period from 1960-2014, sub-fields of Space Science have published 32,2,47 articles, that have been included in the WoS. During this period these articles received 4,24,546citations, and an average of 32657.38 citations per sub-field of Space Science. Citations have appeared in highest number in the sub-field ‘Physical Data and Processes’. Table 5.2 shows the citation behaviour of Space Science research publications within the 13 sub-fields. The 'PDP' ranks first with 74841 (24.85%); MAS with46282 (15.37%), Stars with44732 (14.85%), ACM with 42275 (14.04%) and Cosmology with 40944 (13.59%) ranks2nd, 3rd, 4thand 5threspectively.

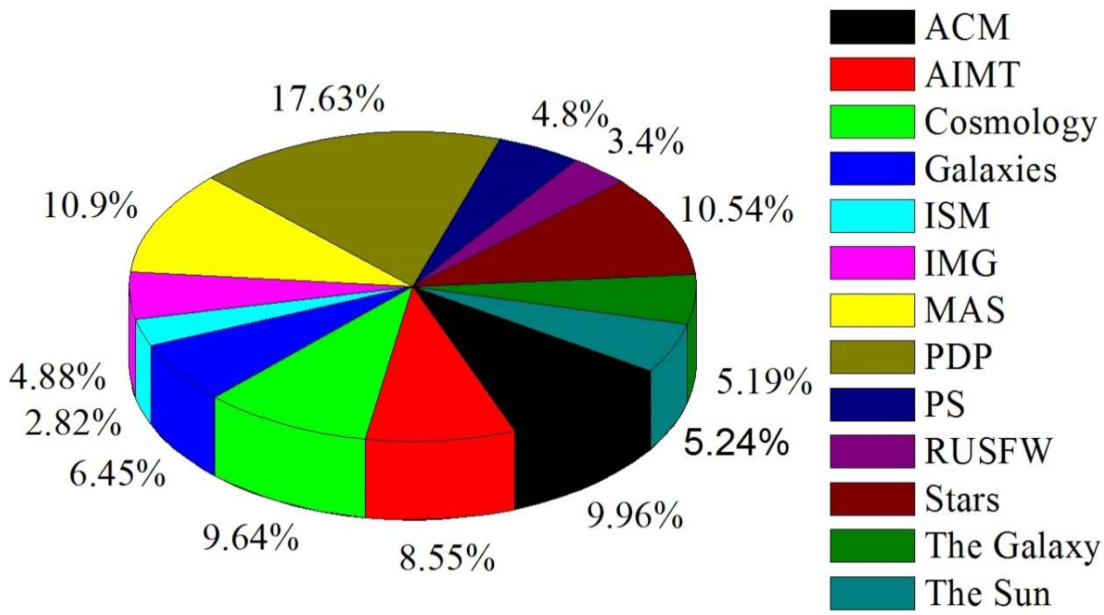

Figure 5.2: Citation behaviour of Space Science Research Publications within the 13 sub-fields

ACM*: Astrometry and Celestial Mechanics;* ***AIMT****: Astronomical Instrumentation, Methods and Techniques;* ***IMG****: Ionosphere, Magnetosphere and Geomagnetism;* ***ISM****: Interstellar Medium;* ***MAS****: Meteorology & Atmospheric Science;* ***PDS****: Physical Data and Processes;* ***PS****: Planetary Systems;* ***RUSFW****: Resolved and Unresolved Sources as a Function of Wavelength*

5.4 Citation Metrics

Citation count indicates the maturity of the field. Impact indicator or Citation indicator like AvgCPA, h-index, etc. are the rough indicator for measuring the impact of research field. The AvgCPA and the h-index are used to identify which sub-fields have the largest number of high quality articles in the Space Science research. It can be seen from the Table 5.1 that the PDP sub-field has received a 74841 of highest citations followed by MAS (46282), Stars (44732) and ACM (42275). The lowest citations appear in ISM i.e. 11952 preceded closely by RUSFW (14439) and the PS (20373) respectively. The other subfields lie in between these highest and lowest values i.e. IMG (20705), AIMT (36316), Cosmology (40944), Galaxies (27403), 'The Galaxy' (22030) and 'The Sun' (22254).

Table 5.1: Citation Metrics of 13 sub-fields of Space Science

Sub-field	TC	TCwoSC	CA	CAwoSC	AvgCPA	h-index
IMG	20705	14278	11098	9355	7.53	48
MAS	46282	35223	25536	22856	9.23	70
ACM	42275	38947	30217	28762	14.03	71
AIMT	36316	32426	23394	22114	15.82	75
Cosmology	40944	34945	22473	20912	16.9	74
Galaxies	27403	23707	16736	15686	17.63	62
ISM	11952	10373	7771	7289	15.00	47
PDP	74841	64403	44648	41291	13.64	91
PS	20373	18424	15769	14869	10.64	54
RUSFW	14439	12487	9988	9319	13.38	49
Stars	44732	39629	28800	27115	16.84	77
The Galaxy	22030	20246	15517	14824	18.37	61
The Sun	22254	18385	13658	12389	10.77	59

TC: *Total no. of citation**;** **TCwoSc:** Sum of Times Cited without self-citations**;** **CA:** Citing Articles **;CIwoSC:** Citing Articles without self-citations**;** **AvgCPA:** Average Citations per Article**; h-index :** no. of h papers among a author's no. of publications that have at least h citations each.* ***Source: WoS***

The Sum of Times Cited without self-citations (TCwoSc) appear in PDP (64403) is the highest value followed by ACM (38947) and lowest value appears in ISM (10373). 'The Galaxy' has the highest average impact (AvgCPA = 18.37) followed by Galaxies (AvgCPA = 17.63) and Cosmology (AvgCPA = 16.90) although the sub-field "PDP" has the highest number of citations but ranked 12th in the AgvCPA index. The sub-field 'PDP' has the highest h-index score (h-index = 91) followed by the sub-field Stars (h-index = 77) and ACM (h-index = 71). The minimum h-index score appears in the sub-field ISM (47).

5.5 Descriptive Statistics

The SPSS software is used to perform a descriptive statistics of productivity which will provide the detailed overview of the characteristics of the literature of each sub-fields of Space Science. It allows calculation of the maximum and minimum number of publications, the mean or the median and Interquartile Range (IQR) in each sub-field of Space Science (Jaric´andGessner, 2012).

5.5.1 Publication

The total number of publications across the 13 fields of Space Science publications is 32247, with a mean of 2480.53 publications. The highest minimum no. of publications is 9 in the field IMG followed by 3 in the sub-field-The Sun and 1 in PDP while rest of the fields have zero publications in the minimum citation column. The Table 5.2 shows MAS sub-field has received a maximum of 507 publications followed by PDP with 500, ACM with 285 and AIMT with 267. Among the lower ones, the maximum publications appear in ISM i.e. 77 precede very closely with RUSFW with 115 and the galaxy with 120 respectively. The other sub-fields lie in between these highest and lowest values.The highest and lowest mean values for publications appear in PDP (127.60) and ISM (18.53) respectively. The mean values for the sub-fields MAS, ACM , IMG, Stars, Cosmology and AIMT lie in between the higher mean values ranging from 116.62 to

53.39, whereas the other sub-fields like the Sun,PS, Galaxies, the Galaxy and RUSFW fall in the lower mean values ranges i.e. from 48.04 to 25.09.

Table 5.2: Descriptive Statistics of publication across 13 sub-fields of Space Science

Sub-Field	Min	Max	Mean	p25	p50	p75	IQR	Variance	Skewness	Kurtosis
IMG	9	152	63.90	34	50	79	45	1398.32	0.93	-0.16
MAS	0	507	116.62	35	66	108	73	19836.76	1.77	2.04
ACM	0	285	70.06	3	59	104.5	101.5	6096.59	1.10	0.37
AIMT	0	267	53.39	0.5	28	79	78.5	4721.10	1.44	1.45
Cosmology	0	235	56.34	5	37	85.5	80.5	4055.99	1.19	0.54
Galaxies	0	144	36.13	2.5	27	54	51.5	1569.26	1.23	0.99
ISM	0	77	18.53	0	12	29	29	498.20	1.13	0.21
PDP	1	500	127.60	26.5	118	170	143.5	15625.48	1.18	0.91
PS	0	223	44.51	6.5	26	50	43.5	2994.30	1.74	2.33
RUSFW	0	115	25.09	0	11	48	48	949.18	1.12	0.49
Stars	0	230	61.76	6.5	50	99	92.5	3851.84	1.01	0.34
The Galaxy	0	120	27.88	2	19	46.5	44.5	1022.91	1.24	0.89
The Sun	3	168	48.04	11	46	62	51	1748.66	0.97	0.24

***IMG**: Ionosphere, Magnetosphere and Geomagnetism; **MAS**: Meteorology & Atmospheric Science; **ACM**: Astrometry and Celestial Mechanics; **AIMT**: Astronomical Instrumentation, Methods and Techniques; **ISM**: Interstellar Medium; **PDS**: Physical Data and Processes; **PS**: Planetary Systems; **RUSFW**: Resolved and Unresolved Sources as a Function of Wavelength*

The 25th percentile of the publication distribution is denoted by ‘p25’. Similarly 50th percentile of the publication distribution is denoted by ‘p50’ or ‘median’and 75th percentile of the publication distribution is denoted by ‘p75’. Within the p25 range the maximum value appears for the sub-field MAS (35), followed by IMG (34) and PDP (26.5). The values in the lower range vary from 6.5 for PS, Stars to 0 in ISM. For Inter Quartile Range (IQR), ranging from p75 to p25, the highest median number (IQR) of publications is 118 (143.5) for PDP followed by 66 (73.00) for MAS and 59 (101.5) for ACM. The lowest value occurs for RUSFW 11 (48) preceded closely by ISM 12 (29).

5.5.2 Citation

Table 5.3: Descriptive statistics of citation across 13 sub-fields of Space Science

Sub-Field	Min	Max	Mean	p25	p50	p75	IQR	Variance	Skewness	Kurtosis
IMG	108	1322	481.51	223	431	637	414	94633.35	1.08	3.64
MAS	0	3248	1076..32	307	743	1963	1656	941264.30	0.74	2.40
ACM	0	4096	983.13	15	740	1798	1783	1212842.00	0.95	3.11
AIMT	0	3287	844.55	0	523	1734	1734	888282.40	0.73	2.33
Cosmology	0	5123	952.20	30	573	1862	1832	1357655.00	1.42	4.98
Galaxies	0	3342	637.27	17	546	1026	1009	575806.10	1.68	6.30
ISM	0	1145	277.95	0	240	484	484	92147.76	0.91	3.04
PDP	3	4526	1740.48	127	1689	3153	3026	2632173.00	0.29	1.53
PS	0	1703	473.79	39	334	813	774	245641.60	0.95	2.86
RUSFW	0	1136	335.79	0	212	666	666	130446.50	0.50	1.77
Stars	0	4347	1040.27	34	868	1679	1645	1264461.00	1.06	3.52
The Galaxy	0	2877	512.32	5	391	855	850	366432.30	1.62	6.48
The Sun	6	1546	517.53	432	92	878	786	193665.60	0.35	1.81

***IMG**: Ionosphere, Magnetosphere and Geomagnetism; **MAS**: Meteorology & Atmospheric Science; **ACM**: Astrometry and Celestial Mechanics; **AIMT**: Astronomical Instrumentation, Methods and Techniques; **ISM**: Interstellar Medium; **PDS**: Physical Data and Processes; **PS**: Planetary Systems; **RUSFW**: Resolved and Unresolved Sources as a Function of Wavelength*

The total number of citations across 13 sub-fields of Space Science publications is 4,24,546 with a mean of 32657.38 citations. The highest minimum number of citations is 108 in the field IMG followed by 6 in the sub-field –'the Sun' and 3 in PDP while rest of the sub-fields have no citations in the minimum citation column. The maximum citations column in the Table 5.3 shows Cosmology sub-field has received a 5123 of maximum citations followed by PDP (4526) and Stars (4347) and ACM (4096). The lowest maximumcitations appear in RUSFW i.e. 1136 preceded very closely by ISM (1145) and IMG (1322) respectively. The other sub-fields lie in between these highest and lowest values. The highest and lowest mean values for citations appear in PDP (1740.48) and ISM (277.95) respectively. The mean values for the sub-fields MAS, the Stars, ACM and Cosmology lie in between the higher mean values ranging from 1076.32 to 952.20, whereas the other sub-fieldslike AIMT, Galaxies, The Galaxy, The Sun fall in the lower mean values ranges i.e. from 844.55 to 512.32.

Within the p25 range, the maximum value appears for the sub-field 'The Sun' (432), followed by MAS (307) and IMG (223). The values in the lower range vary from 127 for PDP to 0 in ISM. For Inter Quartile Range (IQR), ranging from p75 to p25, the highest median number (IQR) of citations is 1689 (3026) for the sub-field PDP followed by 868 (1645) for Stars and 743 (1656) for MAS. The lowest value occurs for the sub-field, 'the Sun' 92 (786) preceded closely by RUSFW 212 (666).

5.6 Growth Pattern

5.6.1 Publication

Figure 5.3 shows the growth pattern of literature among 13 sub-fields of Space Science decade wise. To know the decade wise growth pattern, to assess the trends, the studied period was separated into five 10-years and one 4-year (2010-2014) distinct period. In the first 10-years period (1960-1969), no publication appeared in any of the sub-fields of Space Science.

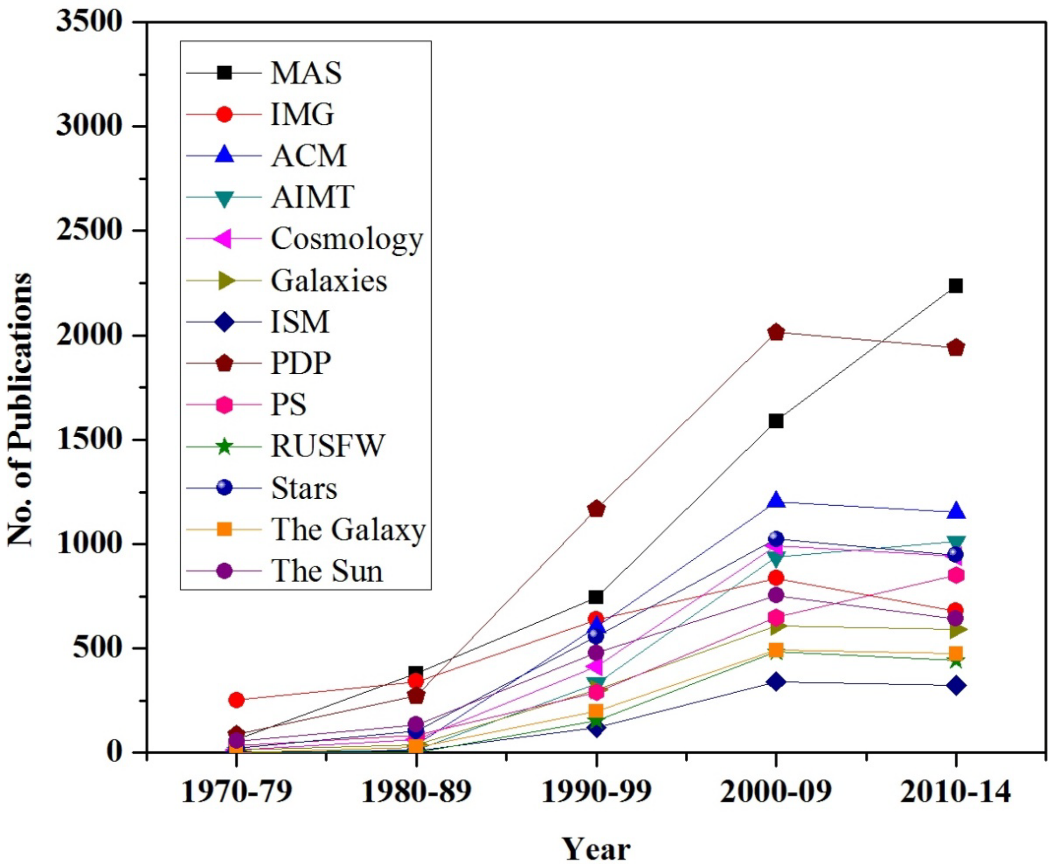

Figure 5.3: Comparison the growth pattern (Publication) among 13 sub-fields of Space ScienceFrom the period 1960-1969, no publication appeared in any of the sub-fields of Space Science.

