PLANEX

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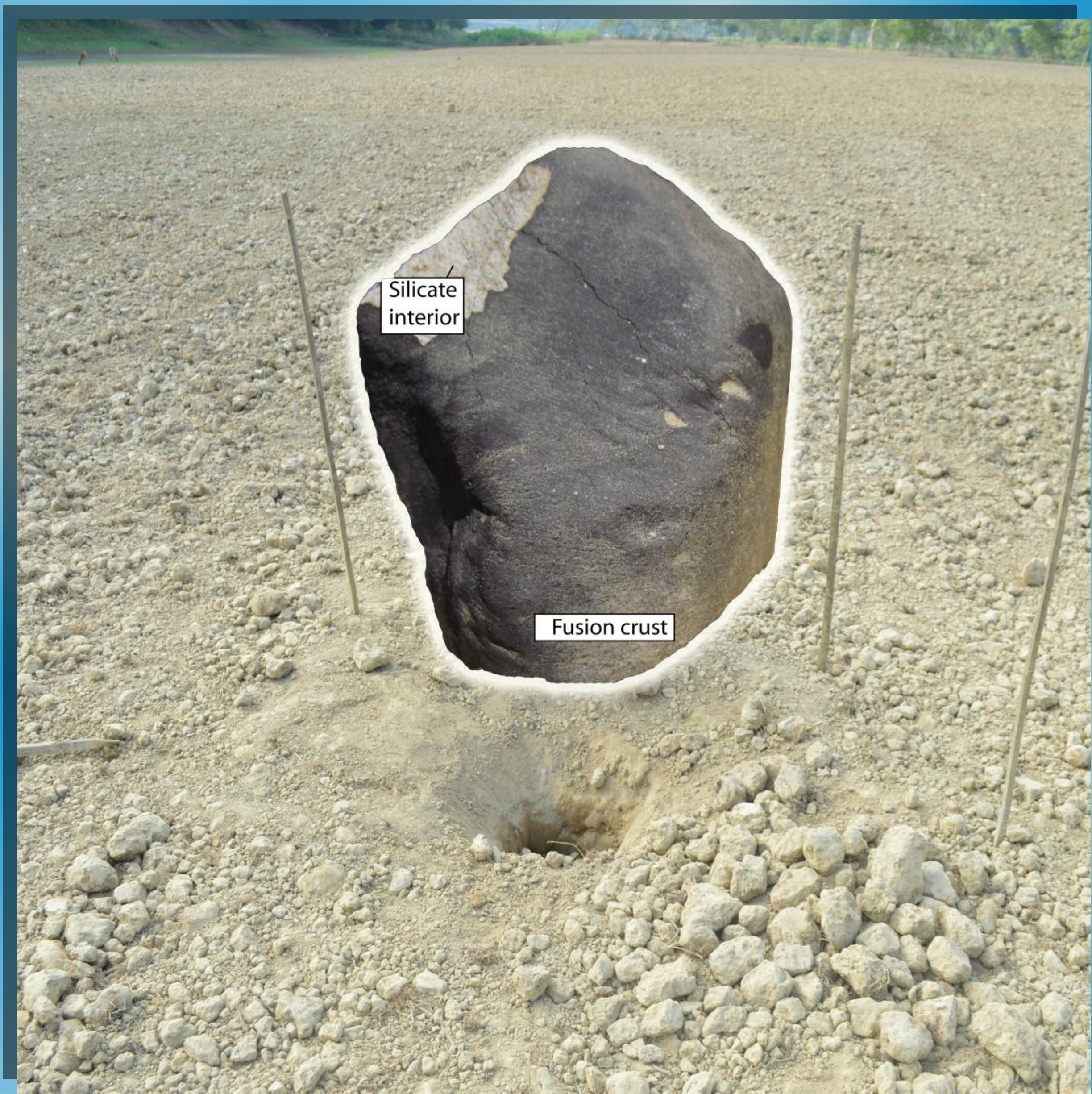
Newsletter



PLANEX

CONTENTS

EDITORIAL BOARD

COVER PAGE

The front page highlights recent meteorite fall near Komargaon town,Assam.The meteorite fell on Nov. 13, 2015. A picture of the meteorite is shown at the centre where the silicate interior and the fusion crust can be clearly distinguished. Shown in the background is the area of the meteorite fall and the crater formed due to the fall. An interesting article about this meteorite is published in this issue.

EDITOR'S DESK

Dear Readers

Wish you all a New Year filled with new accomplishments and novel achievements! Let there be more exciting activities in the planetary sciences and may we bring more interesting things for you to read!

Several interesting discoveries have been made from Chandrayaan-1 data. One of the intriguing ones was the first direct detection of high concentration of Na on the lunar surface by the X-ray spectrometer onboard - C1XS. Dr. P. Subramania Athiray of Manipal Centre for Natural Sciences, Karnataka provides an account of this discovery describing the procedures involved in the data analysis and discussing the plausible implications of this finding. Many of the recent findings from Chandrayaan-1, LRO and Kaguya have changed the age long perception for the Moon that it is geologically inactive. Prof. S. Mukherjee & Ms. Priyadarshini Singh of JNU, New Delhi provide an account of one such study revealing possibility of recent localized tectonic activities on the Moon using Mini-SAR (Chandrayaan-1) & LROC (Lunar Reconnaissance Orbiter) data.

Meteorite collection exercise is an exciting activity for geologists and cosmochemists. On November 13, 2015, a meteorite fell near Komargaon town (lat: 26°39′N; long: 93°46′E) of Golaghat District, Assam. A team from Dibrugarh University led by Dr. T. K. Goswami and Dr. Dwijesh Ray from PRL share their experiences from the field & some preliminary findings for this newly arrived sample from space.

Towards advances on the technological front, Dr. P. Rangababu of National Institute of Technology, Meghalaya, presents an article on FPGA based System on Chip for Space computation, highlighting the concept involved and utility in Planetary Exploration & Astronomy.

Regular columns such as News Highlights & Mission Updates continue to update you with novel findings & developments in the subject across the globe. The Mission Story describes the Venus Express mission of ESA. On the Back Page Prof. K.S. Baliyan of PRL provides glimpses of inception and development of the observatory at Mt. Abu, Rajasthan.

Before signing off, I bid farewell to our advisor Prof. S.V.S. Murty, a core member of the newsletter team since its inception. Also, I would like to acknowledge all the contributors of this issue from outside the editorial team.Best Regards,

Happy Reading
Enjoy !

Neeraj Srivastava

READER'S COLUMN

....Thank for the issue. It has come out really nicely.......

Prakash Chauhan
Space Applications Centre, Ahmedabad

.....Thanks for the recent edition of PLANEX News Letter. I always enjoy getting updated about the broad-spectrum of research happening across our planet......

A.S. Arya
Space Applications Centre, Ahmedabad

......It was so wonderful to look at the next issue of the PLANEX Newsletter. I will print this and keep it in my lab. Thank you. All the best for the upcoming issues.....

Indhu Varatharajan
Department of Physics and Astronomy, UC-London

......Many thanks and congratulations for the current issue of the Planex Newsletter. It started like a small experiment and thankfully developed into a permanent feature of PLANEX due to your dedicated effort......

Jayanta Kumar Pati
University of Allahabad, Allahabad

......The article "worlds beyond our own" (Oct 2014) has been very much appreciated, so much so that they want it to be used as a role-model paper for the new JRFs in PRL. I thought I should bring it to your notice......

Ashok K Singal
Physical Research Laboratory, Ahmedabad

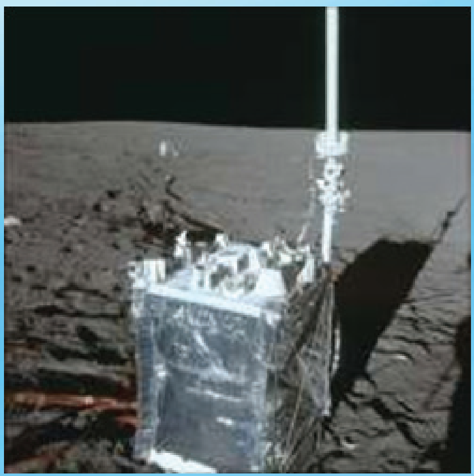
.........It is a beautifully written paper. It is also full of subtle humour, e.g,, if we cannot communicate, we should try to listen. This is so true even in everyday life. I seek your permission to circulate this paper among JRF 2015 as a model paper. Keep up the good work. All the best......

J. Banerji
Physical Research Laboratory, Ahmedabad

NEWS HIGHLIGHTS

Sunrise-driven movements of dust on the Moon

Apollo 12 was a manned flight launched in 1969 by NASA to land on the Moon. The rocket exhausts had disrupted lunar fines and dust storm was created by sunlight at the sunrise time. The Apollo 12 rocket exhausts had disrupted about 2000 kg of smooth fine dust and subsequently the first sunrise after the mission caused dust storms across the site. Later on, a few weaker dust storms were started at the sunrise and Eastern horizon was brightened. The Ground truth measurements were made by a Dust Detector Experiment 100 cm above the surface by Apollo 12 Dust Detector Experiment invented in 1966. During two lunar days after the first sunrise, horizontal solar cells were covered with ~30 % of total dust measured over a span of six years. East-facing vertical solar cell measured horizon brightening on 14th of the initial 17 lunations, and nothing later in 61 lunar days. Based on such measurements, researchers have proposed a sunrise-driven transport model for dust particles freed by Apollo 12 activities. Sudden surface charging is caused by each sunrise and, dust is mobilised and lofted during first few hours. This cautions future landing missions on airless bodies regarding dust hazards after each of the first few sunrises. However, regular natural mitigations of dust consequences are offered and fears of having excessive fine dust globally around the Moon are reduced by the sunrise-driven microscopic smoothing.



Close up of Dust Detector Experiment.
Source: http://phys.org/news/2015-10-uncovers-horizon-mystery-moon.html

Source: http://www.sciencedirect.com/science/article/pii/S0032063315002792

First science results from Mars Orbiter Mission - Estimation of dust variability and scale height in the Valles Marineris on Mars

ISRO's Mars Orbiter Mission (MOM), which created history on reaching the orbit of Mars in its first attempt, has now entered into a phase wherein the acquired datasets are being analysed to demonstrate what potential scientific information about Mars can be derived using them. In a recent study, data have been gathered to conduct temporal analysis of bright hazes observed within Valles Marineris using MOM Mars Colour Camera (MCC) images. It has been noted from the MCC images corresponding to acquisition dates of Oct. 28 (orbit 34), Dec. 5 (orbit 49) and Dec. 13 (orbit 52) 2014 that the valley was initially masked by a thick layer of haze (orbit 34) that reduced to an extent during orbit 49, which again reappeared on orbit 52 (after eight days). In addition, using the contrast comparison of MCC stereo images with 'stereo method', optical depth of Martian atmosphere as a function of altitude has been estimated over the northern and southern walls of Valles Marineris near Coprates Chasma region. This estimation has led to interpretation of possible lee-wave cloud over the southern wall of Valles Marineris. This study, as for now, is the first science result construed using MCC images thereby demonstrating the mapping potential of MCC and motivating several researchers working in similar lines to incorporate MOM datasets in their analysis.
Source: http://www.sciencedirect.com/science/article/pii/S0019103515004832

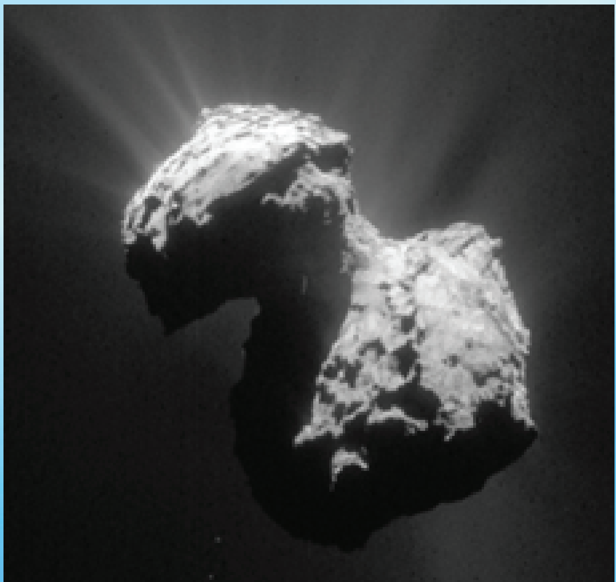
Dust observations at orbital altitudes surrounding Mars

Dust devils are known to occur near the Mars surface and may lift the surface dust to altitudes as high as ~50 km. Atmospheric dust may be normally seen within ~150 km from the surface and no known process can lift appreciable amount of particles above ~150 km. Mars Atmosphere and Volatile EvolutioN (MAVEN) mission was launched in 2013 to study how the planet's atmosphere and water were lost over time. Recent research has reported observations of dust at altitudes ranging from ~150 to above ~1000 km by the Langmuir Probe and Wave instrument on MAVEN. From the dust distribution, authors have interpreted it to be interplanetary in origin. With the assumption of typical grain velocity as ~18 km per second and comparison with laboratory measurements, the dust grain size has been estimated from 1 to 12 µm. The direct observation of dust in Martian atmosphere can improve the understanding of the sources, sinks as well as transport of IDP throughout the inner solar system and also, the associated impacts on Mars's atmosphere.

Source: https://www.sciencemag.org/content/350/6261/aad0398.full

Plentiful molecular oxygen in the comet 67P/ Churyumov–Gerasimenko

From the Rosetta mission, a recent report of molecular oxygen on comet 67P follows another early report on the presence of molecular nitrogen. Therefore, now we can claim with confidence that the cometary nucleus is also a reservoir of simple and super volatile molecules. Though radiolysis of water and carbon dioxide provides molecular oxygen, the amount of molecular oxygen observed suggests that molecular oxygen was trapped in the nucleus of the comet during its formation and is released in phases as more and more subsurface layers are exposed. The finding has an important implication to astrobiology, as comets are known to be the source of water on planet Earth, with the recent finding of molecular oxygen, comets seems to have the necessary ingredient from simple to complex molecules to kick start and support life.



