Preface

The advancement in science and technology is now able to probe far distant space in the universe, which reveals a variety of exotic physical phenomena at disparate spatio-temporal scales and energy. We can name a few, *viz.*, the formation and dynamics of the Sun and its planets, stars and their atmosphere, dynamics of star-forming regions and interstellar space, galactic and nebular dynamics, solar and stellar winds, giant jets and accretion around active galactic nuclei (AGNs), tremendous energy explosions in form of supernovae and Gamma-ray bursts (GRBs), black-hole dynamics, and largely the developments related to the formation and acceleration of the universe in the frame-work of astrophysical and cosmological phenomena, etc. These advancements play a leap forward role in parallel in the development of many other branches of science, and also deliver a variety of new technologies to the mankind, e.g., detector technology and advanced camera, modern optics, cutting edge software developments, etc. With the advent of the telescopes a few centuries back, the first object in the near space, our parental star "The Sun", is explored in greater detail. The general perception of a normal human about the Sun is that it is a source of energy and light that makes their life habitable on the Earth. However, in the scientific pursuit, it is well known as a magnetically active young star which is approximately 4.2 billion years old! The dynamics of its various gaseous atmospheric layers (e.g., starting from bottom to top, the photosphere, chromosphere, transition region, and corona) is found to be governed by the magnetic fields rooted in the photosphere and generated in its interior via suitable dynamo action. The outermost layer of the solar atmosphere is known as the corona, which lies around a million-degree Kelvin temperature. The temperature of the solar atmosphere rises rapidly when we move from the Sun's surface (photosphere) to its outer atmosphere corona lying just few thousand kilometers above. How does the million-degree hot corona maintain it's temperature, and also serve as a platform for the violent solar eruptions constituting even the space weather of the Earth and other planets in our solar system, are still the major riddles for the solar scientists to understand.

The Sun's corona triggers violent plasma eruptions, radiation, and a stream of supersonic charged particles into space. Such violent magnetic activities often cause intense solar storms and constitute the hazardous space weather in the outer atmosphere (e.g., magnetosphere and ionosphere) of the Earth. The solar storms may have the potential to damage the satellites which we use for communications and navigation. It can also disrupt power grids that provide our electricity, interrupt the air aviation and telecommunication, and also causes a potential threat to the astronauts and space stations/satellites orbiting outside the Earth. Therefore, understanding the triggering mechanisms of space weather candidates (e.g., solar flares and coronal mass ejections, eruptive prominence) at the Sun and their physical effects and predictions in the heliosphere, is the research area placed at the forefront in the modern space and heliospheric physics. Moreover, coronal mass ejection (CME) and flares have different signatures at different wavelengths of the radiations emitted from the Sun, which is required to be combined, synthesized, modeled and interpreted to acquire sufficient knowledge that can be applied for prediction purposes of these eruptive phenomena. As mentioned above, it is now widely accepted that these eruptive phenomena such as coronal mass ejections (CMEs) and flares occurring on the Sun are responsible for disturbances in the interplanetary medium. The build-up and release of free energy on the Sun in flares and CMEs, and/or the underlying physical cause of the associated giant eruptive flux-ropes (e.g., prominence/filament/coronal-loop) are the key issues at the Sun to further understand the large-scale dynamics of the outer solar atmosphere and space weather. As the CMEs propagate into the interplanetary medium, they interact with the solar wind, with other CMEs, and drive shocks. When the CMEs arrive at the Earth, they interact with its magnetosphere. As mentioned above, CME interactions with Earth's magnetosphere cause severe geomagnetic storms, and CME-driven shocks accelerate energetic particles that can be hazardous to human technology in space. The core of the CMEs and occurrence of the solar flares both may be associated with the eruption of the solar prominence/filament, therefore, these structures also determine the triggering of the space weather candidates. These advancements in our knowledge of solar eruptions and their relation to space weather are mainly due to the current availability of a vast array of space and ground-based observatories. However, there are many fundamental questions remain, which need to be answered before arriving at a complete understanding of the eruptive phenomena. Such an understanding is needed to accurately predict the impact of the solar eruptions on Earth's space environment. Therefore, the exploitation of available space and ground-based data towards a better understanding of the origin, interplanetary propagation, and geospace impact of the eruptive phenomena are always required.