The 1st publication appeared in 1970 which lies in the first decade. In the decade 1970-79, the growth pattern can be determined as slow growth and it is observed that the sub-fields (e.g., MAS, ACM, Cosmology, Galaxies, PS, Stars, 'The Galaxy' and 'The Sun') belong to this category except IMG and PDP which on the contrary starts with higher values incomparision to other sub-fields. AIMT, ISM starts very poorly i.e. almost zero. In case of RUSFW, no article appeared in the first two decades.

From the second decade (1980-89) to the 4th decade (2000-10) growth pattern appears to have sharp inclination and it is observed that the sub-fields (MAS, ACM, Cosmology, Galaxies, PS, Stars, The Galaxy, and the Sun) fall in this category except IMG and PDP. In the last four years i.e. 2010-2014, the growth pattern can be defined as steady and showed no noteworthy variation and it is observed that the sub-fields (MAS, ACM, Cosmology, Galaxies, PS, Stars, 'The Galaxy', 'The Sun') belong to this category except MAS and PS which start with a higher value in comparison to the other sub-fields.In general, Figure 5.3 depicts the growth pattern of the Space Science' sub-fields, which can be best described by slowgrowth followed by a steep inclinationwhich becomes steady (Olijnyk, 2014; Chun, 1999).

5.6.2 Citation

Figure 5.4shows the growth pattern of citations among 13sub-fields of Space Science decade wise. To know the decade wise citation growth pattern andto assess the trends, the period of study was separated into five 10-years and one 4-year (2010-2014) distinctperiod. In the first 10-years period (1960-1969), none of thesub-fields of Space Science received citations as no publication appeared in the WoSdatabase. The first citation appears from 1970 which lies in the first decade. In the decade 1970-79, the growth pattern can be determined as slow growth and it is observed that the sub-fields(IMG, MAS, ACM, Cosmology, Galaxies, PDP, PS, Stars, 'The Galaxy', and 'The Sun') belong to this category except IMG which on the contrary starts with higher values in comparison to other sub-fields. AIMT, ISM starts with very lowest number of citation i.e. almost zero. In case of RUSFW, no citation is received because no article appeared in the first two decades.

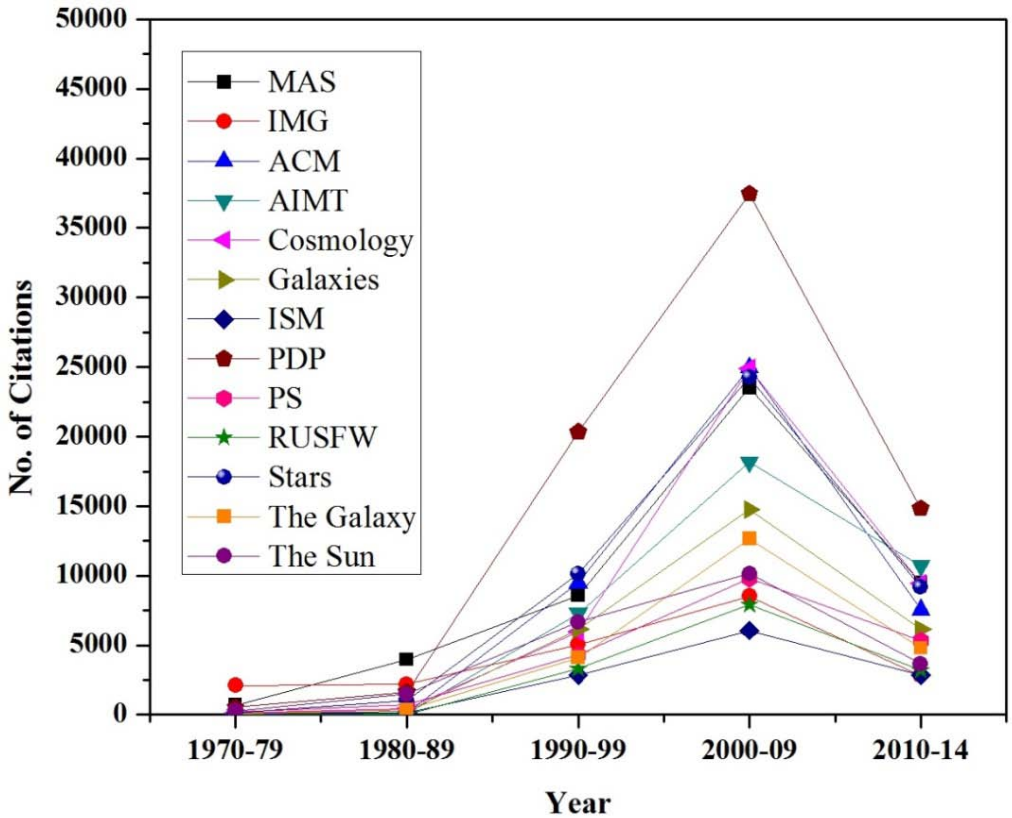

Figure 5.4: Comparison of growth pattern (citation) among 13 sub-fields of Space Science. From 1960-1969, none of thesub-fields of Space Science received citation(s) as no publication appeared in the WoS database.

From the second decade (1980-89) to the fourth decade (2000-10) growth pattern appears to be the sharpest inclined, and it is observed that the sub-fields (IMG, MAS, ACM, Cosmology, Galaxies, PS, Stars, The Galaxy, The Sun) fall in this this category except PDP which on the contrary starts with higher values in comparison to other sub-fields. Inthe last four years i.e. 2010-2014, the growth pattern can be appears to have a sharp drop and it is observed that all the sub-fields of Space Science belong to this category.

In general, Figure 5.4 depicts the citation growth pattern of the Space Science' sub-fields, which can be best described by slow growth followed by a steep inclination which drops sharply at the end. As citations indicate the impact of the publication i.e. quality of publications appear to have a major fall downin the last four years i.e. 2010-2014as compared to others decades (Olijnyk, 2014; Chun, 1999).

5.7 Growth Rate(Percentage): Decade Wise

5.7.1 Publication

Publication rate in percentage of Space Science sub-field can be concluded from Table 5.4 that may have changed over time in this study. The changes that have occurred are discussed in terms of the five distinct period of development: (1) 1970-79; (2) 1980-89; (3) 1990-99; (4) 2000-10 and (5) one 4-year (2010-2014) to examine the trends.The percentage growth rate of papers in the sub-field of MAS is 1.29% in 1970-1979;7.57% in the decade 1980-1989; 14.85% in the decade 1990-1999; 31.68% in 2000-2009 and 44.58% in the last four years i.e. 2010-2014. The growth rates over these time spans shown continuous upward trends. AIMT and PS also shows continuous upward trends in the number of publications (Growth rate of AIMT = 0.04% in 1970-1979; 0.52% in 1980-89; 14.54% in 1990-99; 40.85% in 2000-10 and 44.03% in the last four years i.e. 2010-2014; and Growth rate of PS = 1.88% in 1970-1979; 4.49% in 1980-89; 15.20% in 1990-99; 33.90% in 2000-10 and 44.51% in the last four years i.e. 2010-2014).

Table 5.4: Decade wise growth of publication among sub-field of Space Science

Sub-Fields	1970-79	1980-89	1990-99	2000-09	2010-14
MAS	65 (1.29%)	380(7.57%)	745(14.85%)	1589(31.68%)	2236(44.58%)
IMG	253(9.20%)	340(12.37%)	639(23.25%)	836(30.42%)	680(24.74%)
ACM	16 (0.53%)	38 (1.26%)	604 (20.04%)	1204 (39.96%)	1151(38.20%)
AIMT	1 (0.04%)	12 (0.52%)	334 (14.54%)	938 (40.85%)	1011 (44.03%)
Cosmology	12 (0.49%)	65 (2.68%)	413 (17.04%)	991 (40.89%)	942 (38.87%)
Galaxies	12 (0.77%)	40 (2.57%)	302 (19.43%)	609 (39.18%)	591 (38.03%)
ISM	1 (0.15%)	9 (1.12%)	121 (15.18%)	342 (42.91%)	324 (40.65%)
PDP	88 (1.60%)	275 (5.01%)	1168(21.28%)	2014 (36.70%)	1942 (35.39%)
PS	36 (1.88%)	86(4.49%)	291 (15.20%)	649 (33.90%)	852 (44.51%)
RUSFW	0 (0.00%)	0 (0.00%)	154 (14.27%)	483 (44.76%)	442 (40.96%)
Stars	22 (0.82%)	105 (3.95%)	557(20.97%)	1025(38.59%)	947 (35.65%)
The Galaxy	4 (0.33%)	29 (2.41%)	200 (16.68%)	491(40.95%)	475(39.61%)
The Sun	57 (2.75%)	135(6.53%)	479(23.18%)	753 (36.44%)	642(31.07%)

From 1960-1969, no publication appearedin the WoS database in any of the sub-fields of Space Science

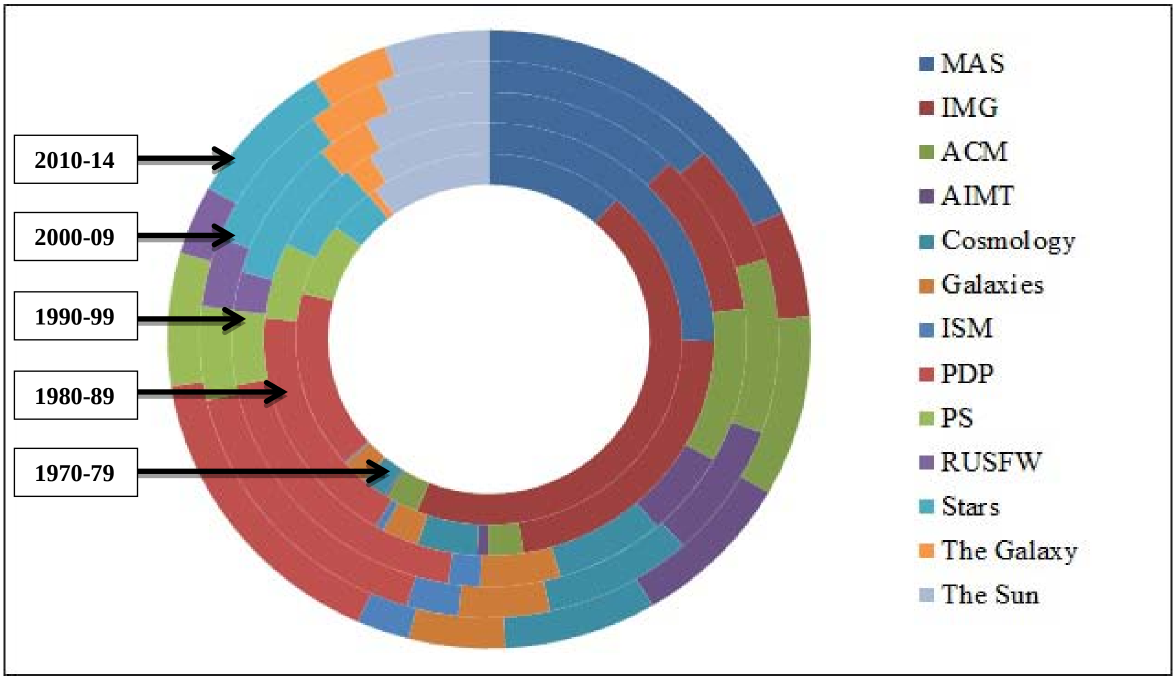

Figure 5.5: Decade wise percentage growth of publication among 13 sub-fields of Space Science

Other sub-fields also show increasing trends during the time span.The sub-fields IMG, ACM, Cosmology, Galaxies, ISM, PDP, 'The Galaxy' and 'The Sun' shows upward trends except last four years i.e. 2010-2014 which shows a downward trend. Growth rate of IMG (9.20% in 1970-1979; 12.37% in 1980-89; 23.25% in 1990-99; 30.42% in 2000-10 and 24.74% in the last four years i.e. 2010-2014); Growth rate of ACM (0.53% in 1970-1979; 1.26% in 1980-89; 20.04% in 1990-99; 39.96% in 2000-10 and 38.20% in the last four years i.e. 2010-2014; Growth rate of Cosmology (0.49% in 1970-1979; 2.68% in 1980-89; 17.04% in 1990-99; 40.89% in 2000-10 and 38.87% in the last four years i.e. 2010-2014); Growth rate of Galaxies (0.77% in 1970-1979; 2.57% in 1980-89; 19.43% in 1990-99; 39.18% in 2000-10 and 38.03% in the last four years i.e. 2010-2014); Growth rate of ISM (0.15% in 1970-1979; 1.12% in 1980-89; 15.18% in 1990-

99; 42.91% in 2000-10 and 40.65% in the last four years i.e. 2010-2014); Growth rate of PDP (1.60% in 1970-1979; 5.01% in 1980-89; 21.28% in 1990-99; 36.70% in 2000-10 and 35.39% in the last four years i.e. 2010-2014); Growth rate of Stars (0.82% in 1970-1979; 3.95% in 1980-89; 20.97% in 1990-99; 38.59% in 2000-10 and 35.65% in the last four years i.e. 2010-2014); Growth rate of 'The Galaxy' (0.33% in 1970-1979; 2.41% in 1980-89; 16.68% in 1990-99; 40.95% in 2000-10 and 39.61% in the last four years i.e. 2010-2014); and Growth rate of 'The Sun' (2.75% in 1970-1979; 6.53% in 1980-89; 23.18% in 1990-99; 36.44% in 2000-10 and 31.07% in the last four years i.e. 2010-2014). The only exception is RUSFW, because no article appears in the first two decades. It shows upward trends for 3rd and 4th decade and downward trend for the last four years i.e. 2010-2014. Growth rate of RUSFW (0.00 % in 1970-1979; 0.00 % in 1980-89; 14.27% in 1990-99; 44.76% in 2000-10 and 40.96% in the last four years i.e. 2010-2014).In general, Table 5.4 and Figure 5.5 depicts the percentage growth rate of publications of the Space Science' sub-fields, which can be best described by continuous upward trends which follow three sub-fields follow (AIMT, MAS and PS) and rest of them follow upward trends in the first few decades and downward trendsin the last four years i.e. 2010-2014 (Jaric´andGessner,2012; Chun, 1999)

5.7.2 Citation

The percentage growth rate of citation received in papers in the sub-field of MAS is 1.51% in 1970-1979; 8.60% in the decade 1980-1989; 18.54 % in the decade 1990-1999; 50.85 % in 2000-2009 and 20.48 % in the last four years i.e. 2010-2014. The changes in percentage growth rates over these time span reflect the upward trends, while the last four years i.e. 2010-2014 shows downward trend.

