Declaration by the Candidate

I, Janmejoy Sarkar, declare that the thesis entitled 'Study of the Solar Atmosphere: Space Instrumentation and Observation' is a record of my own work carried out under the supervision of Prof. Gazi A. Ahmed and Prof. Durgesh Tripathi during the period from September, 2020 to April, 2025. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree in Doctor of Philosophy at Tezpur University where no part of this thesis has previously been submitted for a degree or any other qualification at this university or any other institution.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work. I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Janmejoy Sarkar

Jannejoylanka.

Place: Tezpur, Assam, India Regn. no.: TZ200499 of 2019.

Date: 13 May, 2025





Tezpur University

Certificate of the Supervisor(s)

This is to certify that the thesis entitled 'Study of the Solar Atmosphere: Space Instrumentation and Observation', submitted to the School of Sciences, Tezpur University in partial fulfillment for the award of the degree of Doctor of Philosophy in Physics is a record of original research work carried out by Mr. Janmejoy Sarkar under my supervision and guidance.

All help received by him from various sources have been duly acknowledged. No part of this thesis has been submitted elsewhere for award of any other degree/diploma.

Prof. Gazi A. Ahmed,

Supervisor, Professor Department of Physics School of Sciences Tezpur University Napaam - 784028, India Prof. Durgesh Tripathi,

Co-supervisor, Senior Professor Inter-University Centre for Astronomy and Astrophysics Pune - 411007, India



Acknowledgments

I would like to take this opportunity to thank my doctoral advisors, Prof. Gazi Ameen Ahmed of Tezpur University (TU), Prof. Durgesh Tripathi and Prof. A. N. Ramaprakash of IUCAA, Pune, for their constant guidance and support. I am deeply indebted to them for always having faith in me throughout the development and realization of the Solar Ultraviolet Imaging Telescope (SUIT) on board Aditya-L1.

I would like to express my gratitude to the Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune, for funding my work on developing SUIT with the Junior and Senior Research Fellowships. I thank Tezpur University for providing this PhD opportunity, and the Space Astronomy Group at ISRO Satellite Integration and Testing Establishment for the laboratory and logistic support, which facilitated the evolution of this thesis. It is also essential to mention that I attended the IUCAA-NCRA Graduate School during the first year of PhD, the credits of which were accepted at Tezpur University for the completion of my coursework, helping me build a solid foundation in astronomy and astrophysics.

I would like to thank my doctoral committee member—Dr. Moon Moon Devi, and the HoDs of the Dept. of Physics, TU—Prof. Mrinal K. Das, Prof. Nidhi Bhattacharya, and Prof. Pabitra Nath, for helping me navigate through the academic and administrative aspects of my PhD. I'm extremely grateful to Dr. Kishor Baruah for helping me start astronomical instrumentation at the Tezpur University Observatory and Dr. Rupjyoti Gogoi for inspiring me to take up astrophysics as a career. Many thanks to Mr. Narayan Sarma and Mr. Umesh Patir for their help and guidance with every official document that demanded even the slightest attention. I also wish to thank Ms. Anamika Pegu, Deputy Registrar (GA), TU, and Dr. Papori Baruah, Department of Business Administration, TU, whom I have had the opportunity of getting to know outside their official roles.

I could not have undertaken this journey without the constant support of every member of the *SUIT* and Aditya-L1 teams, encompassing extraordinary minds from various organizations who eventually became resourceful teachers and good friends. My deepest gratitude to Ms. Nigar Shaji, Project Director of Aditya-L1, currently Associate Director of Projects at URSC, ISRO, who played a central role in making the Aditya-L1 mission a reality. I would like to extend my sincere thanks to Prof. Shyam Tandon, Dr. Koteshwara Rao, Prof. P. Sreekumar, and Dr. Seetha Somasundaram for their detailed review, advice and constant support throughout the development and commissioning of *SUIT*. I would also like to thank Mr. Rushikesh Deogaonkar, Mr. Ravi Kesharwani, Ms. Deepa Modi, Dr. Avyarthana Ghosh, Mr. Melvin K. James, Mr.

