Abstract booklet

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Poster

1. Fundamental physical processes and modeling

2. Chromospheric heating and dynamics

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5. Opportunities and challenges

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6. Science together with future facilities

Invited Talk

1. Fundamental physical processes and modeling

Chromospheric modeling on ion-neutral interaction effects and non-equilibrium ionization

Juan Martínez-Sykora[1]

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In the chromosphere is governed by a variety of complex physical processes including ion-neutral interaction effects and non-equilibrium ionization. These two processes have never been combined in radiative MHD models. Although, recently, 2D radiative MHD numerical models using the Bifrost code have revealed the importance of the ion-neutral interaction effects for the formation of the type II spicules and chromospheric heating (Martinez-Sykora et al 2017, Science). However, this work assumed ionization in statistical equilibrium. In addition, non-equilibrium ionization must be also taken into account in IRIS observations for Si IV and O IV. In this talk, focusing on Bifrost models, we will reveal the importance of combining ion-neutral interaction effects and non-equilibrium ionization in order to properly address chromospheric energetics as well as the interpretation of IRIS observations.

Contributed Talk

1. Fundamental physical processes and modeling

Studying radiation-MHD simulations in the Lagrangian frame

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Radiation-MHD simulations of the solar atmosphere are a powerful tool to study physical processes. Such simulations are often analysed in the Eulerian frame, i.e., quantities are analysed on the computational grid. For certain classes of problems this is not the optimal choice.
If one is interested in the evolution of a given fluid parcel instead of the evolution at a given location in the simulation, then a description in the Lagrangian frame is more natural. Typical examples where a Lagrangian description is useful are mass flows during flux emergence, mass loading of chromospheric fibrils, mass and energy cycling between the chromosphere and the corona, and flow acceleration during reconnection.
I will present a method to analyse simulations in the Lagrangian frame based on tracer particles. It allows tracking the history and future of the postion, velocity, all forces, and all energy losses and gains of any gas parcel starting at any given time and any location in the simulation. In addition I will present results using this method on the mass loading of the chromosphere and the mass cycling between the chromosphere and the corona.

IRIS-9, Göttingen, 25-29 June 2018

Contributed Talk

1. Fundamental physical processes and modeling

Simulating CLASP-IRIS co-observations in H I Ly-α and Mg II h

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On September 3, 2015, the Chromospheric Lyman Alpha Spectropolarimeter (CLASP) and the Interface Region Imaging Telescope (IRIS) observed the Sun co-spatially and co-temporally in the H I Ly-α and the Mg II h lines. Slits of the instruments recorded the center-to-limb variation of the line intensities along the same direction towards the solar limb. The slit spectra exhibited some similarities in their profile shapes suggesting that the lines are formed close to each other between the upper chromosphere and the transition layer, as predicted by canonical model atmospheres such as by Vernazza et al. (1981). For both lines, we calculated synthetic spectrograms in non-LTE including effects of the lateral transfer of radiation (3D) and the resonance-line scattering (PRD) using an enhanced-network model atmosphere produced with the radiation-MHD code Bifrost. Contrary to the public release by Carlsson et al. (2016), this non-public model includes additional effects of the non-equilibrium ionization of helium. We reduced the synthetic spectrograms to finite spatio-spectral resolutions of the CLASP and IRIS spectrographs and studied the correspondence between various profile properties. We found that synthetic profiles are less similar than the observed ones because their formation heights are very variable depending on the magnetic structure of the underlying atmosphere. We demonstrated that velocities in the upper chromosphere and the transition layer can be measured using both lines. In addition, we discuss what is important for the modeling of chromospheric lines, which shortcomings have current model atmospheres, and what needs to be improved.

Invited Talk

1. Fundamental physical processes and modeling

Magnetic reconnection in strongly magnetized regions around the solar TMR

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Magnetic reconnection (MR) is the most likely mechanism responsible for the high temperature events that are frequently observed around the solar TMR. We have studied MR in such an environment by employing MHD-based simulations of a partially ionized plasma within a reactive 2.5D multi-fluid model. In strongly magnetized regions with low plasma β, the initially weakly ionized plasmas become strongly ionized during the MR process and the ionized and neutral fluid flows are well-coupled throughout the reconnection region. The reconnection characteristics are then close to those in fully ionized plasmas, the reconnection process resembles the Sweet-Parker model before magnetic islands appear, and the plasmoid instability is the main physical mechanism to result in the fast magnetic reconnection in a high Lundquist number MR process. Decoupling of the ion and neutral inflows appears obviously in a high β case, and we observe MR much faster than the single-fluid Sweet-Parker prediction. The rate of ionization of the neutral component of the plasma is always faster than recombination within the current sheet region even when the initial plasma β is as high as $\beta = 1.46$. The non-equilibrium ionization-recombination dynamics play a critical role in determining the structure of the reconnection region, lead to much lower temperature increases as compared to simulations that assume plasma to be in ionization-recombination equilibrium. However, the plasma temperature increases with time inside the current sheet, we can still find that the maximum value is above 20000 K when the reconnection magnetic field strength is greater than 500 G. Therefore, the Si IV emission lines can still possibly be produced during such a MR process around the solar TMR.

Contributed Talk

1. Fundamental physical processes and modeling

Statistical studies of IRIS data towards better understanding of small-scale reconnection

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Magnetic reconnection is a fundamental plasma process that play a critical role in energizing the solar atmosphere. Despite the fact that it is one of the most widely assumed mechanisms in studies of solar eruptive events, it is still not fully understood. Recently, we used spectroscopic data from the Interface Region Imaging Spectrograph (IRIS) mission to reveal the transient evolution of fast reconnection mediated by plasmoids at several small-scale reconnection sites (Innes & Guo et al. 2015, Rouppe van der Voort et al., 2017). In this presentation, we present statistical studies of explosive events on a large amount of samples with the help of artificial intelligence. The IRIS team obtained a significant number of observations of explosive events in Si IV (and other wavelengths) during 2016 and 2017. We apply machine-learning and deep-learning algorithms on these data sets to detect explosive events. All the events we detect are then categorized according to different aspects (e.g. dynamics, absorption features etc.). For each group, we obtain key parameters of reconnection dynamics (e.g. growth time) and by comparing these parameters in different group, we are able to reveal how reconnection proceeds in different regimes on the Sun.

IRIS-9, Göttingen, 25-29 June 2018

Contributed Talk

1. Fundamental physical processes and modeling

Constraints on active region coronal heating properties from observations and modeling of chromospheric, transition region, and coronal emission

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We discuss how high spatial, spectral, and temporal resolution chromospheric/transition region/coronal observations coupled with detailed modeling can help us diagnose coronal heating properties in active region cores in non-flaring conditions. We will focus on recent results from IRIS, which provides us with unprecedented high spatial, temporal and spectral resolution observations of the chromosphere and transition region. Joint with coronal observations with Hinode (XRT and EIS), and SDO/AIA, these data cover from the upper photosphere to the corona. In particular, we will discuss how IRIS observations of footpoints of hot active region loops, coupled with detailed HD and MHD modeling including chromosphere, transition region and corona, provide tight constraints on the coronal heating mechanisms in the core of active regions.

IRIS-9, Göttingen, 25-29 June 2018

Contributed Talk

1. Fundamental physical processes and modeling

The Curious Conundrum of the Corona of the Mid-F Subgiant Procyon: a Lesson for IRIS?

T. Ayres

Procyon (α Canis Minoris: F5 IV-V) is a nearby late-type subgiant (only 3.5 pc away) that is similar to the Sun in some respects, but different in others (especially its more advanced evolutionary status, although the rotation periods are similar). Studies with the initial generation UV spectrograph on *Hubble Space Telescope* ("GHRS") suggested that the otherwise solar-intensity "transition zone" emissions of Procyon, such as Si IV 1393 Å and C IV 1548 Å seemed to lack the bimodal lineshapes seen in more closely solar-like α Centauri A (G2 V) and B (K1 V), and the Sun itself; displaying instead a more purely Gaussian character. At the same time, X-ray pointings by the Chandra Observatory have shown that the F subgiant has had a nearly constant coronal X-ray brightness over the past decade, perhaps something like a Maunder Minimum, except that the contemporary X-ray-to-bolometric luminosity levels of Procyon are comparable to the Sun at *Solar Maximum.* This creates a curious conundrum in the sense that the Maunder Sun's corona, and transition zone, should have been dominated – in the absence of active regions – by the supergranulation network, but this is exactly where on the Sun the bimodal TZ emission lines are thought to arise. However, the earlier UV assessment of Procyon was based on lower resolution and lower S/N FUV spectra than have become available recently, thanks to *Hubble's* later generation Space Telescope Imaging Spectrograph (STIS). The surprising results of a new analysis of the STIS FUV spectra, of relevance to *IRIS* observations of the same spectral features on the Sun, will be presented.

IRIS-9, Göttingen, 25-29 June 2018

Invited Talk

1. Fundamental physical processes and modeling

Turbulence generated by transverse waves in coronal loops

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In the last decade, it has become clear that the solar atmosphere is filled with waves. Of particular interest are transverse waves in coronal loops and plumes, because their observed energy is not too far off the required energy to heat the solar corona.
I will highlight recent modelling efforts that characterise the coronal heating generated by these transverse waves. In many of the 3D simulations of loops that are driven or excited by transverse waves, the simulated coronal loops evolve into turbulence, either through the Kelvin-Helmholtz instability or uniturbulence. The resulting turbulence is an efficient agent to dissipate the wave energy and deposit it into heat.
By using forward modelling, I will discuss the observational consequences of these turbulent models. I will show in which respects the models agree or disagree with the observations.

IRIS-9, Göttingen, 25-29 June 2018

Contributed Talk

1. Fundamental physical processes and modeling

Twisted currents of coronal loops in 3D MHD simulations

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The magnetic field in the low plasma-beta solar corona is often assumed to be nonlinear force-free. We find that this assumption is not necessarily fulfilled in extreme UV bright loop structures. In a 3D numerical MHD model of a corona above an emerging active region a coronal loop forms self-consistently as a consequence of the emerging magnetic flux and the horizontal motions at the surface. We find that the current along the emerging loop changes its sign from being antiparallel to parallel to the magnetic field from one leg to the other. This is caused by the inclination of the loop together with the footpoint motion. Around the loop, the currents form a complex non-force-free helical structure. This is directly related to a bipolar current structure at the loop footpoints at the base of the corona and a local reduction of the background magnetic field (i.e., outside the loop) caused by the plasma flow into and along the loop. Furthermore, the locally reduced magnetic pressure in the loop allows the loop to sustain a higher density, which is crucial for the emission in extreme UV. We find that twisted currents quantified in terms of current helicity seems to coincide with the hot and bright UV loops, indicating a direct connection between current helicity and to the heating process. This might imply also a link to the underlying dynamo mechanism, where current helicity can be produced and transported to the surface. To investigate the role of current helicity further, we, therefore, also present some results of 3D MHD simulations of the solar corona, where we enhance the current helicity at the photosphere and study its response as seen in the corona.

IRIS-9, Göttingen, 25-29 June 2018

Contributed Talk

1. Fundamental physical processes and modeling

Resonant scattering processes at work in an active region as detected in the transition region Si IV lines near 140 nm with IRIS

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The emission spectrum of the solar transition region is analysed, most of the times, assuming that the photons are emitted only through the electronic collisions processes. As for resonant scattering, it is taken into account only in solar regions such as prominences or the corona. Line doublets formed in the transition region, such as the Si IV 1399Å, 1402Å, recorded with IRIS can be used, through their line ratio, to evaluate the importance of resonant scattering and of optical thickness. We present locations of active region NOAA 12529 where we detected cases with line ratios in the range of $2 < 1393/1402 \leq 3$ suggesting resonant scattering, as well as line ratios in the range of $1.3 \leq 1393/1402 \leq 1.6$ where optical thickness is important. Optical thickness is found along fibril-like structures while resonant scattering seems to be important in bright grains. For the profiles showing resonant scattering we were able to estimate physical parameters such as the electron densities (10^9 up to 10^{12} cm^{-3}). Our work suggests that radiation scattering should be taken into account when analyzing transition region lines.

Contributed Talk

1. Fundamental physical processes and modeling

Transition-Region lines with strong wings: Non-Maxwellian analysis of line profiles and intensities

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We analyze the IRIS observation of an active region containing bright transition-region (TR) loops. Locations showing symmetric profiles of the Si IV and O IV lines are selected. In nearly all of these locations, the Si IV line at 1402.8 Å is much stronger than the neighboring O IV lines. Furthermore, all TR lines show strong ($S/N > 10$) and extended wings, i.e., a non-Gaussian profile. We found that the non-Maxwellian κ-distributions approximate these profiles better or at least equally well as double-Gaussian fits. The values of κ found are typically very low, in the range of $1.7 - 2.5$. Similar κ values are obtained from fitting the intensities of the O IV lines relative to Si IV. Furthermore, all TR lines have the same κ and width, irrespective of whether the line is an allowed or intercombination transition. However, we also found a single location showing very strong but Gaussian Si IV line, indicating that instrumental effects can be ruled out.

Invited Talk

2. Chromospheric heating and dynamics

Magnetic field in the chromosphere

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Measuring the chromospheric magnetic field is a challenging endeavor. In this layer, the fields are typically weak and require highly sensitive spectropolarimetric observations; the gas and plasma motions occur at very high velocities and demand for a high temporal cadence, and the fine structure, visible for example in the Hα filaments, a high spatial resolution. In addition, low plasma densities and the anisotropy of the radiation field lead to a high level of complexity in the physics of the chromosphere. Sophisticated instrumentation installed in ground-based and space observatories, here especially the IRIS mission, have led to a significant improvement of the understanding of the chromosphere during the last decade. In this talk I will highlight some of the recent advances, based on measurements in the He 10830Å triplet and the Ca infrared lines, the Mg data of the IRIS and the Sunrise missions, and give an outlook to future observatories and instruments aimed for improving the understanding this important layer connecting the photosphere and the corona.

Contributed Talk

2. Chromospheric heating and dynamics

Emergence of internetwork magnetic fields through the solar atmosphere

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Internetwork (IN) magnetic fields are highly dynamic, short-lived magnetic structures that populate the interior of supergranular cells. Since they emerge all over the Sun, these small-scale fields bring a substantial amount of flux, and therefore energy, to the solar surface. Because of this, IN fields are crucial for understanding the quiet Sun magnetism. However, they are weak and produce very small polarization signals, which is the reason why their properties and impact on the energetics and dynamics of the solar atmosphere are largely unknown. Here we use coordinated IRIS and SST observations of IN regions at high spatial and temporal resolution. They give us the opportunity to follow the evolution of IN magnetic loops as they emerge into the photosphere. For the first time, our polarimetric measurements provide a direct observational evidence of IN fields reaching the chromosphere. Moreover, we show that IN magnetic loops contribute to the chromospheric and transition region heating through interaction with preexisting ambient fields.