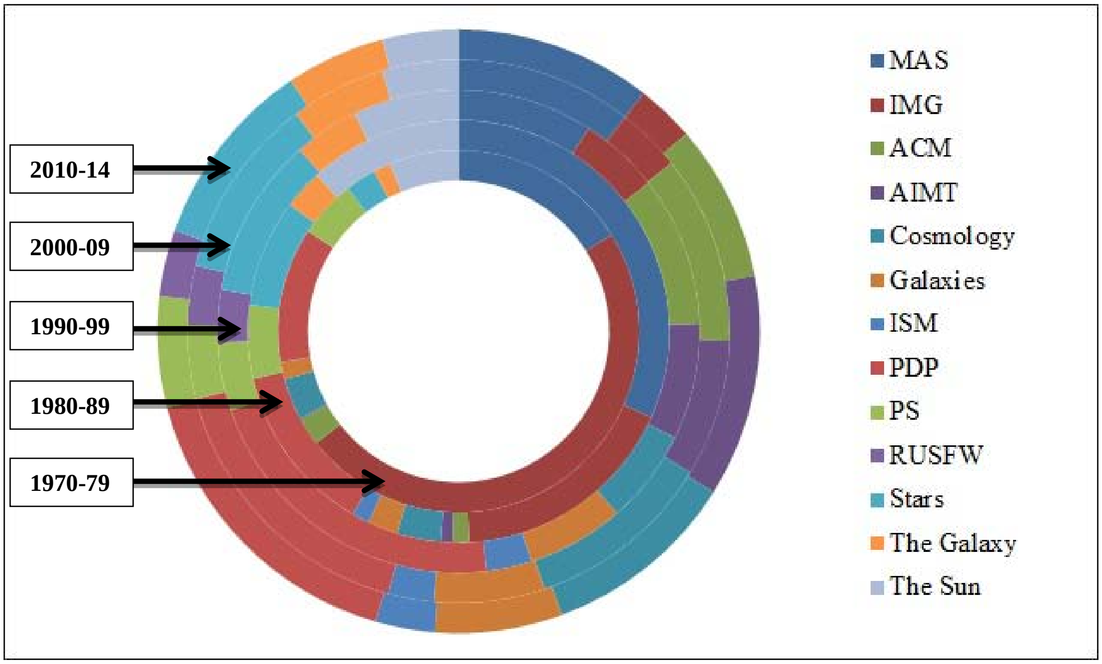

Figure 5.6: Decade wise percentage growth of citation among 13 sub-fields of Space Science

Other sub-fields like IMG, ACM, AIMT, Cosmology, Galaxies, ISM, PDP, The Galaxy and The Sun show upward trends during four decades (1970-79,1980-89,1990-99 and 2000-09) and show downward trends for the last four years i.e. 2010-2014.Growth rate of IMG (10.22% in 1970-1979; 10.63% in the decade 1980-1989; 26.58% in the decade 1990-1999; 41.20 % in 2000-2009 and 13.51 % in the last four years i.e. 2010-2014);Growth rate of ACM (0.25% in 1970-1979;0.36% in the decade 1980-1989; 22.43 % in the decade 1990-1999; 59.04 % in 2000-2009 and 17.89 % in the last four years i.e. 2010-2014); Growth rate of AIMT (0.01% in 1970-1979;0.31% in the decade 1980-1989; 20.11 % in the decade 1990-1999; 50.06 % in 2000-2009 and 29.49 % in the last four years i.e. 2010-2014); Growth rate of Cosmology (0.40% in 1970-1979; 1.03% in the decade 1980-1989; 14.63 % in the decade 1990-1999; 60.88 % in 2000-2009 and 23.04 % in the last four years i.e. 2010-2014); Growth rate of Galaxies (0.24% in 1970-1979; 1.05% in the decade 1980-1989; 22.45 % in the decade 1990-1999; 53.80 % in 2000-2009 and 22.43 % in the last four years i.e. 2010-2014); Growth rate of ISM (0.00% in 1970-1979;1.41% in the decade 1980-1989; 23.87 % in the decade 1990-1999; 50.71 % in 2000-2009 and 23.98 % in the last four years i.e. 2010-2014); Growth rate of PDP (0.70% in 1970-1979;2.18% in the decade 1980-1989; 27.19 % in the decade 1990-1999; 50.07 % in 2000-2009 and 19.84 % in the last four years i.e. 2010-2014); Growth rate of The PS (1.10% in 1970-1979;3.46% in the decade 1980-1989; 21.12 % in the decade 1990-1999; 48.05 % in 2000-2009 and 26.24 % in the last four years i.e. 2010-2014);Growth rate of Stars (0.27% in 1970-1979;2.31% in the decade 1980-1989; 22.71 % in the decade 1990-1999; 54.22 % in 2000-2009 and 20.47 % in the last four years i.e. 2010-2014); Growth rate of ‘The Galaxy’ (0.03% in 1970-1979;1.72% in the decade 1980-1989; 18.71 % in the decade 1990-1999; 57.48 % in 2000-2009 and 21.77 % in the last four years i.e. 2010-2014); Growth rate of ‘The Sun’ (1.21% in 1970-1979; 6.62% in the decade 1980-1989; 30.03 % in the decade 1990-1999; 45.64 % in 2000-2009 and 16.47 % in the last four years i.e. 2010-2014).The exception is RUSFW, because no citation appears in the first two decades. It shows upward trends for 3rd and 4th decade and downward trends for the last four years i.e. 2010-2014. Growth rate of RUSFW (0.00% in 1970-1979; 0.00 % in the decade 1980-1989; 22.96 % in the decade 1990-1999; 54.89 % in 2000-2009 and 22.13 % in the last four years i.e. 2010-2014).

Table 5.5: Decade wise growth of citation among sub-fields of Space Science

Sub-Fields	1970-79	1980-89	1990-99	2000-09	2010-14
MAS	703 (1.51%)	3981 (8.60%)	8581 (18.54 %)	23535 (50.85 %)	9482 (20.48 %)
IMG	2117 (10.22 %)	2203 (10.63 %)	5055 (26.58 %)	8531 (41.20 %)	2799 (13.51 %)
ACM	107 (0.25 %)	156 (0.36%)	9486 (22.43%)	24961 (59.04 %)	7565 (17.89 %)
AIMT	5 (0.01 %)	115 (0.31%)	7304 (20.11 %)	18180 (50.06 %)	10712 (29.49%)
Cosmology	164 (0.40 %)	423 (1.03%)	5991 (14.63%)	24930 (60.88%)	9437 (23.04 %)
Galaxies	67 (0.24 %)	290 (1.05 %)	6153 (22.45%)	14745 (53.80%)	6148 (22.43%)
ISM	1 (0.00 %)	169 (1.41 %)	2853 (23.87%)	6062 (50.71%)	2867 (23.98%)
PDP	527 (0.70%)	1635 (2.18 %)	20350 (27.19 %)	37479 (50.07%)	14850 (19.84 %)
PS	226 (1.10 %)	706 (3.46 %)	4304 (21.12%)	9791 (48.05%)	5346 (26.24 %)
RUSFW	0 (0.00 %)	0 (0.00 %)	3316 (22.96 %)	7927 (54.89 %)	3196 (22.13%)
Stars	121 (0.27%)	1036 (2.31 %)	10159 (22.71 %)	24258 (54.22%)	9158 (20.47%)
The Galaxy	68 (0.03 %)	380 (1.72%)	4122 (18.71%)	12663 (57.48 %)	4797 (21.77%)
The Sun	271 (1.21 %)	1474 (6.62 %)	6685 (30.03 %)	10158 (45.64 %)	3666 (16.47%)

From 1960-1969, none of the sub-fields of Space Science received citation (s) as no publication appeared in the WoS database

In general, Table 5.5 and Figure 5.6 depict the percentage growth rate of citations of the Space Science's sub-fields, which can be best described by all the sub-fields followingupward trends in the first few decades and downward trendsin the last four years i.e. 2010-2014 (Jaric´andGessner,2012; Zyoud et al., 2015).

5.8 Annual Average Growth Rate (AAGR) of Publication

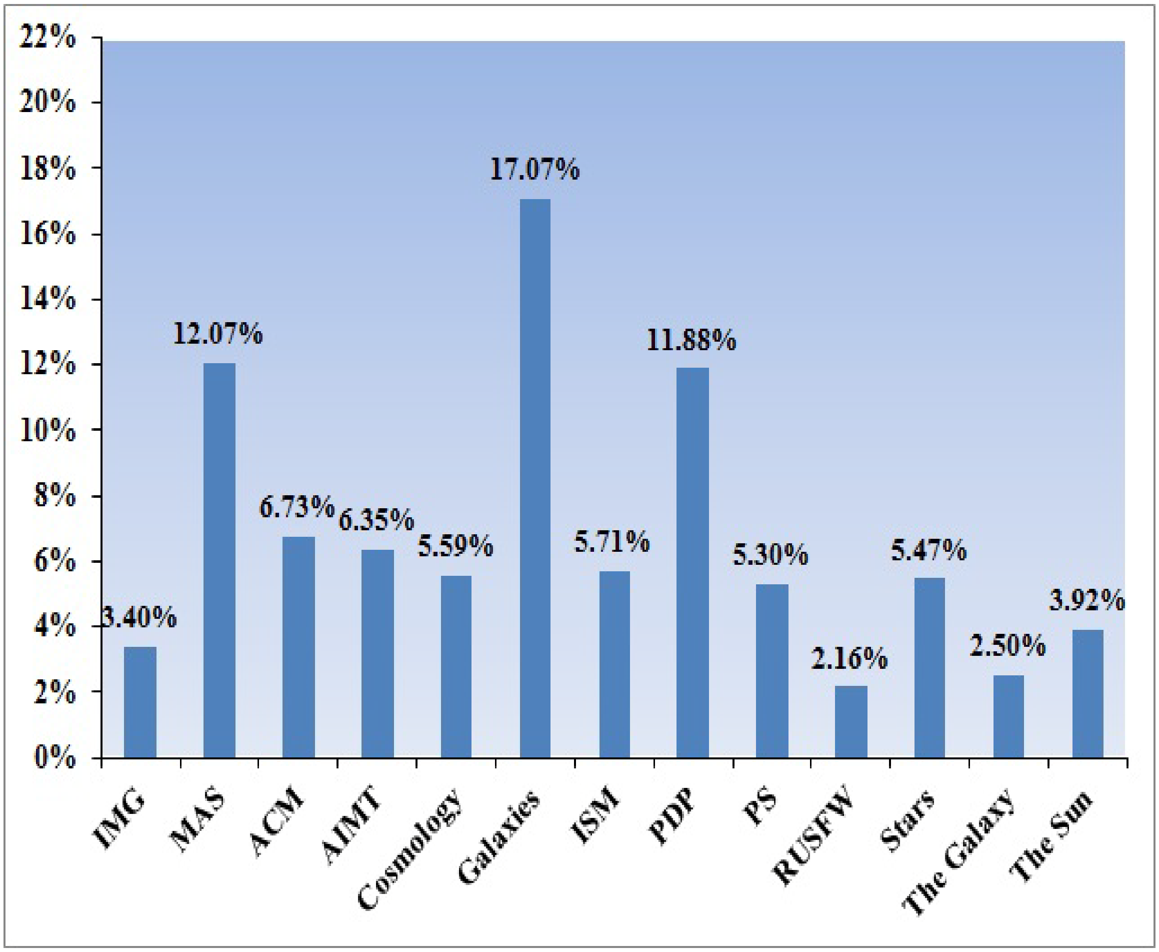

Figure 5.7: Average Annual Growth Rate (percent/Year). Comparison of average annual growth rate among sub-fields of Space Science, 1960-2014.

5.9 Growth Trends

Table 5.6 shows the different modes of growth trends among the sub-fields of Space Science during 1960-2014. Trends are evaluated by using regression analysis with the Regression coefficient (R^2), Growth Rate, AAGR % and CAGR %.Growth models (namely exponential, linear, power, logarithmic and polynomial) arecompared by using R^2 and best fit models are tested.

Table 5.6: Growth Trends of 13 sub-fields of Space Science

Sub-Field	Year	TP	Type of Growth	GR	AAGR %	CAGR %	(R^2)
IMG	1972-2014	2748	Polynomial	1588.88	3.40	0.06	0.8632
MAS	1973-2014	5015	Polynomial	4125.00	12.07	0.09	0.9634
ACM	1972-2014	3013	Polynomial	14150.00	6.73	0.12	0.972
AIMT	1977-2014	2296	Polynomial	26600.00	6.35	0.15	0.985
Cosmology	1974-2014	2423	Polynomial	23400.00	5.59	0.14	0.983
Galaxies	1973-2014	1554	Polynomial	3883.33	17.07	0.09	0.966
ISM	1975-2014	797	Polynomial	23900.00	5.71	0.14	0.958
PDP	1972-2014	5487	Polynomial	49900.00	11.88	0.15	0.974
PS	1973-2014	1914	Polynomial	7333.33	5.30	0.10	0.975
RUSFW	1990-2014	1079	Polynomial	9000.00	2.16	0.19	0.930
Stars	1973-2014	2656	Polynomial	7566.66	5.47	0.10	0.979
The Galaxy	1972-2014	1199	Polynomial	10500.00	2.5	0.11	0.957
The Sun	1972-2014	2066	Polynomial	5500.00	3.92	0.09	0.941

IMG: *Ionosphere, Magnetosphere and Geomagnetism;* ***MAS***: *Meteorology & Atmospheric Science;* ***ACM***: *Astrometry and Celestial Mechanics;* ***AIMT***: *Astronomical Instrumentation, Methods and Techniques;* ***ISM***: *Interstellar Medium;* ***PDS***: *Physical Data and Processes;* ***PS***: *Planetary Systems;* ***RUSFW***: *Resolved and Unresolved Sources as a Function of Wavelength;* ***GR***: *Growth Rate****AAGR***: *Average Annual Growth Rate;* ***CAGR:*** *Compound Annual Growth Rate;* ***R²:*** *Regression Coefficient****;****Source****:*** ***Web of Science***

It is concluded that the polynomial models reasonablyfit the observed data. As seen from the Table 5.6 polynomialgrowth trend is a common type of growth pattern forall the sub-fields of Space Science. Growth Rate(GR) is another notablemeasurement of growth.It appears from Table 5.6, the highest and lowest values of GR are 49900 and 1588.88 for PDP and IMG, respectively. Similarly, Figure 5.7 depicts a comparison of Average Annual Growth Rate(AAGR) among sub-fields of Space Science. In this AAGR, the highest value is 17.07% for Galaxies, followed by MAS with 12.07% and PDP with 11.88%. Analysis of the compound annual growth rate(CAGR), defined as the year-over-year constantgrowth rate over a specified period of timecalculatedas described in (Chapter 3, Section 3.8.2.C) shows quickly growth of sub-fields among all the sub-fields of Space Science research.