The continuous observations of the multiwavelength emissions, highly dynamical plasma processes in form of large and small-scale transient/eruptive events are needed to understand their physical behaviour and their roles in forming the violent eruptions and related energetic plasma processes. Therefore, the modern generation equipment and their solar observations are playing a crucial role to understand the solar transients as they impose rigid constraints on various well-established eruption models to better understand and predict the eruptive phenomena and their propagation in the outer corona and heliosphere. These observations collectively provide cradle-to-grave evolution of solar eruptive phenomena in the solar atmosphere and heliosphere. The present thesis specifically focuses on the study of the dynamics of solar prominence/filaments, and their response in the large-scale corona. The thesis analyzes the multiwavelength observations from ground and space-based observatories (e.g., Solar TErrestrial RElations Observatory STEREO, Solar Dynamics Observatory SDO, Big Bear Solar Observatory BBSO, etc) to understand the formation and eruption of solar prominence and associated dynamical plasma processes in the large-scale corona and interplanetary space. Using these observations, some new scientific results are devised, which are primarily related to a variety of plasma instabilities (e.g., Magnetic Rayleigh-Taylor and Kelvin-Helhmholtz Instabilities), the forced magnetic reconnection, dynamics of prominence vortices and associated reconnection, the flux-rope eruptions, and formation of jet and stealth CMEs, etc.

In the large cohort of space weather candidates (e.g., eruptive prominence/filaments; solar flares; CMEs; large-scale corona jets, etc), we focus to study in greater detail the various prospectives of the eruptive cool prominences in the present thesis. Solar prominence represents the cool and high-density plasma hanging with the support of the magnetic field against the gravity in the solar atmosphere, and basically represent the chromospheric plasma. Historically the chromosphere and prominences were observed during the total solar eclipse. When the Moon covers the solar disk during a total solar eclipse, there is a very short interval of time during which we get radiation only from the gas above the solar surface. The spectrum of such radiation is called the flash spectrum and is indeed found to consist of spectral lines. Since the light coming from the gas above the solar surface appears more colorful than normal sunlight, the layer of solar atmosphere from which this light comes is called the chromosphere and prominences were seen hanging over the limb of the Sun. In the hot and rarefied corona, the solar prominences are characterized as cool and dense plasma regions embedded within the magnetic fields. The photosphere and chromosphere are in the thermal and non-thermal equilibrium respectively, however, the coronal equilibrium is balanced by the heating, thermal conduction, and radiative cooling. The thermal instability may be one of the mechanisms responsible for the prominence formation. This leads to the energy balance of the corona and causes chromospheric plasma condensation in a confined magnetic domain to form a prominence. Solar prominences are one of the most complex (low temperature, high density, partially ionized, and collision dominant) large-scale plasma structures, which suspend against the gravity in the tenous corona with the help of magnetic field. Solar prominences have a long history of observations since 1877. There are two simple models, i.e., a normal polarity prominence and an inverse polarity prominence, to support the prominence material against the gravity in the solar atmosphere. There are several mechanisms (e.g., radiative condensation, levitation, injection, etc.) by which a prominence may also be formed. Solar prominence shows several key phenomena like internal dynamics, formation and disappearance, support and stability, changes in internal magnetic fields, and MHD instabilities in their formation and eruption. Therefore, the internal dynamics and their association with the MHD plasma processes (e.g., instabilities, reconnection, etc.) is an important issue in solar prominence research, which also directs us to understand other eruptive phenomena (e.g., flares and CMEs) linked with their eruption. The observed dynamics in solar prominence strongly depend upon the geometry of the prominence. High-resolution ground-based observatories (e.g., 1m- Swedish Solar Telescope; Big Beer Solar Observatory Hα observations; Dutch Open Telescope; The Rapid Oscillations in the Solar Atmosphere, etc.) and contemporary space-borne instruments (e.g., Solar and Heliospheric Observatory; Hinode, Solr Dynamics Observatory, Interface Region Imaging Spectrograph, etc.) confirmed that these structural components composed of multiple filamentary fine structures known as threads. The dynamics of these threads are very rapid with a lifetime of a few minutes. The size and width (0.15 –0.3”) of threads varies rapidly in different types of filaments/prominence. The solar prominence exhibits several dynamics such as field-aligned flows and magnetohydrodynamic (MHD) waves in the horizontal threads but also can show winding motions, large amplitude and small amplitude oscillations, counter streaming flow, etc. In the present thesis, we basically focus on some peculiar dynamics of the solar eruptive prominences, e.g., MRT/RT and K-H instabilities in the inner corona, outer corona, and further in the interplanetary space; vortex motions and associated reconnection; response of eruptive prominence in triggering forced magnetic reconnection in the large-scale corona; association of coronal prominence channel (CPC) with eruptive jets and stealth CMEs.

