# Measurement of Solar Magnetic Fields: Development of a Polarimeter for *Multi-Application Solar Telescope*

A thesis submitted in partial fulfillment of the requirements for the degree of

## Doctor of Philosophy

by

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# Dedicated to

my parents

### Declaration

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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### CERTIFICATE

It is certified that the work contained in the thesis titled "Measurement of Solar Magnetic Fields: Development of a Polarimeter for *Multi-Application Solar Telescope*" by Alok Ranjan Tiwary (11330020), has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

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Date: June 21, 2018

## Acknowledgements

I would like to start by expressing my sincere and deep gratitude to my PhD adviser, Prof. Shibu K. Mathew for his invaluable guidance, encouragement and support throughout my PhD tenure.

I am deeply grateful to Dr. A. Raja Bayanna for his continuous encouragement and generous support throughout my research endeavor. I have enjoyed talking to him about work and other matters on several occasions.

I am also grateful to Prof. P. Venkatakrishnan for his suggestions and constructive comments to improve the quality of work carried out in this thesis. I express my sincere gratitude to the Doctoral Studies Committee (DSC) members as well as thesis experts, Prof. Nandita Srivastava and Dr. Ramitendranath Bhattacharya for their useful comments and suggestions during my IITGN review reports and for throughly reviewing my thesis.

I express my gratitude to the Director of Physical Research Laboratory (PRL), all faculty members, and administrative staff of PRL, for giving me a nice opportunity to pursue my research work. I also express my gratitude to the academic committee of PRL for reviewing my progress in research periodically. I extend my thank to the staff of computer center and library staff (Specially Dr. Nistha Anil Kumar and Dr. Nurul Alam) at PRL for helping me whenever I needed. I thank the faculty members of USO, Prof. Ashok Ambastha, Dr. Bhuwan Joshi, and Dr. Brajesh Kumar for their generous helps and encouragements throughout my research endeavor. A very special thanks to all other staff members of USO, Mr. Raju Koshy, Mr. Rakesh Jaroli, Mr. Pinakin Shikari, Ms. Ramya Bireddy, Mr. Sudarshan Jain, Mr. Naresh Jain, Mr. Mukesh M. Saradava and all the trainees for their help and support in various ways during my stay at USO.

I must express my sincere gratitude to my seniors at USO; Dr. Anand D. Joshi, Dr. Vema Reddy Panditi, Dr. Suruchi Goel, Dr. Wageesh Mishra, Dr. Dinesh Kumar, Dr. Upendra Kushwaha, Dr. Sajal Dhara, Dr. Avijeet Prasad, Dr. Sowmya, Dr. Supriya, and Dr. Sindhuja for helping me at various stages of the thesis work. I also thank all the seniors at PRL for being supportive whenever I visited PRL especially Dr. Gaurav Tomar and his wife Dr. Bhavya. I would like to thank all my batch-mates; Sanjay Kumar, Arun Pandey, Guru Kadam, Girish Kumar, Manu George, Ikshu Gautam, Sharadha Band, Tanmoy Mondal, Gaurava Jaiswal, Abhaya Swain, Chithrabhanu P., Kuldeep Suthar, and my junior Rahul Yadav, Newton Nath, Pankaj Bhalla, Hemant Saini, Ranadeep Sarkar, Praveer Mitron, and Sushree Sangita for their support during my stay at PRL and USO. I extend my thank to my college and university friends Dr. Mohit Srivastava, Guru Sharan Pathak, Rajkumar Prasad, Baliraj Singh, Arvind Yadav, Arun, Alok, Neeraj, Kaleem, Kishore, Mohit, Mellissa, Anita, Dr. Shipra Pandey and many others who have been always supportive.

I would like to take this opportunity to thank all the family members at USO colony Mrs. Usha Venkatakrishnan, Mrs. Saraswati, Mrs. Mahima, and Mrs. Bharti for inviting me for lunches and dinners on various occasions.

My special thanks to Dr. Dinesh Tripathi sir and Rakesh Bhaiya for their invaluable support, and giving me right-direction at the crucial moment of my life.

I am in dearth of words to thank my parents (Mr. Baliram Tiwary and Mrs. Kalindi Devi) for the encouragement and the support they have provided me throughout my life. Words cannot express my gratitude to them. Therefore, I dedicate my thesis to them. I also thank my dear brothers (Ashutosh Ranjan) and sisters (Majusha and Binu) for their support, suggestions and love. I extend thanks to my other family members, my all cousins (especially Appu Bhaiya and Amod) for their affection and support. I am very thankful to Anamika for her continuous and unconditional support and being with me whenever I felt alone and weak. I am also thankful to her family for their support and faith in me. Last and really not least, I thank all my friends, relatives, teachers and students from whom I have learnt something to be where I am today.