5.10 Summary

The current chapter involved a mapping of literature through bibliometric analysis to evaluate growth trends in research productivity and scientometric and bibliometric measures have been taken into account to map the growth of Space Science literatureand also to examine thetrends, and assess the significance of changes. Distribution of publications, citations, decade wise percentage growth of publication and citation pattern, descriptive statistics of publications and citations and comparison of publication growth trends among 13 sub-field of Space Science, are thoroughly discussed in this chapter. This chapter envisages the whole analytical gist of the research work carried out in this thesis.Furthermore, this chapter reveals that the sub-field PDP produces maximum publication and least contributing sub-field is ISMin theSpace Science research. This chapter also reveals that the heavy concentrations of citations appear in the sub-field PDP and low concentration of citations is in sub-field ISM.Rests of the sub-fields have received citationsto a considerable degree as well.

In general, publication growth pattern of the Space Science's sub-fields, which can be best described by slow growth followed by a steep incline resulting into a steady state i.e. shows no significant variation. Similarly citation growth pattern among 13 sub-fieldsof the Space Science can be described as slow growth followed by a steep incline culminatinginto sharp declines.An observation of the decade wise quantitative growth of publication across all the sub-fields shows that the three sub-fields follow continuous upward trends(AIMT, MAS and PS)and rest of them follow upward trendsin the first few decades and downward trendsin the last four years i.e. 2010-2014.Table 5.6shows the comparison of different modes of growth trends among the sub-fields of Space Science during 1960-2014.

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Chapter 6

SUMMARY, DISCUSSION AND CONCLUSION

6.1 Introduction

The main purpose of this study is to map the literature of Space Science written in English from 1960 to 2014 among the sub-fields of Space Science through Scientometrics analysis of its literature by identifying the growth of literature, productivity and collaboration pattern, assessing the productivity of scientific institutions and journals etc. In order to characterize the Space Science research in India, three approaches were used to perform the analysis. In the first approach, frequency ranking of bibliometric indicators such as number of articles per sub-fields, per journal and per country of publication etc. along with pattern of publication.The second approach involves the study of frequency ranking of impact indicator, e.g. h-index and average citation. As a third approach to the work presented in the thesis, analysis research hotspot and quick rising themes are studied. Different measures, distributions and statistics are applied to the data in order to have high significance values free from errors and to support the findings.

6.2 Findings of the Study

6.2.1 Space Science and its sub-fields

A total of 32247 research publications by the Indian scientists are retrieved from WoS across the 13 sub-fields of Space Science during 1960-2014. The highest and lowest productive sub-fields are Physical Data and Processes (PDP) and Interstellar Medium (ISM) with a publication rate of 17.02% and 2.47% respectively.Meteorology and Atmospheric Science (MAS), Astrometry and Celestial Mechanics (ACM) and Ionosphere, Magnetosphere and Geomagnetism (IMG)ranked 2nd, 3rdand 4thwith a publication rate of 15.55%, 9.34% and 8.52%respectively. Publication distributions among sub-fields of Space Science are illustrated in Figure5.1. The highest Compound Annual Growth Rate (CAGR) of 0.985% which belong to AIMT Sub-field (Table5.6). The highest mean value of publication(127.60) appear in the field of PDP, the highest p25 (26.5) and p50 (118) appear in the sub-field of PDP (Table 5.2). The highest regression coefficient(0.985) appears in the sub-field of AIMT (Table 5.6). It has been found from Table 5.6 that all the sub-fields of Space Science fit polynomial growth curve.

Over the period 1960-2014 sub-fields of Space Science has received a total of 4,24,546 citations with an average of 32657.38 citations per sub-field of Space Science. Citations have appeared in highest number in the sub-field of PDP and least number appeared in the field of ISM. It is observed that the highest mean number of citation, p25 and p50 appear in the sub-field of PDP, MAS and PDP respectively (Table 5.3).

6.2.2 Indicators profile in Space Science

A. Institution

There are 13 corresponding institutions to the top 13 identified sub-fields of Space Science.Appendix - I (a) shows the institutions which have published the highest number of papers in the various sub-fields of Space Science include TIFR, IISc, PRL, IIG, MES, IUCAA and IIA. Apart from these 13 institutions, the research in Space Science has also been carried out in collaboration with the various institutions of USA, UK, Netherlands, Canadaand Sweden. A general glance at the results reveals that almost all of the top-publishing institutions are research organisations funded by different departments or Ministry of Government of India like Department of Science and Technology, Department of Space, University Grant Commission, etc. A careful analysis of these results shows that TIFR is the leading institution in the 7 out of 13 sub-fields of Space Science. It leads the research in the sub-fields of ACM 442 (0.34%), AIMT 584 (0.45%), Galaxies 450 (0.34%), ISM 264 (0.20 %), PDP 858 (0.66%), RUSFW 508 (0.39%) and 'The Galaxy' 329 (0.25 %). Other sub-fields are being led by IIG in - IMG, MES in - MAS, IUCAA in - Cosmology, PRL in - PS and IIA in - Stars and 'The Sun'. In the context of the research impact the most productive institution within the sub-fields of Space Science is IUCAA, Pune. It has received highest number of citations (16132), AvgCPA = 30.38 and h-index=60 in the corresponding sub-field of Cosmology.

B. Journal

The thirteen sub-fields of Space Science have publications in several journals worldwide. Appendix –I (b) showsthe top 13 journals corresponding to each sub-field are IMG, MAS, ACM, AIMT, Cosmology, Galaxies, ISM, PDP, PS, RUSWF, Stars, 'The Galaxy' and 'The Sun'. In this data the most preferred journal is 'Monthly Notices of the Royal Astronomical Society' covering the sub-fields of AIMT, Galaxies, ISM RUSWF, 'The Galaxy' and Stars.'Journal of Geophysical Research: Space Physics' in - IMG; 'Atmospheric Environment' in - MAS; 'Physical Review D' in -ACM, PDP; 'Astrophysics and Space Science' in - Cosmology;'Astronomy Astrophysics' in - PS; 'Solar Physics' in - 'The Sun'.It has been observed from these statistics that out of these thirteen journals, seven are published from the UK followed by the USA, Netherlands, and France. None of these 13 journals is published from Indian sub-continent. This symbolizes that the Indian authors are inclined towards publishing in foreign journals especially those emerging from the European continent.

C. Author

Several authors worldwide participated across the 13 sub-fields of Space Science during 1960-2014. Appendix –I (c) showsRastogi, R.G. is the most productive author who published 165 papers in the sub-field – IMG followed by Chakrabarti, S.K. with 143 papers in the sub-field of PDP. Saikia, D. J. contributed 109 papers in the sub-field of Galaxies and Srianand, R. produced 101 papers in the sub-field of cosmology. The highest number of citation is received by Mitra, S. in the sub-field of AIMT followed by Srianand, R. who received 2800 citations. In the context of the research impact (h-index) the most productive author within the sub-fields of Space Science is Mitra, S. who received the highest h-index score (h-35)in the sub-field of AIMT, followed by Srianand, R.and Antia, H. both received h-index score - 30 in the sub-field of Cosmology and 'The Sun' respectively. Similarly, in the case of AvgCPA, Antia, H. ranked 1st(AvgCPA=31.11) in the sub-field of 'The Sun' followed by Goswami, J.N. (AvgCPA=29.73) in the sub-field of PS and Srianand, R. ranked 3rd with AvgCPA of 27.72 in the sub-field of Cosmology.

D. Collaboration

Collaborative research can be understood as the one in which many researchers work together to produce common scientific output. This collaborative research can be among researchers of same institution, place, countries or continents. This section highlights the foreign Institutions which have worked in collaboration with India to carry out the research in various fields of Space Science. Appendix –I (d) show us the research trends in terms of collaborations among authors of different countries and consequently the continents as well. It also reveals whether the collaborative research symbolizes higher impact publications.In addition, this study used citation count analyses to compare the impact of collaborative publications. This provides a measure of whether multi-institutional and international collaborations are resulting in benefits to Space Science research, with the assumption that more highly cited publications are being more widely disseminated and used within the research community.

Comparing the Tables (Table 4.2.a(vii), Table 4.2.b(vii), Table 4.3.a(vii), Table 4.3.b(vii), Table 4.3.c(vii), Table 4.3.d(vii), Table 4.3.e(vii), Table 4.3.f(vii), Table 4.3.g(vii), Table 4.3.h(vii), Table 4.3.j(vii), Table 4.3.k(vii), Table 4.3.l(vii)) of top 20, we can say that almost all the 13 fields of space science, top-20 list begins with the USA. UK, Germany, France and Japan are among the top collaborating countries. In general, the highest levels of collaboration occurred between Europe and Asia. Other continents with less international collaborations include North America, South America, Africa and Australia. Appendix –III illustrate the collaboration of Space Science publications by continent over the last 54 years.

E. Keyword

An examination of frequently used words in publication text can be helpful in identifying research hotspots or prominent research themes. This approach was used to identify hot topics in Space Science research literature published between 1960 and 2014. Based on the keywords of Space science-relevant publications, Appendix –IV shows a keyword cluster composed of the most prevalent keywords used across all the sub-fields of Space Science publications, as well as the top 20 unique keywords that appeared most often in the respective fields of Space Science publications. These unique keywords provide a snapshot of the most prominent research themes in Space Science publications and how they vary across the 13 sub-fields of Space Science.

6.3 Suggestions for further study

The study has brought forward a number of keywords which are available in a significant amount of literature on Space Science research. These keywords are mostly related to collaborated efforts which are being advocated by scientists and users of the Internet. These sub-domains of Space Science research require further details studies so policy makers can make learned decision. These domains are as follows:

.3.1 Research Impact Measurement Service System (RIMSS)

Research evaluation has become increasingly important in the decisions taken by the management in the universities and research institutions etc. Research metrics provide an objective way to assess the research output of individuals, groups, departments or any R&D institution. Research impact measurement is often described by using the quantitative methods such as citation counts, journal impact factors and researcher specific metrics such as the h-index using Scientometrics and bibliometrics techniques. Research Impact Measurement Services System (RIMSS) can be visualisedas a centralised and distributed bibliometric information services system which would help end user- researchers, research funders, policy makers, practitioners and service users etc.

to track and measure their research publications and citations (The University of Western Australia, 2016).

6.3.2 Ontology

Recent tradition extends the representational scope to include more features of knowledge domains such as the various types of agents in the domain, their intellectual affiliations, and theirresearch activities, all with the aim of enabling more precise queries about the domains. This leads to the development of software artifacts called ontology. This can be utilized to construct ontology for scientific periodicals in Space Science research, enabling precise and efficient retrieval of their contents. In Space Science, Ontology can help in identifying the information sources; and can be used to adopt standards and formats for metadata which are interoperable (Malanga, n.d).

6.4 Research Questions and Answers

6.4.1 What is the quantity of Space Science Research publications and citations since 1960?

A total of 32, 24,7 research publications are identified by the Indian Scientists or India as an affiliation country written in English which were retrieved from WoS across the 13 sub-fields of Space Science during 1960-2014. The distributions of publication across all the sub-fields of Space Science are described in Chapter 5, Section 5.2. All the sub-fields of Space Science received a total of 4,24,546 citations during 1960-2014. The distribution of citations among all the sub-fields of Space Science are described in Chapter 5, Section 5.3.

6.4.2 Which growth trend is being followed? Has the growth trends changed over time?

Percentage growth rate in sub-fields of Space Science has changed over the period of 54 years. Using the simple growth rate formula as described in Chapter 3Section 3.8.2.(A), growth rate are determined.Table5.4 (Chapter 5, Section 5.7.1) shows the publication growth rate of all sub-fields. A quantitative growth of publications for various decades has been observed across all the sub-fields. The three sub-fields (MAS, IMG and PDP) follow continuous upward trends however, the rest of the sub-fields of Space Science follow upward trends for the first few decades, and in the last four years i.e. 2010-2014,a downward trend is observed (Chapter 5, Section 5.6.1).

6.4.3 Which growth model can be used to describe the trend?

Growth models (described in Chapter 3, Section 3.8.1)are mathematical models used for manifesting the growth trend over time. The five growth models / trend lines namely exponential, linear, power, logarithmic and polynomialwere tested to the observed data set across the 13 sub-fields of Space Science using regression analysis and compared by R^2 (regression coefficient) and the best fit models were identified . It is observed that the polynomial models reasonably fit the observed data. As seen from the Table 5.6 (Chapter 5, Section 5.9) that polynomial growth model is a common type of growth model for all the sub-fields of Space Science.

6.4.5 What are the specific characteristics of the literature of sub-fields of Space Science in terms of selected variables pertaining to the year, authors, titles and journals?

As per the taxonomy of Space Science research (Chapter 3,Section 3.3), it comprises of 13 sub-fields. A total of 32247 research publications across the 13 sub-fields of Space Science were retrieved from WoS during 1960-2014. The highest number of research publications appear in the sub-field PDP i.e 17.02% of total publicationfollowed by MAS 15.55%,ACM 9.34% and IMG 8.52%.Section 5.2 of chapter 5 gives a detailed description of distribution of publications.

The descriptive statistics of Space Science publications will provide the descriptive overview of the characteristics of the literature of each sub-field of Space Science. Table5.2 (Chapter 5, Section 5.5.1)shows the maximum and minimum publication numbers, mean, median and interquartile range (IQR), etc. of each sub-field of Space Science with the corresponding years.

IIG is the most productive institution which contributed 532 papers in the sub-field of IMG. Appendix – I (a) shows the most productive institutions within the sub-fields of Space Science research between 1960 and 2014.

The journal ‘Physical Review D’published by APSin USA has the highest number of publications (854) within the sub-fieldof PDP. The most preferred journal is Monthly Noticesof the RoyalAstronomical Society which covers the sub-fields -AIMT, Galaxies, ISM, RUSWF, Stars and ‘The Galaxy’.Appendix – I (b)shows the most productive journal within the sub-fields of Space Science research between 1960 and 2014. Similarly

Appendix – I (c) and Appendix – I (d) show the most productive author and most collaborating country in the respective sub-fields of Space Science.

6.4.6 What are the characteristics of the literature of Space Science, in terms of variables pertaining to the citation, average citation, h-index?

The ‘quality’ of a research publication is a qualitative assessment that depends on the quantitative measurement of the impact of publications and citations which can include citation counts, average citation counts,h-indices and journal impact etc. The bibliometric measure of the impact of a publication within the research arena is the number of times it is cited by other, subsequent publications, or in other words, an aggregated number of citations a publication receives. In total 32247 numbers of publications across all the sub-field of Space Science received4,24,546citations. The measurement of citation impact (citation count, averagecitation and h-index etc.) withrespect to different publication outlets are analysed across the 13 sub-fields of Space Science. Table 5.1 in Chapter 5 represent the citation metrics of 13 sub-fields of Space Science which manifest TC: Total number of citation; TCwoSc: Sum of Times Cited without self-citations; CA: Citing Articles;CIwoSC: Citing Articles without self-citations; AvgCPA: Average Citations Article; h-index: number ofpapers among author’s number of publications that have at least h citations each.The research impacts of publication on Space Science is evaluated using different perspectives like author, institution and journal etc. in the followingappendices (Appendix-I(a),Appendix-I(b), Appendix-I(c) and Appendix-I(d)).(Office of Autism Research Coordination and Thomson Reuters, Inc , 2012; Heilig&VoB, 2014).

