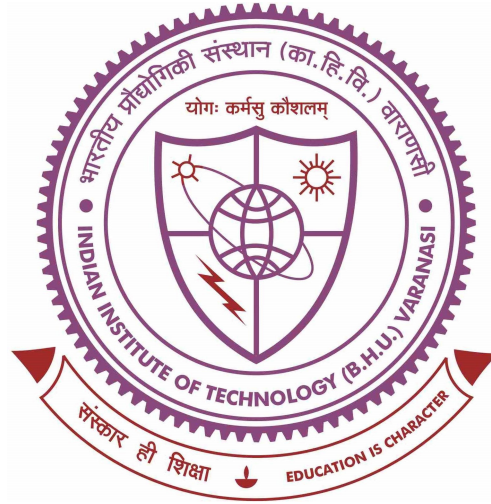


Study of Waves and Quasiperiodic Plasma Processes in the Solar Atmosphere



**Thesis submitted in partial fulfillment for the
Award of Degree**

Doctor of Philosophy

by

Kartika Sangal

DEPARTMENT OF PHYSICS
INDIAN INSTITUTE OF TECHNOLOGY
(BANARAS HINDU UNIVERSITY)
VARANASI - 221005
INDIA

Roll No.: 18171509

2024

Chapter 7

Conclusions and Future Plan

In this chapter, we provide an overview and conclusions of the various scientific works presented in this thesis. We also describe briefly the plans in the framework of these scientific endeavours.

7.1 Summary and Conclusions

This thesis is describing the detection and propagation of waves in the solar atmosphere. We study the physical properties of waves and oscillations in the solar plasma using spectroscopic and imaging observations. Wave dynamics, including their generation, propagation, and dissipation, are important to understand as their physics and roles in wave heating is critical to the solar corona's overall energy balance. In particular the spectroscopic observations recorded by IRIS allows us to investigate these waves and obtain information about their local characteristics of the lower solar atmosphere. Waves are ubiquitous throughout the solar environment, including the photosphere, chromosphere, transition region, and corona. Because of their widespread presence, waves are considered vital for the heating the solar chromosphere, TR, and corona. Specifically, the acoustic waves generated by turbulent movements in the convection zone can penetrate the magnetised solar atmosphere

and cause magnetoacoustic oscillations at the photosphere and lower chromosphere. We statistically examined the propagation of magnetoacoustic waves and oscillations in various magnetic regions of the solar atmosphere (Chapters 3-5). Recent advances in solar physics have greatly improved our knowledge of MHD waves and associated plasma processes in the solar corona. Detailed imaging and spectral data have shown several forms of MHD waves, proving their presence in the solar atmosphere. This work has also given information on the origin, evolution, and properties of quasi-periodic pulsations (QPPs). In Chapter 6, we investigate the presence of QPPs during the commencement of the blowout jets.

The chapter 1 introduces the sun and its atmosphere. It also describes the waves, their detection, and physical properties. This chapter also outlines quasi-periodic pulsations. At the end, it briefly depicts the outline of the present Ph.D thesis. Chapter 2 describes the observational data and details of various instruments and various analyses techniques.

In Chapter 3, spectroscopic data from the IRIS instrument was used to conduct a statistical analysis of oscillations in the solar TR. Using spectral measurements of Si IV lines in the QS, we examined and studied oscillations in the TR. We analyzed both the intensity and Doppler velocity oscillations at the multitude of locations to determine their periodicity. In the network and inter-network portions of the QS, we found that the average period of both intensity and velocity oscillations was constant within the $1-\sigma$ error limit. To get more insight into the physical basis of the oscillations, we also calculated the phase difference between intensity and Doppler velocity oscillations. Our findings revealed the presence of both propagating and standing slow magnetoacoustic waves in the network region, as well as upward and downward propagating magnetoacoustic waves in the inter-network regions.