Comet 67P/ Churyumov–Gerasimenko
Image credit: ESA/Rosetta/NAVCAM

Source: http://www.nature.com/nature/journal/v526/n7575/full/nature15707.html

Summarized By: Bhala Sivaraman, PRL Ahmedabad

An insight from eucrite and angrite meteorites

Understanding the evolution of differentiated bodies in the solar system is important for constraining the evolutionary history of formation of crust, mantle and core. Therefore, the study of meteorites belonging to differentiated classes is necessary. In one of the recent researches, eucrites and angrites (both are differentiated meteorites) were studied to understand the evolutionary paths of crustal reservoirs using the ^{147}Sm-^{143}Nd and ^{176}Lu-^{176}Hf systematics. In the study, it has been shown that there is protracted magmatism within deep crustal layers of eucritic parent body. Further, the study substantiates that the magmatism to have occurred about ~50 Ma, subsequent to the formation of the solar system. This study has a significant bearing on understanding the differentiation processes in other planetary bodies namely Moon, Mars and Earth.

Source: http://onlinelibrary.wiley.com/doi/10.1111/maps.12553/abstract

Summarized By: Ramakant Mahajan, PRL Ahmedabad

Shocked Zircon from terrestrial Impactite: A Planetary Perspective?

The missing record of terrestrial impacts is paradoxical as most of the older impact structures are either eroded or buried over the geological time period. Zircon, due to its high resistivity is capable of retaining the evidences of ancient impacts on Earth. With the advancement of analytical instruments, using electron nano beam technique and isotopic measurements of zircon, an unequivocal formation and degradation history of the oldest (2.02 Ga) and largest (250-300 km) terrestrial multi ring impact basin – Vredefort dome, South Africa has been determined. However, the ex situ shocked zircons from terrestrial impacts differ significantly from zircons reported from the lunar impactite in terms of the rarity of diagnostic shock induced microstructures (e.g. planar deformation features) in the lunar zircon. Based on different morphotypes and careful examination by Electron backscatter diffraction mapping and sensitive high-resolution ion microprobe analyses, zircon from terrestrial impact structures are found useful to yield a very precise U-Pb age of the impact event. The proper identification and documentation of confirmed shock features that enable complete age resetting of ex situ zircon are therefore prerequisite and this study can also qualify for a potential analog to infer shocked zircon-based chronologies for Moon and other rocky planetary bodies of solar system to reconstruct the early impact history.

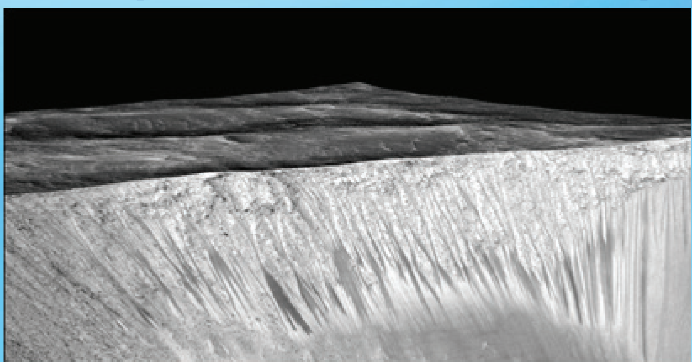
Source: http://geology.gsapubs.org/content/43/11/999

News Highlight Summarized By: Dwijesh Ray, PRL Ahmedabad

Recurring Slope Lineae (RSL) in the Northern Plains of Mars

RSLs (Recurring Slope Lineae) on Mars are narrow, linear features (~0.5 to 5 m wide) with low-albedo, which were first captured in 2011 through high-resolution images acquired by HiRISE (on-board Mars Reconnaisance Orbiter). RSLs are known to descend down steep slopes of craters or hill-sides;

which appear and fade away seasonally and have tendency to reappear yearly. Until now, formation and detection of RSLs was usually constrained to southern mid-latitudes in seasons of high surface temperature (~300 K). But they have also been observed at two locations in the northern plains near Chryse Planitia and Acidalia Planitia at a time when brines supposedly start flowing before the onset of the northern spring equinox and was found to prolong for more than 500 sols (half a Mars-year). Surface temperatures measured using Thermal Emission Spectrometer (TES) indicated values of 238-252K and that the briny flows occurred only in the top ~8 cm of the regolith. These RSLs were found to have a water budget of ~1.5 - 5.6 m^3 per m of headwall, which was subsequently interpreted that this high water budget makes annual recharge through the atmospheric or subsurface diffusion unlikely. The following chronological event was proposed to explain the formation and flow of RSLs. In late autumn, an ice dam is created when the shallowest part of the brine is exposed to the cold Martian temperatures. This stays static until spring arrives and the dam is breached, leading to lengthening of RSL (~1.86 m/sol). As time passes, equilibrium is attained between losses to atmosphere and discharge rate. As autumn approaches, another ice-dam is created as surface temperatures decline rapidly and the water in the brine sublimes out. This northern mid latitude RSL are active for a much longer duration than standard southern mid-latitude RSL, which indicates that RSL at different latitudes have varying source types and regions. Source: http://www.sciencedirect.com/science/article/pii/

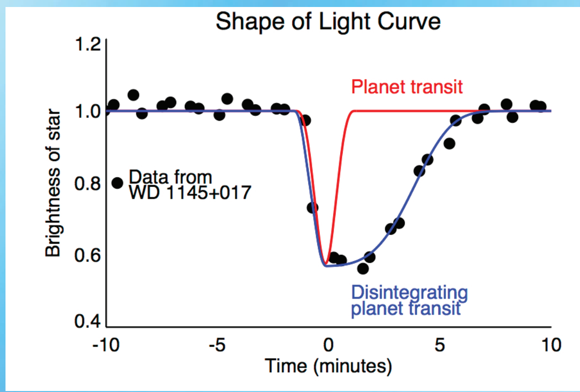


Examples for dark, narrow recurring slope lineae (RSL) streaks emanating from the walls of Garni Crater on Mars. Image Credit: NASA/JPL-Caltech/Univ. of Arizona

S001910351500473X

A comet-like object transiting a white dwarf

In a recent paper in Nature, Vanderburg et al. (Nature, 526, 546–549) discuss the interesting scenario of a white dwarf being orbited by rocky material with a very short period below 5 hours. Generally one expects that all heavy elements would sink into the stellar interior of the white dwarf, but the abundance ratios of heavy elements in white dwarf atmospheres are rather similar to the ratios found in rocky bodies of the Solar system. It had been proposed that the atmospheres were being polluted by dusty material from rocky minor bodies in close orbit around the white dwarfs. Vanderburg et al. discuss observations of WD 1145+017 which shows signatures of a minor body transiting the white dwarf every 4.5 to 5 hrs. The asymmetric light curves with varying depth of eclipse (up to 40% of light from the white dwarf gets blocked) indicate a small object with a cometary tail consisting mainly of dusty outflowing material. The star's spectrum shows strong signatures of heavy elements and has a dusty debris disk. Thus, the authors suggest, that this system provides evidence of white dwarf atmosphere pollution by broken up rocky bodies in close orbit.



When an Earth-size planet passes in front of a star, it creates a symmetric dip in the star's light that's shaped like the red curve here. But astronomers detected the strange-looking, blue dip in light from the white dwarf 1145+017. The team suspects the signal comes from a tiny disintegrating planet or asteroid and its comet-like dusty tail. The black dots are measurements recorded by the Kepler spacecraft during its K2 mission. Image Credits and source: CfA / A. Vanderburg - See more at: http://www.skyandtelescope.com/astronomy-news/white-dwarf-eats-planet2610201523/#sthash.wFbWcnJV.dpuf

Summarized By: Shashikiran Ganesh, PRL Ahmedabad.

Indirect evidence for surface frost at Gale crater, Mars

The Curiosity (Mars Science Laboratory) rover has travelled almost 13 km on the floor of Gale crater till date and has traversed numerous places of geological significance. Through the period of its traverse, it has covered approximately 1200 sols that span close to two full Martian years (more than three Earth years). During these two years, it has encountered distinct Martian

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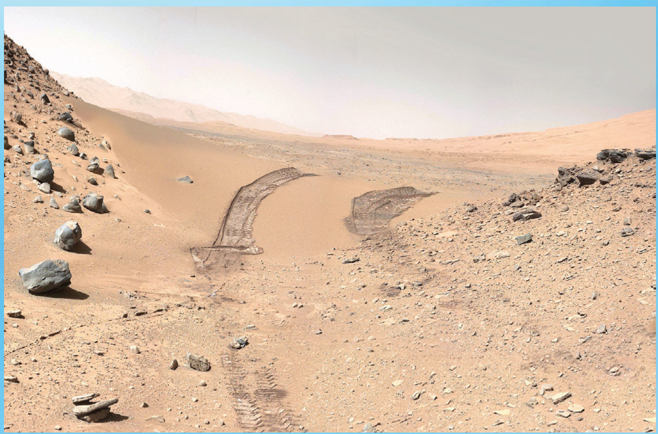
seasons, similar to those back on Earth, thanks to Mars' tilt of about 25°. During the latter part of the first Martian year, the rover, equipped with sensors to measure the surface temperature, pressure and humidity, along with ambient temperature, took several measurements along the way. On one of these events, at a place called Dingo Gap (between sols 529 and 535), researchers have claimed they have indirect evidence that supports frost on the surface at that particular location. The scientist's claims are also substantiated by the fact that when the rover was at Dingo Gap, the season was winter (which means the coldest and most humid part of the year) and the probability of encountering frost on the surface was the most. Moreover, the regional geology of the area consists of loose rocks and small particles of sand and dust with relatively low values of thermal inertia (TI) as compared to the landing site (where thermal inertia was high). This bit of information was important since surfaces with remarkably low TI would actually permit frost to form. Apart from Dingo Gap, the scientist suggest similar conditions prevailed at three other locations: unnamed location (sol 554-560), Kimberley (sol 609-617) and another unnamed location (sol 673-676). The thickness estimate of the frost layer was put at a few tenths of micrometers. At these low latitudes (4°S), water is most likely to exist in the form of frost, as evidenced by the study.



A mosaic obtained from multiple images captured by the Mastcam camera on-board Curiosity, showing the Dingo Gap megaripple in Gale Crater, Mars, where most likely frost events occured.

Image credits: http://www.theskyscrapers.org/stuff/contentmgr/files/2/c05273df6c8dcc82b-c94b730f0d133d6/images/dingo_gap_mosaic_lr.jpg

Source:- http://www.sciencedirect.com/science/article/pii/S0019103515005540

FLASH NEWS

» Higher concentrations of silica reported from MSL
Link: http://www.sciencedaily.com/releases/2015/12/151217143352.htm

» Giant comets and early earth
Link: http://www.sciencedaily.com/releases/2015/12/151222082339.htm

» Innermost inner core of Earth
Link: https://www.sciencenews.org/article/solid-inner-inner-core-may-be-relic-earth%E2%80%99s-earliest-days?mode=topic&context=39&tgt=more

» Lunar crater ejecta through radar and thermal data
Link: http://www.sciencedirect.com/science/article/pii/S0019103515005679

» Hydrous minerals on Martian crater central peaks
Link: http://onlinelibrary.wiley.com/doi/10.1002/2015JE004918/full

» Habitable exoplanets need right stuff
Link: https://www.sciencenews.org/article/exoplanets-need-right-stuff-be-habitable?mode=topic&context=39&tgt=more

» Understanding and constrains in formation of peak ring basins
Link: http://www.sciencedirect.com/science/article/pii/S0019103515005527

» Lunar subsurface through Chang`E-3 radar
Link: http://www.sciencedirect.com/science/article/pii/S0032063315003190

» Exoplanets atmosphere are diverse: observations from Hubble
Link: http://www.sciencedaily.com/releases/2015/12/151214130524.htm

» Auroras on other planets
Link: http://www.space.com/31172-whats-it-like-to-see-auroras-on-other-planets.html

» Rocky planets form by which kind of stars
Link: http://www.spacedaily.com/reports/What_kinds_of_stars_form_rocky_planets_999.html

» Is Ceres extensively contaminated with meteoritic debris?
Link: http://onlinelibrary.wiley.com/doi/10.1002/2015GL065601/full

First direct detection of Sodium on lunar surface from the Chandrayaan-1 X-ray Spectrometer (C1XS)

Introduction

The study of origin and evolution of the Moon has generated scientific curiosity for a long time. With improved technology, larger telescopes and better scientific instruments the lunar surface has revealed and created many more research interests. The surface exploration of the Moon gained momentum soon after samples were brought back by the Apollo and Luna missions. Since then, various remote-sensing experiments explored the lunar surface at multi-wavelengths. Chandrayaan-1, India's first lunar mission was launched on 22nd October 2008 and was in operation until August 2009.

Returned samples by Apollo and Luna missions have given us precise chemical and isotopic composition for samples of specific localities on lunar surface. Space-based remote sensing measurements can enrich our knowledge with a global view of lunar surface chemistry compared to localized findings from landing sites. Even after more than five decades of lunar space exploration, many scientific questions regarding the formation and evolution of the Moon remain unanswered. Diversity in the chemical composition of the Moon can be addressed through mineral mapping and elemental mapping. Surface mineralogy is performed using visible & near-IR (0.4 µm - 3 µm), mid-IR (7 µm - 25 µm) and UV (0.001 µm - 0.4 µm) wavelength bands which measure the spectral reflectance. X-ray and gamma-ray spectroscopy provide the capacity to do direct chemical mapping of the Moon. However, space instrumentation for X-rays and gamma-rays is very challenging and the study is limited by the amount and quality of data. Gamma-ray spectrometers in earlier missions have provided limited data on global maps of U, Th, K and Fe. Since the Apollo era, several lunar missions carried X-ray spectrometers (XRS) to map the surface elemental abundances. XRS on Apollo 15 & 16 covered only 10% of the area on the equatorial region on the nearside of the Moon; XRS on SMART-1 and Kaguya suffered from radiation damage which degraded the capability for precise quantification. Chandrayaan-1 X-ray Spectrometer (C1XS) on board Chandrayaan-1 was designed to map the abundances of major rock-forming elements viz., Mg, Al, Si, Ca, Ti and Fe on the lunar surface using the X-ray fluorescence (XRF) technique.