6.4.7 What is the status of globalisation of Space Science Research?

The analysis of collaboration pattern was performed in order to understand whether Space Science research is becoming a more global endeavor, and if so, if this may be beneficial to the field. It is an established fact that collaboration is especially beneficial to the development of research field by potentially providing researchers with access to a larger pool of expertise, participants, and resources than otherwise possible(Office of Autism Research Coordination and Thomson Reuters, Inc, 2012).

Appendix- III shows themapping of collaboration pattern on Space Science publications for various continentsover the last 54 years. More precisely, it shows the number of times researchers from different parts of the world worked in collaboration with Indian institutions to carry out the research in various sub-fields of Space Science. The map shows that highest level of collaboration occurred with Europe followed by Asia and Africa. Several minor clusters are found distributed in other parts of the world like South America, North America and Australia. Appendix-I(d) shows the research trends in terms of collaborations among authors of different countries and consequently the continents as well. It also reveals the impact of collaborative publications. From the above mentioned appendices it can be said that among all the 13 sub-fields of Space Science, the first 20 entries in the list begins with the USA. UK, Germany, France and Japan.

6.4.8 Which research themes are prominent in Space Science Research publications?

An examination of frequently used keywords in publication text can be helpful in identifying research hotspots or prominent research themes. This approach was used to identify hot topics in Space Science research literature published between 1960 and 2014. Based on the keywords of Space Science-relevant publications, Appendix –IV shows a keyword cluster composed of the most prevalent keywords used across all the sub-fields of Space Science publications, as well as the top 20 (Table 4.2.a(viii), Table 4.2.b(viii), Table 4.3.a(viii), Table 4.3.b(viii), Table 4.3.c(viii), Table 4.3.d(viii), Table 4.3.e(viii), Table 4.3.f(viii), Table 4.3.g(viii), Table 4.3.h(viii), Table 4.3.j(viii), Table 4.3.k(viii), Table 4.3.l(viii)) unique keywords that appeared most often in the respective fields of Space Science publications. These unique keywords provide a snapshot of the most prominent research themes in Space Science publications and how they vary across the 13 sub-fields of Space Science.

6.5 Conclusion

The present study has descriptively illustrated the quantitative and qualitative results of the growth of Space Science in India, as reflected in the WoS database. The present study has examined, evaluated and understood the Space Science research trends in India. This study has been able to fulfill all its objectives byanalysing and deriving the growth of Space Science literature in our country, the current status of its fields and sub-fields, the strengths and gaps in various fields, quantitative and qualitative measurement of research output, and derivation of top authors, institutions and collaborations in the fields and sub-fields.

The results of this study show that the growth rate of publications is increasing every passing year and so are the citation counts, still more research is required to stand in line with the developed countries. This is only possible with the investment of more funds, resources and manpower in this sector of research. In order to understand these dynamics and to put - time, money, efforts and manpower to the best use, this study can be utilised by the policy makers to gain helpful insight into India's Space Science Research and allocate these resources accordingly. This research work will help the scientists and researchers to understand this field, the gaps, the over exploited areas and work in those directions.

As far as fellow professionals are concerned, this study can prove relevant to their skills in collection management. The results can be utilised to procure books and journals in the more prolific areas of research or the less visited niches of the fields and sub-fields of the Space Science. Another important usage of this study is that libraries of institutions can enhance their reference services by understanding the specific needs of the users and catering to them accordingly.

To summarize, it can be said that this study justifies itself as a reality check for the libraries in terms of resources they procure and information they disseminate. It is expected that the study will be helpful for researchers to analyse where they stand now and where they should have been or want to reach. It will also help the policy makers to plan in accordance with the current needs and bring about required changes in allocation of funds, resources and manpower.

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Appendices

Appendix-I (a): The most productive institutions within the sub-fields of Space Science research between 1960 and 2014

Most Productive Institution	TP	TC	AvgCPA	h-index	Sub-fields
Indian Institute of Geomagnetism	532	4156	7.81	27	IMG
Ministry of Earth Sciences	1205	12628	10.48	47	MAS
Tata Institute of Fundamental Research	442	11711	26.50	45	ACM
Tata Institute of Fundamental Research	584	7764	13.29	41	AIMT
Inter University Centre for Astronomy Astrophysics	531	16132	30.38	60	Cosmology
Tata Institute of Fundamental Research	450	8208	18.24	39	Galaxies
Tata Institute of Fundamental Research	264	3596	13.62	33	ISM
Tata Institute of Fundamental Research	858	14986	17.47	56	PDP
Physical Research Laboratory	253	3413	13.49	30	PS
Tata Institute of Fundamental Research	508	6708	13.20	37	RUSFW
Indian Institute of Astrophysics	612	9368	15.31	42	Stars
Tata Institute of Fundamental Research	329	6720	20.43	36	TheGalaxy
Indian Institute of Astrophysics	549	5760	10.49	35	TheSun

TP*= Total no. of sub-field of Space Science related articles published by an institution;* ***TC*** *= Total no. of citation received;* ***AvgCPA****= Average no. of citations per article; h-****index****=defined by the no. of h papers among an institution's no. of publications that have at least h citations each.* ***Source:*** *Table 4.2.a(iv), Table 4.2.b(iv), Table 4.3.a(iv), Table 4.3.b(iv), Table 4.3.c(iv), Table 4.3.d(iv), Table 4.3.e(iv), Table 4.3.f(iv), Table4.3.g(iv), Table 4.3.h(iv), Table 4.3.j(iv), Table 4.3.k(iv), Table 4.3.l(iv)*

Appendix-I (b): The most productive Journals within the sub-fields of Space Science research between 1960 and 2014

Most Productive Journal	TP	TC	AvgCPA	Country	Sub-field
Journal of Geophysical Research Space Physics	324	3400	10.49	USA	IMG
Atmospheric Environment	469	8709	1.537	UK	AMR
Physical Review D	415	9796	1.136	USA	ACM
Monthly Notices of the Royal Astronomical Society	489	6767	1.494	UK	AIMT
Astrophysics and Space Science	434	2771	6.38	Netherlands	Cosmology
Monthly Notices of the Royal Astronomical Society	508	7524	1.494	UK	Galaxies
Monthly Notices of the Royal Astronomical Society	247	3782	1.494	UK	ISM
Physical Review D	854	16152	1.136	USA	PDP
Astronomy Astrophysics	111	2168	0.612	France	PS
Monthly Notices of the Royal Astronomical Society	344	4181	1.494	UK	RUSFW
Monthly Notices of the Royal Astronomical Society	547	8498	1.494	UK	Stars
Monthly Notices of the Royal Astronomical Society	345	5258	1.325	UK	TheGalaxy
Solar Physics	460	4828	1.769	Netherlands	The Sun

TP= *Total no. of Sub-field related articles published by a Journal;* ***TC*** *= Total no. of citation received;* ***AvgCPA***= *Average no. of citations that Sub-field related articles in a journal received;* ***h-index***= *no. of h papers among a journal's no. of publications that have at least h citations each.* ***Source:*** *Table 4.2.a(v),Table 4.2.b(v), Table 4.3.a(v), Table 4.3.b(v), Table 4.3.c(v), Table 4.3.d(v), Table 4.3.e(v), Table 4.3.f(v), Table 4.3.g(v), Table 4.3.h(v), Table 4.3.j(v), Table 4.3.k(v), Table 4.3.l(v)*

Appendix-I (c): The most productive Authors within the sub-fields of Space Science research between 1960 and 2014

Most Productive Author	TP	TC	AvgCPA	h-index	Sub-fields	Affiliation
Rastogi, R.G.	165	1585	9.61	20	IMG	PRL
Moorthy, K.K.	96	2203	22.95	27	MAS	VSSC
Sagar, R.	51	940	18.43	19	ACM	ARIES
Mitra, S.	66	2996	45.39	35	AIMT	IUCAA
Srianand, R.	101	2800	27.72	30	Cosmology	IUCAA
Saikia, D.J.	109	1517	13.92	24	Galaxies	TIFR
Chengalur, J.N.	57	984	17.26	20	ISM	TIFR
Chakrabarti, S.K.	143	2308	16.14	25	PDP	SNBNCBS
Goswami, J.N.	48	1427	29.73	18	PS	PRL
Saikia, D. J.	88	1184	13.45	21	RUSWF	TIFR
Sagar, R.	93	1203	12.94	19	Stars	ARIES
Chengalur, J.N.	63	1036	16.44	20	TheGalaxy	TIFR
Antia, H.M.	82	2551	31.11	30	TheSun	TIFR

TP*= Total no. of Publications of Author in their respective Sub-field;* ***TC*** *= Total no. of citation received;* ***AvgCPA****= Average no. of citations per article;* ***h-index****= no. of h papers among anauthor's no. of publications that have at least h citations each.* ***Source:*** *Table 4.2.a(vi),Table 4.2.b(vi), Table 4.3.a(vi), Table 4.3b(vi), Table 4.3.c(vi), Table 4.3.d(vi), Table 4.3.e(vi),Table 4.3.f(vi), Table 4.3.g(vi), Table 4.3.h(vi), Table 4.3.j(vi), Table 4.3.k(vi),Table 4.3.l(vi)*

Appendix-I (d): The most collaborative countries within the sub-fields of Space Science research between 1960 and 2014

Country	Continent	TP	TC	AvgCPA	h-index	Sub-field
USA	North America	274	4978	18.17	36	IMG
Japan	Asia	114	1399	12.27	21	
England	Europe	73	1950	26.71	24	
USA	North America	482	8234	17.08	43	MAS
Japan	Asia	165	2470	14.97	26	
Germany	Europe	129	2507	19.43	28	
USA	North America	665	19054	28.65	61	ACM
Germany	Europe	323	9941	30.78	48	
France	Europe	223	6377	28.6	42	
USA	North America	789	20661	26.19	66	AIMT
Germany	Europe	412	11723	28.45	54	
France	Europe	381	12221	32.08	52	
USA	North America	464	14425	31.09	53	Cosmology
France	Europe	276	8854	32.08	46	
Germany	Europe	239	7247	30.32	45	
USA	North America	529	14414	27.25	51	Galaxies
Germany	Europe	219	8658	39.53	44	
France	Europe	215	7714	35.88	43	
USA	North America	285	5741	20.14	37	ISM
France	Europe	138	3331	24.14	34	
Germany	Europe	114	2082	18.26	29	
USA	North America	1253	29892	23.86	78	PDP
Germany	Europe	558	14188	25.43	60	
France	Europe	447	13743	30.74	59	
USA	North America	331	7866	23.76	44	PS
Germany	Europe	140	3340	23.86	34	
France	Europe	136	3657	26.89	34	
USA	North America	414	7255	17.52	41	RUSFW
Germany	Europe	145	2865	19.76	34	
England	Europe	122	2169	17.78	27	
USA	North America	660	21946	33.25	66	Stars
Germany	Europe	292	10303	35.28	49	
France	Europe	271	8492	31.34	48	
USA	North America	421	11613	27.58	49	The Galaxy
France	Europe	192	6040	31.46	44	
Germany	Europe	188	6990	37.18	41	

USA	North America	420	8711	20.74	49	The Sun
France	Europe	137	2708	19.77	30	
Japan	Asia	103	1186	11.51	18	

TP (%): *Total no. of Sub-fields of Space Science related articles published by a author* ***TC:*** *Total no. of citation****; TC woSc:*** *Sum of Times Cited without self-citations****; CI:*** *Citing Articles* ***;CIwoSC:*** *Citing Articles without self-citations****; AvgCPA:*** *Average Citations per Article****; h-index :*** *no. of h papers among a author's no. of publications that have at least h citations each.* ***Source:*** *Table 4.2.a(vii),Table 4.2.b(vii), Table 4.3.a(vii), Table 4.3.b(vii), Table 4.3.c(vii), Table 4.3.d(vii), Table 4.3.e(vii), Table 4.3.f(vii), Table 4.3.g(vii), Table 4.3.h(vii), Table 4.3.j(vii), Table 4.3.k(vii), Table 4.3.l(vii)*

Appendix – II: Keyword Bank

Keywords in Fields and Sub-fields of Space Science Research

K1 Ionosphere, Magnetosphere and Geomagnetism

K11 Ionosphere

active experiments
Auroral ionosphere
current system
D region
E region
Electric fields;
Electromagnetic wave propagation
Equatorial ionosphere
F region
Interactions between waves and particles
Ion chemistry and composition;
ionization mechanisms
Ionospheric disturbances,
Ionospheric dynamics and interactions
Ionosphericmodeling and forecasting
Ionospheric soundings;
Ionospheric structure, composition
irregularities,
Meteor-trail physics
Mid-latitude ionosphere
Particle precipitation
Plasma motion;
Plasma temperature and density
Plasmasphere
Polar cap ionosphere
storms
Topside region

K12 Magnetosphere

Auroral phenomena
Auroral zones
Auroras
Inner magnetosphere
Magnetopause
Magnetosheath
Magnetosphere interactions

Magnetospheric configuration and dynamics
Magnetospheric cusp
Magnetosphericmodeling and forecasting
Magnetotail
Outer magnetosphere
Radiation belts
Van Allen radiation belts

K13 Geomagnetism

Dynamics of the middle and upper atmosphere
Equatorial Electrojet (EEJ)
Geomagnetic Pulsations
Global Electric Circuit (GEC)
Ionospheres Irregularities
Magnetic measurements
Solar wind – Magnetosphere – Ionosphere Coupling
Space Weather Prediction

K2. Meteorology and Atmospheric Science

Aerosol
Aerosol meteorology
Aerosol–particles
Agricultural Meteorology
Air
Air Pollution Meteorology
air–pollution
Air-sea interaction
asthma
Asymmetry of the Intertropical Convergence Zone
Atlantic Equatorial mode
Atmosphere
Atmospheric convection
Atmospheric Simulation
Aviation Meteorology
Boundary layer turbulence
Chemical equator
Chemistry
Circulation
Climate
Climatology
Cloud
Coastal Meteorology

Optical–properties
Ozone
Ozone-meteorology
Polar meteorology
Pollution
Precipitation
Prediction
Quasi-biennial oscillation
Radio Meteorology
Regional meteorology
Saharan Air Layer
Scattering
Scientific weather forecasting
Sea Surface Temperature
Seasonal Change
Seasonality
Seawater Intrusion
Simulation
Size distribution
Sodar indexing
South Atlantic Convergence Zone
South Pacific convergence zone
Space Meteorology
Storm surge modelling
Storm track
Storms
Subtropical Indian Ocean Dipole
Sulfate
Surface
Surface meteorology
Synoptic Meteorology
Temperature
Temporal Variability
Top of The Atmosphere
Trace Gas
Transport
Tropical
Tropical Atlantic Variability
Tropical climate
Tropical convection
Tropical Cyclone
Tropical cyclone dynamics
Tropical Meteorology
Tropical rain belt
Tropical storms
Tropical upper tropospheric trough