In Chapter 4, we used spectral observations from the IRIS to investigate wave propagation conditions above the inter-network area. This utilized examining a number of spectral

lines that corresponded to the photosphere, chromosphere, and TR. We determined the dominant oscillation periods at various heights by using wavelet analysis tool. We then estimated the cut-off frequency by computing the phase differences between the Doppler velocity time-series from these various heights using cross wavelet analysis tool. We found that the average behaviour of QS internetwork region fits into a traditional cut-off period model, where 3-minute wave power is more common in the solar chromosphere and TR. On the other hand, 5-minute magnetoacoustic waves dominate in the photosphere. Additionally, this thesis revealed a significant correlation between photospheric oscillations and 3-minute periods in the TR, indicating that these oscillations may be propagating from the photosphere to the TR in form of magnetoacoustic waves. Long-period oscillations that could be locally produced were additionally evident in the solar TR.

In Chapter 5, we used high-resolution data from the Goode Solar Telescope (GST) commissioned at the Big Bear Solar Observatory to study oscillations in the umbral region of a sunspot. We analysed the Doppler velocity associated with the $H\alpha$ line and intensity oscillations at its core and wings. We found the dominance of 3-minute oscillations in the umbral region by means of a thorough statistical investigation at various locations. Furthermore, we detected evidence of both upward and downward propagating waves in the chromosphere, suggesting that the distinctive 3-minute umbral oscillations are generated due to sunspot resonant modes. Through examining the characteristics of magnetohydrodynamic (MHD) waves in different solar regions, we may learn more about their drivers and the processes that transport energy from the lower atmosphere to the corona. This investigation gives important information regarding the function of these waves in coronal heating.

In Chapter 6, we examined a blowout jet using high-resolution imaging data from the Solar Dynamics Observatory (SDO) and spectroscopic data from the Interface Region Imaging Spectrograph (IRIS). We observed the formation of a flux rope with an inverse

gamma shape structure, suggesting the start of the kink instability. Our study indicated bi-directional flows starting near the apex of flux rope, which is a common signature of the magnetic reconnection in the localized solar atmosphere. These findings show that kink instability causes the blowout jet, and that many successive episodes of magnetic reconnection lead to the formation of quasi-periodic pulsations (QPPs) within the jet.

7.2 Future Plans

The solar atmosphere and its inherent plasma is one of the most studied and understood system. Waves and oscillations have been observed and studied in a variety of structures, along with their potential roles in the solar atmosphere. We can understand more precisely their origin and physical properties using multi-wavelength imaging and spectroscopic observations. Waves might transport enough energy to heat the solar chromosphere and corona. In addition to magnetoacoustic wave modes, Alfvén waves go to higher regions and may contribute to the heating in the solar corona. The role of upward-propagating waves may be quantified by computing energy flux at various heights and their dissipation. This study investigates the origin of waves and their propagation properties upto transition region (TR) after passing through the chromosphere. In order to design a comprehensive set of physical parameters to comprehend the origin, evolution, propagation, and dissipation of various MHD waves in different layers of the solar atmosphere, an analysis of imaging, magnetic, spectral, and spectropolarimetric observations along with statistical tools (e.g., power spectra, noise models, wavelet cross-wavelets, phase analysis) will be helpful. Instead of the study wave propagation in isolated region of solar atmosphere, statistical understanding of the origin, propagation, and dissipation of different MHD waves is essential by utilizing multiwavelength observations. As stated above, through statistical analyses of wave propagation using large amounts of observational data (e.g., imaging, spectroscopic, and magnetic), we will be able to determine exact conditions of the origin

of waves for further numerical models of different magnetic structures and provide deep insights into ongoing physical processes. Multi-height, multispectral/imaging data from space-based (e.g., IRIS, forthcoming Solar-C, MUSE, Aditya-L1/SUIT, Solar Orbiter etc) and ground-based (e.g., BBSO, 1m-SST, 4m-DKIST, 4m-EST) observatories can be used for understanding the physics of waves between photosphere to the inner corona. Further these information will also be used to explore the role of these waves in coronal heating and the formation of the solar wind.