Working principle of C1XS instrument:

When an X-ray photon strikes an atom, it may either get absorbed or scattered. If the energy of the incident photon is greater than the binding energy of an atomic shell, an electron will be ejected by the photoelectric effect. The vacancy thus created is then filled by an electron from a higher shell resulting in the emission of an x-ray photon of energy characteristic of the atom, called X-ray Fluorescence (XRF). A schematic representation of XRF principle is shown in Fig. 1. Since the atomic energy levels of each element in the periodic table are distinct and quantized, the XRF emission from atoms can be used to directly identify the presence of elements. X-ray generators or radioactive sources are used in laboratory studies to illuminate the sample under study. For remote-sensing lunar studies, the Sun is the source of X-rays. The changes in solar magnetic configurations give rise to sporadic release of energy referred to as a solar flare where the X-ray emission suddenly increases, reaches a maximum and decays over a time scale of minutes to hours. Flares are often classified according to increasing intensity as belonging to A, B, C, M or X class (see table 1 for details), each class being ten times more intense than the previous. When solar X-ray photons impinge on the surface atoms of the Moon, XRF photons are emitted from the upper few microns (For example in the case of Moon, the upper 2-10 µm of regolith is sampled for Mg, Al and Si abundances). An X-ray detector in the orbiting spacecraft measures the energy spectrum which can be used to map surface chemistry of the Moon. The abundances of elements can be derived from the strength of XRF line intensities. However, the conversion of XRF line flux in to elemental abundances is not a straightforward process as the observed line intensities exhibit many dependencies and depend on the incident solar spectrum, matric effects, particle size, and geometry of observation, all of which can be calibrated or modelled. Thus, X-ray remote sensing offers the best opportunity to study the composition

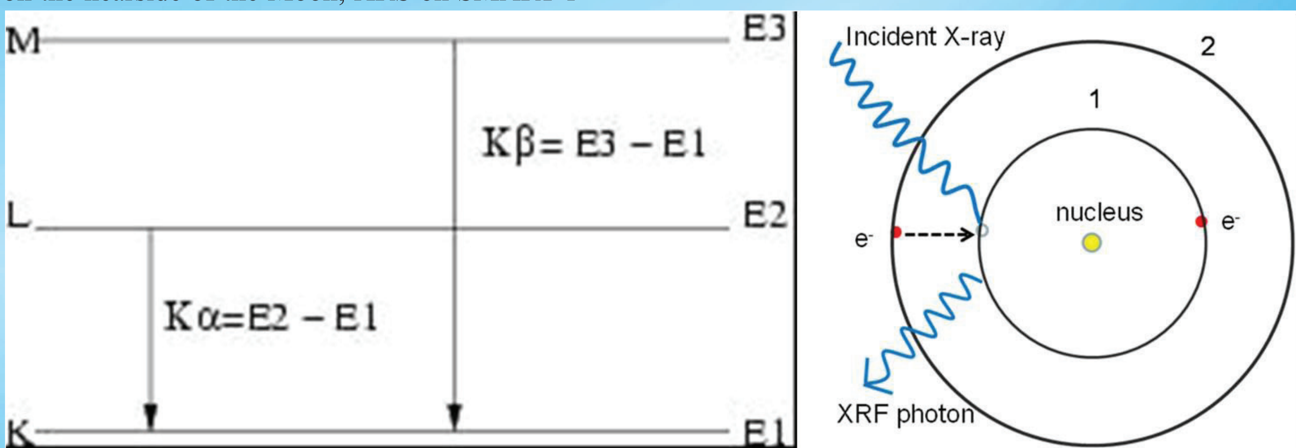


Figure 1: Representation of X-ray Fluorescence.

of lunar regolith which can be different from the bulk lunar composition. It also provides an independent measure of elemental abundances which can be compared with abundances derived from other spectral techniques.

Table 1: GOES classification of solar flares

Class	Flux (W/m^2) . (1.5-12.5 keV)
A	$<10^{-7}$
B	10^{-7} to 10^{-6}
C	10^{-6} to 10^{-5}
M	10^{-5} to 10^{-4}
X	$> 10^{-4}$

Summary of C1XS instrument :

C1XS was a joint collaboration between European Space Agency (ESA) and ISRO; the instrument was built at the Rutherford Appleton Laboratory (RAL), UK, with some design contributions (instrument and thermal) from ISRO and jointly calibrated and operated by RAL and ISRO. The instrument was designed with an array of 24 novel design X-ray detectors (Swept Charge Devices) to have an opening angle of 28.6° using collimators, made of copper coated with gold which define the ground pixel (area seen by C1XS on the lunar surface at a given instance) resolution of 25 km FWHM from 100 km altitude. However, spatial resolution for a single observation varies from 25 km to a few hundreds of kms, depending on spacecraft altitude and co-adding of adjacent pixel data for improved signal to noise ratio. Simultaneous observations of solar X-rays, in the energy range of 1.8 to 20 keV, impinging on the Moon, were obtained from the X-ray Solar Monitor (XSM) on board Chandrayaan-1, developed by the University of Helsinki in Finland.

C1XS observations – first spectral evidence of Na:

C1XS was the first well-calibrated X-ray instrument to reach and observe the Moon that could spectrally resolve the X-ray lines of all major rock- forming elements from the Moon simultaneously under different solar flare conditions. It was nominally operated only during the sunlit portion of the lunar orbit. Extended solar minimum that prevailed during the on-orbit time of Chandrayaan-1 (ie., Nov'08 - Aug'09), left C1XS with only a handful of solar flares (a few C-, B- and A-class flares) when simultaneous observations of the lunar surface were made.

A few A-class flare observations were made during December 2008 and January 2009, sampled around Mare Serenitatis, Mare Insularum, Mare Cognitum and Mare Nubium region [1]. The brightest flare observed by C1XS was a C3 flare which occurred on the 5th July 2009 measuring X-ray signatures of major rock-forming elements viz., Mg, Al, Si, Ca, Ti & Fe simultaneously. This observation covered regions on the lunar southern nearside highlands at detectors' maximum spatial resolution [2]. The Copernican-aged impact crater Tycho and its rays were observed during a C1-class flare that occurred on 6th July 2009. A few other B-class flare observations

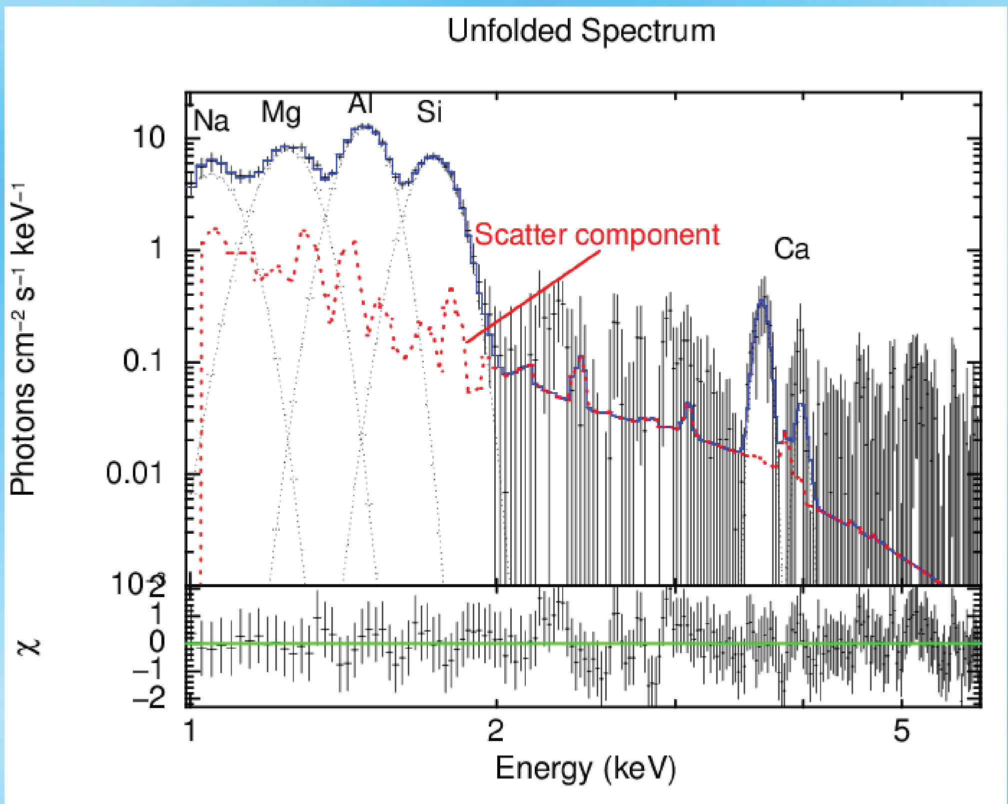


Figure 2: Best fit for the observed XRF spectrum for a C1 class flare on 6 th Jul'09 - (17:10:47 - 17:13:59), with all spectral component. Data points are shown with error bars (black). Residuals of the fit (difference between data and model) in terms of σ are shown in the bottom panel of the figure. (Ref.: Athiray et al., 2014)

were also made on the 4th and 8th July 2009 covering a portion of Tycho rays and around Palus Epidemiarum on the nearside of the Moon. Interestingly, some of the C1XS observations on the nearside highlands of the Moon showed the first direct spectral evidence of sodium on the lunar surface. One of the best fits to a C1XS spectrum observed on 6th July 2009, around the young crater Tycho, showing distinct XRF spectral line feature of Na at ≈ 1.04 keV, along with other rock-forming elements is shown in Fig.2. Due to excitation by a weak solar flare, XRF signatures of Ti & Fe were not visible in these observations. Using detailed spectral analyses, the unambiguous spectral evidence of Na from the lunar surface was firmly established [3,4].

Challenges in the measurement of Na

C1XS was operated in the energy range 1 -20 keV. The observed C1XS spectrum has three major spectral components (a) X-ray background (b) Scattering of solar X-ray spectrum and (c) XRF lines from the Moon. X-ray spectral detection of Na (~1.04 keV) from the Moon with high sensitivity is quite challenging. Extraction of XRF line intensity with less uncertainties require a detailed spectral modelling which demands precise ground calibration of X-ray detectors. Calibration of X-ray detectors at low energies ≤ 1 keV is very difficult. This constraint set a limit to our understanding of the spectral response of detectors which affect the sensitivity of measurements. Precise ground calibration was carried out for all C1XS detectors, using the RESIK X-ray beam-line at Rutherford Appleton Laboratory (RAL), UK. C1XS is the first well-calibrated X-ray instrument which measured the XRF line of Na with a good sensitivity.

It is also very essential to understand scattering of solar X-ray spectrum which could potentially be the origin of measured Na line. The scattering component of solar X-ray spectrum is iteratively computed using measured XSM data. By following rigorous spectral modelling procedures, the first unambiguous detection of Na from the Moon is clearly demonstrated.

C1XS results – Discovery of enhanced Na and possible scientific explanation

Elemental abundances are determined using the XRF inversion algorithm 'x2abundance', where line intensities are converted to elemental abundances incorporating all major dependencies [5]. The derived elemental abundances along with 1-σ uncertainties for selected C1XS observations suggest enhanced Na abundances. C1XS is the first instrument which provided the unambiguous detection and quantification of moderately volatile Na on the lunar surface. The derived Na abundances (2 to 5 wt%) are larger than what has been known so far (< 1 wt%) from earlier geochemical studies of lunar samples. It was also found that the derived Ca abundances are lower for those intervals where Na is observed. Compositional analysis of lunar samples, meteorites and soil does not show any relation between Ca & Na abundances. For the first time, C1XS abundance results suggest an anti-correlation between Ca & Na. It is expected in lunar highlands that an increase in Na abundances should correspondingly decrease Ca and

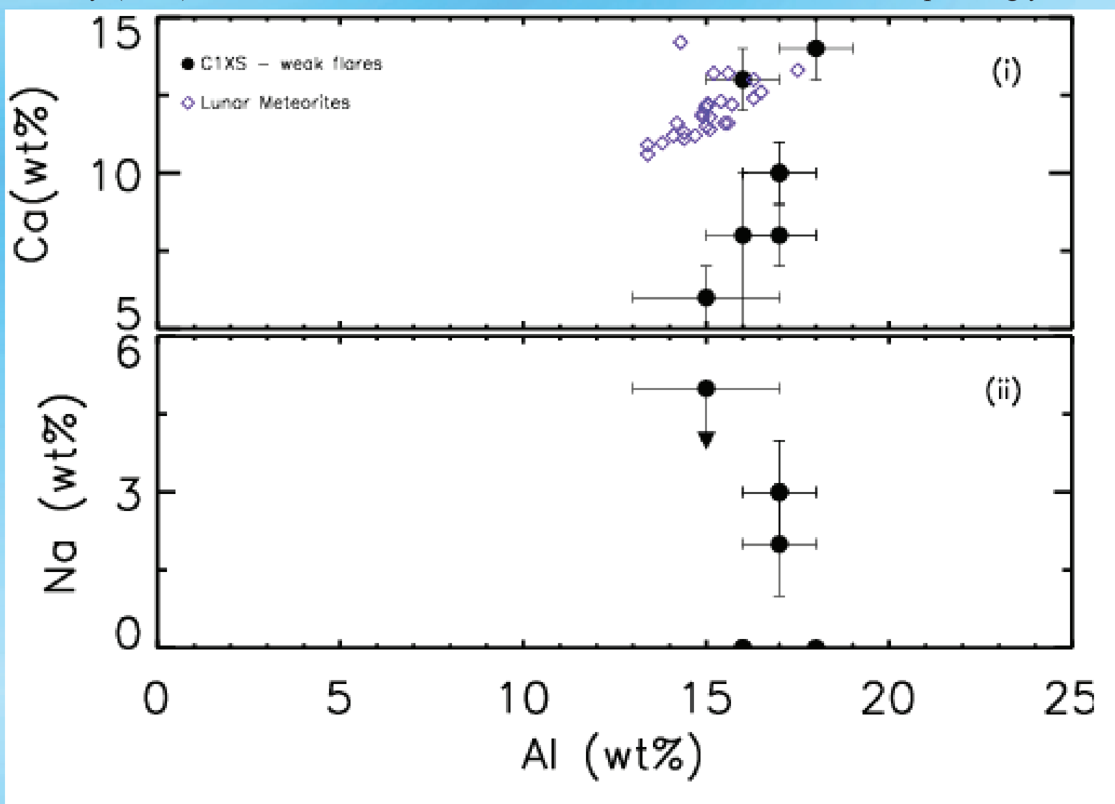


Figure 3: Comparison of C1XS abundance with Lunar Meteorite compositions [6].Variation of Ca and Na abundances with respect to Al (i & ii) with abundance of Ca increasing with Al which do not agree with the established correlation in lunar meteorite collections (Ref:Athiray et al.,. 2014).