Raghavendra T.S., Mr. Mahanthesha DMK, Mr. Mahesh Burse, Mr. Sakya Sinha, Dr. Soumya Roy, Dr. Nived V.N., Mr. Rahul Gopalakrishnan, Mr. Bhushan Joshi, and Mr. Sriram Muley of IUCAA; Dr. Sankarasubramanian K., Mr. Anurag Tyagi, Dr. Anuj Nandi, Dr. Radhakrishna V., Ms. Rwitika Chatterjee, Ms. Netra Pillai, Ms. Swapnil Singh, Mr. Abhilash Sarwade, Mr. Srikar P. Tadepalli, Mr. Koushal Vadodariya, Mr. Manjunath Olekar, Mr. Mohammad Azar, and all other staff members at the Space Astronomy Group, URSC; Dr. Bhargavaram B.S. of LEOS-ISRO; Dr. Manoj Varma of IIA; Mr. Adithya H.N. of MCNS, MAHE; Dr. A. Raja Bayanna of USO/PRL; Mr. Ravi A. and Mr. Nashiket Parate of Aditya-L1 Project Management Office, ISRO; Dr. Abhijit Adoni of the Thermal Systems Group, ISRO; satellite integration team, environmental testing team and satellite checkout team of Aditya-L1. I would especially like to thank Dr. Sreejith Padinhatteeri, Project Scientist of SUIT, MCNS-MAHE, who has been my best support system ever.

Many thanks to my fellow labmates – Dr. Vishal Upendran, Mr. Linn Abraham, Mr. Deepak Kathait, Dr. Sneha Pandit, Dr. Megha A. Rao, and Mr. Biswanath Malaker at IUCAA and Dr. Kabita Deka, Dr. Nishant Shukla, Mr. Kaushik Nath, Mr. Dhanjit Talukdar, Ms. Sahnaz Shabnam, Mr. Debasish Krishnatreya, and Ms. Himakshi Bora at Tezpur University. They have exposed me to various knowledge bases and skill sets, which have helped me inculcate a wide gamut of capabilities over the years.

I am thankful to the book 'All About Telescopes' by Sam Brown and Edmund Scientific Co. The impressive illustrations in the book helped me start amateur astronomy in my teens and were my first practical guide to telescope making. I am also very fortunate to have accidentally come across the novel 'First Light' by Richard Preston about a decade ago, which nudged me further towards instrumentation. All the quotes in this thesis are some of my favorite lines from this book.

I am deeply indebted to Antara for helping me recognize my skills in instrumentation. Also, I would like to thank my close friends- Swapnil, Syed, Subham, Sayan, and Arghyadeep, my friends at IUCAA- Bikram, Partha, Tathagata, Premvijay, Sayak, Eshita, Pushpak, Manish, Rajendra, Soumil, Swarnim, Anshuman, Sourav, Prashant, Snehil, Biplab, Priyanka, Balpreet, Sudeb, Govind, Nayan, Suryansh; my friends at Tezpur University- Biprav, Bidhan, Bikash, Debasish, Hritwik, Jubaraj, Niranjan, Subham, Souvik, Sree, Neelim, Juganta, and all members of Sky Watchers' Association of North Bengal (SWAN) for always being by my side and helping me selflessly.

Finally, I would like to thank my father for always inspiring me to look at the sky, and my mother for lifting my spirit when I believed I had lost.

— Janmejoy, May, 2025.



List of Figures

1.1	Structure of the Sun	3
1.2	Temperatures across the solar atmosphere	3
1.3	The solar spectrum from SOLSTICE and SOLSPEC combined.	9
1.4	A CAD model of the Aditya-L1, illustrating the position of $SUIT.$	15
1.5	A schematic diagram [top] and a photograph [bottom] of the $SUIT$ payload	16
1.6	Full disk images in all eleven filters recorded by SUIT on May 17, 2024	18
2.1	Schematic representation of filter characterization setup	28
2.2	Spatial Variation of Transmission for $SUIT$ narrowband filters	29
2.3	Spatial Variation of Transmission for <i>SUIT</i> broadband and bandpass filters	30
2.4	Out-of-band characteristics of $SUIT$ narrowband filters	33
2.5	Out-of-band characteristics of $SUIT$ broadband and bandpass filters	34
2.6	Out-of-band characteristics of $SUIT$ narrowband science filter combinations	35
2.7	Out of band characteristics of $SUIT$ broadband science filter combinations	36
2.8	Transmission profiles for various tilt angles for $SUIT$ narrowband filters	40
2.9	Exploded view of the science filter mounting system on the $SUIT$ filter wheel assembly	43
2.10	Assembled flight model of $SUIT$ Filter Wheel Assembly	43