Tropical Warm Pool
Tropopause
Tropospheric Ozone
Upper troposphere
Upper Troposphere Lower Stratosphere
Variability
Vortex dynamics
Walker circulation
Water
Wave dynamics
Wave modelling
Western Hemisphere Warm Pool
Wind stress modeling

K3. Astrometry and Celestial Mechanics

Astrometry
Celestial mechanics
Eclipses
Ephemerides
Occultations
Parallaxes
Proper motions
Reference systems
Time

K4. Astronomical Instrumentation, Methods and Techniques

Astronomical detectors
balloons
Early astronomical instruments
High altitude balloons
instrumentation: adaptive optics
instrumentation: detectors
instrumentation: high angular resolution
instrumentation: interferometers
instrumentation: miscellaneous
instrumentation: photometers
instrumentation: polarimeters
instrumentation: spectrographs
Interferometers
light pollution
methods: analytical

methods: data analysis
methods: laboratory: atomic
methods: laboratory: molecular
methods: laboratory: solid state
methods: miscellaneous
methods: numerical
methods: observational
methods: statistical
Polarimeters
Siderostats
site testing
Solar instruments
Spectrometers
Stellar tracking devices
techniques: high angular resolution
techniques: image processing
techniques: imaging spectroscopy
techniques: interferometric
techniques: miscellaneous
techniques: photometric
techniques: polarimetric
techniques: radar astronomy
techniques: radial velocities
techniques: spectroscopic
Telescopes
Transit instruments

K5. Cosmology

(cosmology:) cosmic background radiation
(cosmology:) cosmological parameters
(cosmology:) dark ages, reionization, first stars
(cosmology:) dark energy
(cosmology:) dark matter
(cosmology:) diffuse radiation
(cosmology:) distance scale
(cosmology:) early universe
(cosmology:) inflation
(cosmology:) large-scale structure of universe
(cosmology:) primordial nucleosynthesis
Anthropic principle
Astronomical evolution
Astronomical radiation sources
Astrophysical dust processes
Beyond the Standard Model
Bianchi cosmology

Big Bang theory
Blueshift
Brane cosmology
Cooling flows
Cosmic electrodynamics
Cosmic inflation
Cosmochemistry
Cosmochronology
Cosmogony
Cosmological models
Cosmological parameters
Cosmological phase transitions
Cosmological principles
cosmology: miscellaneous
cosmology: observations
cosmology: theory
Curved space
Dark energy
Hierarchical cosmology
Large-scale structure of the universe
Mass transfer
Metagalaxy
Non-Gaussianity
Observational cosmology
Origin of the universe
Plasma astrophysics
Quantum cosmology
Radiative transfer
Redshift
Relativistic cosmology
Steady-state theory
Stellar evolution

K6. Galaxies

(galaxies:) BL Lacertae objects: general
(galaxies:) BL Lacertae objects: individual (..., ...)
(galaxies:) intergalactic medium
(galaxies:) Local Group
(galaxies:) Magellanic Clouds
(galaxies:) quasars: absorption lines
(galaxies:) quasars: emission lines
(galaxies:) quasars: general
(galaxies:) quasars: individual (..., ...)
(galaxies:) quasars: supermassive black holes

Active galaxies
Bipolar galaxies
Blue galaxies
Bright galaxies
Compact galaxies
Companion galaxies
Disk galaxies
Dwarf galaxies
Early-type galaxies
Elliptical galaxies
Faint galaxies
Field galaxies
galaxies: abundances
galaxies: active
galaxies: bulges
galaxies: clusters: general
galaxies: clusters: individual (..., ...)
galaxies: clusters: intracluster medium
galaxies: distances and redshifts
galaxies: dwarf
galaxies: elliptical and lenticular, cD
galaxies: evolution
galaxies: formation
galaxies: fundamental parameters
galaxies: general
galaxies: groups: general
galaxies: groups: individual (..., ...)
galaxies: halos
galaxies: high-redshift
galaxies: individual (..., ...)
galaxies: interactions
galaxies: irregular
galaxies: ISM
galaxies: jets
galaxies: kinematics and dynamics
galaxies: luminosity function, mass function
galaxies: magnetic fields
galaxies: nuclei
galaxies: peculiar
galaxies: photometry
galaxies: Seyfert
galaxies: spiral
galaxies: star clusters: general
galaxies: star clusters: individual (..., ...)
galaxies: star formation
galaxies: starburst

galaxies: statistics
galaxies: stellar content
galaxies: structure
Galaxy components
Giant galaxies
High-redshift galaxies
Infrared excess galaxies
Interacting galaxies
Irregular galaxies
L galaxies
Late-type galaxies
Massive galaxies
Multiple galaxies
Nearby galaxies
Peculiar galaxies
Primordial galaxies
Protogalaxies
Quasar-galaxy pairs
Radio jets
Starburst galaxies

K7. Interstellar Medium (ISM)

(ISM:) cosmic rays
(ISM:) dust, extinction
(ISM:) evolution
(ISM:) Herbig–Haro objects
(ISM:) HII regions
(ISM:) photon-dominated region (PDR)
(ISM:) planetary nebulae: general
(ISM:) planetary nebulae: individual (..., ...)
ISM: abundances
ISM: atoms
ISM: bubbles
ISM: clouds
ISM: general
ISM: individual objects (..., ...) (except
ISM: jets and outflows
ISM: kinematics and dynamics
ISM: lines and bands
ISM: magnetic fields
ISM: molecules
ISM: structure
ISM: supernova remnants
planetary nebulae

K8. Physical Data & Processes

acceleration of particles
accretion, accretion disks
asteroseismology
astrobiology
astrochemistry
astroparticle physics
atomic data
atomic processes
black hole physics
chaos
conduction
convection
dense matter
diffusion
dynamo
elementary particles
equation of state
gravitation
gravitational lensing: micro
gravitational lensing: strong
gravitational lensing: weak
gravitational waves
hydrodynamics
instabilities
line: formation
line: identification
line: profiles
magnetic fields
magnetic reconnection
magnetohydrodynamics (MHD)
masers
molecular data
molecular processes
neutrinos
nuclear reactions, nucleosynthesis, abundances
opacity
plasmas
polarization
radiation mechanisms: general
radiation mechanisms: non-thermal
radiation mechanisms: thermal
radiation: dynamics
radiative transfer
relativistic processes

scattering
shock waves
solid state: refractory
solid state: volatile
turbulence
waves

K9. Planetary Systems

Asteroid belt
Cis-Neptunian objects
comets: general
comets: individual (..., ...)
Earth
Heliosphere
interplanetary medium
Interplanetary medium
Kuiper belt objects: individual (..., ...)
Kuiper belt: general
meteorites, meteors, meteoroids
Meteoroids
Meteors
Minor planets
minor planets, asteroids: general
minor planets, asteroids: individual (..., ...)
Moon
Natural satellites
OortCloud
Planetary rings
planet–disk interactions
planets and satellites: atmospheres
planets and satellites: aurorae
planets and satellites: composition
planets and satellites: detection
planets and satellites: dynamical evolution and stability
planets and satellites: formation
planets and satellites: fundamental parameters
planets and satellites: gaseous planets
planets and satellites: general
planets and satellites: individual (..., ...)
planets and satellites: interiors
planets and satellites: magnetic fields
planets and satellites: oceans
planets and satellites: physical evolution
planets and satellites: rings
planets and satellites: surfaces

planets and satellites: tectonics
planets and satellites: terrestrial planets
planet–star interactions
protoplanetary disks
Small solar system bodies
Solar neighborhood
Solar system planets
The Moon
Trans-Neptunian space
zodiacal dust

K10. Resolved and Unresolved Sources as a Function of Wavelength

gamma rays: diffuse background
gamma rays: galaxies
gamma rays: galaxies: clusters
gamma rays: general
gamma rays: ISM
gamma rays: stars
infrared: diffuse background
infrared: galaxies
infrared: general
infrared: ISM
infrared: planetary systems
infrared: stars
radio continuum: galaxies
radio continuum: general
radio continuum: ISM
radio continuum: planetary systems
radio continuum: stars
radio lines: galaxies
radio lines: general
radio lines: ISM
radio lines: planetary systems
radio lines: stars
submillimeter: diffuse background
submillimeter: galaxies
submillimeter: general
submillimeter: ISM
submillimeter: planetary systems
submillimeter: stars
ultraviolet: galaxies
ultraviolet: general
ultraviolet: ISM
ultraviolet: planetary systems
ultraviolet: stars

X-rays: binaries
X-rays: bursts
X-rays: diffuse background
X-rays: galaxies
X-rays: galaxies: clusters
X-rays: general
X-rays: individual (..., ...)
X-rays: ISM
X-rays: stars

K11. Stars

(stars:) binaries (including multiple): close
(stars:) binaries: eclipsing
(stars:) binaries: general
(stars:) binaries: spectroscopic
(stars:) binaries: symbiotic
(stars:) binaries: visual
(stars:) blue stragglers
(stars:) brown dwarfs
(stars:) circumstellar matter
(stars:) gamma-ray burst: general
(stars:) gamma-ray burst: individual (..., ...)
(stars:) Hertzsprung–Russell and C–M diagrams
(stars:) novae, cataclysmic variables
(stars:) planetary systems
(stars:) pulsars: general
(stars:) pulsars: individual (..., ...)
(stars:) starspots
(stars:) subdwarfs
(stars:) supergiants
(stars:) supernovae: general
(stars:) supernovae: individual (..., ...)
(stars:) white dwarfs
stars: abundances
stars: activity
stars: AGB and post-AGB
stars: atmospheres
stars: black holes
stars: carbon
stars: chemically peculiar
stars: chromospheres
stars: coronae
stars: distances
stars: dwarf novae

stars: early-type
stars: emission-line, Be
stars: evolution
stars: flare
stars: formation
stars: fundamental parameters
stars: general
stars: horizontal-branch
stars: imaging
stars: individual (..., ...)
stars: interiors
stars: jets
stars: kinematics and dynamics
stars: late-type
stars: low-mass
stars: luminosity function, mass function
stars: magnetars
stars: magnetic field
stars: massive
stars: mass-loss
stars: neutron
stars: oscillations (including pulsations)
stars: peculiar (except chemically peculiar)
stars: Population II
stars: Population III
stars: pre-main sequence
stars: protostars
stars: rotation
stars: solar-type
stars: statistics
stars: variables: Cepheids
stars: variables: delta Scuti
stars: variables: general
stars: variables: RR Lyrae
stars: variables: S Doradus
stars: variables: T Tauri, HerbigAe/Be
stars: winds, outflows
stars: Wolf–Rayet

K12. The Galaxy

(Galaxy:) globular clusters: general
(Galaxy:) globular clusters: individual (..., ...)
(Galaxy:) local interstellar matter
(Galaxy:) open clusters and associations: general

(Galaxy:) open clusters and associations: individual (..., ...)
(Galaxy:) solar neighborhood
Galaxy classification systems
Galaxy cluster counts
Galaxy clusters
Galaxy collisions
Galaxy components
Galaxy counts
Galaxy distances
Galaxy distribution
Galaxy dynamics
Galaxy encounters
Galaxy evolution
Galaxy formation
Galaxy groups
Galaxy interactions
Galaxy kinematics
Galaxy mergers
Galaxy pairs
Galaxy photometry
Galaxy rotation curves
Galaxy triplets
Galaxy voids
Galaxy: abundances
Galaxy: bulge
Galaxy: center
Galaxy: disk
Galaxy: evolution
Galaxy: formation
Galaxy: fundamental parameters
Galaxy: general
Galaxy: halo
Galaxy: kinematics and dynamics
Galaxy: nucleus
Galaxy: stellar content
Galaxy: structure

K13. The Sun

(Sun:) solar wind
(Sun:) solar–terrestrial relations
(Sun:) sunspots
CNO anomaly
Helioseismology
Solar abundances

Solar activity
Solar atmosphere
Solar electromagnetic emission
Solar faculae
Solar filaments
Solar flares
Solar granulation
Solar interior
Solar magnetism
Solar motion
Solar oscillations
Solar particle emission
Solar properties
Solar radiation
Solar rotation
Solar spicules
Solar surface
Solar transition region
Solar wind
Sun: abundances
Sun: activity
Sun: atmosphere
Sun: chromosphere
Sun: corona
Sun: coronal mass ejections (CMEs)
Sun: evolution
Sun: faculae, plages
Sun: filaments, prominences
Sun: flares
Sun: fundamental parameters
Sun: general
Sun: granulation
Sun: helioseismology
Sun: heliosphere
Sun: infrared
Sun: interior
Sun: magnetic fields
Sun: oscillations
Sun: particle emission
Sun: photosphere
Sun: radio radiation
Sun: rotation
Sun: transition region
Sun: UV radiation
Sun: X-rays, gamma rays
Sunspots