Al abundances. C1XS results show a trend of increasing Na with decrease in Al abundances (Fig. 3).Sodium is a moderately volatile element and is considered to be lost during the early formation and evolution of the Moon via the giant impact event. C1XS results with high Na content contradict the extreme loss of volatiles by vaporization. The Moon can have intermediate plagioclase composition under different temperature and pressure conditions. The first direct detection of enhanced abundances of Na from certain regions on the Moon suggests a relatively cooler lunar surface evolution than expected. However, more precise elemental maps are required to understand the global evolution of the lunar surface.

If the presence of enhanced Na is considered to be widespread, then it could well be signature of serial magmatism, an alternative to global magma ocean where the temperatures could be relatively low. C1XS observed regions where enhanced Na abundances are found are likely to be dominated by the impact ejecta and disturbed regolith due to the young impact crater Tycho. Physical processes that could give rise to this enhancement eg., variable thermal cooling of magma or secondary processing of lunar surface remains equivocal. It is also to be mentioned that the measured XRF signal of Na cannot originate from deep layers of lunar regolith (within a few μm). If the observation of Na is localized only in certain regions on the Moon, then it can be well considered as an extra-lunar material present on the lunar surface. Volatile elements, such as sodium, are expected to be higher in unprocessed bodies such as comets and meteors which are formed in the outer regions of the protoplanetary disc. Now, it is well established that sodium lines are omnipresent in meteor spectra. Thus by mapping the abundance of moderately volatile elements on the lunar surface, one can identify and trace the extralunar material on the lunar regolith. In particular, a global map of Na can answer whether the bulk Moon is alkali depleted or not. This can also provide more clues on the diversity of plagioclase on the lunar highlands which is directly related to the thermal evolution of the Moon. Recent results from LADEE shows cyclic variation of Na abundances in the lunar exosphere illustrating the contribution of impacts and surface composition [7].

Summary

The first direct detection of enhanced abundances of Na from certain nearside highland regions on the Moon suggests a relatively cooler lunar surface evolution than expected. However, more precise elemental maps are required to understand the global evolution of the lunar surface. Our understanding of higher levels of sodium abundances on the lunar surface is still incomplete. Surface elemental abundances derived from limited C1XS observations raise the following questions:

- Can large amount of sodium be still present on the lunar surface?
- What causes the enrichment of volatile element Sodium on the lunar surface?
- Is the observed sodium enrichment on the lunar surface a local effect or suggestive of wide-spread enhancements?
- How are the elements Ca and Na distributed on the lunar surface?
- Can loss in Ca abundance lead to enhanced Na?

To answer all these questions, good measurements of elemental abundances with finer spatial resolution for the entire lunar surface are required. Simultaneous measurements of Ca & Na abundances along with other rock-forming elements can provide more further insights to the formation and thermal evolution of the Moon. To complete the science goals left behind by the C1XS experiment, an improved spectrometer (Chandrayaan-2 Large Area Soft x-ray Spectrometer (CLASS)) is being developed for the next Indian Moon mission, Chandrayaan-2.

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Komargaon, Assam (India) witnessed a new meteorite fall

'Meteorites are broken pieces early members of the Solar system, thought to have formed within 20 Ma of the origin of Solar System and their age ranges between 4.55 and 4.57 Ga. Majority of Meteorites are probably derived from the Main Asteroid belt, located between Mars and Jupiter. A significant number of meteorites have also been reported from other inner solar system bodies like Moon and Mars. Therefore, study of the meteorites provides more insights in to the early Solar system. Quick weathering of meteorites in terrestrial environment warrants for fresh meteorite falls rather than finds and are important not only to enhance the database of World's meteorite fall, but also to understand the dynamics of the Main Asteroid belt through the estimate of frequency and trajectory of falls. There is a uniformity of time of fall of meteorites (afternoon to day time chondrite fall yields a value ~ 0.61), however global anomaly between afternoon to day time fall is largely controlled by climatic variations.

A look at the World Meteorite Database reveals the relative abundance of fall - find statistics of two broad groups of stony meteorites, chondrites (equivalent of Earth's mantle) and Achondrites (equivalent of Earth's differentiated mafic- ultramafic crust). Stones account for 94% of total meteorite falls, comprising 86% chondrites and 8% achondrites whereas finds of stony meteorites are 70% including 60% chondrites and 10% achondrites. Interestingly, the rate of meteorite fall in Indian subcontinent ($0.19/10^6 Km^2/yr$) is recorded higher as compared to the global fall rate ($0.037/10^6 km^2/yr$). This disparity accounts for several factors mainly involving longer day light hours, higher population density and public awareness. Our earth constantly encounters extra terrestrial fragments or stones of different types and sizes, some of which survives through the atmosphere and reach finally to the Earth's surface. During the sojourn through the Earth's atmosphere at high velocity the outer surface of the stones undergoes melting due to high friction and forms "fusion crusts" of several generations associated with repeated fragmentations besides implantation of several markings like regmeglypts, striations, flow lines, stagnation zones, oil patches etc. On November 13, 2015, at 12:00 hrs, IST, villagers of Bali Chapori near Komargaon town (lat: 26°39′N; long: 93°46′E) of Golaghat District, Assam witnessed the fall of a huge meteorite. (Fig.1). According to the eye witness account of the local villagers, "It was a bright sunny day when we heard a thunderous sound in the sky and found a burning piece of material is coming at a tremendous speed from the clear sky to the ground". Very soon it fell and hit the soft ground nearby in a wide open area ploughed for plantation of mustard oil seeds. Immediately we rushed to the spot where the meteorite hit the ground. The fireball penetrated the ground and got buried inside a small hole, 1.5 ft in diameter and 3 feet in depth. Subsequently, the material was recovered and cleaned when the local police from the nearby police station reached to the spot within half an hour and took the material into their custody. According to the local news report published in Dainik Janambhumi, dated Nov. 14, page 13 it was a single piece stony meteorite, 10″ x 9″ x 8″ in dimension, with a total recovered weight of 12.095 kg. The present meteorite fall probably represents the third fall in northeast Assam (Table 1).

a

b

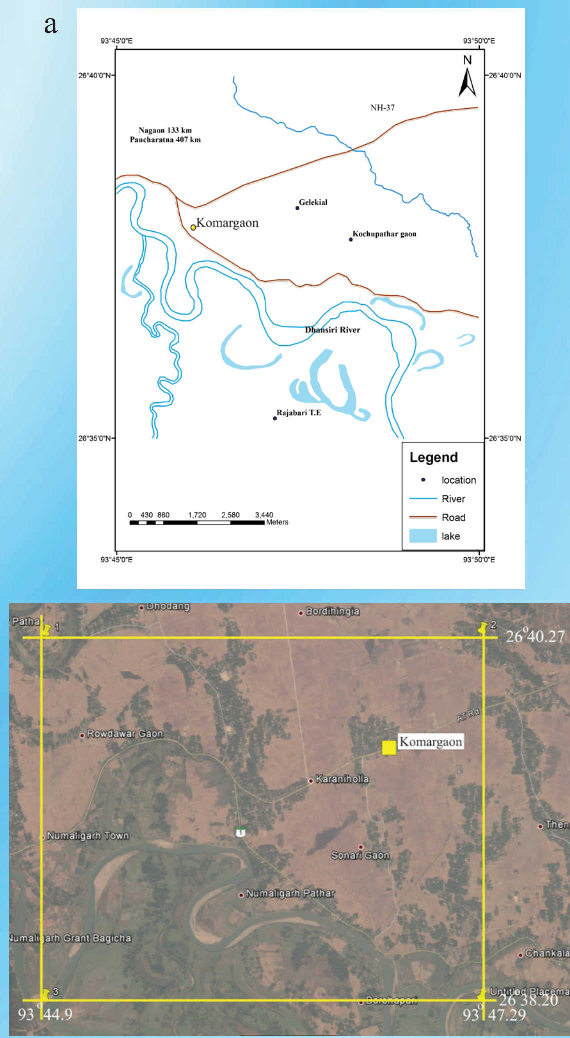

Fig. 1 :Location map of the Komargaon Meteorite fall (a) location in toposheet (b) location in google earth

The location of the fall of the meteorite and the crater is shown in Fig.2a while the inside of the crater is shown in Fig.2b Megascopic studies in hand specimen identify the Komargaon meteorite as an Ordinary chondrite covered with at least three generation of fusion crusts of different colour, texture and thickness. Older most crust is smooth, dull brown, thick (~ 1mm) fusion crust with almost no regmaglypt and represents the rear surface during flight through the atmosphere (Fig.3). In contrast, the younger most crust is irregular with several shallow simple regmaglypts, black, thin and a bit glossy with the flow lines radiating away from it. The face marked with the convergence of flow lines indicates the front side during its last stage of flight through the atmosphere. Tiny brownish spots in the grayish fractured surface are the signs of oxidized metal and sulphides present in the silicate matrix. A fresh cut slice of the sample exposes the internal composition and texture where numerous shining specs of metal are clearly seen integrated in a grayish white recrystallised silicate matrix (Fig. 4). There are some rounded oil patches on the fusion crust denoting the presence of chondrules altered by frictional heat in the atmosphere. On the contrary, the chondrules inside the meteorites are noticeable as indistinct rounded outlines in the matrix of similar mineralogy in spite of high degree of chondrule- matrix integration. The other interesting feature is the presence of shock veins, often bifurcating in nature. In addition, some irregular fracture lines on the fusion crust are generated due to hammering at police station.

a b

Figs. 2.(a) Photograph of the location of the crater and a local villager Nabin Borah who witnessed the fall of the meteorite. (b) Photograph of the inside of the crater

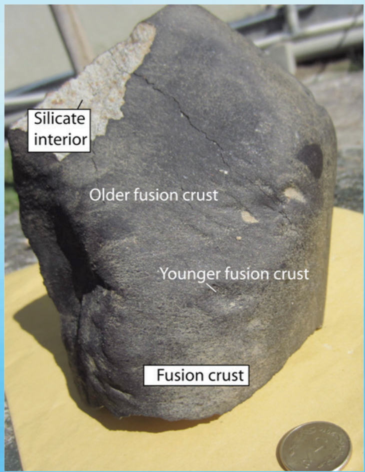

Fig. 3 Hand specimen of Komargaon Meteorite Fragment for study at Dibrugrah University

Table 1 Recent Record of Stony Meteorite Falls in Northeast India

Number of falls	Year	Meteorite Name
1	1999	Sabrum (23°05'N/ 91°40'E) in Tripura
2	2001	Dergaon (26°41′N/ 93°52′E) in Assam
3	2007	Mahadevpur (27°40′N/ 96°47′E) in Arunachal Pradesh
4	2015	Komargaon (26°01′N/ 93°02′E) in Assam

Detailed laboratory studies are presently under progress jointly at Department of Applied Geology, Dibrugarh Univeristy, Assam and at Physical Research Laboratory, Ahmedabad.

Fig. 4 Cut slice of Meteorite showing shining Fe- Ni metal specs

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Tectonic features on the lunar south pole

Tectonic activities on planetary bodies are studied regularly to understand the complex nature of the planets interior. For e.g., during the movement of the crustal plates on the Earth topographic variations are observed resulting into geomorphological features that are mapped by rigorous field investigations and supported by remotely sensed data. The information content generated through various sensors including microwave sensors are inferred from spatial platforms. The current study uses Narrow Angle Camera (NAC) and Wide Angle Camera (WAC) data from LRO mission and m-chi decomposition images derived from Mini- SAR data from Chandrayaan-1 to infer the presence of crustal tectonic activity in the south polar region of the moon (Figure.1) [Mukherjee and Singh, 2014].

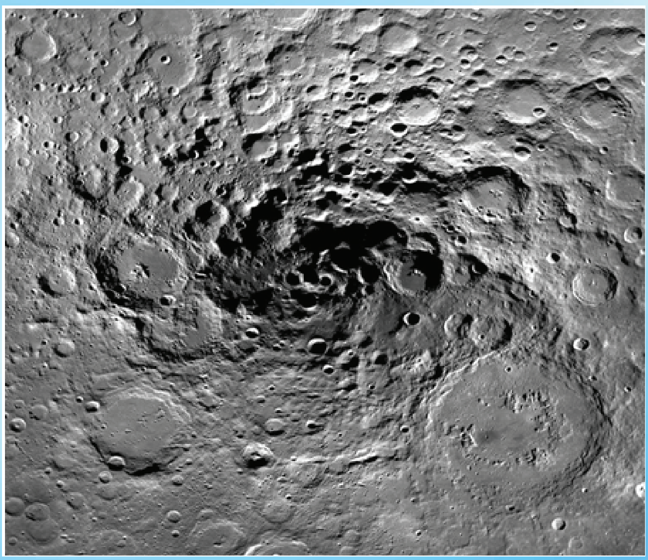

Figure.1. South Polar region of the Moon [Wide Angle Camera Image Mosaic from LRO]

Mini-SAR imaging radar on-board Chandrayaan-1 mission was the first mono-static lunar orbiting synthetic aperture radar. Mini-SAR data is primarily used to identify signatures suggesting the possibility of the presence of water ice within the permanently shadowed regions of the lunar poles. Further, this data has been used to observe various other geological features such as melt flows, crater ejecta blankets, secondary craters etc (Mukherjee and Singh, 2015, Saran et al, 2014). Therefore, identification of distinct morphological features in the shadowed as well as illuminated regions of lunar surfaces can be easily done using mini-SAR data. The SAR technology can also penetrate the surface and therefore is an effective tool to look for hidden fault lines in the shadowed portions on the lunar regolith (Mukherjee and Singh, 2015). The Mini-SAR data strips each having four bands were downloaded from NASA Planetary Data system (PDS) node. The S-band mini-SAR radar data has a resolution of 150 m/ pixel [Saran et al., 2013]. The relevant data strips were projected and mosaiced using ISIS software. Each pixel in an image strip consists of 16 bytes data in four channels of 4 bytes each as |LH|2, |LV|2, Real (LH.LV*) and Imaginary (LH. LV*). The first two channels represent the intensity images of the'horizontal' and 'vertical' receive, respectively. The last two channels represent the real and imaginary components respectively of the complex value for the cross power intensity image between 'horizontal' and 'vertical' receive. This data was then used for deriving Stokes vectors (Mukherjee and Singh, 2015). Mini-SAR data has a phase shift of 45° in the anticlockwise direction which exaggerates the number of pixels showing volume backscattering [Mohan et al., 2011]. Therefore, phase calibration was done for Band 3 and Band 4 using the following band math equations on ENVI software:

$$\mathrm{Re}(LH\ LV^*)_{calib} = \mathrm{Re}(LH\ LV^*)\cos 45^\circ - Im(LH\ LV^*)\sin 45^\circ \quad (1)$$

$$Im(LH\ LV^*)_{calib} = \mathrm{Re}(LH\ LV^*)\sin 45^\circ + Im(LH\ LV^*)\cos 45^\circ \quad (2)$$

Stokes Parameters (S_0,S_1,S_2,S_3) were calculated using Bands 1 and 2 and phase calibrated Bands 3 and 4 for each data strip using the equations in (3) as described in [Spudis et al., 2010]:

$$S = \begin{bmatrix} S_0 = \langle |E_{LH}|^2 + |E_{LV}|^2 \rangle \\ S_1 = \langle |E_{LH}|^2 - |E_{LV}|^2 \rangle \\ S_2 = 2\Re e\langle E_{LH}.E^*_{LV} \rangle \\ S_3 = -2\Im m\langle E_{LH}.E^*_{LV} \rangle \end{bmatrix} \quad (3)$$

Equations from Saran et al, 2012 were used to calculate the degree of polarization (m) and CPR. Equations from Raney, 2012 and Raney, 2012 were used to calculate the degree of circularity (χ) and m-χ scattering contributions for each pixel on ENVI software. The equations used are as follows:

$$m = \sqrt{\{(S_1)^2 + (S_2)^2 + (S_3)^2\}} / S_0 \quad (4)$$

$$CPR = (S_0 - S_3)/(S_0 + S_3) \quad (5)$$

$$Sin\ 2\chi = -S_3/(m * S_0) \quad (6)$$

$$B = \sqrt{\{(S_0) * m * [1 - \sin(2\chi)]\}/2} \quad (7)$$

$$G = \sqrt{\{(S_0) * (1 - \mathrm{m})\}} \quad (8)$$

$$R = \sqrt{\{(S_0) * m * [1 + \sin(2\chi)]\}/2} \quad (9)$$

Here blue (B) in (7) indicates single-bounce (Bragg) backscattering, green (G) in (8) represents the randomly polarized constituent or volume scattering and red (R) in (9) corresponds to double–bounce scattering.

