

List of figures

- 1.1 This image provides a basic overview of the Sun’s parts. The three major interior zones are the core, radiative zone, and convective zone. The core is the innermost part of the Sun where energy is generated by nuclear reactions. The radiative zone is the layer where energy travels outward by radiation through about 70% of the Sun. The convective zone is the sub-surface layer in which convection currents circulate the Sun’s energy to the surface. The flare, sunspots and photosphere, chromosphere, and the prominence are all clipped from actual SOHO images of the Sun and overlaid on this particular image. (Courtesy: SOHO, ESA/NASA) 3
- 1.2 Top-panel: The Solar Dynamics Observatory (SDO)/Helioseismic and Magnetic Imager (HMI) vector magnetogram showing a solar active region AR 12192 and its sunspot groups on October 24, 2014 at 21:10 UT. To infer the large-scale coronal magnetic field, a non-force-free field (NFFF) extrapolation is shown overlaid on the pair of sunspot mimicking large-scale closed magnetic field lines (Courtesy: A. Prasad et al., IAUS 340, 2018). Bottom-panel: The active region magnetic loops are shown above the solar-disk as observed by Transition Region and Coronal Explorer (TRACE) on 28th September 2000. (Courtesy: M. Aschwanden; LMSAL; TRACE, and NASA) 5

- 1.3 Left-panel: Quiet Sun at the disk center as observed by the Hinode spectropolarimeter on 10th March 2007 between 11:37 and 14:37 UT. The top panel shows a continuum intensity map recorded at 630 nm. The other panels display the corresponding maps of longitudinal magnetic flux density (middle) and transverse magnetic flux density (bottom). These images are made using the circular and linear polarization signals as observed in the Fe I 630 nm line pair. Right-panel: Magnetogram showing inter-network magnetic patches within a supergranular cell in a quiet Sun surface. The observations were taken by the Hinode NFI. Different magnetic elements are shown with different colours overlaid on the magnetogram image of supergranular cell. The boundary of the supergranular cell is represented with red and yellow corks that are estimated using respectively the local correlation tracking (LCT) of the continuum intensity and line-of-sight (LOS) velocity structures. The zoomed super-granular cell in right-panel does not hold one-to-one correspondence with the one in the boxed area in left-panel. (Courtesy: Bellot Rubio & Orozco Suárez (2019); Springer Nature) 7
- 1.4 A composite image shows the various layers of the solar atmosphere, e.g., the photosphere or surface of the Sun in visible light showing sunspots also, the chromosphere visible in $H\alpha$ 6563 Å emissions, and the corona as seen in soft X-rays. (Courtesy: NASA) 9
- 1.5 An empirical model of the solar atmosphere showing the variation of temperature and density w.r.t height. (Courtesy: Hardi Peter) 12

- 1.6 The left panel shows the full disk image of the Sun as seen in 193 Å emissions corresponding to the coronal temperature. The different features are then identified as Quiet Sun (QS), Active-region (AR), and Polar Coronal Hole (PCH). The right panel shows the photospheric (sunspots) and coronal (magnetic loops) counterparts of an active region. The zoomed loop system and sunspot groups in the right panel do not possess one-to-one correspondence with the AR shown in the boxed area in left-panel. These image panels are shown just to collectively represent the three major regions (QS, CH, AR) in the solar corona, with an emphasis on AR magnetic loops. (Courtesy: SDO/AIA; SST) 14
- 1.7 SUMER Ne VIII 770 Å line-of-sight Doppler velocity images from the midlatitude region (left), and the polar region (right) of the Sun. The chromospheric network boundaries are superimposed over the Doppler maps. The top images as displayed in 'A' are fitted and derived using a moments technique on unbinned data and used off-limb solar observations to provide the 'zero' velocity reference. The bottom two images as displayed in 'B' are obtained using Gaussian fitting routines on binned data to increase the signal-to-noise ratio. The details of the observational data and scientific results shown in this picture are described by Hassler et al. (1999). (Courtesy: SoHO/SUMER; ESA/NASA; D.M. Hassler) 16