3.1	SUIT	50
3.2	Flight model of the Primary (left) and the secondary (right) mirror assemblies	50
3.3	Contribution of Zernike coefficients (Z#) to wavefront error	51
3.4	Flight model of field corrector lens assembly	51
3.5	Final wavefront map of $SUIT$ after optical alignment of M1, M2 and FCLA	52
3.6	Flow chart summarizing the sequence of activities undertaken for optical alignment and defining the optical axis of $SUIT.$	53
3.7	The position of the alignment cube on the $SUIT$ payload. The alignment cube sits on a cylindrical stand, next to the primary mirror (M1)	55
3.8	Schematic diagram of the optical setup used to find the <i>SUIT</i> optical axis and for measuring the angular offsets with the alignment cube axis	56
3.9	Angular offset of the alignment cube axis with the $SUIT$ axes	56
3.10	Schematic diagram and picture of the $SUIT$ detector assembly	59
3.11	Isometric view (left) and actual photo (right) of the thermal filter assembly mounted on the $SUIT$ optical bench	60
4.1	The effective area curves for $SUIT$ science filters	66
4.2	Diagram [top] and schematic flowchart [bottom] for photometric calibration and spectral validation of $SUIT$ showing the section view of the turbo vacuum chamber	69
4.3	Spectral transmission profile of $SUIT$ in (a) NB06 and (b) NB07 bands with solar spectrum from SOLSPEC data	71
4.4	Images captured at various wavelengths for the NB02 filter of $SUIT$	76
4.5	Spectral validation for various filter combinations inferred from the imaging measurements	77
4.6	The ghost reflections of the optical fiber as seen with the NB08 filter	78

5.1	Encircled energy plot for <i>SUIT</i> PSF measured in the lab at various locations of the CCD for the NB07 filter	87
5.2	Line profile of 16 lines per mm pattern on USAF resolution target. The image of the target is shown here as an inset	87
5.3	Modulation Transfer Function (MTF) curve for vertical and horizontal patterns on the USAF target	91
5.4	Solar off pointing scheme for flat-field creation	91
5.5	SUIT flat field generated from off-pointed sun images	92
5.6	Nature of vignette at field corner	92
5.7	Simulated encircled energy plots for different field points in the $SUIT$ field of view	95
5.8	Events during a flare trigger and localization	95
5.9	Flat field correction of SUIT images	97
5.10	Comparison of NB04 images before and after scattered light removal	98
5.11	Comparison of NB08 images before and after ghost removal	101



List of Tables

1.1	Technical specifications of the $(SUIT)$	12
1.2	SUIT science filters, their bandpasses and science targets of observation	15
2.1	Environmental tests performed on $SUIT$ science filters	24
2.2	Proton irradiance test results for <i>SUIT</i> science filter witness coupons	25
2.3	Filter transmission variation with spatial location	31
2.4	Percentage of out-of-band transmission on red and blue wings of the filters, with respect to in-band transmission	37
2.5	Percentage of out-of-band transmission on red and blue wings of the filter combinations, with respect to in-band transmission.	38
2.6	Optimal tilt angles applied to $SUIT$ filters upon mounting	41
3.1	Zernike coefficients representing the extent of optical aberrations of the $SUIT$ payload and collimator	52
3.2	List of uncertainties in co-aligning the alignment cube with $SUIT$ optical axis	56
3.3	Offset of $SUIT$ Optical axis with respect to VELC optical axis before and after alignment correction	61
4.1	Comparison of the photometry: Measured vs. modeled	71
5.1	Comparison of scatter level (in $\%$) with respect to the mean sun center intensity before and after the scatter subtraction 1	101
5.2	Consolidated list of calibration tests performed on SUIT	103



"If I were to write down how I made my telescopes, it would so shock the astronomers and the opticians that I'd probably never get another order to construct anything."

> — Bernhard Woldemar Schmidt Inventor of the Schmidt Telescope