M-χ decomposition images display a false colour composite showing "blue" for surface scattering, "red" for double

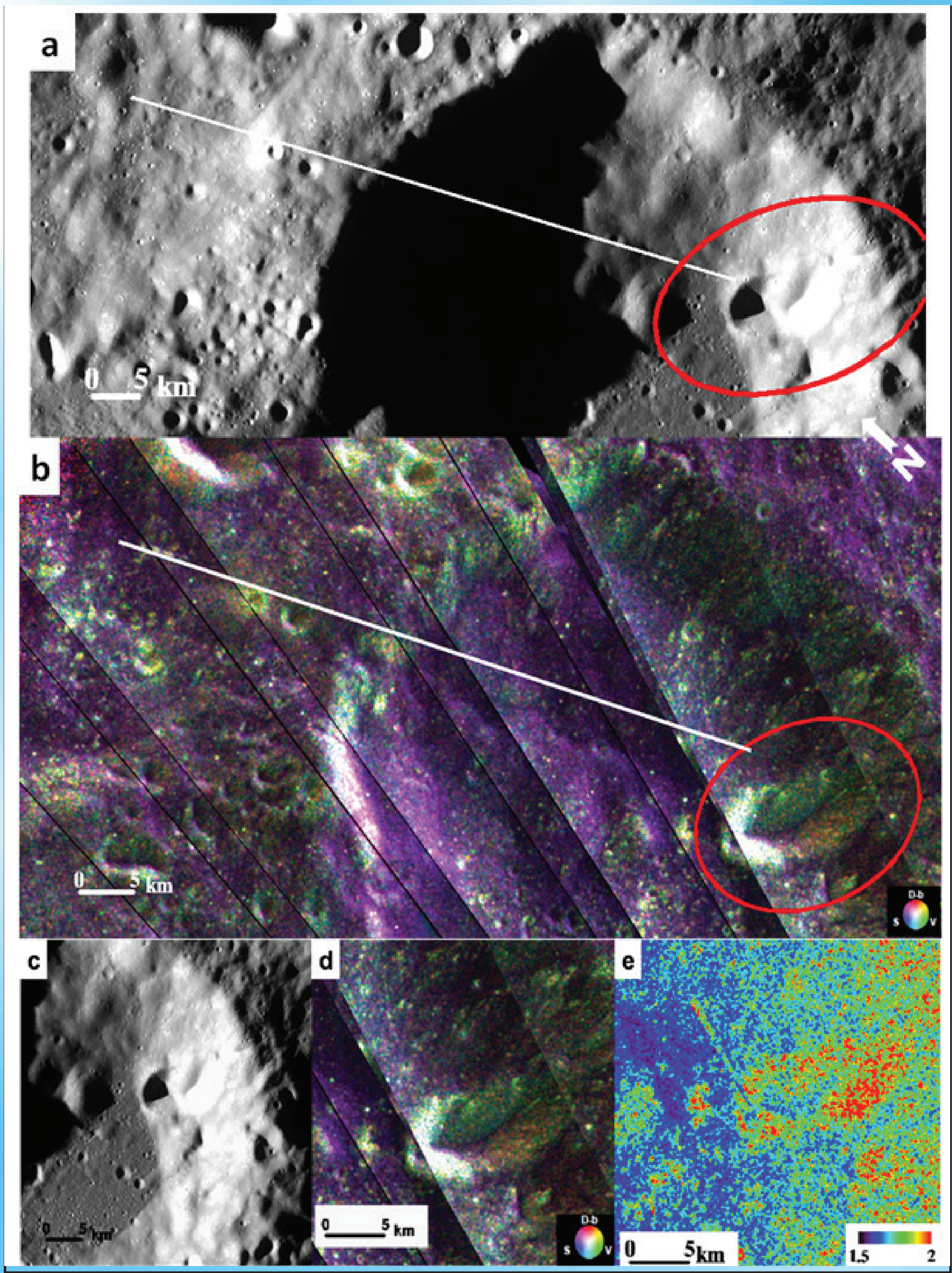

Figure 2. a) WAC image of the partially shadowed region of the Cabeus B crater floor in the lunar south pole. b) m-chi decomposition image of the fault running within Cabeus B crater and beyond. c) WAC image of the debris avalanche possibly triggered from movement along the identified fault. d) m-chi decomposition image of the debris avalanche. e) CPR image of the debris avalanche showing the surface roughness. [Figure Ref. Mukherjee and Singh, 2015; fig 4].

bounce scattering and "green" for volume/diffuse scattering. The images obtained along with optical data (Wide Angle Camera with 100m/ pixel resolution from LROC) were used to study the surface features in and around the identified craters within the South Polar Region of the moon.

Earlier studies have tried to study the deformational features such as faults and grabens on the lunar crust and compared them to similar features present on the Earth (Schwarz, 1928). Another study observed the presence of compressional and extensional features such as lobate scarps and grabens on the farside lunar highlands that are indicative of recent crustal tectonic activity (Watters et al, 2014). Dasgupta et al., 2014, have also found features within a rille, Rima Hyginus, located on the near side of the lunar surface, showing horizontal displacement of crustal blocks indicative of some shear stress. The findings in this study also suggest the manifestation of crustal tectonic activity on the moon in the form of faults and grabens due to the above mentioned forces. Previous studies investigating lunar tectonic activity have used optical data primarily to study lunar tectonics. Present work confirms that partially and completely shadowed crater interiors present in the Polar Regions can also contain unique features indicative of tectonic activity using microwave sensor data such as mini-SAR.

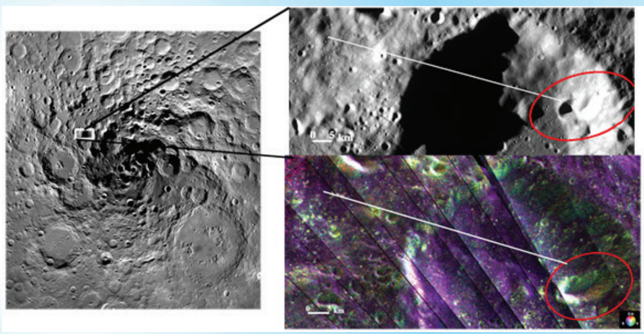

Figure 3. Region in the south polar region of the moon having the fault and the debris avalanche.

It has been proposed that thermal stress may also have been responsible for the lineaments observed on the lunar lithosphere. Such lineaments are tectonic landforms which indicate the occurrence of subsurface geological perturbations as a result of dislocation along fault planes resulting in surface disruptions, evidence of which gets buried over time under the lunar regolith or degraded due to space weathering [Anand et, al. 2004]. M-χ decomposition of Mini-SAR data [Patterson et al 2012] has therefore been used to demarcate such hidden lineaments and associated dislocation features in the study region (Figure 2, 3).

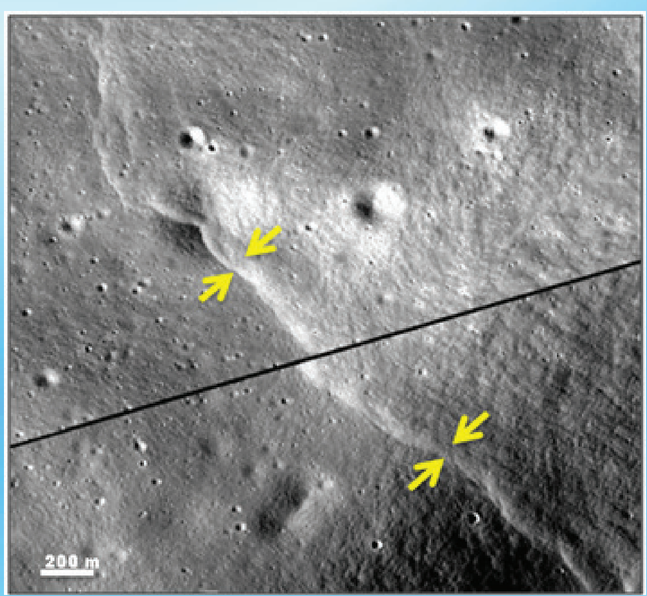

Figure 4. Inferred Lunar Fault developed by recent compressional crustal tectonic activity lying between Boltzman and Doerfel Craters within the lunar south polar region using Narrow Angle Camera images. [Figure Ref. Mukherjee and Singh, 2015; fig. 2d]

The structural geological information observed in the form of scarps, faults and the associated debris avalanches observed on the surface of the Moon suggests present and past tectonic activities on this satellite. These structural features are comparable with the features of the Earth. This investigation is useful in view of future manned and unmanned lunar investigation and suitable landing sites for future scientific investigations of the Moon.

Crustal tectonic activity therefore helps to demarcate regions experiencing physical and geological stress within the planetary interior. The geological activity and the related geodynamics lead to the formation of unique features suitably addressed as the surface manifestations of underlying subsurface perturbations. The formation of such tectonic features derived from perturbations along faults is suggestive of the recent crustal movement of the lunar body. Also, the shallow (<100 km depth) moonquakes recorded on Apollo data could have resulted due to activity along such type of tectonic deformations present at different locations on the lunar surface [Nakamura et al., 1979]. The inferred crustal dislocation features reported in this paper suggest that the lunar interior could be seismically active and that further geological perturbations as such can be expected [Figure 4].

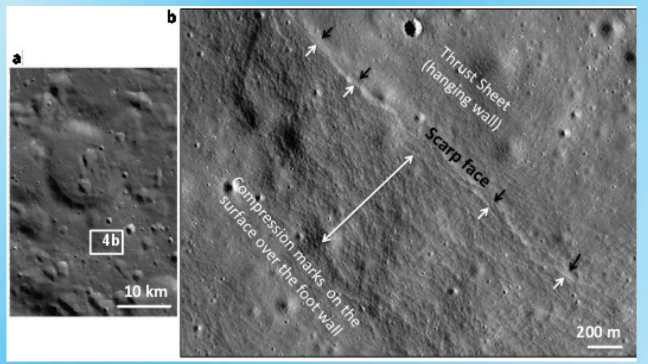

Figure 5. Compression marks on Scarp segment. a, Wide Angle Camera image of the scarp region. b, Narrow Angle Camera Image of a segment of the inferred scarp marked in a showing compression marks on the surface of the foot wall of the thrust fault.[Figure ref. Mukherjee and Singh, 2015; fig. 3]

Furthermore, the use of radar data can reveal hidden tectonic land deformations possibly formed due to disturbances along the subsurface faults. Application of m-χ decomposition technique on mini-SAR data effectively helps to demarcate fault lines in shadowed as well as illuminated regions underneath the lunar regolith due to the unique capability of microwaves to penetrate the regolith, completely independent of solar illumination. Therefore, using SAR data and the derived parameters, several complex lineament systems portraying the tectonic peculiarities of a region can be identified. The study region should be focused more using a fine resolution and deeper penetrating radar sensor or a ground based rover with ground penetrating radar to study the uniqueness of the underlying geodynamics of the south polar lunar surface and derive comparisons with other polar and equatorial regions (Mukherjee and Singh, 2014).

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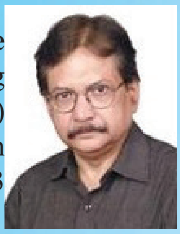

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FPGA based System on Chip (SoC) for Space computation

Abstract:
The demand for developing reconfigurable embedded systems for space compatible instrumentations has increased in recent times. Often these systems include interdisciplinary applications domains such as signal processing, wireless communication, multimedia, evolutionary computation etc. Performing these computations using embedded processors alone, cannot achieve the desired computational capability to fulfill the requirements of massive parallelism, higher memory bandwidth, and higher execution speed. In order to meet these requirements, Field Programmable Gate Arrays (FPGAs) are used by exploiting the reconfigurable resources by implementing the algorithms in parallel or pipelined fashion using HDL languages. Beyond this flexibility, embedded processors inside in FPGA are used for running software application along with custom hardware by making use of reconfigurable resources, all on same package as System on Chip (SoC). These systems can provide the speedup of custom hardware without the cost of development for Application-Specific Integrated Circuits (ASICs).