#### Alok Ranjan Tiwary

## Abstract

The solar magnetic field governs all the solar activities occurring at the outer atmosphere of Sun. The magnetic field lines in the solar atmosphere are stressed or deformed by the convective motion at the photosphere. These stressed magnetic field configuration is believed to be responsible for activity phenomena like flares, filament eruptions, coronal mass ejections (CMEs) etc. Majority of the eruptive events occur in the regions of strong and complex magnetic fields called as active regions. These eruptive phenomena directly affect near-Earth space weather by the accompanying high-energy radiation and charged particles. In order to predict these events a detailed investigation of solar magnetic structures is required. Thus, measurement of solar magnetic fields is of utmost importance in solar physics. However, measurement of solar magnetic field is done remotely by measuring the polarization of solar spectral lines induced by Zeeman effect. Polarization measurement is quite a challenging task because the polarization state of incoming light can be modified due to several factors/components (Earth atmosphere, Telescope, other optical components) coming in the path of light beam.

Multi-Application Solar Telescope (MAST), a 50 cm off-axis Gregorian telescope, was installed at Udaipur Solar Observatory (USO), India, which has been made operational recently. For understanding the evolution and dynamics of solar magnetic and velocity fields, an imaging spectropolarimeter has been developed at USO as one of the back-end instruments of MAST. This system consists of a narrow-band imager and a polarimeter. This instrument is intended for the simultaneous observations in the spectral lines at 6173 Å and 8542 Å, which are formed in the photosphere and chromosphere, respectively. The focus of this thesis is on the development of a polarimeter for measuring the polarization signal induced in the photosphere and chromosphere. The polarimeter includes a linear polarizer and two sets of Liquid Crystal Variable Retarders (LCVRs). It is known that the retardance of LCVR depends on the voltage and temperature. Voltage at a constant temperature is used for fast modulation.

However, fluctuations in the temperature and voltage reduces the accuracy in the polarimetric measurements. Thus we have characterized LCVRs of the polarimeter for various combinations of voltages and temperatures. Further, to achieve a sufficient polarimetric accuracy of  $10^{-3}$ , it is necessary to calibrate the polarimeter and remove the cross-talk arising from the polarimeter itself. The calibration of the polarimeter is performed by introducing a calibration unit (CU) consisting of a linear polarizer and a zero order quarter wave plate (QWP). Both elements are placed in computer controlled rotating mounts. The calibration unit is placed just after the folding mirror (M6) of MAST. Thus, during operations with MAST, calibration unit is used to generate known polarization by rotating QWP. The polarimeter response function or X-matrix is determined from a comparison between created input and measured output. The application of the inverse matrix  $X^{-1}$  on the measured Stokes vector removes the cross-talk arised due to properties of the polarimeter components.

In the thesis, spectropolarimetric observations of various active regions obtained with the imaging spectropolarimeter for MAST are also presented. For verification, we have made comparison of line-of-sight observations of a selected active region obtained from the Helioseismic Magnetic Imager (HMI) onboard the Solar Dynamics Observatory (SDO) with that obtained from observations in the spectral line 6173 Å from MAST telescope. We found good agreement between both the line-of-sight observations, considering the fact that MAST observations are limited by atmospheric seeing.

It is important to note that MAST is a nine mirror system with two offaxis parabolic and seven plane oblique mirrors, the oblique reflections of these mirrors complicate the measurement as the instrumental polarization corrupts the incoming radiation. The polarization induced due to mirrors of telescope is linear. In order to get the vector magnetic field Stokes Q, and U profiles need to corrected using telescope matrix. We have planned to obtain the telescope matrix both theoretically and experimentally. The thesis is concluded with a discussion on the ongoing experiment for the determination of telescope matrix using sheet polarizer.

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## List of Publications

### **Publications in Journals**

- Tiwary, A. R., Mathew, Shibu K., Bayanna, A. Raja, Venkatakrishnan, P., Yadav, Rahul, 2017. Imaging Spectropolarimeter for the Multi-Application Solar Telescope at Udaipur Solar Observatory: Characterization of Polarimeter and Preliminary Observations. Solar Physics, 292, 49.
- Tiwary, Alok Ranjan, Bayanna, A. Raja, Mathew, Shibu K., 2017 Estimation of order parameter of a Liquid crystal variable retarder using Hallers approximation. Applied Optics, 56, 14.
- Mathew, Shibu K., Bayanna, A. Raja, Tiwary, Alok Ranjan, Bireddy, R., Venkatakrishnan, P., 2017. First observations from the Multi-Application Solar Telescope (MAST) narrow-band imager. Solar Physics, 292, 106.
- Yadav, Rahul, Mathew, Shibu K., Tiwary, Alok Ranjan, 2017, SPIN: an inversion code for the photospheric spectral line, Solar Physics, 292, 105.

## Publications attached with thesis

- Tiwary, A. R., Mathew, Shibu K., Bayanna, A. Raja, Venkatakrishnan, P., Yadav, Rahul, 2017. *Imaging Spectropolarimeter for the Multi-Application Solar Telescope at Udaipur Solar Observatory: Characterization of Polarimeter and Preliminary Observations*. Solar Physics, 292, 49.
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