- 1.8 Top-panel: Flowing magnetic funnels are shown in a quiet region of the Sun. The magnetic field lines (red) are originating from the funnel boundary, while the black lines are open field lines outside small funnels. The Ne VIII Doppler shift image is placed at zero megameter, and the color coding is given at the bottom. The positive and negative values represent redshifts and blueshifts respectively in the observed Doppler maps. The map of the vertical component of the extrapolated magnetic field at 20 Mm is placed at the height of 20 Mm, and the color coding is given on the right-hand bar. Bottom-panel: Projection of the extrapolated quiescent magnetic loops reaching higher than 4 Mm onto the x-y plane together with the map of the Ne VIII Doppler shift are shown. Regions with positive and negative magnetic flux density are depicted with the green and pink colors, while the contour level of the magnetic fields is given as 15 G and -15 G respectively. The details of the observational data and associated results shown in this image is described by Tian et al. (2009). (Courtesy: SoHO/SUMER; ESA/NASA; Hui Tian). 17
- 1.9 This picture is an illustration after Tu et al. (2005) of the solar magnetic transition region, showing the solar disk (left) together with a segment of the coronal magnetic field at the pole (a) and a further zoomed part of that field (b). The magnetic field attains a shape of the rapidly expanding coronal funnel. The open magnetic field lines are drawn in magenta in this funnel. The field strength is indicated in blue on the top plane at a height of 20 Mm. At this height, the outflow speed of the plasma is found to be $\approx 10 \text{ km s}^{-1}$ that is indicated by hatched areas. (Courtesy: Marsch (2018); SoHO/SUMER; ESA/NASA) 18

1.10 Left-Top: EIS Fe XII radiance image in arbitrary units is mapped with various magnetic field lines of the extrapolated coronal magnetic field as shown in the projection. The intensity is displayed on the gray scale as set by the bar on the right side of the given image. The spatial solar coordinates are represented in arcsec. Left Bottom: The EIS Dopplergram of the corresponding Fe XII line shift is shown in the similar format. The velocity scale ranging between -20 and $+20$ km s^{-1} is defined by the red/blue colour bar at the right side of the given image. Note that the magnetic field lines start and end in patches of predominant plasma flows either in red- or blue-shifts, i.e., footpoints are associated with either up- or down-flows there. Right Top: The SUMER Ne VIII radiance in arbitrary units is mapped with various magnetic field lines of the extrapolated coronal magnetic field as shown in the projection. The magnetic fields represented by green and yellow lines indicate open and closed field lines respectively. The intensity is given in the gray scale set by the bar on the right of the given image. The spatial solar coordinates are given in arcsec. The red and blue contours indicate the field strength at 30 Gauss level for the opposite polarities. Right Bottom: SUMER Dopplergram of the corresponding Ne VIII line shift is displayed in the similar format. The velocity scale ranging between -20 and $+20$ km s^{-1} is defined by the red/blue bar at the right side of the given image. It should be noted that the magnetic field lines start and end in patches of predominant flows either red- or blue-shift, i.e., footpoints are associated with either up- or down-flows there. In particular, in the area defined by the intervals $x=(-140", -90")$ and $y=(250", 310")$, there are locations with adjacent alternating red/blueshifts and varying magnetic connections to mostly the same Doppler shift at both the loop footpoints. The details of the data presented in this figure is described by Marsch et al. (2008). (Courtesy: SoHO/SUMER; Hinode/EIS; ESA/NASA; Hui Tian) 21