Introduction

FPGAs are prefabricated programmable logic devices composed of Look Up Table (LUT) based programmable logic blocks connected by a programmable routing network. These devices are programmed on field as opposed to devices having internal functionality fixed and hardwired by the manufacturer such as Application Specific Integrated Circuits (ASICs) and Application-Specific Standard Parts (ASSPs). These devices include resources such as Flip-Flops (FF), Random Access Memory (RAM), Multiply and Accumulate (MAC) units, DSP48E and soft/ hard microprocessor cores. It also has several third party Intellectual Properties(IPs) like Ethernet MAC controller, Digital Video Interface (DVI), High speed serial I/O's etc. Several grades (Consumer, radiation tolerant, low-power, high performance) of FPGAs are available from different vendors from Fab-less industry like Xilinx, Altera, Microsemi, Lattice Semi-conductors etc.

The primary objective of the usage of FPGAs for implementing the algorithms into hardware is to minimize the gap between idea/ algorithm development to embedded system design. The advantage of FPGAs is its reconfigurability, low design costs and low time-to-market. During the last decade, modern FPGAs are available with soft and hard embedded processor cores to enable the designer for building complex embedded applications. To enhance the execution speed of the algorithm, dedicated hardware accelerators have been developed and interfaced with the processor as a coprocessor in System on Chip (SoC) platform.

There are several preferences for choosing a platform such as Micro-Controllers (MC), Digital Signal Processors (DSP), FPGA and Application Specific Integrated Circuits (ASIC), for developing an embedded system. In order to achieve higher performance, applications need to be implemented either in multi-processors or in dedicated hardware accelerators/coprocessors. The platform selection depends on factors such as performance, power consumption, and cost per chip. The ease of tools accompanied by a specific platform to assist the developers for developing the system within the constraints of system cost and project time also plays an important role. MC and DSP platforms make use of embedded software oriented methodologies to develop the system. However, the designers using FPGAs as their development platform have the ability to use the processor-based approach, developing their system partly in firmware and partly in hardware, or entirely developing the system in the hardware [3].

In future, space projects, requires advanced technologies to miniaturize the various instruments of spacecrafts which includes those for on-board computing as well. For instance, a generic single-chip computing platform can be used on-board small spacecraft, which can be reconfigured remotely from the ground station.

FPGA based SoC design is chosen because of the following reasons:

1.Selecting Off-The-Shelf (OTS) microprocessor for a particular application which can meet all system requirements (like floating point arithmetic, power, speed, ease of tool) is time-consuming. So it is advantageous to find an alternative which allows the designer to tailor a processor and a specific set of features and peripherals for the application to be implemented. FPGA based design gives this flexibility to the designer over either MC or DSP based system.

2.The designer of FPGA based embedded system has flexibility to customize the design by adding any combination of peripherals and controllers. A unique set of peripherals can also be designed for specific applications, and the designer has privilege to add as many peripherals to meet the system requirements, which cannot be done in MC or DSP based system. Features not present in the initial phase of the design can also be added in the later part of the design.

3.Hardware and software concurrent development and coexistence on a single chip, is one of the compelling reason for choosing FPGA/SoC platform. If a segment of the algorithm is computationally complex then a custom coprocessor units can be designed to eliminate such problems.

4.These kinds of systems are preferred over ASIC based SoC solution, due to its re-programmability, Intellectual Property (IP) reuse and cheaper development cost. Although ASIC has advantages over FPGA based SoC in terms of customized chip size, power, delay etc. But FPGAs are feasible solutions for prototyping a device before building an ASIC.

5.FPGA enables selection of an optimal platform of SoC configuration for a typical application involving trade-offs between flexibility, cost, performance and power consumption.

6.The FPGA's enables the change of part of hardware in run-time execution of application without changing the complete hardware by Dynamic Partial reconfiguration (DPR) which allows lower-power, dynamical hardware – change etc.

Hardware Software Co-design

In general, signal processing applications are developed using DSP processor which has dedicated hardware blocks for certain computations like MAC, multipliers, dividers etc. The disadvantages of using DSP processor is that it executes the instructions in a sequential manner thus limiting the speed of the design. So, in order to speed-up the processing of an application, parallelization is needed. This can be achieved using various ways like multi-threading of application, Graphic Processing Unit (GPU), hardware design using FPGA etc. The main difference between execution of hardware and software tasks is concurrency, which allows the hardware to execute a task much faster than the software in a processor. The designed hardware can be further accelerated by making use of the parallel and pipelined architecture techniques. This is not possible in a General Purpose Processors (GPP) and DSP processors which performs computational tasks in software by executing the application sequentially. The difference between these platforms is tabulated in Table.1. HW/SW co-design is a popular approach being used to accelerate computational intensive DSP applications.

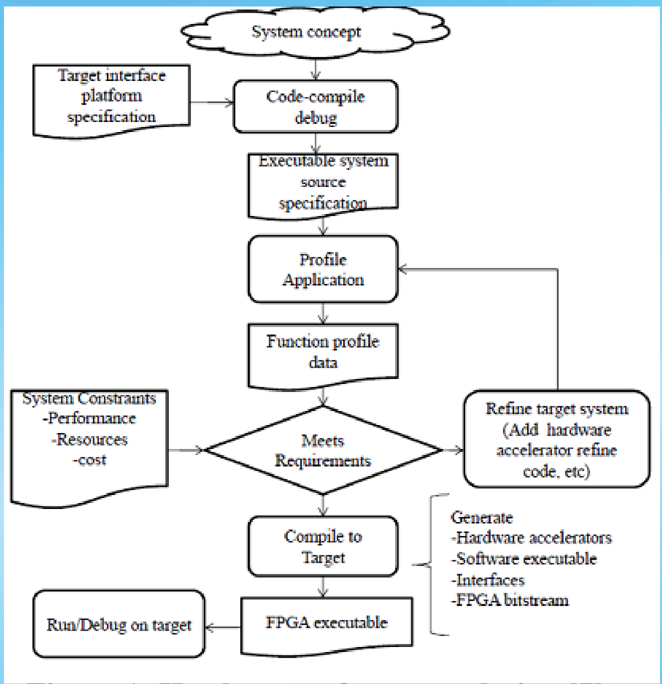

Figure 1: Hardware software co-design [7]

Table 1: Comparison of Processor/DSP, FPGA, ASIC based solutions [6]

Characteristic	Processor/ DSP	FPGA	ASIC
Programmability	High	High	Low
Development Cycle	HW+SW	HW+SW	HW
Area Efficiency	Medium	Low	High
Power Efficiency	Medium	Low	High
Efficiency	Low	Medium	High

In co-design approach, most time consuming tasks/subtasks of the application/algorithms are implemented in the hardware while the less computational intense tasks/subtasks are implemented in the embedded processor. In co-design, partitioning of the algorithm into software (SW) and hardware (HW) is a critical task. The partitioning of HW and SW is decided by the profiling results of the application as shown in Figure.1. During the profiling, the computationally intense tasks/subtasks are identified. Subsequently these are designed and implemented either in the hardwired logic or by using a dedicated co-processor unit [8-9]. FPGA based embedded system design is still relatively new compared to standard processors. So the software design tools are relatively undeveloped and difficult to debug the entire system [1-3]. There are prominent issues like IP interface, cross clock handling and memory management that imposes design bottlenecks in SoC design. So in order to resolve these things new design methodologies and easier integration methods are needed.

Programmable System on Chip design:

FPGAs no longer act as only glue logic resource in a complex hardware system, because modern FPGAs have processor units along with glue logic as processing elements. This way traditional system on board design has been replaced by SoC design. If the designer needs to develop SoC in a reconfigurable approach then FPGA device is used and the platform is named as Programmable System on Chip (PSoC). It is an integrated system with processor, peripherals, Memory, custom IP components on a single Integrated Circuit (IC) like FPGA. With a provision of including operating system, such as Linux, these systems begin to appear more like a desktop Personal Computer (PC) in terms of functionality and capability on a single IC chip. The SoC development cycle has two different platforms a) Software development b) Hardware development.

Software development platform

MATLAB and C programming language are used for algorithm development and validation. Eclipse platform GCC complier specific to Processor tool chain (ARM/PPC/Microblaze) is used to software. Xilinx Software Development Kit (SDK) is used for profiling the algorithm in PPC440/MB processors.

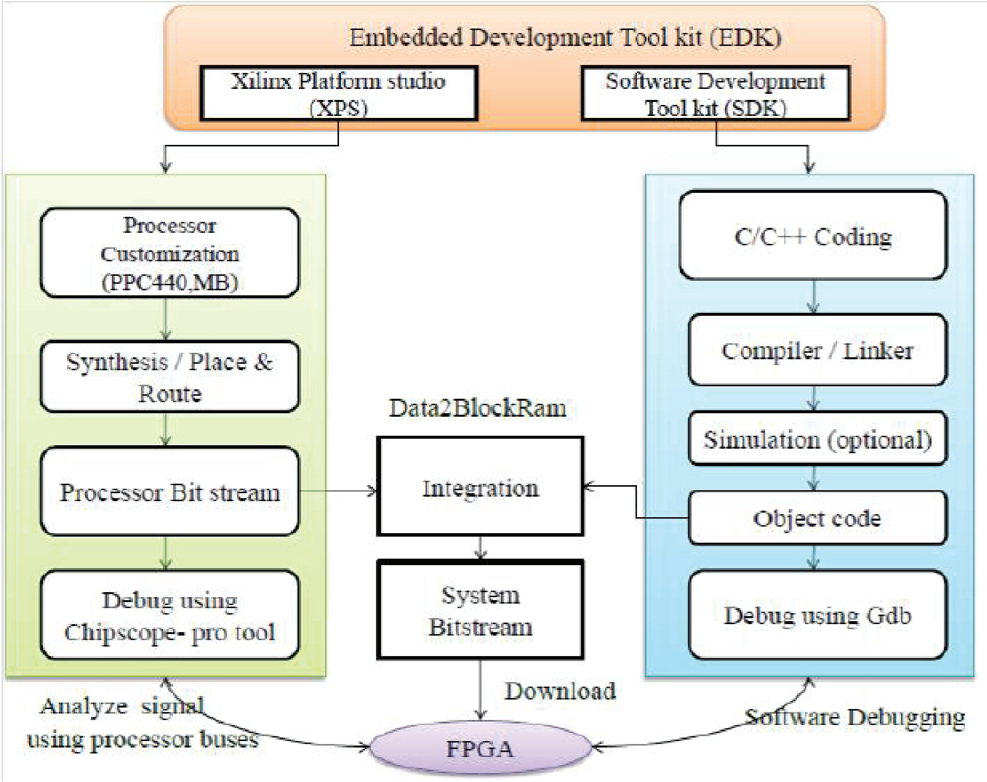

Figure 2: Hardware software co-design approach using embedded development kit (EDK) [12]

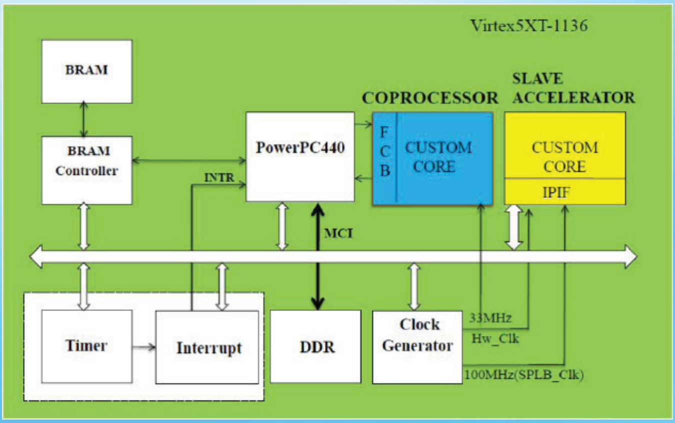

Figure 3: Basic SoC system

Hardware development platform:

The hardware development cycle in FPGA design flow uses various tools for HDL coding, simulation, synthesis, debugging tools as shown in Figure 4. Mentor graphics Modelsim, Xilinx ISim simulation tools are used for coding and simulation. For hardware development Xilinx Integrated Development Environment (IDE) with Integrated Software Environment (ISE) is used.

Embedded Development Kit (EDK) is used for building the SoC and generating custom peripherals. The PSoC platform can be designed using Xilinx platform studio (XPS) in Xilinx EDK and SDK as shown in Figure.2. In has two different design steps namely hardware (HW) and software (SW). These two steps run in parallel. In HW, Base System Builder (BSB) wizard provides an efficient way to create the FPGA based embedded system. The choice of the memory types, memory controllers, peripherals, peripheral controllers, size and type of instruction and data cache memories and size of local memory, choice of processor, bus and peripheral clock frequency are configured in BSB [11-12]. The proposed FPGA based SoC platform inside in FPGA incorporating a co-processing unit or accelerator can be interfaced to the processor through shared bus (Processor Local Bus (PLB)/AXI bus) and dedicated bus (Auxiliary Processing Unit (APU)) as shown in Figure.3.

On-chip memory and external memory are used for initializing the processor program. The Universal Synchronous and Asynchronous Receive and Transmit (UART) and Joint Test Action Group (JTAG) ports are used to monitor, debug and download the bit-stream on to the FPGA. The proposed custom/DSP IP in SoC has design objectives of high-speed in terms of operating frequency and reduced cost in terms of FPGA fabric resources. During simulation, synthesis and compilation of the embedded processor system, an appropriate optimization scheme must be selected to achieve the above design objectives. The processor internal timer along with interrupt is used for measuring the execution time of the algorithm.