Contributed Talk

2. Chromospheric heating and dynamics

Coronal Holes and Quiet Sun in Mg II lines observed by IRIS

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Quiet Sun (QS) and coronal hole (CH) regions are very well distinguished in the radiation recorded at coronal temperatures. However, in those recorded at chromospheric (except in He II lines) and transition region temperatures, they appear very similar. In this study, to understand the similarities and differences between QS and CHs at chromospheric heights, we make use of the high-resolution spectroscopic observations recorded by the Interface Region Imaging Spectrograph (IRIS) in Mg II 2796.35 Å spectral line. We find that, in Mg II lines, the QS and CH regions are visually strikingly similar to each other. However, when we compare the radiance in the MgII (k3 and k2v) in areas with similar magnetic field strength, we find that CHs are significantly dimmer than QS. Moreover, the difference in radiance increases with increasing magnetic field. We note that the difference in radiance decreases with decreasing spectral resolution and almost vanishes at a resolution of 11 Å. The region-specific dependence of radiance of Mg II line suggest that the magnetic field plays a vital role in the heating of the quiet chromosphere. Moreover, this study provides essential ingredients for solar spectral irradiance modelling for the better understanding of the Sun-climate relationship.

IRIS-9, Göttingen, 25-29 June 2018

Invited Talk

2. Chromospheric heating and dynamics

A modeler's perspective on UV bursts

Sanja Danilovic[1]

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UV bursts are small, intense, transient brightenings visible in ultraviolet images of solar active regions. They are usually associated with small-scale flux cancellation in emerging flux regions, moving magnetic features in sunspot moats, but also sunspot light bridges. They show complex spectral signatures that also indicate that the underlying process might be magnetic reconnection taking place in the lower solar atmosphere. In this talk, I will review some the efforts to model these features and try to identify the requirements that have to met in order to reduce or eliminate current discrepancies between models and observations.

Recurrent chromospheric jets at a magnetic flux cancellation site

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Chromospheric activities associated with a magnetic flux cancellation in emerging active region NOAA 12654 were successfully observed with IRIS, IBIS and FIRS at the DST, and Hinode on May 2, 2017. IRIS observed the cancellation site with a 4-slit raster mode at a cadence of 12s. Spectro-polarimetric observations of the Ca II 854 nm line were done with IBIS/DST for three hours under good seeing conditions, and a time series of Stokes profiles of He I 1083 nm were also observed with FIRS/DST. We find that the core intensity of Mg II k is suddenly blue shifted and then gradually changes to red shift at the cancellation site. Such a phenomenon recurrently appears during the decrease of photospheric magnetic flux. Similar behavior is observed in the Ca II 854 nm line, as transitional dark threads over the polarity inversion line at the cancellation site simultaneously appear in the Ca II 854 nm images. The timescale of the transition from blue shift to red shift is of the order of minutes in Ca II 854 nm. In addition, more frequent transitions on a shorter timescale can be seen in Mg II k. A signature of magnetic reconnection in the lower atmosphere (UV bursts) is also obtained: the intensity of the Mg II 280 nm wing is enhanced when a sudden blue shift appears in the line core, while an enhancement of Si IV 139 nm with absorption features is sometimes observed simultaneously. These results suggest that the ejections of cool plasma due to magnetic reconnection in the lower chromosphere are recurrently happening at the cancellation site, after which the ejected plasma falls back due to gravity. The different behavior of the temporal evolution in Mg II 280 nm and Ca II 854 nm indicates that some disturbances at higher frequency develop along the ejected plasma.

IRIS-9, Göttingen, 25-29 June 2018

Contributed Talk

2. Chromospheric heating and dynamics

Observations of Large Penumbral Jets from IRIS and Hinode

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Recent studies using *Hinode* (SOT/FG) data revealed the presence of large penumbral jets (widths $\geq$500 km; larger than normal penumbral microjets, which have widths $<$ 400 km) repeatedly occurring at the same locations in a sunspot penumbra, at the tail of a penumbral filament or where the tails of several penumbral filaments apparently converge (Tiwari et al. 2016, ApJ). These locations were observed to have obvious mixed-polarity flux in Stokes-V images from SOT/FG, whereas no obvious mixed-polarity field could be detected at the ostensible base of microjets. Large penumbral jets displayed direct signatures in AIA 1600, 304, 171, and 193 channels; thus they were heated to at least transition region temperatures. Because large jets could not be detected in AIA 94 Å, whether they had any coronal-temperature plasma remains unclear. In the present work, for two other sunspots, we use IRIS Mg II k 2796 slit jaw images and spectra and magnetograms from Hinode SOT/FG and SOT/SP to examine: whether penumbral jets spin, similar to spicules and coronal jets in the quiet Sun and coronal holes; whether they stem from mixed-polarity flux; and whether they produce discernible coronal emission, especially in AIA 94 Å images.

Nature of Surge-like Activities above Sunspot Light Bridges: Magnetic Reconnection or Shocks?

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We analyzed the surge-like oscillatory activity above sunspot light bridges using data taken by the Interface Region Imaging Spectrograph (IRIS) and the 1.6-m Goode Solar Telescope (GST). From the IRIS 2796 slit-jaw images, we detected surge-like activity above the entire light bridge at any time. The 1400 slit-jaw images reveal an oscillatory bright front ahead of the surges. The wavelength-time diagrams of the Mg II 2796.35 Å line within the surges show clear sawtooth patterns, suggesting that the oscillations are highly nonlinear and likely caused by shocks. We also find a positive correlation between the acceleration and maximum velocity of the moving front, which is consistent with numerical simulations of upward propagating slow-mode shock waves. These results, together with the fact that the oscillation period stays almost unchanged over a long duration, lead us to propose that the surge-like activity above LBs is mainly caused by shocked p-mode or magnetoacoustic waves leaked from the underlying photosphere. In observations of another sunspot, similar surge-like activity is seen in the Hα core images taken by GST. Some surges appear to reach larger distances and they are clearly associated with fast jets visible in the Halpha wing images, which occasionally occur at selected locations in the light bridge. Many of these jets are found to have an inverted Y-shape and rooted in transient brightenings with line profiles typical of UV bursts, indicating the occurrence of magnetic reconnection at the footpoints of the jets. In conclusion, our analysis clearly shows that the surge-like activity above light bridges has two components: the ever-present short surges likely to be related to the upward leakage of magneto acoustic waves from the photosphere, and the occasionally occurring long and fast surges that are obviously caused by the intermittent reconnection jets.

IRIS-9, Göttingen, 25-29 June 2018

Contributed Talk

2. Chromospheric heating and dynamics

An IRIS Optically Thin View of the Dynamics of the Solar Chromosphere

Mats Carlsson[1,2]

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We analyze the formation of the O I 1356 and Cl I 1351 lines and show that they are formed in the mid-chromosphere and are optically thin. Their non-thermal line-widths are thus a direct measure of the velocity field along the line of sight. We use this insight to analyze a large set of observations from the Interface Region Imaging Spectrograph (IRIS) to study the dynamics of the Solar Chromosphere.

IRIS-9, Göttingen, 25-29 June 2018

Contributed Talk

2. Chromospheric heating and dynamics

Three-dimensional modeling of chromospheric spectral lines in a simulated active region

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Recently, the 3D MHD code Muram was extended to include the corona (Rempel, 2017). A simulation was run that included an active region containing sunspots and a solar flare. We present for the first time 3D non-LTE radiative transfer calculations from this active region simulation.

We synthesized Ca II H&K/8542 Å, Mg II h&k, and Hα using the Multi3D code, where we included horizontal radiative transfer (3D effects). For hydrogen, we solved the charge conservation equation and statistical equilibrium simultaneously to obtain NLTE electron densities. For Ca II and Mg II we included partially-coherent scattering of photons (PRD effects).

This simulation reproduces long fibrils that span the active regions and shows structures in Hα that look like flare ribbons. We compare our results to high resolution observations.

A disturbance propagating from the chromosphere into a heated coronal loop

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The origin of propagating disturbances in the solar corona is still an open issue. Here, we present observations of disturbances clearly showing a coupling of the solar atmosphere from the low chromosphere into the heated coronal loop. These observations provide clues about the role of magnetic field dynamics in generating the detected disturbances. We use imaging diagnostics of the solar atmosphere (IRIS, SDO/AIA) and photospheric magnetic field maps (HINODE, SDO/HMI) to investigate the temporal and spatial evolution of propagating disturbances and their relation to the underlying magnetic field.
We detect a clear time delays between the intensity maxima of the propagating disturbances that increase with the plasma temperature. The speeds of the propagating disturbances in the highly inclined loop increase from the transition region ($\sim$20 km s^{-1}) to the hot corona ($\sim$220 km s^{-1}), suggesting that these disturbances are subsonic. The relation between magnetic field evolution and intensity changes requires further investigation, but preliminary results show that the evolution of small-scale magnetic field concentrations at the base of the loop play an important role in the generation of propagating disturbance.
We suggest that the propagating disturbances are governed by reconnection of magnetic field in the lower solar atmosphere. The energy released in the process is transported upwards, and the apparent motion of the heat-front is then observed as a propagating disturbance.

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Invited Talk

3. Magnetic coupling and mass flux through the atmosphere

Magnetic coupling through the atmosphere

L. P. Chitta[1]

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Probing the magnetic coupling through the solar atmosphere is central to deciphering a wide range of plasma dynamics observed above the visible surface of the Sun. The Interface Region Imaging Spectrograph in coordination with the current fleet of ground- and space-based telescopes provides unprecedented details of the magnetic processes and magnetic-field-regulated mass and energy transport through the solar atmosphere. In this talk, we will review some recent studies that highlight the complex nature of magnetic coupling at the chromospheric interface of coronal loops. The role of apparent chromospheric magnetic reconnection at the base of coronal loops in the heating of discrete hot structures in active region cores will be discussed.

Contributed Talk

3. Magnetic coupling and mass flux through the atmosphere

Interactions between emerging and pre-existing magnetic fields observed with IRIS

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We report multi-wavelength ultraviolet observations taken with the IRIS satellite, concerning the emergence phase in the upper chromosphere and transition region of an emerging flux region (EFR) embedded in the unipolar plage of active region NOAA 12529. These data are complemented by full-disk, simultaneous observations of the SDO satellite, relevant to the photosphere and the corona, and Hinode spectropolarimetric measurements.
Recurrent intense brightenings that resemble UV bursts, with counterparts in all coronal passbands, are identified at the edges of the EFR and in the region of the arch filament system (AFS) cospatial to the EFR. Jet activity is found at chromospheric and coronal levels as well. The analysis of the IRIS line profiles reveals the heating of dense plasma in the low solar atmosphere and the driving of bi-directional high-velocity flows with speeds up to $\pm 100\,\mathrm{km\,s^{-1}}$ at the same locations. We also find a correlation between line centroid and skewness in the UV bursts, with blue-shifted lines having a redward asymmetry and red-shifted lines having a blueward asymmetry.
Comparing these signatures with previous observations and numerical models, we suggest evidence of several long-lasting, small-scale magnetic reconnection episodes between the emerging bipole and the ambient field.

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Contributed Talk

3. Magnetic coupling and mass flux through the atmosphere

Photospheric connection of a transition region brightening

A. A. Cilla, L. P. Chitta, A. Lagg, H. Peter

Max Planck Institute for Solar System Research, Göttingen, Germany.

IRIS observations of active regions exhibit various small-scale ($1''$) extreme UV bursts heated to $\sim 10^5$ K. The transition region (TR) spectroscopic diagnostics of these brightenings display non-Gaussian, often double-peaked emission profiles, indicative of outflows of heated plasma from the reconnection site. Recent studies suggest that these bursts are triggered deep in the solar atmosphere, i.e. in or even below the chromosphere.
Here we present photospheric and chromospheric spectropolarimetric observations from GREGOR of a TR burst observed with IRIS. Our data show that the TR Si IV signal from this burst carries a clear counterpart in the polarisarion of the photospheric Si I line. Spectropolarimetric inversions reveal the presence of small-scale magnetic concentrations that are co-spatial with the Si IV emission (to within $0.5''$). More interestingly, we detect no peculiar polarimetric signal in the He I emission from this region. Instead the He I data show a smooth (horizontal) magnetic canopy covering a larger area. This suggests that the TR Si IV brightening should originate from below a chromospheric canopy where He I forms, and is well connected to the photosphere. This implies that the Si IV emission in the burst indeed originates deep in the atmosphere, and it is not coupled to the higher layers. Our observations offer better insights into the physics of the TR bursts.
This case is another example that magnetic reconnection deep in the chromosphere or even in the photosphere heats small pockets of gas to high temperatures such that they are visible in the TR diagnostics. This leads to an interesting question: do most of the TR brightenings (viz. explosive events, bursts) actually originate at low heights, much deeper than we thought so far?

Statistical Investigation of Supersonic Downflows in the Transition Region above Sunspots

Tanmoy Samanta[1], and Hui Tian[1]

[1] *Peking University, China*

Downflows at supersonic speeds have been observed in the transition region (TR) above sunspots for more than three decades. These downflows are often seen in different TR spectral lines above sunspots. We have performed a statistical analysis of these downflows using a large sample which was missing earlier. The Interface Region Imaging Spectrograph (IRIS) has provided a wealth of observational data of sunspots at high spatial and spectral resolution in the past few years. We have identified sixty datasets obtained with IRIS raster scans. Using an automated code, we identified the locations of strong downflows within these sunspots. We found that around eighty percent of our sample show supersonic downflows in the Si IV 1403 Å line. These downflows mostly appear in the penumbral regions, though some of them are found in the umbrae. We also found that almost half of these downflows show signatures in chromospheric lines. Furthermore, a detailed spectral analysis was performed by selecting a small spectral window containing the O IV 1400/1401 Å and Si IV 1403 Å transition region lines. Six Gaussian functions were simultaneously fitted to these three spectral lines and their satellite lines associated with the supersonic downflows. We calculated the intensity, Doppler velocity and line width for these lines. Using the O IV 1400/1401 Å line ratio, we find that the downflow components are one order of magnitude less denser than the regular components. Results from our statistical analysis suggest that these downflows may originate from the corona and that they are independent from the background TR plasma.