Prominences also consist of turbulent dynamics and gravity-driven fluid instabilities (e.g., magnetic Rayleigh-Taylor instability, Kelvin-Helmholtz instability, thermal instability, hybrid instability, etc) on which two chapters of this thesis outline some new results. The observations of these instabilities in the solar prominences are useful to understand the complex linkage between magnetic fields and fluid flows that play an important role in the energy and mass transfer in the solar atmosphere *via* the eruption of prominence channels. The localized reconnection and related energy release, and subsequent heating and prominence plasma are also one of the primary research themes in solar physics. These plasma processes (instabilities, reconnection) are responsible to trigger the large-scale eruptions of the solar prominence/flux-ropes and thus associate with the energy and mass eruptions processes known as solar flares and CMEs respectively, which further link from the atmosphere from the surface to the outer corona and interplanetary space causing the severe space weather as well. The evolution of the instabilities and their associated dynamics at different spatio-temporal scales in the eruptive prominence is least explore regimes in solar research. These instabilities can be used as a tool to understand the internal plasma dynamics and internal magnetic field of the prominence using high-resolution observations of the solar prominences by revealing several morphological structures and internal dynamics (e.g., plumes, fingers, vortex, plasma bubbles, mushroom-like structures, spikes, etc.) developing at different spatio-temporal scale.

In this thesis, we have investigated the dynamical behavior of prominence plasma at different spatial scales. This thesis attempts systematic observational studies of the dynamical behavior of MHD plasma processes of eruptive prominences and their responses from lower corona to interplanetary space using high-resolution space-based imaging instruments and contemporary ground-based observations. The novelty of these results is the extensive effort to combine the localized small/large-scale MHD plasma processes in the prominences, and their connection with the large-scale eruptions. Moreover, the overall physical processes associated with these prominences from lower corona to the interplanetary space have extensively studied and conclusive arguments have drawn. The thesis is organized in the following chapters:

Chapter 1: Introduction

This chapter provides an introduction to the Sun and its atmosphere. We present an overview of prominence and their internal dynamical behavior such as the evolution of instabilities, thread dynamics, relationship with the other large-scale solar eruptions, and their response in the solar atmosphere. The brief history of the observational study of the MHD plasma processes (MHD instabilities, reconnection) in solar prominence is also presented. We discussed the motivation of the thesis work in this section.

Chapter 2: Space and Ground-based Observations and Their Analysis Techniques

In this chapter, we briefly describe space-borne and ground-based instruments/observatories, which have been used to observe the dynamics of the prominences in this thesis work. To understand the magnetic field topology and cause of the evolution of the prominence/filament, we used HMI magnetogram onboard SDO. Global Oscillation Network Group (GONG) Hα data is used to observe the chromospheric dynamics of the prominence. High-resolution imaging observations from AIA and STEREO/A & B provides a wide range of multi-temperature views and is used to observe the small to large-scale dynamical behavior of the prominence/filament and associated CME from lower corona to interplanetary space.

Chapter 3: MRT Unstable Plumes and Hybrid KH-RT Instability in Eruptive Prominence

This chapter describes that how the internal dynamics of the eruptive prominence are evolved at the prominence-cavity interface that is focused on the evolution of magnetic Rayleigh-Taylor (MRT) plumes and hybrid KH-RT instability (plasma bubbles+vortex-like rolled plasma structures) in the lower corona. This interface supports the magneto-thermal convection process, which triggers the dark, hot, and turbulent plume passing through the overlying prominence. High-resolution imaging observation of SDO/AIA permits us to observe the sequential development of MRT unstable plume from the linear phase to the nonlinear phase of the instability. The estimated observational and theoretical growth rate of the MRT instability is consistent with each other. By using the linear dispersion relation (linear stability theory) of MRT instability, we provide a tool to estimate the strength of the magnetic field in the solar atmosphere (lower corona). The MRT unstable plumes get stabilized *via* Kelvin-Helmholtz unstable vortex-like rolled plasma formation at the interface. In the later stage, a tangled thread triggers a hybrid KH-RT instability, which is responsible for the eruption of this prominence. Therefore, we conclude that hybrid KH-RT instability is more energetic than normal MRT instability, which triggers the prominence for an eruption.