Hardware accelerator

A hardware that accelerates the execution of a task as a separate unit other than processor is referred as hardware accelerator. The accelerators can be designed using ASIC or FPGA approach depending on the specification of applications. ASIC-based accelerators cannot be usually leveraged by a gained speedup due to larger design development costs and longer development cycle. Moreover, an accelerator designed for a specific application

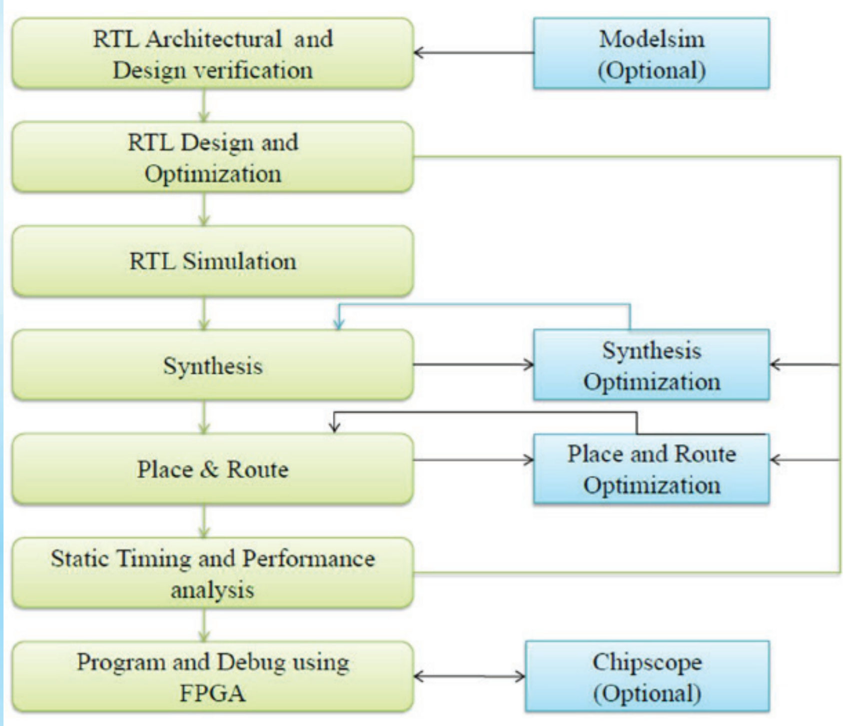

Figure 4: FPGA design flow [2]

cannot be utilized by another application. With the advent of SoC platform using FPGA, the situation has changed. The hardware rigidity is lowered by re-programmability of FPGA devices in SoC platform and it allows interfacing of designed hardware IPs with the processors for desired DSP applications. The ability of on-demand FPGA reconfiguration also enables the accelerator to adapt to the actual needs of an application executed in the processor . Several issues need to be taken into consideration while designing a SoC system. The important issues are processor to accelerator interface, mutual communication and synchronization. All these effects have crucial impact on the acceleration. The former issue comprises of communication protocol and amount of data transfer. Selection of a proper communication/interface scheme affects the quantity of the data transfer from processor to coprocessor/slave accelerator. The improper bus interface may result in slowdown of the accelerated system. Another issue is to synchronize the data transfer between processor and hardware unit by handshaking, direct or interrupt mechanism. The selection of the particular synchronization system depends on the chosen communication granularity and scheduling of the algorithm. The coprocessors can be interfaced with the processors using three different techniques i) System bus connected, ii) I/O connected, and iii) Instruction-pipeline connected.

System bus connected:

In this approach accelerators are interfaced to the processor as a slave peripheral/ slave unit (SU) using system bus i.e. Processor Local Bus (PLB) as shown in Fig. 2.4. The accelerator can transfer data and send commands to the processor through the system bus. Typically a single/multi data transactions, consumes many processor cycles due to bus arbitration. This kind of systems have two major bottlenecks i.e. insufficient peripheral bus throughput and bus arbitration, this leads to data transfer and synchronization overheads which in turn lowers the execution speed.

I/O connected:

In this approach, the accelerators are interfaced directly to a dedicated I/O port of a processor. In order to reduce the bus overhead and arbitration, a dedicated First-In-First-Out (FIFO) type of interface like Fast Simple Link (FSL) in Microblaze (MB) processor is used [11]. These interfaces are typically clocked faster than the processor bus. Often data and control are typically provided through GET or PUT instructions. This enables the bus interface to have lower latency and higher data rate compared to the system bus.

Instruction Pipeline connected:

In this approach, the accelerators with desired computing core are interfaced directly to the processor. Being coupled to the instruction pipeline, instructions not recognized by the CPU can be executed by the co-processor. This type of accelerators exposes no communication overhead and offers quick synchronization between the processor and coprocessor. The bottleneck is the implementation of the acceleration unit itself. If the critical path of the whole system goes through the acceleration unit, then the whole processor will decrease its operational speed [4-5]. Recent FPGAs include processors like ARM, PowerPC family processors, which utilize both specialized functional units and instruction set extensions for interfacing an IP. The APU interface is capable of transferring higher data volumes per second, approaching to the speed of Direct Memory Access (DMA).

Examples of SoC Applications for Space and Astronomy :

Recent internal studies at NASA's Jet Propulsion Laboratory (JPL) expect an estimate of approximately 1–5 Terabytes of raw data per day (uncompressed). Therefore, higher computational platforms are required. An FPGA/SoC approach to On-Board Data Processing enables in new Mars Science with Smart Payloads. The aim of this proposed Mars Scout Mission known as MARVEL (MARs Volcanic Emission and Life Scout) is to search for volcanic activity on Mars. In this mission one of its primary instruments, MATMOS, an FTIR spectrometer, will produce large volumes of data in short; 3-minute bursts during its on-orbit observation of sunrise and sunset. In this work data processing relies heavily on floating-point FFTs. Virtex-4 FPGA platform uses auxiliary processor unit (APU) that provides a flexible high bandwidth interface for fabric co-processor modules (FCM) to the PowerPC405 processor core. The coupling of FPU FCM with the APU provides sufficient computation power to meet MATMOS's data processing requirements when implemented in a multi-processor, dual-FPGA system. Bekker.et.al, developed MATMOS Fourier Transform Infrared (FTIR) spectrometer instrument designed to measure the Mars atmospheric composition using solar occultation from orbit. MATMOS requires high sampling rate, high dynamic range data acquisition to record time-domain interferograms which get converted to spectra on-board the space-craft in on chip FPGA. The complete design is ported into the hardcore PowerPC processor of Virtex 5-FPGA. By enabling the Floating Point Unit (FPU) of the APU an acceleration of 4x is reported. Several other works for on board signal processing for space applications have also reported the advantages of FPGA based SoC system . Fons.et.al., developed a FPGA based runtime reconfigurable coprocessor for computational applications using dynamic partial reconfiguration approach and is validated by executing several signal processing algorithms .This kind of system has good applicability for evolvable hardware based space applications.

Fiethe et. al. developed reconfigurable System-on-Chip Data Processing Units for Space Imaging Instruments. The work uses new radiation tolerant high density FPGA and processor technology enables the instrument to new system architecture and it is used in space on Venus express. An advanced SoC design integrates special functions (e.g. data compression or formatting/coding) together with the processor system completely on a single or few high density FPGAs. CASPER Astronomy computing group is using FPGA based SoC platforms for high performance computation.

Further Reading:

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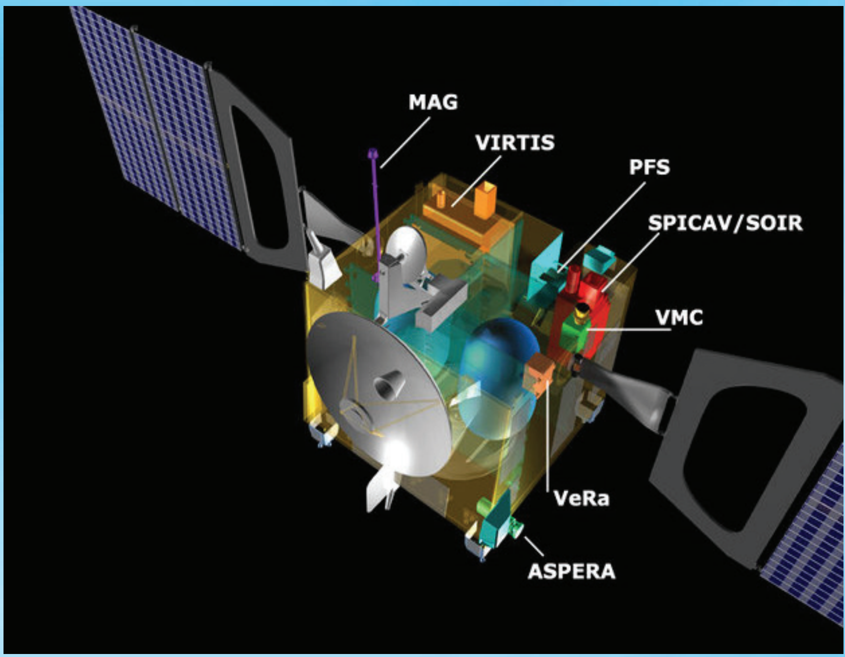
MISSION STORY – VENUS EXPRESS

Every one of us recognises Venus as the brightest object "star" in the sky after Sun and Moon. But, Venus, with its intriguing features – complex atmosphere, extreme environment with surface temperatures nearing 465°C, oldest crater on the surface being just 500 million years old etc. has been a puzzling cosmic object to scientists too. Although Venus seems to be a twin of Earth in terms of mass and size, observations indicate that Venus might have evolved completely in a different manner. Venus reconnaissance dates back to early 60s with several missions failed in an attempt to have a glimpse of Venus surface. Of course there were successes too. One such mission is ESAs Venus Express which was built in just 33 months. Venus Express aimed at atmospheric investigations of complex and exotic Venusian atmosphere and surface temperatures.

Launch and Mission profile:

Launched on 9 Nov. 2005 from Baikonur cosmodrome, Venus Express spacecraft weighs around 1270 kg with 93 kg dedicated for scientific payloads. Built on the heritage of Mars Express spacecraft, Venus Express is a ~1.5 metres wide aluminium honeycomb structure. The spacecraft cruised a distance of ~400 million kilometres for nearly 160 Earth days till it reached Venus on 11 April, 2006 after several manoeuvres. The spacecraft was finally out into a highly elliptical polar orbit of 250 km x 66000 km. Although, the planned lifetime of the mission was 486 Earth days, the spacecraft survived longer till the mission ended in 2014 due to lack of fuel.



Venus Express Spacecraft and Instruments Image
Credit: http://www.esa.int/var/esa/storage/images/esa_multimedia/images/2005/08/cutaway_diagram_showing_size_and_location_of_instruments/10020471-2-eng-GB/Cutaway_diagram_showing_size_and_location_of_instruments_large.jpg

Instrument suite:

Venus Express carried seven science instruments to investigate the mysterious world of Venus. Most of these instruments were targeted at in-depth observations of Venusian atmosphere. The instruments were:

ASPERA (Analyser of Space Plasma and Energetic Atoms): targeting the study of interaction of solar wind with Venusian atmosphere.

MAG (Magnetometer): aims at studying the magnetic field generated due to solar wind interaction with atmosphere.

PFS (Planetary Fourier Spectrometer): for temperature measurements of atmosphere and surface of Venus. PFS will also aid in measuring the composition of atmosphere.

SpicaV/SOIR (Spectroscopy for Investigation of Characteristics of Atmosphere of Venus): for stellar and solar occultation experiments. These measurements will help determine small amounts of water in atmosphere, if it exists.

VeRa (Venus Radio Science Experiment): to reveal density, temperature and pressure from surface to a height of ~35 to 100 km.

VIRTIS (Visible and Infrared Thermal Imaging Spectrometer): aimed for investigating the composition of the lower atmosphere and also to track clouds and understand atmospheric dynamics.

VMC (Venus Monitoring Camera): is a wide-angle multi-channel CCD camera for global imaging of Venus in NIR, UV and visible bands.

Venus Express mission has provided several new discoveries and interesting results. A few are: evidence of magnetic reconnection, variable or unstable polar vortex, possibilty of recent volcanism, frigid regions in atmosphere and so on.

Venus Express has performed flawlessly beyond expectations and provided new discoveries and unfolded several interesting facts till it lost its contact with the ground station during Nov-Dec 2014.

MISSION UPDATES (Source: Websites of various space agencies, press releases and published articles)

ISRO celebrates 50th launch from SDSC-SHAR

With the successful launch of PSLV-C29 on Dec. 16, 2015, ISRO celebrates 50th launch from SDSC-SHAR, Sriharikota. PSLV-C29 carried six Singapore satellites and placed them in a circular orbit of 550 km. Earlier, the 11th Indian communication satellite , GSAT-16, was also successfully launched from Kourou, French Guiana, on Nov. 11, 2015.

Akatsuki finally in Orbit around Venus, clicks picture

After a long wait of five years, JAXA could successfully put Akatsuki in an orbit around Venus on 9 Dec. 2015 during its recent attempt. The probe missed Venus in Dec. 2010 after a failed attempt of orbit insertion. Akatsuki which is in a good health is placed in a highly elliptical orbit. Images were already started beaming back and regular science operations are expected to start from April 2016.

Cassini's historic flyby of Enceladus

Cassini spacecraft orbiting Saturn has completed a historic flyby of its Moon, Enceladus, on 28 Oct. 2015. Cassini flew by about 49 kms passing through the geysers at at Enceladus' south pole. Images of this dramatic flyby were already transmitted by the spacecraft and currently under analysis.

DAWN in low-altitude final mapping orbit

NASAs DAWN mission, currently orbiting Ceres, is now in its final mapping orbit at its lowest orbit at an altitude of 380 kms. After completing 2 months of observations in 1470 km orbit, the spacecraft moved to its final orbit on Oct 23, 2015.

InSight mission suspended due to a leak in SEIS instrument

The planned launch of InSight mission to Mars has been suspended after its important instrument, Seismometer (SEIS), has encountered a vacuum leak in its container. Attempts to repair the leak failed. InSIGHT Lander was under shipping phase for 2016 launch, after completing assembly and testing when this problem was detected.

Curiosity heads towards active dunes

Curiosity rover headed towards higher areas called "Bagnold Dunes" during Nov. 2015 for providing investigations of active dunes.For the past three weeks, curiosity has travelled around 315 meteres on its duty drilling and sampling its targets.

Rosetta and Philae's first anniversary at 67P/CG

Rosetta spacecraft and its Lander, Philae, has successfully completed one year exploring the comet 67P/Churyumov-Gerasimenko. Rosetta reached the comet on Aug 6, 2014 and Philae performed bounced landed on Nov. 12, 2014.

MROs onboard flash memory updated

Mars Reconnaissance Orbiter team has successfully updates the flash-memory of one of its onboard computers. This memory carries tables that provide the location information of Earth and the sun to the spacecraft. The tables loaded at launch provide information only upto July 2016 and hence an update was required.

Juno on its way towards the giant planet

After its launch in Aug. 2011, Juno spacecraft is actively heading towards the giant planet, Jupiter. Juno, which is travelling at a velocity of ~30 km/s relative to Earth, is now at a distance of nearly 841 million kilometres from Earth. The spacecraft is reported to be in good health.

James Webb Telescope getting ready for 2018 launch

James Webb Space Telescope, the succesor for Hubble Space Telescope, is geeting ready in full swing for its 2018 launch. The "Pathfinder Telescope" has successfully completed second Super-cold Optical test and the assembly of the mirrors half way completed. The hexagonal mirrors measuring ~1.3 metres and weighing around 40 Kgs, are being assembled using robotic arms.