Invited Talk

3. Magnetic coupling and mass flux through the atmosphere

Thermal coupling through the atmosphere

Tiago M. D. Pereira[1,2]

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[2] *Institute of Theoretical Astrophysics, University of Oslo, Norway*

Energy flows through the solar atmosphere in mysterious ways. Structures may appear out of nowhere through rapid heating or cooling, plasma can evaporate or condense quickly. Understanding the thermal coupling through the atmosphere is key to uncover the origin of many solar phenomena. To probe different temperatures, we must combine spectral lines formed over a wide range of plasma properties, a challenging task. The advent of the *IRIS* mission has made this task easier by providing a broad thermal coverage and high spatial resolution. Combining *IRIS* with other observatories has significantly improved our understanding of phenomena as diverse as spicules, penumbral micro-jets, Ellerman bombs, the unresolved fine structure, and many others in both quiet and active regions. I will cover some of *IRIS*'s successes in mapping the thermal coupling between the chromosphere and transition region. More generally, I will argue how the multi-instrument approach is becoming an essential tool to understand phenomena that can no longer be regarded as separate manifestations in different layers, and are intrinsically multi-thermal.

Invited Talk

3. Magnetic coupling and mass flux through the atmosphere

Dynamics of Flux Emergence: Combining IRIS with Other Observations, Modeling, and New Capabilities

S. Toriumi[1]

[1]*National Astronomical Observatory of Japan*

This review talk is dedicated to the summary of what we have learned in the IRIS era about the flux emergence and related activity phenomena as well as to the perspective of what we will achieve in the near future. We first review some important findings of, especially, the UV bursts in newly emerging flux regions and the plasma dynamics in sunspot light bridges. It is shown that many of the key achievements are made through the comparison of satellite observations (IRIS, Hinode, SDO, etc.), ground-based observations (SST, GST, etc.), and a variety of numerical simulations. However, the only physical parameters we can compare between observations and simulations are the vector magnetic fields in the photosphere and the Doppler velocities of a few spectral lines. Therefore, in general, the quantitative comparison is not easy. However, this difficulty may be overcome by new instruments in the coming decade. For example, DKIST has a capability to measure magnetic fields in the atmospheres (e.g. in the chromosphere) with high spatial resolutions. The proposed Solar-C_EUVST will monitor atmospheres with wide temperature coverage from the chromosphere to the corona, providing rich plasma diagnostics of various layers. Combined with existing observations and numerical modeling, these new capabilities may open a door to the quantitative evaluation of mass and energy transport, seamlessly from the photosphere to the corona through the interface region.

Observations and Modeling of Transition Region and Coronal Heating Associated with Spicules

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Spicules have been proposed as significant contributors to the coronal energy and mass balance. While previous observations have provided a glimpse of short-lived transient brightenings in the corona that are associated with spicules, these observations have been contested and are the subject of a vigorous debate both on the modeling and the observational side so that it has remained unclear whether plasma is heated to coronal temperatures in association with spicules. We use high-resolution observations of the chromosphere and transition region with the Interface Region Imaging Spectrograph (IRIS) and of the corona with the Atmospheric Imaging Assembly (AIA) onboard the Solar Dynamics Observatory (SDO) to show evidence of the formation of coronal structures as a result of spicular mass ejections and heating of plasma to transition region and coronal temperatures. Our observations suggest that a significant fraction of the highly dynamic loop fan environment associated with plage regions may be the result of the formation of such new coronal strands, a process that previously had been interpreted as the propagation of transient propagating coronal disturbances (PCD)s. Our observations are supported by 2.5D radiative MHD simulations that show heating to coronal temperatures in association with spicules. Our models also matches observations of TR counterparts of spicules and provides an elegant explanation for the high apparent speeds of these "network jets".

Contributed Talk

3. Magnetic coupling and mass flux through the atmosphere

A comparison of propagating coronal disturbances (PCDs) in sunspot and plage loops.

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Propagating coronal disturbances (PCDs) have long been observed as low-amplitude intensity perturbations travelling along (fan)loops in plage regions as well as in sunspot loops (loops anchored in the umbra of sunspots). Combining high resolution IRIS and SDO/AIA data, De Pontieu et al (2017) showed that the PCDs observed in plage fan loops are closely associated with spicules and the formation of new loop strands; in plage loops, PCDs appear to be a mixture of newly forming loop strands, flows and waves. Here, we compare IRIS and AIA observations of PCDs in plage loops with PCDs observed in sunspot loops and demonstrate that they are fundamentally different. We show that sunspot PCDs are associated with chromospheric and TR sunspot shock waves, travelling into the corona as slow magneto-acoustic waves.

Contributed Talk

3. Magnetic coupling and mass flux through the atmosphere

Ellerman bombs and UV bursts: reconnection at different atmospheric layers?

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The emergence of magnetic flux through the photosphere and into the outer solar atmosphere produces, amongst many other phenomena, the appearance of Ellerman bombs (EBs) in the photosphere. EBs are observed in the wings of H(alpha) and are highly likely to be due to reconnection in the photosphere, below the chromospheric canopy. But signs of the reconnection process are also observed in several other spectral lines, typical of the chromosphere or transition region. An example are the UV bursts observed in the transition region lines of Si IV. In this work we analyze high cadence coordinated observations between the 1-m Swedish Solar Telescope and the IRIS spacecraft in order to study the possible relationship between reconnection events at different layers in the atmosphere, and in particular, the timing history between them. High cadence, high resolution H-alpha images from the SST provide us with the positions, timings and trajectories of Ellerman bombs in an emerging flux region. Simultaneous co-aligned IRIS slit-jaw images at 1400 and 1330 A and detailed Si IV spectra from the fast spectrograph raster allow us to study the possible transition region counterparts of those photospheric Ellerman bombs. Our main goal is to study whether there is a temporal and spatial relationship between the appearance of an EB and the appearance of a UV burst.

Contributed Talk

3. Magnetic coupling and mass flux through the atmosphere

Dissecting bombs and bursts: non-LTE inversions of low-atmosphere reconnection from SST-IRIS observations

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Ellerman bombs and UV bursts are compact transient brightenings that are ubiquitously observed in the lower atmospheres of active and emerging flux regions. While some Ellerman bombs display clear UV burst signatures, not all have correlated UV signal or vice versa, suggesting the underlying atmospheric and magnetic properties may vary. As both pinpoint sites of magnetic reconnection in reconfiguring fields, understanding their detailed evolution may provide helpful insights in the overall evolution of active regions. Here we present results from observations and non-LTE inversions of SST/CRISP and CHROMIS, as well as IRIS data of several such transient events. Combining information from the Mg II h & k, Si IV, Ca II 8542 Å and Ca II K lines we aim to infer the temperature and velocity stratifications, as well as the magnetic field configuration within which they occur. At unprecedented spatial resolution the CHROMIS Ca II K observations reveal dynamic fine structure suggesting plasmoid-mediated reconnection and we find that the events correspond to average temperature enhancements of order 2500–4000 K, with localised hot pockets of up to 10,000–15,000 K. Several events show clear bi-directional jet signatures with line-of-sight velocities of order 5–15 $\mathrm{km\,s^{-1}}$ and the inversions suggest increased horizontal fields close to the larger temperature enhancements. While a response in Si IV can be reproduced for some cases, this generally comes at the expense of overestimating the emission in the other lines considered. We will address the difficulties of successfully inverting all diagnostics and discuss our results in light of the current debate on the connection between UV bursts and Ellerman bombs, their occurrence heights and in particular the temperatures that they may (or may not) reach.

Invited Talk

5. Opportunities and challenges

Machine learning to investigate magnetic field and other complex data sets

Andres Asensio-Ramos[1]

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In the last decade, machine learning has experienced an enormous advance, thanks to the possibility to train very deep and complex neural networks. In this contribution I show how we are leveraging deep learning to solve difficult problems in Solar Physics. I will focus on how differentiable programming (aka deep learning) is helping us to have access to velocity fields in the solar atmosphere, correct for the atmospheric degradation of spectropolarimetric data and carry out fast 3D inversions of the Stokes parameters.

Invited Talk

5. Opportunities and challenges

Machine learning and inversions of Mg II h/k spectra

A. Sainz Dalda[1], J. de la Cruz Rodríguez[2], M. Gošić[1], and B. De Pontieu [3]

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Up to date, IRIS has obtained roughly 16500 datasets containing the Mg II h/k spectra. The variety of targets observed, the different set-ups used, and the large number of pixels involved in any of these datasets make their inversion a computationally expensive task. We present a new method to invert the Mg II h/k spectra observed by IRIS. This new approach is based on the STiC inversion of Representative Profiles (RPs). STiC takes into account non-LTE lines and continua including the effects of partial redistribution. The RPs are calculated using an easy-to-understand, easy-to-implement machine learning technique. Thus, a massive number of Mg II h/k profiles can be easily inverted and interpreted in a feasible, meaningful way. As a consequence of this new framework, we are able to recover in a few minutes the thermodynamics at the chromosphere from most of the IRIS Mg II h/k observations.

Invited Talk

5. Opportunities and challenges

ALMA: what is it good for?

S. M. White

Air Force Research Lab.

A large number of solar researchers have now received ALMA science data, and have started their analysis, confronting the attendant difficulties as they do. This talk will present a personal viewpoint on what we can expect from ALMA data, and from joint use of ALMA data with other sources such as IRIS. I will likely make provocative claims in the hope of stimulating strong discussion and feedback.

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Contributed Talk

5. Opportunities and challenges

Does ALMA help state-of-the-art inversions of the solar atmosphere ?

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We present a study of the performance of inversions of synthetic optical and UV spectral lines together with ALMA mm-bands computed from a snapshot of a 3D radiation-MHD Bifrost simulation.
Distinctly from photospheric lines, most chromospheric diagnostics such as CaII 854.2 nm and MgII h & k form under non-LTE conditions, therefore they are weakly coupled to the local conditions of the plasma. On the other hand, 1.2 mm and 3 mm continuum emission as probed by ALMA forms in the chromosphere and its source function can be treated in LTE, hence it can be used to estimate chromospheric temperatures. However, proper use of ALMA data requires successful imaging at very high resolution which is a rather challenging endeavor. In fact, ALMA observations will be most useful when combined with other spectral ranges, but the combined diagnostic potential is not yet fully assessed.
We found that coordinated observations from ALMA, SST and IRIS can be used to estimate the full thermodynamical state of the plasma as a function of optical depth. Notably, the addition of ALMA bands to the pre-existing diagnostics should help constraining both chromospheric temperatures and magnetic fields. We found, nonetheless, that multi-line non-LTE inversions already present strong constraints especially when optical and UV lines are used simultaneously, emphasizing the importance of the new CaII K observations with SST/CHROMIS.

PROBING THE TURBULENT QUIET CHROMOSPHERE WITH ALMA, IRIS AND IBIS

Momchil Molnar[1,2,5], Kevin Reardon[2,3], Yi Chai[4], Steven Cranmer[1,5]

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We present an exploratory study of the dynamics of the quiet solar chromosphere observed simultaneously with the Atacama Large Millimeter/submilimeter Array (ALMA), the Interface Region Imaging Spectrograph (IRIS) and the Interferometric Bidimensional Spectropolarimeter (IBIS) at the Dunn Solar Telescope (DST) in April 2017. This first-of-its-kind dataset comprises high resolution, co-temporal observations of the chromosphere spanning from the far ultraviolet (FUV) with IRIS, through the optical and near infrared parts of the spectrum (IBIS and FIRS at the DST) to the mm-wavelengths with ALMA. Using the high cadence and high angular resolution of ALMA, IRIS and IBIS observations we study the heating mechanisms in the chromosphere, including the role of steepening acoustic waves. We explore the power spectra and phase delay properties of the observed solar regions to study the dynamics of the observed chromospheric structures. Furthermore, our observations of turbulence in the chromosphere extend previous work by Reardon et al. (2008) up to higher temporal frequencies and further consolidate the idea of turbulent dissipation of the wave energy propagating upward from the photosphere as a heating mechanism.

ALMA and IRIS observations of the solar chromosphere on the polar limb

Takaaki Yokoyama[1], Masumi Shimojo,[2]
Takanori J. Okamojo,[2] Haruhisa Iijima[3]

[1] *The University of Tokyo*
[2] *National Astronomical Observatory of Japan*
[3] *Nagoya University*

We report results of the Atacama Large Millimeter/sub-millimeter Array (ALMA) observations of the solar chromosphere on the southern polar limb. The coordinated observation with the Interface Region Imaging Spectrograph (IRIS) is also carried out. From Cycle-4 of the ALMA proposal period, solar observation capability became open to the community. ALMA has provided us unprecedented high spatial resolutions (approximately 2.0 arcsec) in the millimeter band at 100 GHz frequency with very high cadence (20 sec). The results are as follows: (1) A clear solar limb in the millimeter band is located at approximately 5 arcsec above the photosphere. Many dynamic saw-tooth patterns are identified on the chromospheric edge. They are co-located with the similar structure in the EUV emission taken by SDO/AIA 171 band and can be interpreted as low-temperature high-density materials. (2) A blob-ejection event is found. By comparing with the UV images taken by IRIS Mg slit jaw, the trajectory of the blob is located along the spicular patterns. The ejection is accompanied by a brightening jet event at the footpoint area.

What are the outstanding issues with coronal jets?

Alphonse C. Sterling[1]

[1] *NASA/MSFC*

Solar coronal jets have been observed in X-rays since the early 1990s. Since then, high-cadence, high-resolution observations of them in the EUV with SDO/AIA, and similar advances in magnetic field information with SDO/HMI, resulted in a revolution in thinking about the mechanisms leading to and driving the jets. It now appears that at least many jets result when a small-scale filament (minifilament) erupts, and the field of that erupting minifilament undergoes magnetic reconnection with pre-existing surrounding field. Moreover, a primary - if not exclusive - mechanism for building the minifilaments and triggering them to erupt is cancelation of magnetic flux in the photosphere near the location from where the minifilament/fluxrope erupts. This presentation will discuss outstanding questions regarding coronal jets, such as the need to verify the above scenario with more data; confirming whether the same mechanism(s) drive jets in all solar regions, including active regions, quiet Sun, and coronal holes; and determining whether there is a threshold condition (or set of conditions) necessary for driven reconnection to result in explosive jets.

Contributed Talk

4. Eruptions in the solar atmosphere

The derivation of mass flows in an erupting prominence from simultaneous observations with IRIS, AIA/SDO, EUVI/STEREO and K-COR

Ping Zhang[1], Éric Buchlin[2], Jean-Claude Vial[3]

[1] *Institut d'Astrophysique Spatiale*
[2] *Université Paris-Sud*

From simultaneous observations of an eruptive prominence performed with IRIS, AIA/SDO, EUVI/STEREO and the ground-based K-COR coronagraph, we focus on the determination of mass flows during the pre-eruptive and early phases of the eruption. As far as velocities are concerned, we combined an optical flow method on the AIA 304 and IRIS Mg II h&k observations in order to derive the POS velocities in the prominence and a Doppler technique on the IRIS Mg II h&k profiles to compute the LOS velocities. We used the STEREO observations to derive the 3D geometry of the prominence in order to define velocity vectors. As far as densities are concerned, we tried to characterize the Mg h and k profiles (time and space-dependent) and compare with the signatures of more than one hundred prominence models through NLTE radiative transfer computations (I.A.S. PROM7 code). We paid much attention to the exact incident radiation in various lines and continua. The model parameters include pressure, temperature, height, thickness, radial and turbulence velocities. As a first step, we focused on the k and h integrated intensities and selected the best (fitting) models. We were able to derive the total (hydrogen) density and consequently compute the mass flows. We also used the K-COR observations to derive the density later on in the process of eruption. Applying this method to more prominences observed by IRIS could help to reduce the large range of thermodynamic parameters in eruptive prominences and to improve their MHD modeling.

