Chapter 7

Conclusions and Future Plan

In this brief chapter, we outline the conclusions and future plan.

7.1 Conclusions

The thesis has presented observations and modelling of plasma flows in the different loop systems and open magnetic structure, and focuses on the physical processes driving these motions. Chapter 3 discusses one of the first detailed multi-spectral study of plasma flows in the cool loop systems and Chapter 4 uses numerical modelling of plasma motions along bipolar magnetic loop strands. Chapter 5 describes the plasma flows at the footpoints of the quiescent coronal loops anchored in the moss region using multiple spectral lines observed by IRIS. Finally, Chapter 6 showed a multi-wavelength analysis of the impulsive plasma outflow driven due to magneteacoustuic waves turning into shocks. These results are concluded below, and ideas for further work to build upon these findings are presented in section 7.2.

Multi-spectral observations of low-lying cool loop systems for three different datasets are observed by IRIS highlighting the plasma flows inversions in cool loop systems leading to the mass transport and their formation (Chapter 3). Spectral lines such as Ni I, Mg II k, C II, and Si IV formed between the photosphere and transition region (TR) have been used to investigate radiances, Doppler shifts, and line widths. The analysis showed the dominance of blueshifts or redshifts on either footpoints of the loop threads. The Doppler velocity along the co-spatial height at the blueshifted footpoints shows a transition from very small upflow velocities ranging from (-1 to +1) km s^{-1} in the Mg II k line (2796.20 Å ; formation temperature: log(T/K) = 4.0) to the high upflow velocities from (-10 to -20) km s^{-1} in Si IV. So, the consistent similar transition of plasma flows from redshift (downflows) to the blueshift (upflows) above the footpoints of these loop systems in the spectral line C II (1334.53 Å ; log(T/K) = 4.3) lying between Mg II k and Si IV (1402.77 Å ; log(T/K) = 4.8) were found out in all the three observational datasets. The redshifted footpoint indicates the downflowing plasma at the other end. These sudden initiation of plasma flows from the blueshifted footpoint to the redshifted are caused by small-scale reconnection above loop footpoint and releases energy impulsively. In this work, it is firstly shown that the plasma flows start in the cool loops somewhere around the formation temperature of C II, which is a TR line. This enables us to explore further the underlying physical causes most likely associated with TR and impulsively drive the plasma to form the flowing cool loops.

One such a localized transient was observed in the form of explosive events (EEs). Numerical modelling of the plasma flows initiated by these explosive events (EEs) at the footpoints of the cool loop systems was performed in chapter 4 to support our previous results described in chapter 3 of this thesis. The numerical simulation of MHD equations in the bipolar magnetic loop environment having both the active footpoints elucidate the impulsive behaviour of such flows driven by EEs. The cool loop identified using Si IV (1403 Å) line having TR temperatures are observed to have highly broadened profiles which are generally attributed to the explosive events. Such perturbations having velocity pulse of amplitude ≈200 km s^{-1} are implemented to show the observational features. The data-driven numerical simulation shows the evolution of plasma motions similar to the observation in IRIS in the form of flowing plasma streaks filling the skeleton of a cool loop system. This comparison of the spatio-temporal evolution of the cool loop system in the frame-work of our model with the observations concludes that their formation is mostly associated with the transient energy release at their foot points in the upper chromosphere/TR. Such EEs are found to be the main candidates for the dynamics and energetics of the flowing cool loop systems in the lower solar atmosphere. These new results further encourage us to lead an idea to examine the plasma flow structures from the photosphere to TR above the footpoints of the hot coronal loops anchored in the moss region using spectral observations from IRIS, which we have investigated in chapter 5.

The impulsive heating mechanism for the quiescent coronal loops was further explored in chapter 5. The combination of SDO/AIA imaging observations along with the IRIS spectral lines provides multi-wavelength coverage for the flows at the footpoints of such loop systems. The Doppler velocity distributions at the footpoints lying in the moss region show the negligible or small flows at Ni I, Mg II k3 and C II line corresponding to upper photospheric and chromospheric emissions. Significant red-shifts (downflows) ranging from (1 to 7) km s^{-1} are observed at Si IV (1393.78 Å ; log(T/K) = 4.8) which is found to be consistent with the existing results regarding dynamical loop systems and moss regions. These results validate the impulsive heating mechanism leading to plasma flows in quiescent coronal loops as has already been reported for other loop systems.