1.11	Schematic structure of the atmospheric layers in the quiet Sun regions of the solar atmosphere, i.e. in and outside the strongest network magnetic field concentrations, exhibiting a multitude of different physical phenomena. The black solid and dotted lines represent magnetic field lines. The arrow to the left and coloured bars illustrate the height range mapped by ALMA. Aspect ratio is not to scale. (Courtesy: S. Wedemeyer)	26
2.1	Schematic view of the arrangement of different instruments onboard Solar Dynamics Observatory. (Courtesy:-LMSAL, NASA, SDO)	35
2.2	Multi-wavelength view of the Sun using AIA and HMI instruments onboard SDO highlighting different features. (Courtesy: NASA/SDO/Goddard Space Flight Center)	37
2.3	Zoomed in view of an active region in different channels of AIA onboard SDO along with the magnetic polarities at their base shown by HMI. (Courtesy: Lemen et al., 2012)	39
2.4	Schematic view of IRIS instruments with the telescope from which light is fed into the spectrograph box. (Courtesy: IRIS, LMSAL, NASA)	41
2.5	Schematic view of the path taken by light in the IRIS spectrograph and slit-jaw imager. (Courtesy: IRIS, LMSAL, NASA)	42
2.6	The solar atmosphere as observed by IRIS in different wavelength bands. (Courtesy: https://iris.lmsal.com/itn51/iris_data.html)	43
2.7	From left to right, annual images from the 304 Å channel taken between 2011 and 2018 are displayed, before (top row) and after (bottom row) correcting for changes in the instrument sensitivity. It should be noted that top and bottom rows of the EUV images are already corrected for other artefacts using aia_prep. (Courtesy: LMSAL, NASA, SDO/AIA)	44

-
- 2.8 The HMI magnetogram images before (left-panel) and after (right-panel) image calibration. (Courtesy: LMSAL, NASA, SDO/AIA) 46
- 2.9 Few samples of our fitting model on the observed profiles of Mg II k 2796.35 Å within the different features, e.g., umbra (panel a), penumbra (panel b), QS (panel c), high-intensity (panel d & e) and loop regime (panel f). The black shows the observed profiles while the red line is fitted model on the observed profiles. We have also displayed the parameters (peak intensity, centroid and Gaussian sigma) from positive Gaussian (black) and negative Gaussian (blue) in each panel. These samples illustrates the variations of Mg II k line within the different features in the observed region. The fitting model capture the line behaviour very well, which justify our fitting model for Mg II k line. 48
- 2.10 Left-panel: SDO/AIA images during C4.9 flare from 03-Nov-2010 at 12:14:36 UT. Right-panel: DEM maps at different temperature produced by regularized inversion method of Hannah and Kontar (2012). The colour scales in bottom mosaic represents DEM value for each temperature range. The hot erupting material is clearly visible in the 8.9MK map. (Courtesy: Ian G. Hannah and E. Kontar) 51

- 2.11 Example of a wavelet analysis: The multiple harmonics of the sausage oscillations are firstly detected in cool loop system in the solar atmosphere. Top-left image is observed by 15-cm ARIES Solar Tower Telescope in $H\alpha$, while top-right is the aligned image panel as observed by SoHO/EIT in Fe IX/FeX 171 Å line. This case study demonstrates the use of wavelet as a powerful tool to derive novel scientific results. The top panel in each wavelet diagram shows the original light curves derived from the cool loop system. The middle-left panels display the intensity wavelet with the COI region in form of cross-hatched area, while the middle-right panels represent global wavelet power. The bottom most panels represent the variation of the probability. (Courtesy:- Srivastava et al., 2008) 54
- 3.1 The region of interest displaying the cool loop system in different spectral lines: Mg II k (2796.20 Å), C II (1334.53 Å), and Si IV (1402.77 Å) along with the underlying magnetic polarities indicated by HMI LOS magnetogram are shown for three different datasets. The left column corresponds to Dataset 1 observed on 27th December 2013 targeting AR 11934. The middle column indicates Dataset 2 observed on 10th December 2015 targeting AR 12465. The right column shows the Dataset 3 observed on 29th March 2017 targeting AR 12645. 60
- 3.2 Spectral fitting of (a) Ni I (2799.47 Å), (b) Mg II k (2796.2 Å), (c) C II (1354.53 Å), and (d) Si IV (1402.77 Å) lines for averaged profile over the box labelled as B5 shown in the Si IV left panel of Fig. 3.4 corresponding to Dataset 1. 61