Appendix – III: Mapping the Growth models of 13 sub-fields of Space Science

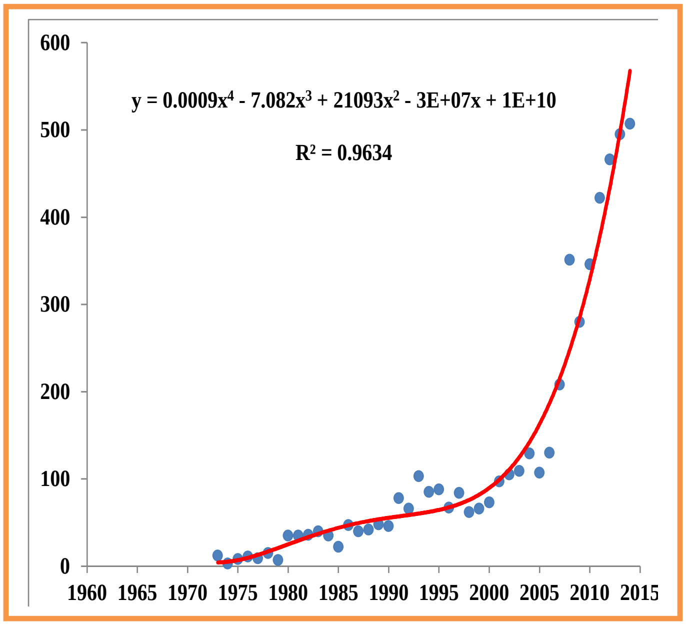

Figure 7.1: MAS

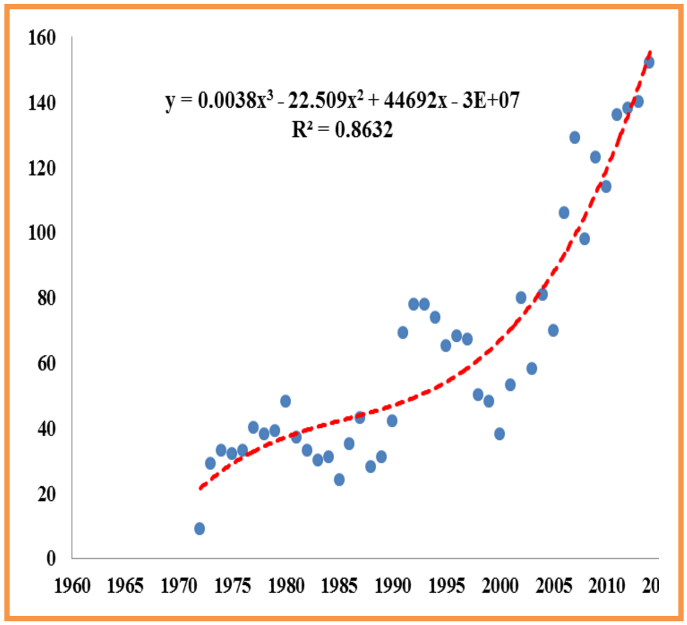

Figure 7.2: IMG

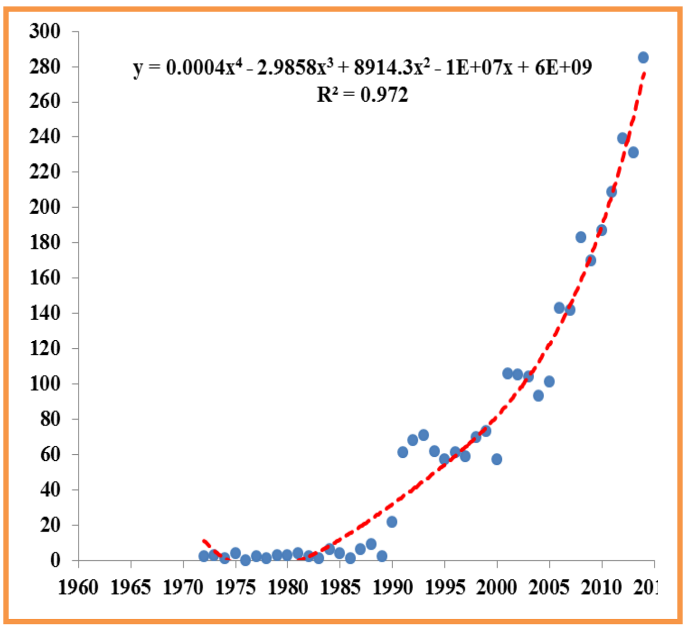

Figure 7.3: ACM

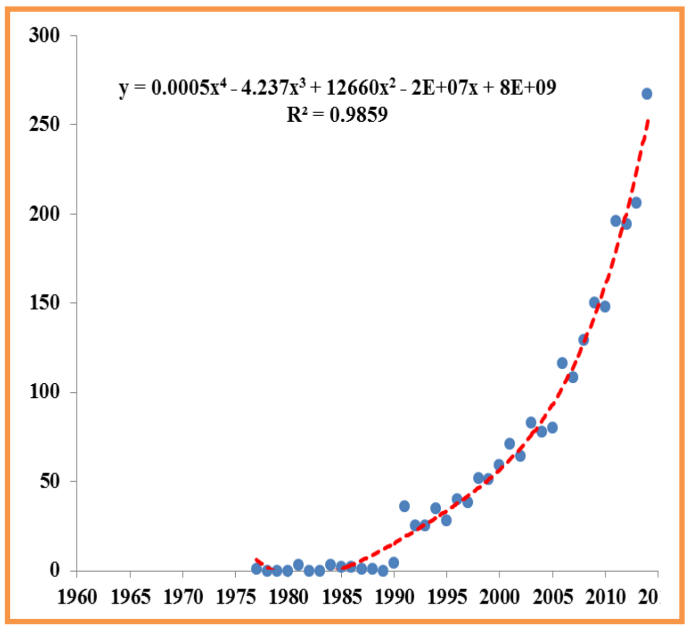

Figure 7.4: AIMT

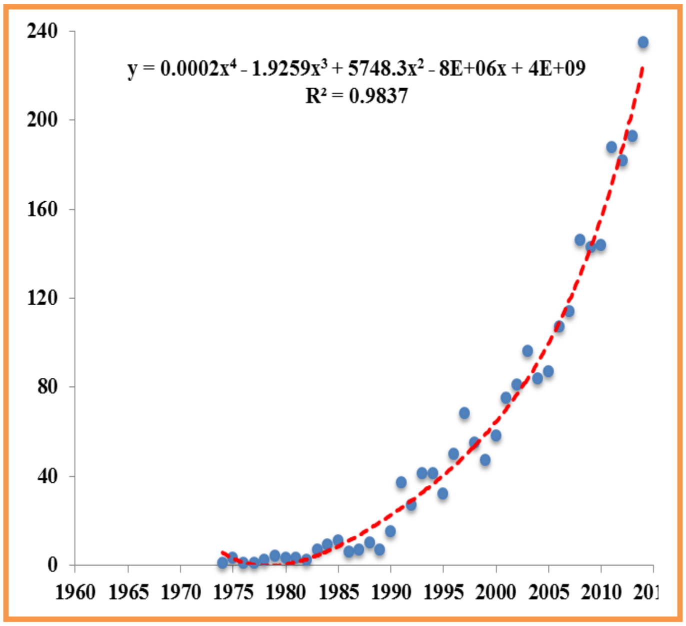

Figure 7.5: Cosmology

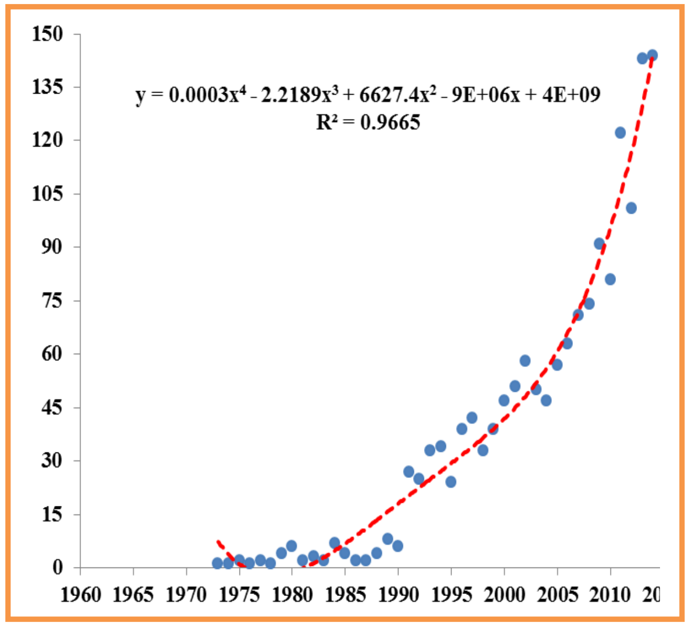

Figure7.6: Galaxies

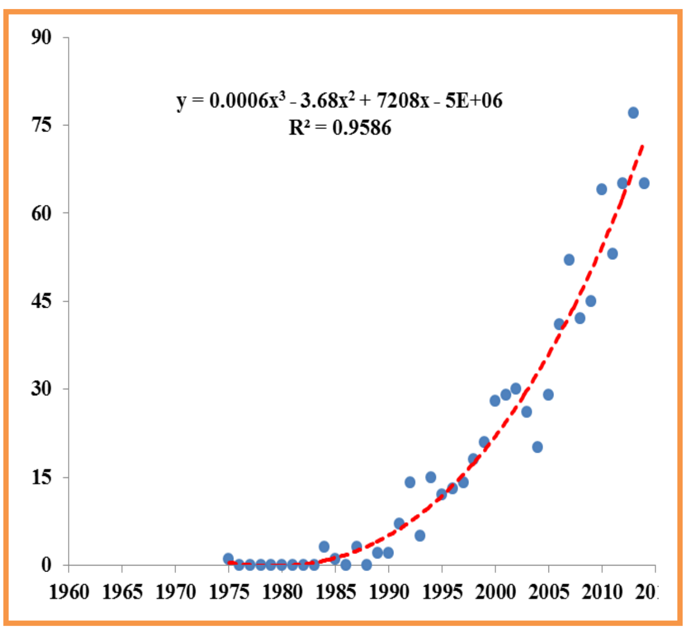

Figure7.7: ISM

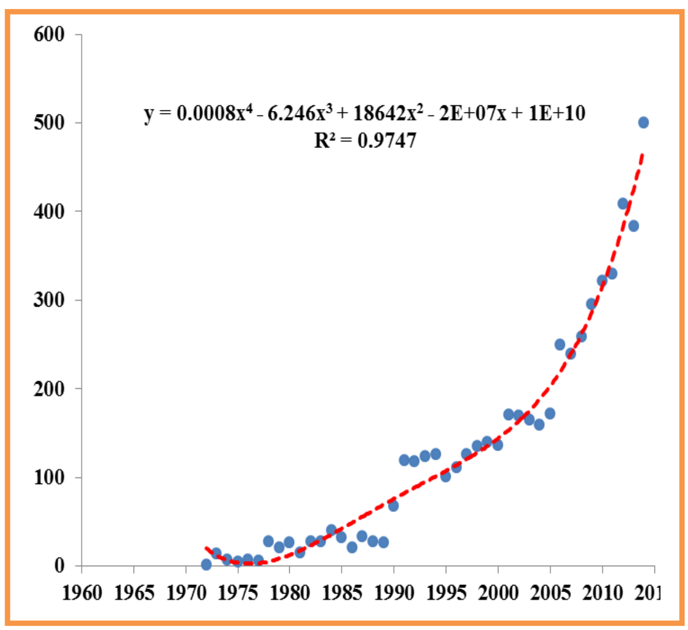

Figure 7.8:PDP

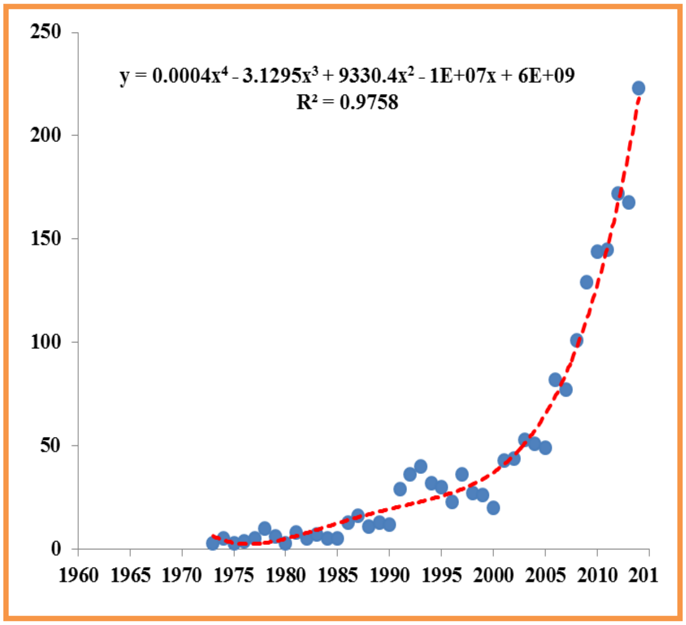

Figure 7.9: Planetary System

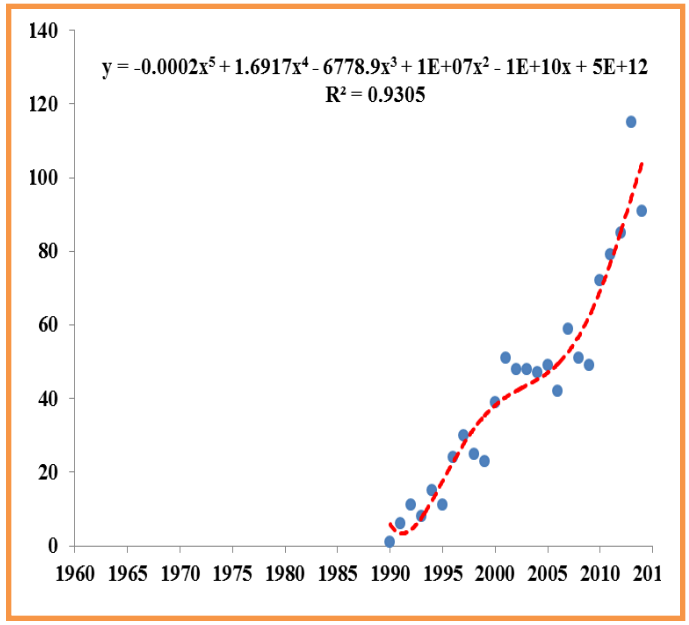

Figure 7.10: RUSWF

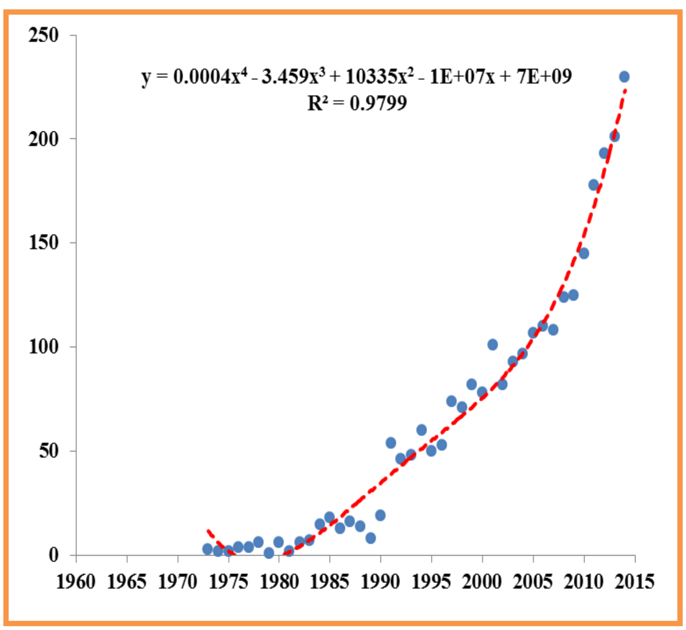

Figure 7.11: Stars

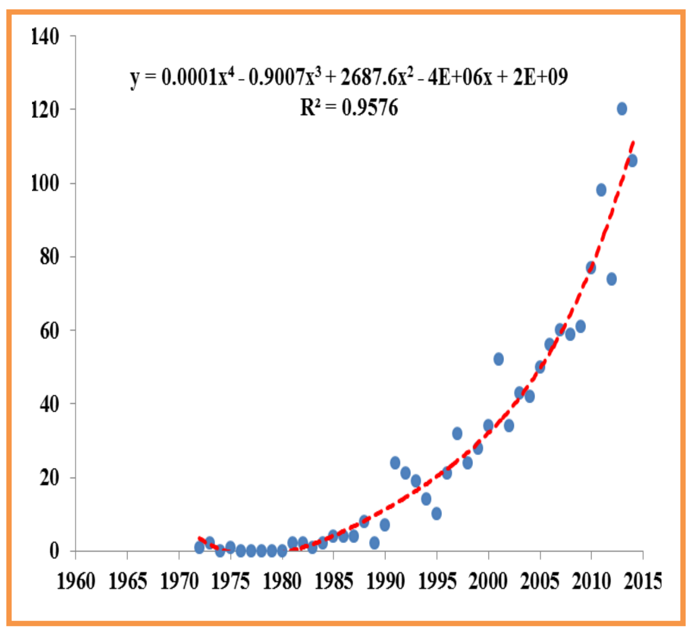

Figure 7.12: The Galaxy

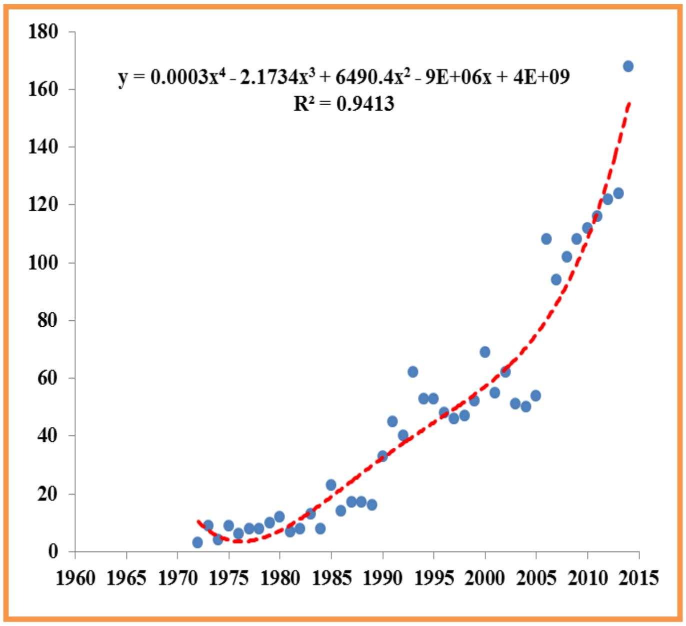

Figure 7.12: The Sun

Figure7.1-7.13: Growth model of 13 sub-fields of Space Science

Appendix –III: Collaboration (Continent wise) of Sub-fields of Space Science Research