Chapter 4: Vortex Motion and Plasmoid Ejections in the Twisting Prominence

In this chapter, we further explore the internal and external dynamics of an eruptive polar prominence and their response in terms of magnetic reconnection in the solar atmosphere. The apparent rotating motion is responsible for the evolution and growth of the polar prominence, which consists of large-scale vortex motion in the upper part of the prominence. The slow-motion of the footpoint twist the legs of the prominence, which leads to two different types of magnetic reconnection. Due to the magnetic shear of the prominence legs, the first stage reconnection initiates internally *via* the resistive tearing mode instability causing multiple plasmoids ejection in the elongated current sheet. The multiple plasmoid ejection destroys the current sheet that is responsible for the collapse of magnetic arcades near the X-point and causes for the external reconnection. The external reconnection is responsible for the eruption of the prominence.

Chapter 5: The Forced Reconnection in the Solar Corona driven by a Prominence

In this chapter, we explore the bulk local dynamics of an eruptive prominence that is responsible for triggering the forced magnetic reconnection in the large-scale corona. The eruptive prominence locally disturbs the small-scale prominence associated magnetic field that triggers an externally driven forced magnetic reconnection. A novel physical scenario has presented for the formation of a temporary X-point in the solar corona, where plasma dynamics are forced externally by a moving prominence. The prominence driven inflow occurred first, thereafter outflow happens along with a thin current sheet and the estimated reconnection rate is $\sim 0.2-0.3$ near the X-point. Observations in relation to the numerical model reveal that forced reconnection may rapidly and efficiently occur at higher rates in the solar corona. The parametric study concludes that increasing the strength of the external driver increases the rate of the reconnection even the requires resistivity for creating the normal diffusion region decreases at the X-point.

Chapter 6: MRT-unstable Eruptive Prominence and Its Propagation between Sun and Earth

In this chapter, we understand the dynamical behavior of an unbound active region eruptive prominence and their response in the interplanetary space. We have used STEREO data to observe an active-region associated prominence erupted on 7 June 2011. The unbound fragmenting eruption of the prominence occurs due to large-scale expansion, which stretches out the ejected plasma from the eruption site, resulting in the development of small-scale cavities. Magnetic Rayleigh-Taylor unstable fingers are formed within these cavities from the lower to intermediate corona (1.1-4 $R_{\odot}$). We conjecture that the prominence plasma is supported by the tension component of the magnetic field against gravity and the density gradient. The linear stability theory of MRT instability has been used to estimate the required magnetic field to suppress the instability in the observed finger structures up to 4 $R_{\odot}$. These MRT unstable fingers further passes through the outer corona (6-14 $R_{\odot}$) and get converted into mushroom-like structures, which indicate the nonlinear phase of MRT instability. The final phase of MRT instability is governed by the turbulent mixing and fragmented plasma spikes, which further propagate into the interplanetary space and even reach up to Earth's magnetosphere as observed by STEREO-A/HI1 and HI2. It enhances our understanding of the sequential development of MRT instability in an eruptive prominence and their responses from the intermediate corona up to the interplanetary space.

Chapter 7: Linkage of Geoeffective CMEs with the Eruption of A Filament-like Coronal Plasma Channel (CPC) and Jet

In this chapter, we investigate the dynamical effect of large-scale eruptions of the solar prominence/flux-ropes that is associated with the coronal mass ejections (CMEs), which is responsible for the space weather activities when they interact with the Earth's atmosphere. Finally, We explore the linkage of geoeffective stealth CMEs, which is associated with an eruption of filament associated Coronal Plasma Channel (CPC). The CPC is analogous to filament channel, which is similar to confined hot coronal plasma and does not contain cool prominence plasma but it may be observed in terms of magnetic field lines. The CPC erupted first with its very faint coronal signature in the lower corona. The spreading CPC interacts with the open field lines of the coronal hole and responsible for the triggering of the thin flux rope and rotating jet-like structure with a very faint signature in the lower corona. These eruptions were collectively associated with the stealth-type CMEs and CME associated with a jet-like eruption. The compound CME further interacts with the Earth atmosphere and onset of an intense geomagnetic storm (GMS) with Dst index = -176 nT, $[B_z]$=18 and K_p=7.

Chapter 8: Conclusion and Future Works

This chapter contains a summary of the entire scientific work of this thesis. In conclusion, we summarize our results and provide some suggestions for future analysis, observations, and ideal observing capabilities.