-
- 3.3 Intensity, Doppler velocity, and Full width at half maximum (FWHM) maps of Mg II k (2796.2 Å), C II (1334.53 Å), and Si IV (1402.77 Å) lines are shown for the Dataset 1 in the left, middle, and right columns respectively. 63
- 3.4 Left panel: The intensity map of Si IV (1402.77 Å) line with the boxes overlaid showing different locations at the footpoints of the cool loop systems. Top-right panel: The variation of Doppler velocity with the formation heights of different spectral lines for different boxes at the blueshifted footpoint indicated in the left panel. Bottom-right panel: The variation of Doppler velocity with the formation heights of different spectral lines for different boxes at the redshifted footpoint indicated in the left panel. 65
- 3.5 Spectral fitting of (a) Ni I (2799.47 Å), (b) Mg II k (2796.2 Å), (c) C II (1354.53 Å), and (d) Si IV (1402.77 Å) lines for averaged profile over the box labelled as B4 shown in the left panel of Fig. 3.7 corresponding to Dataset 2. 67
- 3.6 Intensity, Doppler velocity, and Full width at half maximum (FWHM) maps of Mg II k (2796.2 Å), C II (1334.53 Å), and Si IV (1402.77 Å) lines are shown for the Dataset 2 in the left, middle, and right columns respectively. 69

-
- 3.7 Left panel: The intensity map of Si IV (1402.77 Å) line with the boxes overlaid showing different locations at the footpoints of the cool loop systems. Top-right panel: The variation of Doppler velocity with the formation heights of different spectral lines for different boxes at the blueshifted footpoint indicated in the left panel. Bottom-right panel: The variation of Doppler velocity with the formation heights of different spectral lines for different boxes at the redshifted footpoint indicated in the left panel. . . . 70
- 3.8 Spectral fitting of (a) Ni I (2799.47 Å), (b) Mg II k (2796.2 Å), (c) C II (1354.53 Å), and (d) Si IV (1402.77 Å) lines for box labelled as B3 in the left panel Fig. 3.10 for Dataset 3. 74
- 3.9 Intensity, Doppler velocity, and Full width at half maximum (FWHM) maps of Mg II k (2796.2 Å) , C II (1334.53 Å), and Si IV (1402.77 Å) lines are shown for the Dataset 3 in the left, middle, and right columns respectively. 76
- 3.10 Left panel: The intensity map of Si IV (1402.77 Å) line with the boxes overlaid showing different locations at the footpoints of the cool loop systems. Top-right panel: The variation of Doppler velocity with the formation heights of different spectral lines for different boxes at the blueshifted footpoint indicated in the left panel. Bottom-right panel: The variation of Doppler velocity with the formation heights of different spectral lines for different boxes at the redshifted footpoint indicated in the left panel. . . . 77
- 4.1 Left: A cool loop system as seen in the IRIS SJI 1400 Å . Right: The magnetic field distribution at loop footpoints from SDO/HMI. 85
- 4.2 Intensity (left), FWHM (middle), and Doppler velocity (right) maps derived from the Si IV 1403 Å line showing the evolution of the cool loop system. 86

-
- 4.3 The representative enhanced line-profiles of Si IV 1403 Å line at 4 different pixels near the EE location showing a velocity enhancement of around $\approx 200 \text{ km s}^{-1}$. Three individual dashed lines show the single Gaussian profiles used to fit the wing-enhancements. 88
- 4.4 The histogram showing the distribution of maximum enhanced velocity over the wing of the observed line profiles. 89
- 4.5 Left-panel: Equilibrium bipolar magnetic field vectors in the model solar atmosphere. X-axis and Y-axis are given in Mm. Right-panel: Temperature profile derived from the model of Avrett & Loeser (2008). 90
- 4.6 Left-panel: Bipolar initial solar atmosphere. $\phi_e = \text{constant}$ represents the equipotential line and $A_{e_z} = \text{constant}$ are lines of magnetic force, which are perpendicular to each other. All these lines are represented in white-colour. The low-lying bipolar loop system is shown within the blue-curved box area, where plasma flows fill the magnetic field lines. Initially mass is not filled and the transient cool-loop system is not formed there. Right-panel: Equilibrium normalized mass density profile along the chosen curved magnetic fields. The mass density is expressed in units of $10^{-15} \text{ g cm}^{-3}$ 91
- 4.7 Spatio-temporal evolution of the cool-loop system. 94
- 4.8 A_z vs ϕ representation of the cool-loop system providing the straight view of the plasma flows along the chosen set of the magnetic field skeleton of the cool loop. The evolution of the plasma flows and associated fine structures is clearly evident in it. Straightened region in this figure is equivalent to the region shown in the blue box in Figs. 4.6 - 4.7. 96
- 4.9 Temporal evolution of the mass density (left) and flows (right) along the chosen set of the curved field lines along which the cool loop system evolved. 97