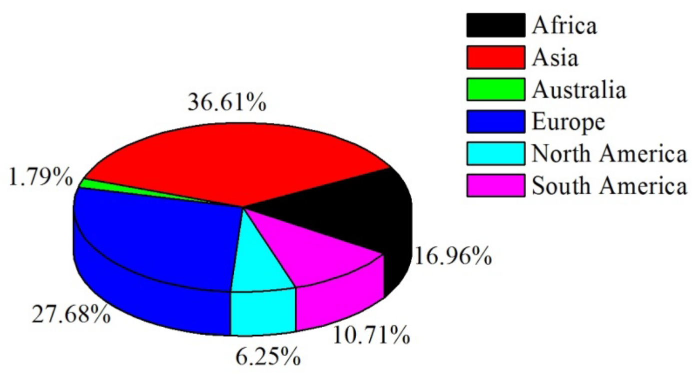

Figure 8.1: MAC

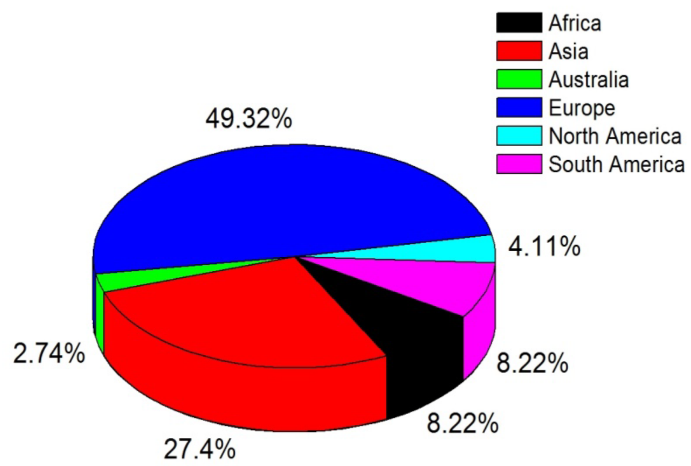

Figure 8.2: IMG

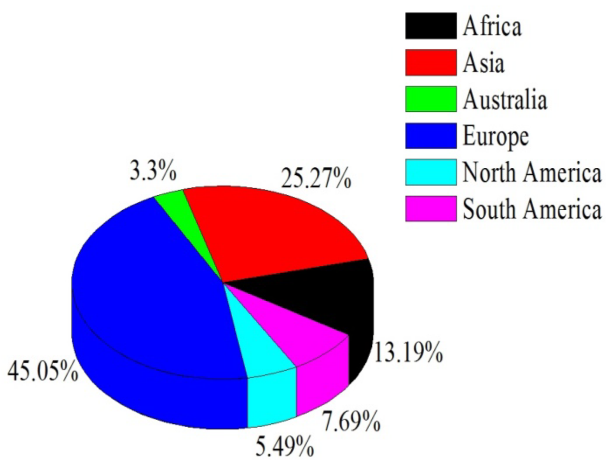

Figure 8.3: ACM

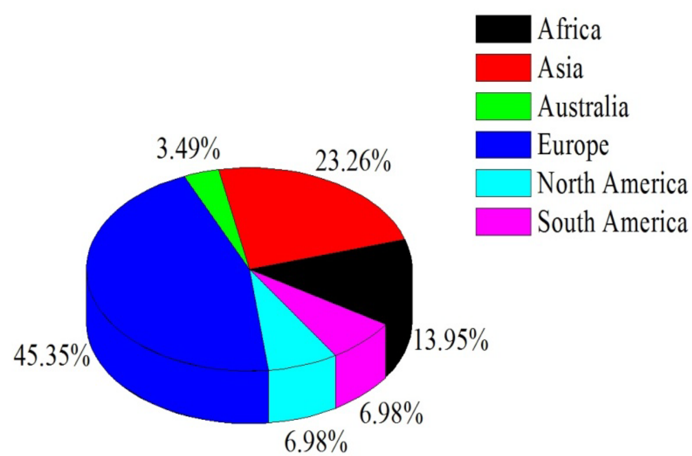

Figure 8.2: AIMT

Appendix –III: Collaboration (Continent wise) of Sub-fields of Space Science Research

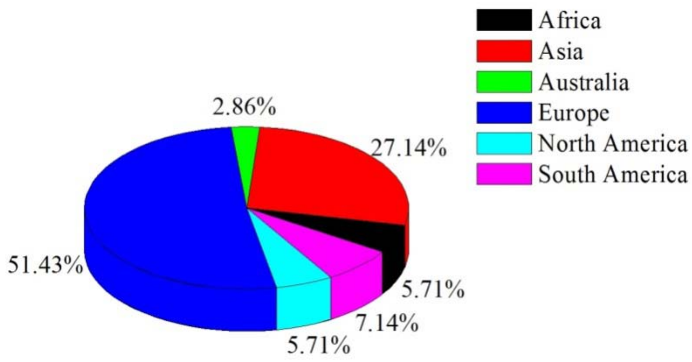

Figure 8.3: Cosmology

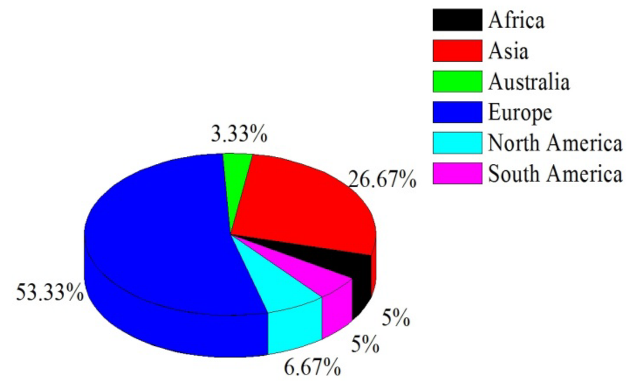

Figure 8.6: Galaxies

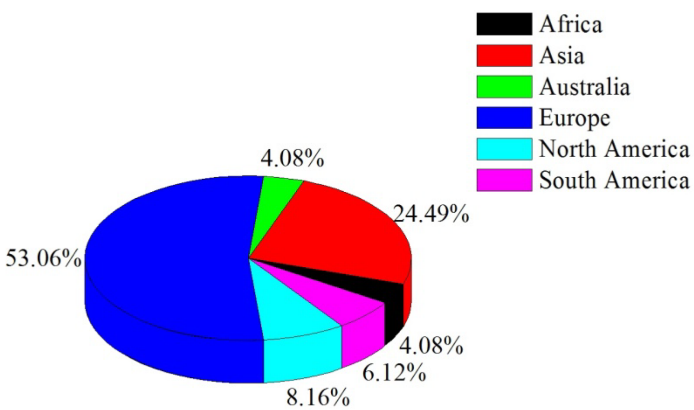

Figure 8.7: ISM

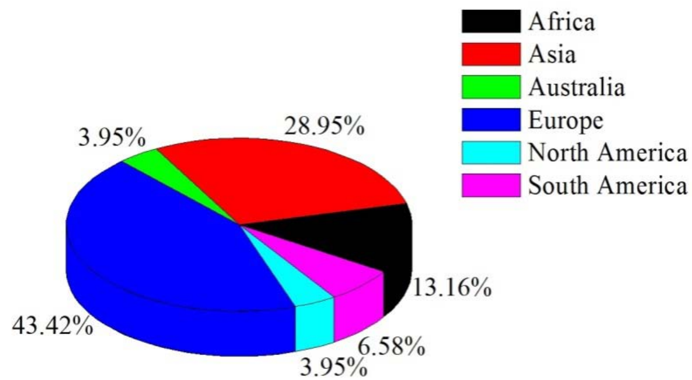

Figure 8.4: PS

Appendix –III: Collaboration (Continent wise) of Sub-fields of Space Science Research

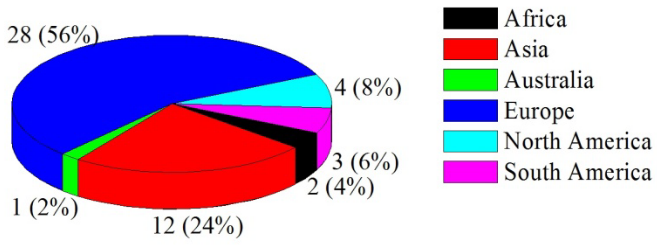

Figure 8.5: RUSW

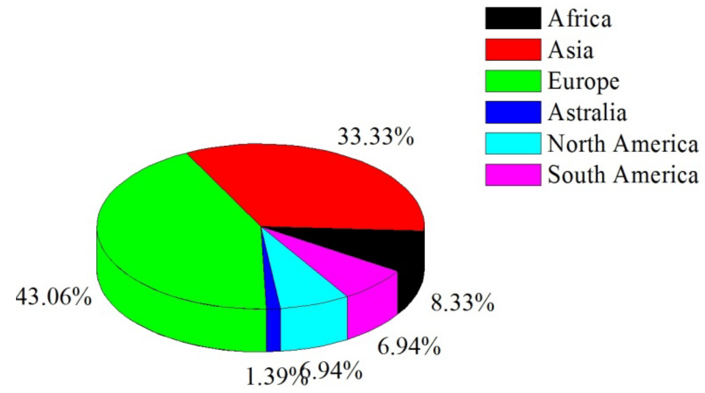

Figure 8.70: Stars

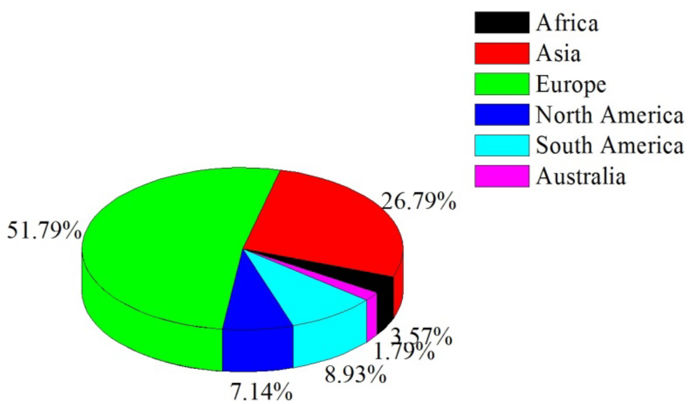

Figure 8.61: The Galaxy

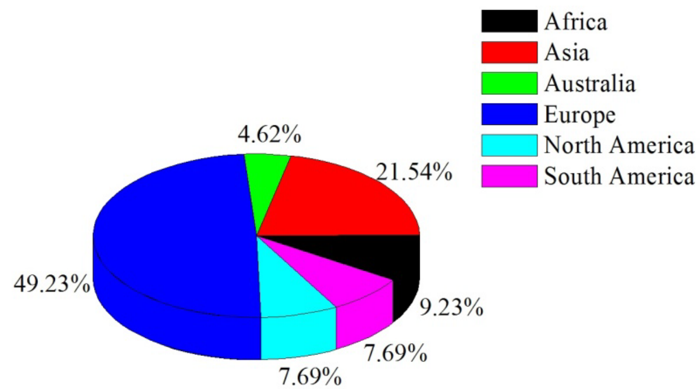

Figure 8.8: The Sun

Appendix –III: Collaboration (Continent wise) of Sub-fields of Space Science Research

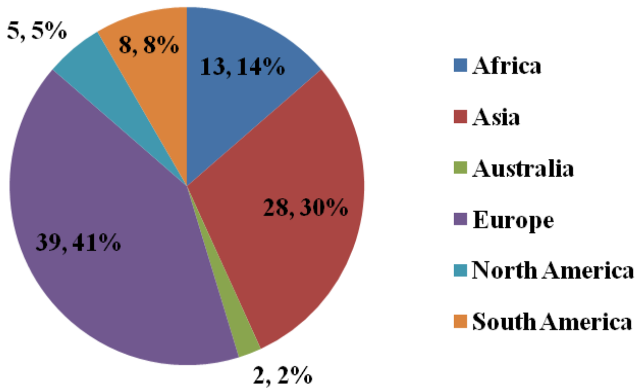

Figure 8.9: PDP

Figure 8.1-8.13: Continent Collaboration of 13 sub-field of Space Science

ACM: Astrometry and Celestial Mechanics; **AIMT**: Astronomical Instrumentation, Methods and Techniques; **IMG**: Ionosphere, Magnetosphere and Geomagnetism; **ISM**: Interstellar Medium; **MAS**: Meteorology & Atmospheric Science; **PDS**: Physical Data and Processes; **PS**: Planetary Systems; **RUSFW**: Resolved and Unresolved Sources as a Function of Wavelength

Appendix-IV: Keyword Cluster of Sub-fields of Space Science Research

Astronomy& Astrophysics

ACM
Stars
Model
Time
Universe
Region

Cosmology
Theory
Redshift
Observations
Dark Energy
Cosmological constant

AIMT
Telescopes
Methods: Data analysis
Methods: Numerical
Instrumentation: Detectors
Techniques: Spectroscopic

Galaxies
Individual
Active
Clusters
Evolution
Quasars

RUSFW
X-rays : stars
radio continuum : galaxies
X-rays : binaries
X-rays : galaxies
infrared: stars

PS
Comets
Earth
Meteorites
Formation
Moon

ISM
Clouds
Lines
Dust
Evolution
General

Stars
Emission
Evolution
Supernovae
Binaries
Neutron

The Galaxy
Structure
Evolution
Disk
Dynamics
Formation

The Sun
Corona
Flares
Magnetic Fields
Coronal Mass Ejections
Activity

Aeronomy

MAS
El-nino
Aerosol
Rain
Monsoon
Ocean

IMG
Plasma
Waves
Irregularities
Spread-f
F-region

PDP
Waves
Radiation
Polarization
Scattering
Magnetic fields