IRIS and SDO Observations of Solar Jetlets Resulting From Flux Cancelation

Navdeep K. Panesar[1], Alphonse C. Sterling[1], Ronald L. Moore[1,2], Sanjiv K. Tiwari[3], Bart De Pontieu[3], Aimee A. Norton[4]

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Solar jets of all sizes are magnetically channeled narrow eruptions; the larger ones are often observed in the solar corona in EUV and coronal X-ray images. Recent observations show that the buildup and triggering of the minifilament eruptions that drive coronal jets result from magnetic flux cancelation under the minifilament, at the neutral line between merging majority-polarity and minority-polarity magnetic flux patches. Here we investigate the magnetic setting of on-disk small-scale jets (also known as jetlets; small jets of base widths 2-3",$\sim$10 times smaller than typical base widths of classical coronal jets) in a coronal hole by using IRIS and SDO/AIA images and line-of-sight magnetograms from SDO/HMI. We observe recurring jetlets at the edges of the magnetic network in the coronal hole. From magnetograms co-aligned with the IRIS and AIA images, we find that the jetlets stem from sites of flux cancelation between merging majority-polarity and minority-polarity flux patches, and that the jetlets show brightenings at their bases reminiscent of the base brightenings in coronal jets. Based on these observations of $\sim$10 obvious jetlets and our previous observations of $\sim$50 coronal jets in quiet regions and coronal holes, we infer that flux cancelation is the essential process in the buildup and triggering of jetlets. Our observations suggest that jetlet eruptions are small-scale analogs of both larger-scale coronal jet eruptions and the still-larger-scale eruptions that make major CMEs.

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Contributed Talk

4. Eruptions in the solar atmosphere

Recurrent CME-like Eruptions in Flux Emergence Simulations

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[1] *School of Mathematics and Statistics, University of St. Andrews, UK*
[2] *Department of Physics, University of Athens, Greece*

We report on three-dimensional MHD simulations of recurrent small-scale Coronal Mass Ejection (CME)-like eruptions using flux-emergence simulations and study their formation and eruption mechanism. These eruptions have the size and energies of small prominence eruptions. The erupting flux ropes are formed due to the reconnection of J-loops (formed by shearing and rotation) and are located inside magnetic envelope field favouring torus instability. The flux rope eruptions are triggered by the action of a tension removal mechanism, such as the typical tether-cutting where the envelope field reconnects with itself. Another side tether-cutting is also found. There, the envelope field reconnected with the J-loops. The two tether-cutting mechanisms transfer hot plasma differently inside the erupting structures. We report similar mechanisms creating three more eruptions in a recurrent manner.

Invited Talk

4. Eruptions in the solar atmosphere

Connecting flares to the atmosphere

Vanessa Polito[1]

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Thanks to its capability of combining images and spectra formed over a broad range of temperatures (log (T/K) = 3.7 – 7) with unprecedented spatial and spectral resolution, IRIS has enabled significant advancements in our understanding of flares. In particular, the observation of the high-temperature Fe XXI flare line has contributed to address some of the long-standing issues regarding the chromospheric evaporation process. On the other hand, TR and chromospheric lines (e.g. Si IV, O IV, Mg II, C II) allow us to investigate the lower atmospheric conditions during the impulsive phase of flares and have been used to provide important constraints to the properties of flare models. This talk will give an overview of some of the new insights gained from IRIS, while also mentioning how IRIS observations can be enhanced and complemented by observations from other space and ground-based instruments.

Solar jets rooted on flare ribbons in the major events in September 2017

Xiaohong Li[1,2]

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Employing the multi-wavelength observations from the Atmospheric Imaging Assembly on board the *Solar Dynamics Observatory*, we investigated the jets that occurred during the most impressive flare in Solar Cycle 24, an X9.3 class flare in NOAA active region (AR) 12673 on 2017 September 6. There were dozens of jets appearing as bright structures in the 1600 Å images. The footpoints of the jets were all rooted on the northwestern flare ribbon and brightened up successively as the propagation of the flare ribbon. We also investigated two jets about their performances in 131 Å. With the high tempo-spatial *Interface Region Imaging Spectrograph* 1330 Å observations, we also studied the X8.2 class flare in this AR on September 10 and found that numerous jets were rooted on the flare ribbons. We examined 15 jets, and the mean values of the lifetimes, projected widths, lengths and velocities of the jets were 87 s, 885 km, 2.7 Mm and 70 km s^{-1}, respectively. This was the first time that jets were reported to be rooted on the flare ribbons.

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4. Eruptions in the solar atmosphere

Spectroscopic Observations of Magnetic Reconnection and Chromospheric Evaporation in an X-shaped Solar Flare

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We present observations of distinct UV spectral properties at different locations during an atypical X-shaped flare (SOL2014-11-09T15:32) observed by the Interface Region Imaging Spectrograph (IRIS). In this flare, four chromospheric ribbons appear and converge at an X-point where a separator is anchored. Above the X-point, two sets of non-coplanar coronal loops approach laterally and reconnect at the separator. The IRIS slit was located close to the X-point, cutting across some of the flare ribbons and loops. Near the location of the separator, the Si IV 1402.77 Å line exhibits significantly broadened line wings extending to 200 km s^{-1} with an unshifted line core. These spectral features suggest the presence of bidirectional flows possibly related to the separator reconnection. While at the flare ribbons, the hot Fe XXI 1354.08 Å line shows blueshifts and the cool Si IV 1402.77 Å, C II 1335.71 Å, and Mg II 2803.52Å lines show evident redshifts up to a velocity of 80 km s^{-1}, which are consistent with the scenario of chromospheric evaporation/condensation.

IRIS-9, Göttingen, 25-29 June 2018

Contributed Talk

4. Eruptions in the solar atmosphere

Structure and dynamics of cool flare loops

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Cool flare loops appear during the flare evolution as the result of a gradual appearance of hot loops which cool down to chromospheric temperatures. They have been observed during several flares by IRIS, and namely in MgII and CII lines, or in SiIV within hotter parts. We will present our analysis of MgII lines in such loops which exhibit significant downward flows (also called coronal rain). Using the cloud model technique we have determined the line source function which is decreasing with increasing flow velocity. This is interpreted as the effect of Doppler dimming in MgII lines. Cool lines also exhibit a strong non-thermal broadening and we will discuss its possible nature. We will present 2D non-LTE models of magnetic loops and compare the synthetic line intensities with IRIS observations, in order to estimate the electron densities in cool loops. Other observations of flare loops have been obtained recently by SDO/HMI and AIA and we will show their characteristics. Detailed non-LTE diagnostics of cool loops is needed to understand the gradual evolution of solar and stellar flares.

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Invited Talk

4. Eruptions in the solar atmosphere

Completing solar flare models with spectroscopic (IRIS) observations

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Solar flares are amongst the most energetic events in our solar system. Generally seen as intense brightenings in the UV and X-ray domains, they also inject solar energetic particles and coronal mass ejections (CMEs) into the interplanetary medium. Their effects on the space environment of planets are non-negligible, with the known consequences on human activities. A better understanding of the processes taking place during flares is needed in order to develop future prediction capacities.

In the last decades, the wealth of data from space and ground missions as well as developments of numerical models have provided a deeper knowledge of the behaviour of magnetic fields during solar flares. From flux ropes to flare loops, from electric currents to flare ribbons, we will see how both observations and modelling help bring together a generic 3D picture of the mechanisms taking place prior and during solar flares. The evolution of different magnetic structures, well reproduced with a magnetohydrodynamic (MHD) model, is dictated by magnetic reconnection, which converts magnetic energy stored in the Suns corona. In particular, consequences of magnetic reconnection can be seen in the different layers of the solar atmosphere, which allows us to go back to its intrinsic properties in 3D.

We will then show that while 3D MHD models are mostly focussed on the behaviour of the magnetic field due to the low-beta condition of the corona, spectroscopic observations can come in handy when completing the cartoon with the plasma behaviour. In particular, as IRIS reveals the dynamics of the chromosphere and the transition region, it brings new understandings on the exchange of energy via non-thermal particles and plasma flows prior and during solar flares. We will discuss how the observations of flaring regions (heating, kernel brightening, ribbons, plasma velocities) help us getting a better understanding of flares throughout the different layers of the Sun's atmosphere.

Do all flares share the same chromospheric physics?

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IRIS observes over a large range of atmospheric heights including the chromosphere where the majority of flare energy is dissipated. The strong Mg II h&k spectral lines are capable of providing excellent atmospheric diagnostics but have not been fully utilized for flaring atmospheres. We aim to investigate whether the physics of the chromosphere is identical for all flare observations and if there are certain spectra that occur in all flares. To achieve this, we automatically analyze hundreds of thousands of Mg II h&k line profiles from a set of 33 flares and use a machine learning technique known as k-means to classify all profile shapes. We identify a single peaked Mg II profile, in contrast to the double-peaked quiet Sun profiles, appearing in every flare. Additionally, we find extremely broad profiles with characteristic blue shifted central reversals occurring at the front of fast moving flare ribbons. We present strong evidence that these profiles are correlated both temporally and spatially with X-ray signatures. The ratio of the integrated Mg II h&k lines can also serve as an opacity diagnostic and we find higher opacities during each flare maximum. Our study shows that machine learning is a powerful tool for large scale statistical solar analyses. We plan to extend our methods to include additional spectral lines, and use the diagnostics available for each line to further understand the dynamic flaring atmosphere.

Contributed Talk

4. Eruptions in the solar atmosphere

What do non-LTE inversions tell us about flares in the upper chromosphere?

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Solar fares have long been studied observationally and theoretically with radiation-MHD simulations. However, both approaches have struggled to fully explain the observed line profiles in chromospheric lines. In this talk we present and discuss time-series of 3D empirical models derived from non-LTE inversions performed simultaneously in Ca II H&K, Ca II 8542 and, for some targets, including also Mg II h&k from IRIS.

Previous studies involving depth-stratified inversions have focused in the Ca II 8542 line, that samples the lower chromosphere. By including Ca II H&K and Mg II h&k we can reach the upper chromosphere, and better constrain velocity and temperature gradients in the entire chromosphere.

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Contributed Talk

4. Eruptions in the solar atmosphere

Optically Thick Si IV Emission During Solar Flares: Non-LTE, Non-equilibrium Simulations

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IRIS has routinely observed the strong Si IV resonance lines during solar flares and other heating events. When analyzing, or simulating, quiescent observations of these lines it has typically been assumed that they are optically thin and resources such as CHIANTI used to produce synthetic spectra from simulations with which to compare to observations. However, this assumption has also been applied to the flaring scenario. We used radiation hydrodynamic simulations of solar flares, computed using the RADYN code, to probe the validity of this assumption. Using flare atmospheres we solved the formal radiation transfer to obtain the non-LTE, non-equilibrium populations, line profiles, and opacities for a 30 level Si atom. Our electron beam-driven flare simulations covered a range of beam parameters: energy flux, $F = [5 \times 10^8 - 1 \times 10^{11}]$ erg cm^{-2} s^{-1}, low energy cutoffs, $E_c = [20, 30, 40]$keV, and spectral indices, $\delta = [4, 6]$. All simulations with an injected energy flux $F > 5 \times 10^{10}$ erg cm^{-2} s^{-1} resulted in optically thick Si IV emission. Lower energy flares (down to $F \sim 5 \times 10^9$ erg cm^{-2} s^{-1}) also resulted in optically thick Si IV emission, depending on the other beam parameters. Beams which penetrated deeper were less likely to produce optically thick emission compared to those which strongly heated the upper chromosphere and transition region. Flares that deposit energy at higher altitude than in our simulations might also produce optically thick Si IV emission, even if the energy flux is low. Since we demonstrate that Si IV can become optically thick in flaring conditions we urge caution when analyzing observations, or when computing synthetic emission using the coronal approximation.

Invited Talk

6. Science together with future facilities

New science windows with future ground-based observations - the Daniel K. Inouye Solar Telescope

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The NSO-led, 4-m Daniel K. Inouye Solar Telescope (DKIST) is nearing completion on Maui, Hawaii, with first light foreseen for early 2020. The DKIST will herald a new era of ground-based solar observations, with its polarimetric capabilities, unprecedented spatial resolution, and novel diagnostics in the near IR. In particular, DKIST is expected to revolutionize coronal science, providing high-sensitivity, high-resolution measurements of the coronal polarized spectrum.
After a brief update on the current status of the project, I will present the efforts under way to prepare for the scientific exploitation of the new data during the first two years of operation, the so-called "Critical Science Plan". A number of thematic workshops are currently being held, involving a large fraction of the solar physics community, with the final goal of identifying science topics that can best be addressed with the DKIST capabilities. Many of these science projects, in particular the ones addressing the physics of the outer solar atmosphere, will benefit from coordination with IRIS, exploiting its high spatial and temporal resolution, and complementary diagnostics.

Invited Talk

6. Science together with future facilities

The Parker Solar Probe (PSP) and IRIS

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Invited Talk

6. Science together with future facilities

Science with CLASP 1 & 2

Javier Trujillo Bueno and the CLASP team[1]

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Spectroscopic observations with IRIS of the radiation intensity in ultraviolet (UV) spectral lines have led to very important advances in our empirical understanding of the thermal structure and dynamic behavior of the interface region between the chromosphere and corona of the Sun. Yet, to quantitatively explore the magnetic field of the upper solar chromosphere and the transition region requires spectropolarimetry in magnetically sensitive UV spectral lines, such as hydrogen Lyman-α and the Mg II h & k lines. The sensitivity to the presence of magnetic fields in the upper solar chromosphere is caused mainly by the Hanle effect, which operates in the core of the linear polarization profiles produced by scattering processes, but recently we have learned that in such strong resonance lines the Zeeman effect can also introduce magnetic sensitivity in the wings of their linear polarization profiles. The observation and modeling of the polarization produced in UV lines by the joint action of scattering processes and the Hanle and Zeeman effects are not easy, but solar physics has always benefited when new diagnostic windows are pursued and eventually opened. On 3rd September 2015 an international team of scientists from USA, Japan and Europe carried out a challenging experiment with the Chromospheric Lyman-Alpha Spectro-Polarimeter (CLASP), a vacuum UV telescope with a spectropolarimeter launched by a NASA suborbital rocket. Here we provide an overview of this successful mission that has allowed us to observe for the first time the linear polarization produced by scattering processes in the hydrogen Lyman-α line of the solar disk radiation. We also inform about the second flight of CLASP, planned for 2019, which will hopefully measure the linear and circular polarization across the Mg II h & k lines. The emphasis of this lecture will be on the scientific aspects of both sounding rocket experiments.