5.1	Intensity emission due to 171 Å wavelength of SDO/AIA at 19:13:22 UT. The yellow box is overlaid to show the region of interest (ROI) taken to analyse the flows at the footpoints of quiescent coronal loops.	104
5.2	Mosaic representation of the zoom-in-view of the region of interest at different wavelength of SDO/AIA as mentioned on the corresponding panels.	105
5.3	Left panel: HMI map indicating the magnetic polarities at the moss region indicted by blue contours. Right panel: Identification of the footpoints of quiescent loops anchored at the moss regions. The different small boxes are taken at the footpoints of the individual loop strands are shown in both the panels.	106
5.4	Differential Emission Measure maps of the plage region containing the moss associated to footoints of quiescent coronal loop systems.	107
5.5	The different parametric plots of Si IV (1393.78 Å) line with the footpoints of the quiescent coronal loop systems indicated by different boxes.	108
5.6	The velocity distributions for different spectral lines corresponding to different temperatures at box B1.	109
5.7	The velocity distributions for different spectral lines corresponding to different temperatures at box B2.	111
5.8	The velocity distributions for different spectral lines corresponding to different temperatures at box B3.	112
5.9	The velocity distributions for different spectral lines corresponding to different temperatures at box B4.	112
5.10	The velocity distributions for different spectral lines corresponding to different temperatures at box B5.	113

-
- 5.11 Average Doppler velocity variations for different spectral lines dominating at different heights in the solar atmosphere for boxes B1, B2, B3, B4, and B5 at the footpoints of quiescent coronal loops. 114
- 6.1 (a) Identification of brightening and energy release site at the top of the photosphere as observed by SDO/AIA 1600 Å . A small-scale current sheet and X-point is evident at the base of the outflow as shown also in the schematic. (b) Light curve derived from the selected box showing the variation of intensity with time. 120
- 6.2 The emissions from the impulsive energy release site observed in different filters of AIA at the peak of the plasma outflow at 05:18 UT. All the bands of AIA show a similar morphological behaviour. 121
- 6.3 The light curves of co-temporal emissions from the impulsive energy release site at different wavelength filters of AIA. Different colors represent different filters as mentioned. 124
- 6.4 Left panel: The plasma outflow associated with the impulsive energy release site. The contours of the 1600 Å wavelength are overlaid on the 193 Å wavelength at 05:18 UT. Right panel: The kinematics of the outflows co-temporal with the initial enhancement of the energy release. The intensity curve is overplotted by the height-time plot which has been obtained by tracing the tip of the outflow starting from the X-point of the small-scale current sheet as shown in the schematic illustration of the Fig. 6.1 125
- 6.5 Differential Emission Measure (DEM) maps of the outflow at different temperatures of the outflow observed on 30th March 2011 127

-
- 6.6 Time sequence of images taken from SDO/HMI showing the evolution of magnetic polarities from 05:11:02 UTC to 05:18:32 UTC at the footpoint of the outflow. The positive and negative polarities near the tip of the arrow corresponding to the energy releasing site leading to magnetic reconnection. The box with the bold lines encloses the magnetic polarities the footpoint of the brightening. The bigger dashed box represents the area around the negative polarity and the smaller one represents the area around positive polarity which are used to calculate the magnetic flux. In the last image, the 1600Å continuum image contours are overlaid on the aligned HMI image. 129
- 6.7 Left panel: HMI contours on the 1600 Å SDO/AIA image where blue indicates negative polarity and red indicates the positive polarity. Right panel: Plots showing the magnetic flux from the positive and negative polarities at the footpoint of the brightening. Vertical dashed line shows the onset time of the outflow and bold lines represent the duration for which wavelet analysis has been carried out. 130
- 6.8 Top-panel: Wavelet analysis of the flux caused by the negative polarity. Bottom-panel: Wavelet analysis of the intensity curve obtained by 1600 Å SDO/AIA image. 131