Along with pursuing the detailed spectroscopic studies on understanding plasma flows in the cool and hot loops as described above, we have explored the plage region of quiet Sun and its transient brightening that leads a supersonic plasma flow in form of an impulsive isolated jet. The multi-wavelength observational study of an impulsive plasma outflow in the quiet-Sun from the AIA/SDO is pursued in Chapter 6 of this thesis. The outflow rising with a high terminal speed of 1250 km s^{-1} to the upper solar atmosphere also peaks at the same time in different channels of SDO/AIA (logT(K)=4.7 to logT(K)=7.0) when there was a brightened energy release at its footpoint. This indicates the impulsive origin of this supersonic jet/plasma flow. The multitemperature plasma contained in the outflow is evident from the line-of-sight differential emission measure maps. Thus, the investigation of underlying physical process driving such outflows required an outlook at the SDO/HMI magnetic field data at its footpoint. It showed the emergence of negative polarity oscillating at the period of 442 s. The oscillations are also observed in the intensity of 1600 Å almost co-temporally at the base of the outflow with the almost same period (≈416 s). The ∼7.0 min periodicity in the magnetic flux and 1600 Å flux is present both prior to and during the onset, and even after the outflows for the duration of ≈1 h. This indicates that the magnetoacoustic waves are generated and present at the base of the outflow and interact with the localized small-scale current sheet and associated X-point. Magnetoacoustic waves encounter with the discontinuity at the X-point that may further develop into the fast magnetic shocks leading to the formation of the observed shock cusp and triggering of the impulsive plasma outflows.

7.2 Future Plans

Further work is required to give more insights into the chromospheric dynamics using high-resolution observation from different space-based as well as ground-based telescopes such as Solar Orbiter, Parker's Solar Probe, 4-m Daniel K. Inouye Solar Telescope (DKIST), 1-m Swedish Solar Telescope (SST), and upcoming 2-m Indian National Large Solar Telescope (NLST), 4-m European Solar Telescope (EST). As mentioned above also, some upcoming missions like Aditya-L1, NLST, EST, Solar-C will further be used to compliment these studies. I plan to understand the chromospheric dynamics using high-resolution observations from 4-m DKIST. The study of fine structures of corona and formation of transition region lines will be performed using DKIST observations. I will conduct these studies with the help of the Visible Broadband Imager (VBI) which provides high-resolution image of the Sun's surface showing the convective cells (granules) with the spatial resolution of 25 km. The imager includes various lines such as Ca II K (39.327 nm), G-band (430.520 nm), Hα (486.139 nm; 656.282 nm), TiO (705.839nm), Fe XI (789.186 nm). Such observations have high potential to resolve twisted magnetic flux tubes having ability to channelise the energy and mass into the corona. Such magnetic fields will give better insights into transient events like reconnection of twisted magnetic fields, as well as evolution of waves and flows therein.

These high-resolution observations of the magnetic flux interaction with the mass flows exhibiting the dynamical nature of the Sun will be well-coordinated with other instruments (e.g., IRIS, SDO, upcoming Aditya-L1/SUIT) to cover different regions of the solar atmosphere. Also, Visible Spectro-polarimeter will be giving promising data including spectral lines corresponding to broadband imager widely covering different layers of the Sun's atmosphere. The DKIST telescope also has two other instruments working in the infrared domain near wavelength 1.5 μm which would be high beneficial for magnetic fields measurements. So, coupling of different layers of the solar atmosphere using multi-wavelength and multi-spectroscopic observations will enhance the variety of plasma dynamics including flows at diverse saptio- temporal scales, as well as wave activities in the highly structured flux tubes. These coordinated observations will provide some scientific information on mass and energy transport processes in the lower atmosphere, and their responses in the more large-scale magnetic structures (loops or open arches) in the overlying transition region (TR) and corona.