Contributed Talk

6. Science together with future facilities

Preview of First Results from Hi-C 2.1 and IRIS

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The spatial and temporal resolutions of the available coronal observatories are inadequate to resolve the signatures of coronal heating. High-resolution and high-cadence observations available with the Interface Region Imaging Spectrograph (IRIS) and the High-resolution Coronal Imager (Hi-C) instrument hint that $\sim$0.3 arcsec resolution images and < 10 s cadence provide the necessary resolution to detect heating events. Hi-C was originally launched from White Sands Missile Range on July 11, 2012 and obtained images of a solar active region in the 19.3 nm passband. It will be launched again as Hi-C 2.1 in May, 2018 with a 17.1 nm passband and acquire co-temporal and co-spatial observations with IRIS. These data are expected to provide a unique method of testing the energy flow between the chromosphere and corona. Here, we will present a preview of the performance from this latest flight of the Hi-C rocket in conjunction with the coordinated IRIS data set in anticipation of a full release of results and data products to the broader solar community in the coming months.

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Poster

1. Fundamental physical processes and modeling

Modelling, synthetic imaging and high-resolution observations of fine structures of prominences and filaments

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To understand links between the distribution of the prominence plasma, configuration of its magnetic field and observations of the prominence/filament fine structures obtained in UV/EUV, optical and radio domains from various vantage points, we need complex 3D prominence models. The first such a model was developed by Gunr&Mackay (2015). This 3D whole-prominence fine structure (WPFS) model allows to simulate entire prominences including their numerous fine structures. It combines a 3D magnetic field configuration of an entire prominence obtained from NLFF simulations, with a detailed description of the prominence plasma located in magnetic dips and distributed along hundreds of fine structures. The modeled prominence plasma has a realistic distribution of the density and temperature, including the prominence-corona transition region. Recently, we have included into the model a new magnetic field configuration of a polar crown prominence based on the LFF extrapolations of the photospheric flux distributions.

Such a complex 3D model can provide comprehensive information on the 3D distribution of the prominence plasma and magnetic field that can be consistently studied both as a prominence on the limb and as a filament on the disk. For example, 3D WPFS model can provide high-resolution synthetic images produced in the optical Hα line, at the SMM radio wavelengths, or in the Si IV (1402.8 Å) FUV line observed by IRIS. The model may thus serve as a complex, yet well-controlled environment for testing and development of techniques for analysis of the state-of-the-art observations. As en example may serve the analysis of the thermal properties of the prominence/filament fine structure plasma using the ALMA observations, or the development of inversion techniques for the inference of the magnetic field from the spectro-polarimetric observations.

We will present the capabilities of the 3D WPFS model and its potential for the analysis and interpretation of high-resolution observations of the prominence and filament fine structures, such as those obtained by IRIS.

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Poster

1. Fundamental physical processes and modeling

Non-LTE modelling of active filaments observed in the Hα line using the 2D flux-tube model

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We present development, current state and plans for future improvements of our non-LTE 2D flux-tube model. The model is used for simulations of spectroscopic observations in the Hα line of small-scale filaments in active regions, arc filaments and filaments in state of activation. We assume that filaments of these types are composed of flux-tubes located in the transition region and/or corona and relatively cool plasma can flow along these flux-tubes with various velocities. The flux-tube system is approximated in the model by a 2D horizontal slab where its finite dimensions form its cross section and the infinite dimension is parallel to the solar surface. The isothermal and isobaric slab is irradiated from the bottom and sides and the non-LTE radiative transfer in the 2D geometry is solved using the MALI numerical technique. The orientation of plasma flows in the slab is defined by the azimuth and inclination angles. The influence of different plasma flow velocities on the emerging radiation from the slab can be regulated using filling factors. The model was already successfully applied to several filament Hα line spectroscopic observations made with the echelle spectrograph at the Vacuum Tower Telescope (VTT) and the IBIS interferometer at the Dunn Solar Telescope. In further development of the model we also plan to introduce fine structures in 2D geometry composed of individual flux-tubes and variation of the temperature and pressure within each flux-tube.

Mass and energy supply of a cool coronal loop near its apex

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Different models for the heating of solar corona assume or predict different locations of the energy input: concentrated at the footpoints, at the apex, or uniformly distributed. The brightening of a loop could be due to the increase in electron density n_e, the temperature T, or a mixture of both. Based on the simultaneous imaging and spectral observation from Interface Region Imaging Spectrograph (IRIS), we investigate possible reasons for the brightening of a cool loop at transition region temperatures. The loop first appears at transition region temperatures and later also at coronal temperatures, indicating a heating of the plasma in the loop. During the heating phase, the appearance of a possible accelerating upflow in Si IV and the 3D magnetic field lines extrapolated from the HMI magnetogram suggest that the loop heating is probably affected by accelerating upflows, which are probably launched by magnetic reconnection between small-scale magnetic flux tubes underneath the envelope loop. Before and after the possible heating phase, the intensity changes in the optically thin (Si IV) and optical thick line (C II) are mainly contributed by the density variation without significant heating. This study emphasizes that in the complex upper atmosphere of the Sun, the dynamics of the 3D coupled magnetic field and flow field plays a key role in thermalizing 1D structures such as coronal loops.

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Poster

1. Fundamental physical processes and modeling

Modelling the corona of stars more active than the Sun using 3D MHD simulations

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Solar-like stars are surrounded by a million K hot corona. Observations show that faster rotating stars tend to have stronger magnetic field at the surface. This should lead to an increased energy input to the corona and thus to a brighter and hotter corona, just as seen in X-ray observations.
3D numerical magnetohydrodynamic (MHD) models of an active region in the Sun were successful in reproducing aspects of the coronal structure and dynamics. Our goal is to apply this model to stars more active than the Sun and understand the relation between the surface magnetic field and the heat input into the corona. For this purpose we use the Pencil Code to solve the MHD equations with the heating being through the Ohmic dissipation of currents. These are induced by the surface magnetic field being driven around by convective motions.
In our project we change the strength of the magnetic field at the bottom boundary (i.e the unsigned flux) as a first step to understand how the heat input into the corona will change quantitatively. Preliminary results show that the average temperature in the model corona relates to the coronal energy input as expected from the Rosner, Tucker, Vaiana(RTV) scaling laws. More importantly, we can also quantify how the coronal energy input relates to the magnetic flux at the surface indicating that the corona with temperatures from 1 MK to 10 MK can be heated by flux-braiding/nanoflare heating.

Non-equilibrium synthetic Si IV and C IV spectra formed by a periodic electron beam

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Solar transition region is highly dynamic and inhomogeneous. Its heating can be connected with short term particle acceleration processes and formation of the electron distributions with high-energy tails. Such distributions strongly affect the rates of impact ionization, but also recombination and excitation. We study how the plasma can be driven out of ionization equilibrium by a time-dependent presence of high-energy tails. Our model assumes a periodic electron beam passing through the Maxwellian plasma. Ambient plasma during the first half-period has a Maxwellian distribution and the same Maxwellian plasma together with an electron beam during the second half-period is represented by a κ-distribution. The periods 5, 10 seconds and electron densities 10^{10}, 10^{11} cm^{-3} were considered, in addition to different strength of the electron beam indicated by the parameter κ. Transient ionization states and synthetic IRIS spectra of Si IV and O IV were calculated. Naturally, stronger non-equilibrium effects are presented for shorter periods and lower electron densities. Synthetic IRIS spectra show a faster response of silicon ions to the presence of the electron beam in the comparison with the oxygen. This can enhance silicon line intensities in the comparison with an equilibrium state. The line ratio of Si IV to O IV depends on the strength of the electron beam, electron density, and period. For short periods and weak electron beams, the IRIS spectra containing only Si IV lines can be formed. Reversely, strong electron beam and long periods can lead to strong O IV intensities, resembling high-temperature equilibrium spectra. Our results show that the electron beam can drive the plasma out of ionization equilibrium, creating a variety of departures from the equilibrium ones.

Poster

1. Fundamental physical processes and modeling

An optimization principle to reconstructing magneto-hydro-static equilibria in the lower solar atmosphere

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Modelling the interface region between solar photosphere and corona is challenging, because the relative importance of magnetic and plasma forces changes by several orders of magnitude. While the solar corona can be modeled by the force-free assumption, we need to take care about plasma-force (pressure and gravity) in photosphere and chromosphere, here within the magneto-hydro-static (MHS) model. We solve the MHS-equations with the help of an optimization principle and use photospheric measurements as boundary condition. Positive pressure and density are ensured by reformulating the MHS-euqations by introducing two new basic variables which are derived by a transformation from pressure and density. Furthermore, we use the Lorentz force information during optimization to update the plasma pressure on the bottom boundary. Our code is tested by application to a linear MHS solution. Although the code works in ideal conditions, there are obstacles still to be overcome before the code can be applied to real data.

Poster

2. Chromospheric heating and dynamics

Intermittent reconnection and plasmoids in UV bursts in the low solar atmosphere

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Magnetic reconnection is thought to drive a wide variety of dynamic phenomena in the solar atmosphere. Yet the detailed physical mechanisms driving reconnection are difficult to discern in the remote sensing observations that are used to study the solar atmosphere. We exploit the high-resolution instruments Interface Region Imaging Spectrograph (IRIS) and the new CHROMIS Fabry-Perot instrument at the Swedish 1-m Solar Telescope (SST) to identify the intermittency of magnetic reconnection and its association with the formation of plasmoids in so-called UV bursts in the low solar atmosphere. The Si IV 1403A UV burst spectra from the transition region show evidence of highly broadened line profiles with often non-Gaussian and triangular shapes, in addition to signatures of bidirectional flows. Such profiles had previously been linked, in idealized numerical simulations, to magnetic reconnection driven by the plasmoid instability. Simultaneous CHROMIS images in the chromospheric Ca II K 3934A line now provide compelling evidence for the presence of plasmoids, by revealing highly dynamic and rapidly moving brightenings that are smaller than 0.2 arcsec and that evolve on timescales of order seconds. Our interpretation of the observations is supported by detailed comparisons with synthetic observables from advanced numerical simulations of magnetic reconnection and associated plasmoids in the chromosphere. Our results highlight how subarcsecond imaging spectroscopy sensitive to a wide range of temperatures combined with advanced numerical simulations that are realistic enough to compare with observations can directly reveal the small-scale physical processes that drive the wide range of phenomena in the solar atmosphere.

Poster

2. Chromospheric heating and dynamics

Observations of solar chromospheric heating at sub-arcsec spatial resolution

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A variety of dynamic phenomena ranging from slender fibrils ($\sim$100 km) to compact ultraviolet (UV) brightenings or bursts ($\sim 1''$) are associated with the heating of the solar chromosphere. Observations with high spatial and temporal resolutions are required to capture the finer details of these rapidly evolving events, which will provide constraints to chromospheric heating models. Here we report the observations of a chromospheric burst imaged at diffraction-limited spatial resolution of $0.1''$, at a cadence of 7 s obtained with balloon-borne Sunrise telescope. This burst displays a spatial morphology similar to that of a large-scale solar flare with circular ribbon. It is composed of extended ribbon like features and a rapidly evolving arcade of thin magnetic loop-like features, similar to post-flare loops. Based on magnetic field extrapolations, this heating event is associated with a complex fan-spine magnetic topology. Our observations strongly hint at a unified picture of magnetic heating in the solar atmosphere from some large-scale flares to small-scale bursts, all being associated with such a magnetic topology.

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Poster

2. Chromospheric heating and dynamics

Coronal bright point dynamics as seen by SDO and IRIS

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We study the quiet Sun bright point as seen by the Atmospheric Imaging Assembly (AIA), Helioseismic and Magnetic Imager (HMI) aboard Solar Dynamics Observatory (SDO), Slit-Jaw Imager (SJI) from Interface Region Imaging Spectrograph (IRIS) and spectral line data. We focus on the morphological changes associated with bright point seen in different atmospheric layers, and photospheric magnetic field changes. We explore the unique data set, consisting seven hour long time series spectral data covering three-arc-seconds of bright point, near one of the foot point. Long period oscillations in the intensity of the bright point are probed. We explore on the source/sources of the observed quasi-periodic oscillations in the context of repeated reconnection scenario. We propose that the long period oscillation are due to intermitant episodes of magnetic flux cancellation and morphological changes. Which in turn are resultant of magnetic reconnection. We also propose that the short periods observed are due to the repeated reconnection that happen through out the duration of the observations.

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Poster

2. Chromospheric heating and dynamics

High-frequency dynamics of a moss regions as observed by IRIS

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High-frequency oscillations have become interestingly important in very recent past and are proposed to be one of the sources of coronal heating. The high temporal, spatial and spectral resolution of IRIS has provided a new insight into understanding the different small-scale processes occurring at the chromospheric and transition region heights. We study the dynamics of high-frequency oscillations of an active region (AR 2376) moss as captured by simultaneous imaging and spectral data of IRIS, mapping the solar transition region. We detect high-frequency oscillations (1-2 minutes) while looking at the power maps deduced from the time-sequence of the slit-jaw images in Si IV 1400 Å passband and sit-and-stare spectroscopic observations of the Si IV 1403 Å spectral line. We find the small periodicities to be generally having significant power in the bright moss region. In particular, the high-frequency oscillations appear to possess high power in the small localised regions within the bright moss, which reveals the finer structures in the active regions moss. These high-frequency oscillations could possibly be manifestations of different magnetohydrodynamic (MHD) waves, or quasi-periodic flows or a combination of both, occurring at small spatial extents. This study sheds a new light on the dynamics of high-frequency oscillations observed in transition region and their role in heating the upper solar atmosphere.