ANNOUNCEMENT AND OPPORTUNITIES

- "*The 2nd Conference on Astrophysics and Space Science (APSS 2016)*" will be organized during Feb. 28 - Mar. 1, 2016 in Beijing, China. The last date for submission of abstracts is Jan. 18, 2016. For more details, please visit:-http://www.engii.org/ws2016/Home.aspx?id=686

- ***"International Symposium and Workshop on Astrochemistry"*** will be held from Jul. 3-8, 2016 at Campinas University, Campinas, Brazil. The last date for submission of abstracts is Mar. 15, 2016. For more details, please visit:-http://www1.univap.br/gaa/iswa/

- ***"Australian Astrobiology Meeting"*** will be held from Jul. 10-12, 2016 at Perth, Australia. The last date for submission of abstracts is Feb. 29, 2016. For more details, please visit:-http://www.aa-meeting2016.com/

- ***"EXOPLANETS - I"*** will be held from Jul. 3-8, 2016 at Davos, Switzerland. The last date for submission of abstracts is Mar. 31, 2016. For more details, please visit:-http://www.exoplanetscience.org/

- "***The 79th Annual Meeting of The Meteoritical Society***" will be organized during Aug. 7 - 12, 2016 in Berlin, Germany. For more details, please visit: http://www.metsoc-berlin.de/

- "***The 9th meeting on Cosmic Dust***" will be organized during Aug. 15-19, 2016 at Tohoku University (Aobayama Campus) in Sendai, Japan. The last date for submission of abstracts is May 13, 2016. For more details, please visit: https://www.cps-jp.org/~dust/Welcome.html

- "***EXOCLIMES 2016***" will be held during Aug. 1 - 4, 2016 at Quest University, Squamish, British Columbia, Canada. For more details, please visit: http://www.exoclimes.org/

- "***Martian Gullies and their Earth Analogues***" will be organized during Jun. 20-21, 2016 at The Geological Society (Burlington House) in London, UK. The last date for submission of abstracts is Jan. 29, 2016. For more details, please visit: https://www.geolsoc.org.uk/martiangullies

- "***2016 Scientific Ballooning Technologies Workshop***" will be held during May 9 - 11, 2016 at University of Minnesota, Twin Cities, Minneapolis Campus, USA. For more details, please visit: http://2016balloontech.umn.edu/home

- "***Resolving planet formation in the era of ALMA and extreme AO***" will be held during May 16 - 20, 2016 Santiago, Chile. For more details, please visit:-http://www.eso.org/sci/meetings/2016/Planet-Formation2016.html

- "***The 32nd International Association of Sedimentology (IAS)***" will be organized during May 23-25, 2016 at The Ibn Battuta Centre (Marrakech), Morocco. The last date for submission of abstracts is Feb. 1, 2016. For more details, please visit: https://www.sedimentologists.org/ims2016

- "***Summer course in Volcanism, Plate Tectonics, Hydrothermal Vents and Life"*** will take place from Aug. 23-Sep. 1, 2016 at Angra do Heroismo, Azores, Portugal, 23. For more details, please visit: http://www.nordicastrobiology.net/Azores2016/Programme.html

- "***Next-Generation Suborbital Researchers Conference***" will be held during Jun 2 - 4, 2016 at The Omni Interlocken Resort in Broomfield, Colorado, USA. For more details, please visit: http://nsrc.swri.org/

- "***CMG 2016: 31st IUGG Conference on Mathematical Geophysics, Paris***" is to take place during Jun. 6-10, 2016 at The Institut Henri Poincare, Paris, France. The last date for submission of abstracts is Jan. 15, 2016. For more details, please visit: http://cmg2016.sciencesconf.org/

Physical Research Laboratory
Ahmedabad 380009

Planetary Sciences and Exploration Programme (PLANEX)

Sixteenth Workshop on "Exploration of inner solar system objects"
7-10 March 2016 at PRL, Ahmedabad

The Indian Space Research Organisation (ISRO) has embarked on an exciting planetary exploration program. After the successful Mars Orbiter Mission, the first Indian mission to Mars, and upcoming Lunar mission, planetary missions to Mars and Venus are under consideration. With the aim of creating awareness amongst students and research scholars in the universities, research laboratories and academic institutions and to attract bright talented young scholars to take up research in the challenging area of Planetary Science and Exploration, the PLANEX programme has been organizing periodic workshops and training programmes. The 16th Workshop in this series is planned to be held during 7-10 March 2016 on the theme "Exploration of inner solar system objects" at PRL, Ahmedabad. The Workshop will consist of lectures by experts, group discussions, tutorials and presentations by participants.

Eligibility for Application:

- Final year M.Sc. students in Physics/Chemistry or Earth/Planetary/Space Sciences
- Final year B.E./B.Tech./M.Tech. students with interest in the above areas
- Research Scholars working towards their Ph.D. degree in any of the above areas

Support: Selected participants will be provided travel support (Sleeper class by train or Bus as per PRL norms), accommodation and boarding for the duration of the workshop.

Instructions:

- Interested students/scholars should e-mail their application (e-mail correspondence is preferred) or send the application by post (see Convener's address below) on or before 1st February 2016, enclosing a brief bio-data, research interests (in ~200 words) and a reference letter from Department Head/Research Supervisor. Those candidates who have attended earlier PLANEX workshops are not eligible to apply.

Contact Address:

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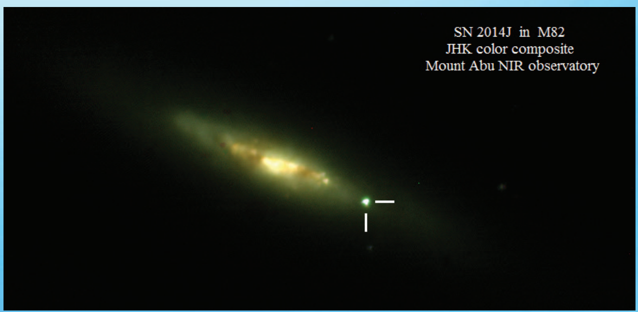
The "first Light" image of star alpha Arietis was acquired with the 1.2m telescope on 19 November 1994 establishing excellent quality of its optics. The observatory started regular operation immediately with lunar occultation study of IRC-10557 (v Aquarii) on December 7, 1994. Over the years, it has catered to the observational requirements of the main scientific programs of the Astronomy & Astrophysics faculty. The research programs cover a wide range of objects and events, such as, star formation, stellar structure and evolution, comets, Novae and binary systems, supernovae, lunar occultation studies, star-burst galaxies and active galactic nuclei. The techniques used are imaging photometry, spectroscopy and polarimetry.

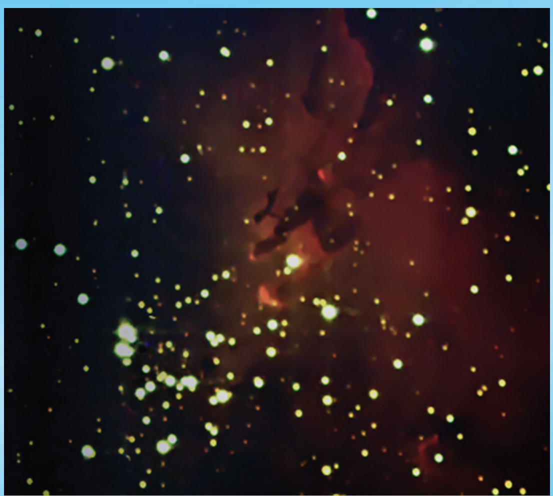
Prof. UR Rao with some staff members of A&A Division, on Feb 9, 1995.

Astronomical data obtained from the observations carried out from the Mt. Abu InfraRed Observatory have resulted in more than 150 peer reviewed research publications and more than a dozen doctoral theses as of now. In addition to it, Observatory has trained a large number students in astronomy alongwith significant contribution to the science awareness activities of PRL. This is significant achievement considering rather modest astronomical facilities at the MIRO. The Observatory is in the process of acquiring a larger, 2.5m, telescope which is expected to give big boost to its scientific programs.

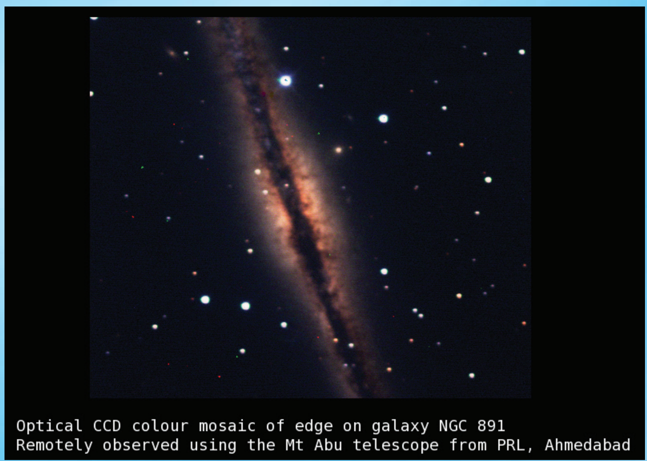
Several interesting and important results have been obtained on a large number of astronomical sources using the observations from Mt. Abu InfraRed Observatory, making a significant contribution to their understanding and universe in general. Very important contributions have come from the study of several planetary nebulae, starforming regions, high resolution studies of stars, star-burst galaxies, active-galactic nuclei, binary systems, variable stars, comets and asteroids. Study of novae in near infrared, a very successful program, has resulted in large number of publications leading to much better understanding of these sources. MIRO was the first Indian observatory to have optical polarimeter to measure polarization in stellar, cometary and AGN environments. Some of the very recent results from the Mt Abu Observatory are, detection and detailed coverage of the supernova SN2014J in near IR, detection, association and classification of CGRaBS J0211+1050, a Fermi Gamma-ray source, as low energy peaked blazar and several interesting novae. A new program of detecting and characterizing planets in the stellar systems beyond our solar system is going on using radial velocity measurement technique. The 1.2m telescope is in very good health to serve the community for many more years to come. In addition to 1.2m telescope, 0.5 m CDK telescope also has started functioning in automated mode which is essential requirement for the continuous monitoring of variable sources, such a blazars. The upcoming new 2.5 m telescope will further strengthen the capability of the MIRO. With the successful commissioning of all the payloads onboard ASTROSAT, Indian community can now boast of a wonderful multi-wavelength platform, right from radio to high energy gamma-rays, to explore the enigmatic universe.



Near IR image of M 82 galaxy taken from MIRO, showing location of the supernova SN2014J which exploded on January 21, 2014.



Starforming region M16 in our Galaxy, RGB image taken with 0.5m CDK telescope, Mt Abu.



Edge-on galaxy NGC 891, 1.2m CCD image taken remotely from Ahmedabad, shows dust lane along its equator.

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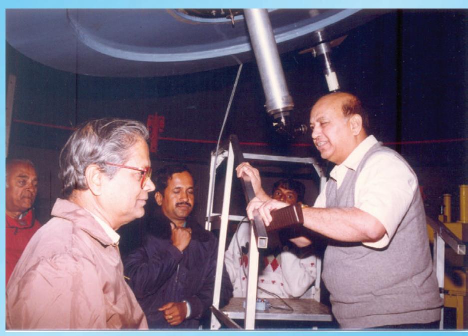
Mount Abu InfraRed Observatory (MIRO), Gurushikhar, Mt Abu

Mt. Abu Infrared Observatory, situated at an altitude of 1680 meters with a latitude of 24:39:10N & longitude of 72:46:47 E, on top of the Gurushikhar peak of Aravali range, in Mount Abu, a hill resort of the state of Rajasthan, India, is operated by the Physical Research Laboratory, Ahmedabad, and funded by the Department of Space, Government of India. It houses a 1.2m Cassegrain focus f/13 telescope, optimised for infrared and optical observations and a 0.5m CDK telescope for variability studies. The observatory has a host of back-end instruments, such as 1kx1k & 2kx2k CCDs, Near Infrared Spectrographs (NICMOS-III and NICS), optical polarimeter, PARAS- spectrograph for radial velocity measurements (for exo-planet hunting program) and Fabry-perot spectrograph. MIRO has its own aluminization plant for mirror coating, liquid nitrogen plant to supply liquid nitrogen to cool astronomical detectors and a small mechanical workshop. The observatory also houses atmospheric and space science laboratory to perform studies related to aerosols and other atmospheric physics experiments.

Mt Abu InfraRed Observatory (MIRO), Gurushikhar, Mt Abu, Rajasthan: Then (1990- no vegetation) and now: picture with star-trails (Courtesy, AstroProject), trees can be seen in front of the building.

The idea of setting up an optical and IR observatory and, in fact, initiating the infrared and optical astronomy program as such, was put forth by Late Prof. Devendra Lal, director, PRL sometime in 1970s. The task of starting the program and the setting up of the astronomical observatory was entrusted to Prof. PV Kulkarni. After an extensive astronomical site survey of several locations, Gurushikhar, the highest peak of Aravali range in Mt Abu, Rajasthan, was found most appropriate due to its low water vapour content, more than 220 observable nights in a year with reasonably good seeing and site's vicinity to Physical Research Laboratory in Ahmedabad, which is about 240 kms away. The responsibility of developing the site, including the construction of the access road, telescope building and other facilities, telescope mount and dome etc., was given to ISRO. The design of telescope drives, mount and other support systems, including telescope control, was taken up by the ISRO SHAR center which also supervised the fabrication work at Prabhakar Products, Chennai. The mirror fabrication, polishing and other optics was the responsibility of the Indian Institute of Astrophysics, Bangalore. Several staff members recruited at PRL and a large contingent from ISRO set out to develop optical/IR observatory in Mt Abu. Therefore, the observatory was designed and developed in indigenously by ISRO, PRL and IIA. All the back-end instruments, one of the most important components of the astronomical observations, were developed, in parallel with the setting up of the observatory, by the faculty and staff of the astronomy & astrophysics division at PRL. The instruments developed in house were fast photometers, Fabry-Perot spectrograph, polarimeter, optical fibre-fed spectragraph etc. Some of those initial instruments are still functional and competing with new age instruments. Later on, optical CCD and near infrared camera and spectrograph (NICLOS-III) were acquired and integrated with the telescope. Very recently an optical imaging polarimeter and eschelle spectrograph for radial velocity measurements, PARAS were developed and are in operation now.



Prof. UR Rao looking through the eye-piece of 1.2m telescope on Feb 9, 1995 along with Prof. MR Deshpoande and Prof. NM Ashok

Contributed by :
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