Automated detection of transient moss features with AIA

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Rapidly varying active region moss was observed by Testa et al. 2013 in a short time series (∼150s) dataset from Hi-C (High-resolution Coronal Imager). The intensity fluctuations in sub-arcsecond 193A images (∼1.5 MK plasma), on the order of 15 seconds, were uncharacteristic of steadily heated moss and were considered as an indication of heating events connected to the corona. Intriguingly, these brightenings displayed a connection to the ends of high temperature loops seen in the corona.
Following the same active region AR11520, for 6 days across the solar disk we demonstrate an algorithm designed to detect the same temporal variability in lower resolution AIA data, thereby significantly expanding the number of events detected. Analogous regions are successfully detected at the footpoints of loops and in several areas appear to "sparkle" prior to a clear brightening in connected high-temperature loops; as confirmed in the hot AIA channels and the Fe XXVII line isolated by filter ratio. The result is illuminating as the same behavior has recently been shown by nano-flare simulations by Polito et al. 2018 using a thick-target beam approach. Here we investigate the correspondence of coronal heating events to loop footpoint response for the full time period, providing insight into the conditions required for such events to occur.
Results for several other regions are also presented with data obtained using the recently implemented search features at http://iris.lmsal.com/search/ for co-observed IRIS and AIA datasets.

IRIS-9, Göttingen, 25-29 June 2018

Poster

2. Chromospheric heating and dynamics

Tracing non-vertical acoustic shock propagation in the chromosphere

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We report on preliminary progress toward quantifying the energetic impact of acoustic shocks to the chromosphere in magnetic regions. We use the Bifrost simulation to track the hydrodynamic and radiative evolution of shocks in both vertical and inclined field regions in 2D and 3D simulations. It is well known that the telltale Ca II H&K shock signature is near wing emission (grain) followed by a protracted blue-to-red Doppler shift in absorption (sawtooth) for a vertical fluxtube. Given that the chromospheric magnetic field is highly structured and that the formation height of chromospheric lines vary, we build off that earlier work by identifying the signature of shocks in a broader environmental and spectral context. In particular, we focus on the Mg II h&k lines which are observed by IRIS and the Ca II 8542A line which is observed by the Swedish Solar Telescope. We plan to use the diagnostics derived from the simulations to derive an occurrence rate and an energetic deposition rate for a shocks in a plage region.

IRIS-9, Göttingen, 25-29 June 2018

Poster

2. Chromospheric heating and dynamics

Effect of viscosity on propagation of MHD waves in astrophysical plasma

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We determine the general dispersion relation for the propagation of magnetohydrodynamic (MHD) waves in astrophysical plasma by considering the effect of viscosity with anisotropic pressure tensor. Basic MHD equations have derived and linearized by method of perturbation to develop the general form of dispersion relation equation. Our result indicates that astrophysical plasma with anisotropic pressure tensor is stable in the presence of viscosity and strong magnetic field at considerable wavelength.

IRIS-9, Göttingen, 25-29 June 2018

Poster

2. Chromospheric heating and dynamics

Non-equilibrium energy balance in solar chromosphere

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The enormous increase in computing resources in recent years has made it feasible to approximate the solar photosphere in great detail using numerical magneto-hydrodynamic (MHD) simulations. Extending these simulations to the solar chromosphere, that lies above, has been challenging, due to the dominant role played by radiative losses there. These losses are driven by a small number of strongly scattering spectral lines, so that the approximation of local thermodynamic equilibrium cannot be used. In addition, the dynamic time scale of the atmosphere is similar or below that of the dominant collisional processes, so that even statistical equilibrium cannot be assumed. We present a time-implicit numerical method that simultaneously solves the atomic population evolution and radiative transfer equations, together with the MHD quantities. The method is being implemented as a module for the MHD code MURaM. We present here, some results from our study of non-equilibrium evolution of hydrogen in a one-dimensional atmosphere.

Poster

2. Chromospheric heating and dynamics

How Fibrils Appear in the Ca II K Data in Comparison to Hα Data

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Observations show that fibrils cover most of the chromosphere in line–core images in Ca II H&K and Hα. We observed these lines with the Swedish 1–meter Solar Telescope using the CHROMIS and CRISP imaging spectrographs. We investigate fibrils that appear bright in wavelength–integrated Ca II K images. They are bright because their K2 intensity is higher than their surroundings. The width of the emission peaks in the fibrils is the same as in their surroundings. Only a fraction of the fibrils has a clear counterpart in Hα. Those that do also appear bright in the Hα line–core. We will discuss possible explanations for this behavior.

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Poster

2. Chromospheric heating and dynamics

Downflows in the solar chromosphere

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In earlier studies employing observations from VTT, a population of supersonic downflows with speeds up to 40 $\mathrm{km\,s^{-1}}$ coexisting with a second slow population were reported. Magnetic field was found to have different strength and orientation for the two populations. In this work, we carry out a statistical analysis of these downflows in observations recorded by the GRIS instrument at GREGOR in the He I 10830 Å triplet. Using multi-component and multi-line inversions of the spectropolarimetric data assuming Milne-Eddington-type atmospheres, we derive the velocities and magnetic vector for several data sets. Making use of the line-of-sight velocity and magnetic field vector maps retrieved from inversions, we investigate the velocity structure and its relation with the magnetic fields in the chromosphere where the He lines are formed (8000–10000 K).

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Poster

2. Chromospheric heating and dynamics

Magnetic field variations associated with umbral flashes and penumbral waves

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Oscillations in sunspots are extensively studied phenomenon for last several decades. These studies mostly concentrate on variations in the intensity and Doppler velocities. Fewer observational studies focused on variations in the magnetic field in the photosphere, report contradicting results. Some recent studies have reported variations in the chromospheric magnetic field strength associated to umbral flashes (UFs) and running penumbral waves (RPWs). These changes could be explained by opacity effects or by intrinsic changes in the magnetic field strength. In this study we investigate the origin of these periodic variations of the magnetic field strength by analyzing a time-series of high temporal cadence observations acquired in the Ca II 8542 Å line with the CRISP instrument at the Swedish 1-m Solar Telescope. In particular, we investigate the temporal variations in the magnetic field associated to UFs and RPWs and their relation to opacity changes in the Ca II 8542 Å line. We obtained stratified atmospheric parameters by performing non-LTE data inversion of the Fe I 6301.5 & 6302.5 Å and Ca II 8542 Å spectral using the NICOLE code. Our results indicate that the Ca II 8542 Å line in sunspots is greatly sensitive to magnetic fields at $\log \tau_{500} = -5$ during UFs and quiescence. However this optical depth value does not correspond to the same geometrical height during the two phases. Our results indicate that during UFs and RPWs the $\log \tau = -5$ is located at a higher geometrical height than during quiescence. Additionally, the inferred magnetic field values are higher in UFs (up to ~ 270 G) and in RPWs (~ 100 G). Our results suggest that opacity changes caused by UFs and RPWs cannot explain the observed temporal variations in the magnetic field, as the line seems to form at higher geometrical heights where the field is expected to be lower.

Umbral Oscillations in NOAA AR 12384

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We investigate umbral oscillations in NOAA AR 12384 AR utilizing H-alpha off band data acquired on 14 July 2015 with the Visible Imaging Spectrometer (VIS) operating at the Goode Solar Telescope (GST) in Big Bear Solar Observatory. To analyze intensity fluctuation at each individual pixel we used the wavelet analysis method and found the following: i)The darkest core of the sunspot umbrae showed the shortest oscillations (about two minutes), while the outer part of the umbrae showed much longer oscillation (about four minutes); ii) The oscillation period decreases gradually from darker to relatively less darker regions. We thus speculate that oscillations inside sunspot umbrae are strongly related to magnetic field strength.

Poster

2. Chromospheric heating and dynamics

Observations of upward propagating waves in the transition region and corona above Sunspots

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We present observations of persistent oscillations in the transition-region above sunspots taken by IRIS SJ 1400 Å and upward propagating disturbances along coronal loops rooted in the same region taken by AIA 171 Å passband. The oscillations of the features are cyclic oscillatory motions without any obvious damping. The amplitudes of the spatial displacements of the oscillations are about $1''$. The apparent velocities of the oscillations are comparable to the sound speed in the chromosphere. The intensity variations can take 24–53% of the background. The FFT power spectra of the oscillations show dominant peak at a period of about 3 minutes, in consistent with the omnipresent 3 minute oscillations in sunspots. The amplitudes of the intensity variations of the upward propagating coronal disturbances are 10–15% of the background. The coronal disturbances have a period of about 3 minutes, and propagate upward along the coronal loops with apparent velocities in a range of $30\sim80\,\mathrm{km\,s^{-1}}$. We propose a scenario that the observed transition region oscillations are powered continuously by upward propagating shocks, and the upward propagating coronal disturbances can be the recurrent plasma flows driven by shocks or responses of degenerated shocks that become slow magnetic-acoustic waves after heating the plasma in the coronal loops at their transition-region bases.

Poster

2. Chromospheric heating and dynamics

A Magnetic Reconnection Event in the Solar Atmosphere Driven by Relaxation of a Twisted Arch Filament System

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We present high-resolution observations of a magnetic reconnection event in the solar atmosphere taken with the New Vacuum Solar Telescope, Atmospheric Imaging Assembly (AIA), and Helioseismic and Magnetic Imager(HMI). The reconnection event occurred between the threads of a twisted arch filament system (AFS) and coronal loops. Our observations reveal that the relaxation of the twisted AFS drives some of its threads to encounter the coronal loops, providing inflows of the reconnection. The reconnection is evidenced by flared X-shape features in the AIA images, a current-sheet-like feature apparently connecting post-reconnection loops in the $H_\alpha + 1$ Å images, small-scale magnetic cancelation in the HMI magnetograms and flows with speeds of 40–80 km s^{-1} along the coronal loops. The post-reconnection coronal loops seen in the AIA 94 Å passband appear to remain bright for a relatively long time, suggesting that they have been heated and/or filled up by dense plasmas previously stored in the AFS threads. Our observations suggest that the twisted magnetic system could release its free magnetic energy into the upper solar atmosphere through reconnection processes. While the plasma pressure in the reconnecting flux tubes are significantly different, the reconfiguration of field lines could result in transferring of mass among them and induce heating therein.
Key words: Sun: chromosphere C Sun: corona C Sun: filaments C magnetic reconnection

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Poster

2. Chromospheric heating and dynamics

Dopplershifts in quiescent prominences observed by the IRIS and MSDP spectrographs

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Quiescent solar prominences are generally considered to be stable. However, these prominences consist of a multitude of small-scale structures or threads that are often significantly dynamic. To understand the nature of the plasma dynamics we use the high spatial, temporal and spectral resolution observations obtained by IRIS during coordinated campaign with the MSDP spectrograph at the Meudon Solar Tower. Mg II h and k lines observed by IRIS represent a good diagnostic tool for investigation of the prominence fine structure dynamics, as they are optically thick under the prominence conditions. We will present detailed IRIS observations of Mg II lines, e.g. the Dopplershift, the line width obtained with diferent methods of fitting the profiles (quantile method, gaussian method). We explain significant asymmetries in the observed Mg II spectra by the presence of several threads located along the line of sight with different velocities. In such a case, the decrease of the intensity of individual components of the observed spectra with the distance from the central wavelength can be explained by the Doppler dimming effect. To interpret the observed Mg II profiles in terms of dynamics we use 1D or 2D radiative transfer models including a prominence-corona transition region.

Poster

3. Magnetic coupling and mass flux through the atmosphere

Magnetic braids in eruptions of a spiral structure in the solar atmosphere

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We report on high-resolution imaging and spectral observations of eruptions of a spiral structure in the transition region, which were taken with the Interface Region Imaging Spectrometer (IRIS), the Atmospheric Imaging Assembly (AIA) and the Helioseismic and Magnetic Imager (HMI). The eruption coincided with the appearance of two series of jets, with velocities comparable to the Alfvén speeds in their footpoints. Several pieces of evidence of magnetic braiding in the eruption are revealed, including localized bright knots, multiple well-separated jet threads, transition region explosive events and the fact that all these three are falling into the same locations within the eruptive structures. Through analysis of the extrapolated three-dimensional magnetic field in the region, we found that the eruptive spiral structure corresponded well to locations of twisted magnetic flux tubes with varying curl values along their lengths. The eruption occurred where strong parallel currents, high squashing factors, and large twist numbers were obtained. The electron number density of the eruptive structure is found to be $\sim 3 \times 10^{12}\,\mathrm{cm}^{-3}$, indicating that significant amount of mass could be pumped into the corona by the jets. Following the eruption, the extrapolations revealed a set of seemingly relaxed loops, which were visible in the AIA 94 Å channel indicating temperatures of around 6.3 MK. With these observations, we suggest that magnetic braiding could be part of the mechanisms explaining the formation of solar eruption and the mass and energy supplement to the corona.

Poster

3. Magnetic coupling and mass flux through the atmosphere

Magnetic loops in a flux-emerging region viewed by IRIS, Hinode and SDO

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Magnetic loops are one of the fundamental structures of the solar atmosphere. Due to their high contrast to the background emission, they are the perfect objets to investigate how magnetic field and energy are transported into the higher solar atmosphere. Using coordinated observations from IRIS, Hinode and SDO, here we study a set of magnetic loops in a flux-emerging region. While the high resolution data from IRIS reveal fine threads of the loops, the XRT and AIA images also show clear response. The electron density measured with EIS Fe XII $\lambda\lambda 186.8/195.1$ show significant unbalance with $\sim 10^{10}\,\mathrm{cm}^{-3}$ at one footpoint and $\sim 2.5 \times 10^{9}\,\mathrm{cm}^{-3}$ at the other. The Si IV spectra of these loops show clear blue shifts in the loop top with order of 10 km/s, while the hotter lines observed in EIS present red shifts. The temperature distribution of the region will be also investigated using DEM method with EIS spectral data. The imaging and IRIS spectral data reveal clear activities in the loops with signatures of UV bursts. These UV bursts are likely energetic events associated with interactions between emerging flux and pre-existing flux. These observations should improve our understanding to the process of flux emergences and their responses in the upper solar atmosphere.

Poster

3. Magnetic coupling and mass flux through the atmosphere

Relationship between Transition Region Explosive Events and Network Jets

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The solar transition region (TR) is the interface between the chromosphere and corona. The dominant structures in the TR are the network structures. Recent imaging observations of the TR have revealed prevalent intermittent jets from the network lanes. The apparent speeds of the jets are normally in the range of 80-250 km/s. Another type of TR dynamic event is the TR explosive events (EEs) occurring mainly around network lanes. These events are characterized by non-Gaussian line profiles with enhanced emission at the line wings. They are generally believed to result from local magnetic reconnection. Using simultaneous imaging and spectroscopic observations from the IRIS mission, we have studied the relationship between EEs and the network jets. We first identified all EEs from the Si IV 1393.76 line profiles in our observations, then examined related features in the 1330 slit-jaw images. Some EEs appear to be located at either the foot points or higher parts of the network jets. The Si IV line profiles of these EEs often exhibit clear enhancement at the blue wings, likely resulting from the superposition of the high-speed jets on the TR background. Other EEs clearly have no connection to the network jets. Instead, they appear to be accompanied by strong compact brightenings in the 1330 images. The Si IV line profiles of these EEs are often very broad and reveal multiple peaks, likely related to magnetic reconnection.

Poster

3. Magnetic coupling and mass flux through the atmosphere

UV bursts at the earliest stage of flux emergence

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On 2016 September 20, IRIS observed an active region during its earliest emerging phase for almost 7 hours. SDO/HMI observed continuous emergence of small-scale magnetic bipoles with a rate of $\sim 10^{16}$ Mx s^{-1}. The emergence of magnetic fluxes and interactions between different polarities lead to frequent occurrence of ultraviolet (UV) bursts, which exhibit as intense transient brightenings in the 1400 Å images. In the meantime, discrete small patches with the same magnetic polarity tend to move together and merge, leading to enhancement of the magnetic fields and thus formation of pores (small sunspots) at some locations. The spectra of these UV bursts are characterized by the superposition of several chromospheric absorption lines on the greatly broadened profiles of some emission lines formed at typical transition region temperatures, suggesting heating of the local materials to a few tens of thousands of kelvin in the lower atmosphere by magnetic reconnection. Some bursts reveal blue and red shifts of ~ 100 km s^{-1} at neighboring pixels, indicating the spatially resolved bidirectional reconnection outflows. Many such bursts appear to be associated with the cancellation of magnetic fluxes with a rate of the order of $\sim 10^{15}$ Mx s^{-1}. We also investigate the three-dimensional magnetic field topology through a magneto-hydrostatic model and find that a small fraction of the bursts are associated with bald patches (magnetic dips). Finally, we find that almost all bursts are located in regions of large squashing factor at the height of ~ 1 Mm, reinforcing our conclusion that these bursts are produced through reconnection in the lower atmosphere.

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Poster

4. Eruptions in the solar atmosphere

Are IRIS bombs connected to Ellerman Bombs?

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Recent observations by the Interface Region Imaging Spectrograph (IRIS) have revealed pockets of hot gas ($\approx$ 2–8 $\times 10^4$ K) potentially resulting from magnetic reconnection in the partially ionized lower solar atmosphere (IRIS bombs; IBs). Using joint observations between IRIS and the Chinese New Vacuum Solar Telescope, we have identified 10 IBs. We find that 3 are unambiguously and 3 others are possibly connected to Ellerman bombs (EBs), which show intense brightening of the extended Ha wings without leaving an obvious signature in the Ha core. These bombs generally reveal the following distinct properties: (1) the O IV 1401.156 Å and 1399.774 Å lines are absent or very weak; (2) the Mn I 2795.640 Å line manifests as an absorption feature superimposed on the greatly enhanced Mg II k line wing; (3) the Mg II k and h lines show intense brightening in the wings and no dramatic enhancement in the cores; (4) chromospheric absorption lines such as Ni II 1393.330 Å and 1335.203 Å are very strong; and (5) the 1700 Å images obtained with the Atmospheric Imaging Assembly on board the Solar Dynamics Observatory reveal intense and compact brightenings. These properties support the formation of these bombs in the photosphere, demonstrating that EBs can be heated much more efficiently than previously thought. We also demonstrate that the Mg II k and h lines can be used to investigate EBs similarly to Ha, which opens a promising new window for EB studies. The remaining four IBs obviously have no connection to EBs and they do not have the properties mentioned above, suggesting a higher formation layer, possibly in the chromosphere.

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Poster

4. Eruptions in the solar atmosphere

Statistical analysis of IRIS compact bursts

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Compact bursts are frequently observed by IRIS in both NUV and FUV channels. They appear as small and intense short-time brightenings visible in solar active regions. We present the statistical analysis of active regions with emerging flux areas based on the IRIS observations in Mg II h and k lines. We used dense and large rasters for searching of compact bursts with the size of the order of $1''$. Only brightenings with the intensity contrast greater than 2 (in Mg II h line wings at +1.0 and -3.5 ang) were chosen for the analysis. Using Mg II h and k line profiles for all brightening we run statistical analysis of some parameters of the line profiles: peak separation, peak ratio, line centre intensity and contrast in characteristic profiles points. This analysis allows us to categorise bursts in the way as it was done in Grubecka et al. (2015). We also searched for correlations between the emission of Mg II lines and hotter Si IV line in order to find which of events are linked with IRIS bombs.

Poster

3. Magnetic coupling and mass flux through the atmosphere

Multi-scale observations of thermal nonequilibrium cycles in coronal loops

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The long-period intensity pulsations reported by Auchere et al. (2014) are widely observed in the solar corona and especially in coronal loops. Recently, these pulsations have been identified as the coronal counterpart of thermal nonequilibrium cycles (evaporation and condensations) by Froment et al. (2015, 2017). Thermal nonequilibrium can occur in coronal loops when the heating is quasi-constant and highly-stratified. Understanding the characteristics of thermal nonequilibrium cycles is thus essential to understand the circulation of mass and energy in the corona.
Here, we report on combined observations of long-period (6 hours) intensity pulsations in the coronal channels of SDO/AIA and coronal rain with the CRISP and CHROMIS instruments at the Swedish 1-m Solar Telescope (SST) in the same coronal loop bundle. The high-resolution spectroscopic instruments at the SST allowed us to probe the cooling phase of one of the cycles, down to chromospheric temperatures. These current observations are focused on one footpoint of the observed loop bundle and reveal the fine-structured rain strands. We present the thermal analysis of the cycles with the channels of AIA (DEM, time lag analysis) on three days of off-limb evolution. Further, we also report statistics on the coronal rain blobs that we derive from CRISP and CHROMIS data (temperature, velocities, density, sizes of the blobs). These observations further strengthen that long-period intensity pulsations and coronal rain are two aspects of the same phenomenon.

Doppler shifts in the transition region of active regions.

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Since the first observations in 1976, emission lines from the transition region (TR) have shown, on average, persistent redshifts in the quiet Sun (QS). There are many observations of the QS at TR temperatures (with SUMER) and there are numerous studies of active regions (ARs) at coronal temperatures (with EIS). However, there is a lack of investigations of (average) AR Doppler shifts at TR temperatures. The aim of this study is to use IRIS data to investigate TR Doppler shifts in ARs and their spatial distribution. By this we close an observational gap.

We investigate large dense rasters by IRIS of 8 ARs. To characterise the average Doppler shift of the respective region, we compute the average spectrum of all data points in the covered field-of-view. In general, this is asymmetric with an extended wing towards the red. Actually, the spatial distribution of the Doppler shifts (i.e. the histogram of the shifts of individual spectra) shows a similar asymmetric profile.

Our results indicate that the net Doppler shifts in the TR of ARs is smaller than thought before, and is close to values found for the QS, i.e. about 6 km/s to 8 km/s. However, the spatial distribution of the Doppler shifts in an AR is significantly different to the QS. These observational results provide another aspect for a test of 3D MHD models and would be consistent with ARs models based on heating of the corona by field line braiding.

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Poster

3. Magnetic coupling and mass flux through the atmosphere

Spectral evolution along a flux loop observed with IRIS

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Using far ultraviolet (UV) spectra and slit-jaw images from IRIS, we studied an emerging active region loop, connecting two plage-type faculae with opposite polarities, scanned by the IRIS raster. Single Gaussian (SG) fit is employed to the line core of the Si IV (1394 Å) line, and the residual of the observed line profiles to the SG is obtained. Several parameters about the line profiles are measured to indicate the evolution and distribution of the emission line along the loop. A proper motion just before the IRIS raster scanning is observed along the loop, indicating that the slit scanned the moving plasma parcel. The Doppler shift map shows blueshift in the east, and redshift in the west, consistent with a siphon flow along the loop. Spectral tilts are detected along the loop, meaning the inside twisting motions. The enhancements in the blue and red wings, and their distribution and evolution along the loop, are observed. These, also, lead to the evolution of the RBA of the transition region line along the loop. The enhanced emission in the blue wing near the eastern footpoint indicates an injection at this footpoint. The proper motion along the loop and the Doppler shift support that the loop is a flat one. The twisting motions of the plasma parcel may cause the evolution and distribution of the enhancements of the line wings and the RBA.

Tracing the magnetic and dynamic evolution of photospheric supersonic flows

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Photospheric high-speed flows, some of them with supersonic velocities, have been observed in active regions and the quiet Sun. The origin of these flows is still not well understood. We analyzed observations of the AR12552 made in June 2016 at the 1.5 m German telescope GREGOR with the spectropolarimeter instrument GRIS. We also studied observations of the same region by HINODE/SP and followed the temporal evolution of the active region with SDO/HMI over 5 days. In addition, we combined IRIS and SDO/AIA observations to gather information about the transition region and corona. The spectropolarimetric data were inverted to obtain the magnetic field vector and LOS velocities in the photosphere and chromosphere. Furthermore, we used deep machine learning to enhance the HMI images, trace the evolution of the horizontal velocities of the plasma, and track the location of photospheric vortices. We found blueshifted (BS) and redshifted (RS) flows in the IR photospheric Ca I and Si I lines, as well as the Fe I lines observed by HINODE/SP. These velocities were supersonic and exceeded 15 KM/S in the deep photosphere. The chromospheric He I triplet, as well as the transition region and coronal channels did not present any resemble to the location of the supersonic flows. The first well formed BS flow region emerged on June 8 2016 at 04:35 UT and lasted for more than three days. The RS flows appeared on 05:05 June 8 2016 and had a duration of 18 h. At the time when RS flows reached their maximum, two vortices appeared right next to the location of the RS and BS flows. The presented multi-instrument analysis allows us to identify purely photospheric supersonic BS and RS flows that were orientated along the filament channels in particular related to Evershed and siphon flows.

Poster

3. Magnetic coupling and mass flux through the atmosphere

Dynamics of Small-scale Vortices in the Solar Atmosphere

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Recent advances in both observational and simulation techniques have allowed us to detect small-scale structures in the solar atmosphere. These structures are believed to be play an important role in the heating of solar atmosphere. The aim of present work is to investigate the dynamics of small-scale vortices in a plage region in detail, to explore their physical properties, and to calculate their quantitative contribution in the Poynting flux transport to upper solar atmospheric layers.Using three-dimensional (3D) magnetohydrodynamic (MHD) simulation code 'MURaM', we have performed numerical simulation of a solar plage region. For detecting and isolating the vortices, the 'Swirling Strength' criteria is used. After extraction of vortices, we have investigated the response of vortices to the 3D atmosphere i.e. how the different physical quantities e.g. density, temperature etc. varies with height on vortex locations and compared it to the average values on the same geometrical height. We found the photospheric magnetic elements are abundant of small-scale vortices, having average diameter of ∼60 km. These small-scale vortices have higher temperature, higher mass density than the average values and are found to carry more than 50% of the total energy flux passing through the chromosphere. A subset of vortices is also found, which is loop-like, low lying, and is more inclined. From these results, we conclude that these vortices are denser, hotter small-scale magnetic structures ubiquitous in the plage region, and provide an important path for energy and mass transport from the photosphere into the chromosphere.

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Poster

3. Magnetic coupling and mass flux through the atmosphere

Quantifying the role of spicules in the lower transition region

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Despite decades of active study, we do not yet have a satisfactory model of the source of the radiative output of the lower transition region ($T < 10^5$ K). On the other hand, it is now well established that at least type II spicules do reach transition region temperatures. It is therefore natural to assume that spicules may contribute significantly to the observed transition region emission.
We present here results of an analysis of IRIS data providing a quantitative assessment of the fraction of the transition region output below 10^5 K due to spicules.
In particular, we combine off-limb measurements of isolated spicules with a geometric model to simulate the average radial profile of Si IV emission. We then compare the synthetic off-limb emission thus obtained against the observed radial profile.

Poster

3. Magnetic coupling and mass flux through the atmosphere

Doppler shifts, line widths and the orientation of the magnetic field

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Observations show a clear center-to-limb variation of the Doppler shifts of transition region emission lines with the cosine of the heliocentric angle. As argued since more than a decade, this would be consistent with the flows causing the shifts being predominantly vertical. This would fit into the picture of the transition region emission originating mostly from the footpoints of coronal loops, where the magnetic field would be predominantly vertical at the low heights where the transition region is located. The line width observations show no (or at least no clear) center-to-limb variation. If field-aligned flows would cause non-thermal broadening, then the width should drop to the limb. If motions across the (guide) field would dominate the broadening, like for Alfvénic waves, then the line width should increase toward the limb. The observation of a missing center-to-limb variation thus implies that the two effects would have to balance, which sounds unlikely but could be possible in principle.

To test the hypothesis if the flows in the transition region are indeed predominantly vertical, we investigate the results from 3D MHD models. Here we concentrate on one model for an active region and another one for quiet Sun or enhanced network. To our surprise, both these models show that the bulk part of the transition region emission originates from regions where the magnetic field is not vertical, but has an inclination of very roughly 45° or even more horizontal. While this result helps in understanding the missing center-to-limb variation of the line width, it challenges the traditional interpretation of the center-to-limb variation of the Doppler shifts.

Poster

3. Magnetic coupling and mass flux through the atmosphere

Quiescent prominence observed by IRIS

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Here we present one of the first quiescent prominence observations made by IRIS spectrograph on October 22, 2013 with very large dense 16-step raster. We analyzed spectra of C II 1334 & 1336 and Si IV 1394 lines in FUV channel together with Mg II k & h lines in NUV channel. We found out various statistical relations between the observed quantities and compared Mg II observations with a grid of 1D non-LTE models of magnesium lines. Our results point to the necessity of considering 2D multithread models with PCTR, similar to those used for analysis of hydrogen Lyman lines observed by SOHO/SUMER.

Poster

5. Opportunities and challenges

Investigating Chromospheric and Transition Region Morphological Structures Seen in IRIS and ALMA Observations

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We present observations of a plage region obtained simultaneously by IRIS and ALMA on April 22, 2017. IRIS spectra were obtained at a fast (26 s cadence) 16-step dense raster mode with slit positions intersecting both plage and quiet sun. The corresponding ALMA observations were taken at λ=1.3 mm (Band 6). The ALMA field of view (FOV) contained the area observed with the IRIS rasters, enabling us to perform a detailed analysis on the morphology and dynamics of fibril-like structures and transient brightenings in the chromosphere and low transition region. We analyze the spectra from IRIS and use brightness temperature maps derived from the ALMA observations as an estimate of the local temperature for the mid-to-high chromosphere. This work demonstrates the benefits of synergy between IRIS and ALMA.

Poster

5. Opportunities and challenges

irisreader - A Python Library for IRIS Data Processing

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Irisreader is a Python library created at FHNW that facilitates machine learning applications on IRIS level 2 data. Machine learning libraries, such as scikit-learn, tensorflow, keras, etc. are readily available for Python, but IRIS data has very specific headers and keywords that are usually obtained using the IDL SolarSoft routine read_iris_l2.pro. Irisreader gives simple and efficient access to headers and data through a Python-based implementation of read_iris_l2.pro, thus enabling machine learning tools to directly access the data. In addition, irisreader currently allows for downloading single observations from the LMSAL repository, basic pre-processing of the data (such as cropping images and interpolating between different spectral resolutions) and basic plotting of slit-jaw images and spectra. Particularly useful features of irisreader are its ability to provide structured access to whole observations at once and to iterate efficiently through years of IRIS data. Irisreader will be released on Github before the 9th IRIS workshop.

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Poster

5. Opportunities and challenges

Classification scheme for the solar wind based on the main MHD parameters

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A new magnetohydrodynamic (MHD) classification of the solar wind is presented and discussed. This classification is based on four main MHD parameters: proton speed V, temperature T, density n and dimensionless plasma parameter β for protons. In the space of these parameters the boundaries for fast (f) and slow (s), hot (h) and cold (c), dense (d) and rarefied (r), magnetized (m) and nonmagnetized (n) wind are set. In total, we obtain 16 solar wind types: fhdm, fhdn, fhrm, etc. We also add a zero type, which corresponds to the solar wind streams, where value of at least one parameter is close to the statistical average.

We analyzed 1-minute OMNIWeb data for 23^{rd} and 24^{th} solar cycles and tried to find a correspondence of common and rare types with their sources at the Sun. All of the above types occur due to different solar activity phenomena and appear with various frequency at different phases of the solar cycles.

We also propose that there is only a little sense to search localized coronal sources of the solar wind with average properties. It is due to nonlocality of the phenomenon.

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Poster

4. Eruptions in the solar atmosphere

Statistical investigation of low atmospheric response during flares using the multi-wavelengths observations by IRIS, Hinode, and SDO

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When a flare occurs, we can observe solar plasma response in multi-wavelengths from optical to HXR. Especially, some strong flares produce white light emissions, white light (WL) flares, and flare ribbons are observed in the low atmosphere. To understand how the energy transports to the low atmosphere and how the low atmosphere responses to the solar flares, we investigated the UV and EUV spectral lines and WL continuum images statistically. We have investigated the Mg II triplet, Si IV emission and WL continuum in 60 M and X class flares, which detected by the IRIS, SDO/HMI and Hinode/SOT from 2014 to 2016. From the analysis, we have found that the Mg II triplet mostly becomes emission during flares along the flare ribbons and footpoints of the flaring loop region, which indicates that the low atmospheric heating. At the same time, we also examined the Doppler velocity of the Si IV emission, and mostly they show the red-shifted emission ($\sim$40 km s^{-1}) correlated in time and location of the Mg II triplet emission. WL continuum also enhanced during several flares (17 flares), but not in all the flares. By comparison between the Mg II triplet and WL continuum, we also discuss the energy transport process, such as thermal conduction, electron beam, or Alfvn wave, in the flares with/without WL flares.

Poster

4. Eruptions in the solar atmosphere

Chromospheric Condensation and Quasi-periodic Pulsations in a Circular-ribbon Flare

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We report our multiwavelength observations of the C3.1 circular-ribbon flare SOL2015-10-16T10:20 in active region (AR) 12434. The flare consisted of a circular flare ribbon (CFR), an inner flare ribbon (IFR) inside, and a pair of short parallel flare ribbons (PFRs). During the impulsive phase of the flare, "two-step" raster observations of *IRIS* with a cadence of 6 s and an exposure time of 2 s show plasma downflow at the CFR in the Si IV λ1402.77 line ($\log T \approx 4.8$), suggesting chromospheric condensation. The downflow speeds first increased rapidly from a few km s^{-1} to the peak values of 45−52 km s^{-1}, before decreasing gradually to the initial levels. The decay timescales of condensation were 3−4 minutes, indicating ongoing magnetic reconnection. Interestingly, the downflow speeds are positively correlated with logarithm of the Si IV line intensity and time derivative of the *GOES* soft X-ray (SXR) flux in 1−8 Å. The radio dynamic spectra are characterized by a type III radio burst associated with the flare, which implies that the chromospheric condensation was most probably driven by nonthermal electrons. Using an analytical expression and the peak Doppler velocity, we derived the lower limit of energy flux of the precipitating electrons, i.e., 0.65×10^{10} erg cm^{-2} s^{-1}. The Si IV line intensity and SXR derivative show quasi-periodic pulsations with periods of 32−42 s, which are likely caused by intermittent null-point magnetic reconnections modulated by the fast wave propagating along the fan surface loops at a phase speed of 950−1250 km s^{-1}. Periodic accelerations and precipitations of the electrons result in periodic heating observed in the Si IV line and SXR.

Explosive Chromospheric Evaporation in a Circular-ribbon Flare

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In this paper, we report our multiwavelength observations of the C4.2 circular-ribbon flare in active region (AR) 12434 on 2015 October 16. The short-lived flare was associated with positive magnetic polarities and a negative polarity inside, as revealed by the photospheric line-of-sight magnetograms. Such magnetic pattern is strongly indicative of a magnetic null point and spine-fan configuration in the corona. The flare was triggered by the eruption of a mini-filament residing in the AR, which produced the inner flare ribbon (IFR) and the southern part of a closed circular flare ribbon (CFR). When the eruptive filament reached the null point, it triggered null point magnetic reconnection with the ambient open field and generated the bright CFR and a blowout jet. Raster observations of the *Interface Region Imaging Spectrograph* (*IRIS*) show plasma upflow at speed of $35-120$ km s^{-1} in the Fe XXI 1354.09 Å line ($\log T \approx 7.05$) and downflow at speed of $10-60$ km s^{-1} in the Si IV 1393.77 Å line ($\log T \approx 4.8$) at certain locations of the CFR and IFR during the impulsive phase of flare, indicating explosive chromospheric evaporation. Coincidence of the single HXR source at $12-25$ keV with the IFR and calculation based on the thick-target model suggest that the explosive evaporation was most probably driven by nonthermal electrons.

Poster

4. Eruptions in the solar atmosphere

Multi-episode Chromospheric Evaporation Observed in a Solar Flare

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With observations of IRIS, we study chromospheric heating and evaporation during an M1.6 flare SOL2015-03-12T11:50. At the flare ribbons, the Mg II 2791.59 Å line shows quasi-periodic short-duration red-wing enhancement, which is likely related to repetitive chromospheric condensation as a result of episodic heating. On the contrary, the Si IV 1402.77Å line reveals a persistent red-wing asymmetry in both the impulsive and decay phases, suggesting that this line responds to both cooling downflows and chromospheric condensation. The first two episodes of red-wing enhancement occurred around 11:42 UT and 11:45 UT, when two moving brightenings indicative of heating fronts crossed the IRIS slit. The greatly enhanced red wings of the Si IV and Mg II lines at these occasions are accompanied by an obvious increase in the line intensities and the HXR flux, suggesting two episodes of energy injection into the lower atmosphere in the form of nonthermal electrons. The Mg II k/h ratio has a small value of$\sim$1.2 at the ribbons and decreases to$\sim$1.1 at these two occasions. Correspondingly, the Fe XXI 1354Å line reveals two episodes of chromospheric evaporation, which is characterized as a smooth decrease of the blueshift from$\sim$300 km s^{-1} to nearly zero within$\sim$3 minutes. The Fe XXI 1354Å line is entirely blueshifted in the first episode, while it appears to contain a nearly stationary component and a blueshifted component in the second episode. Additional episodes of blueshifted Fe XXI emission are found around the northern ribbon in the decay phase, though no obvious response is detected in the Si IV and Mg II emission.

Diagnostics of source plasma characteristics in ^{3}He-rich flares

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^{3}He-rich solar energetic particles (SEPs) show peculiar ion abundance enhancement, markedly different from solar corona or solar wind. Such enrichment is believed to be generated by the energy dissipation processes in solar flares, frequently observed in a jet-like form, but the exact mechanism remains unclear. A relation between the element abundances in ^{3}He-rich SEPs and plasma characteristics (temperature, emission measure) has been previously studied from the soft X-ray observations. These works have shown that in the relatively narrow and high-temperature range, the heavy-ion abundances correlate with the temperature but ^{3}He/^{4}He does not. We examine the relation between the temperature and density of source plasma and the elemental composition in several ^{3}He-rich SEP events with anomalous enhancement of S and Si. The differential emission measure analysis is applied to study the temperature evolution/distribution of the source regions. Preliminary results show that the temperature of the associated solar source is ranged between 1.2-3.1 MK.

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Poster

4. Eruptions in the solar atmosphere

Continuum emission enhancements in flares observed by IRIS and ROSA

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During solar flares, magnetic energy can be converted into electromagnetic radiation from radio waves to γ rays. In the most energetic events, enhancements in the continuum at visible wavelengths may be present (white-light [WL] flares). Recently, the WL emission has also been correlated with enhancements in the FUV and NUV passbands. In this context, we describe observations acquired by ground-based (ROSA@DST) and satellite (IRIS) instruments during two consecutive C7.0 and X1.6 flares occurred in active region NOAA 12205 on 2014 November 7.
The results of the analysis of these data show the presence of continuum enhancements during the evolution of the events, observed both in ROSA images and in IRIS spectra. Moreover, we analyze the role played by the evolution of the δ sunspots of the active region in the flare triggering, discussing the disappearance of a large portion of penumbra around these sunspots as a further consequence of these energetic flares.

Flare detection from discrete Fourier transforms of SJI

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We present a new method to detect solar flares based on the IRIS SJI. Usually the detection is made based on intensity cutoffs, but this can easily result in the detection of small energetic events without any actual flare appearing. Our method reduces the false detections of flares by taking in consideration the specific pattern of flares.
By using sequences of 10 consecutive SJIs, we place importance on the temporal component of flares. These short videos are parcelled in small blocks of size 20×20 pixels to analyse the local variations of the frequencies by looking at the variance of the discrete Fourier transform (DCT) of the signal. Each frame is also pre-passed through the 2-dimensional DCT in order to be well aligned. We then found parameters to distinguish the flare sequences from the non-flare sequences.
For now we have a 99% detection accuracy on 500 sequences of 10 consecutive frames for 1400A SJI, with 1 sequence missed and no sequence with false detection.
To conclude, we would like to present results of our method in a E-Poster to show videos of results. We use some handcrafted supervised machine learning techniques to show that it is possible to accurately detect flares from the SJI with this method. Firstly, it will allow us to create a complete automatic list of flares in the IRIS database. Secondly, our tool will also help us analyzing the flares with more machine learning techniques. Our work is supported by the Swiss National Science Fondation (SNF) National Research Program 75 "Big Data" and we want to acknowledge LMSAL for the access to the IRIS database.

Observations of Electron-driven Evaporation in a Flare Precursor

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We investigate the relationship between the blueshifts of a hot emission line and the nonthermal emissions in microwave and hard X-ray (HXR) wavelengths in the precursor of a solar flare on 2014 October 27. The flare precursor is identified as a small but well-developed peak in the soft X-ray and extreme-ultraviolet passbands before the GOES flare onset, which is accompanied by a pronounced burst in microwave 17 and 34 GHz and in HXR 25−50 keV. The slit of the Interface Region Imaging Spectrograph (IRIS) stays on one ribbon-like transient during the flare precursor phase, which shows visible nonthermal emissions in Nobeyama Radioheliograph and RHESSI images. The IRIS spectroscopic observations show that the hot line of Fe XXI 1354.09 Å (log T $\sim$ 7.05) displays blueshifts, while the cool line of Si IV 1402.77 Å (log T $\sim$ 4.8) exhibits redshifts. The blueshifts and redshifts are well correlated with each other, indicative of an explosive chromospheric evaporation during the flare precursor phase combining a high nonthermal energy flux with a short characteristic timescale. In addition, the blueshifts of Fe XXI 1354.09 Å are well correlated with the microwave and HXR emissions, implying that the explosive chromospheric evaporation during the flare precursor phase is driven by nonthermal electrons.

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Poster

4. Eruptions in the solar atmosphere

Non-damping oscillations at flaring loops

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We investigate the properties of non-damping oscillations at flaring loops using observations from the IRIS, SDO, Fermi and GOES. The double-component Gaussian fitting method is used to extract the line profile of Fe XXI 1354.08 Å at the spectral window. The quasi-periodicity of loop oscillations are identified in the Fourier and wavelet spectra. A quasi-period of about 40 s is detected in the line properties of Fe XXI 1354.08 Å, hard X-ray emissions in GOES 1−8 Å derivative, and Fermi 26−50 keV. The Doppler velocity and line width oscillate in phase, while a phase shift of about $\pi/2$ is detected between the Doppler velocity and peak intensity. The amplitudes of Doppler velocity and line width oscillation are about 2.2 km s^{-1} and 1.9 km s^{-1}, respectively, while peak intensity oscillate with amplitude at about 3.6% of the background emission. The observations show that 40 s oscillations are not damped significantly, which could be linked to the global kink modes of flaring loops. The magnetic field strengths at flaring loops are estimated to be about 120−170 G using the MHD seismology diagnostics and the flux rope insertion method. Meanwhile, a quasi-period of about 155 s is identified in the Doppler velocity and peak intensity of the Fe xxi 1354.08 Å line emission, and AIA 131 Å intensity, and it is likely a signature of recurring downflows after chromospheric evaporation along the flaring loops.

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Poster

4. Eruptions in the solar atmosphere

Two Episodes of Magnetic Reconnections During a Confined Circular-ribbon Flare

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We analyze a unique event with an M1.8 confined circular-ribbon flare on 2016 February 13, with successive formations of two circular ribbons at the same location. The flare had two distinct phases of UV and EUV emissions with an interval of about 270 s, of which the second peak was energetically more important. The first episode was accompanied by the eruption of a mini-filament and the fast elongation motion of a thin circular ribbon (CR1) along the counterclockwise direction at a speed of about 220 km s^{-1}. Two elongated spine-related ribbons were also observed, with the inner ribbon co-temporal with CR1 and the remote brightenings forming $\sim$ 20 s later. In the second episode, another mini-filament erupted and formed a blowout jet. The second circular ribbon and two spine-related ribbons showed similar elongation motions with that during the first episode. The extrapolated 3D coronal magnetic fields reveal the existence of a fan-spine topology, together with a quasi-separatrix layer (QSL) halo surrounding the fan plane and another QSL structure outlining the inner spine. We suggest that continuous null-point reconnection between the filament and ambient open field occurs in each episode, leading to the sequential opening of the filament and significant shifts of the fan plane footprint. For the first time, we propose a compound eruption model of circular-ribbon flares consisting of two sets of successively formed ribbons and eruptions of multiple filaments in a fan-spine-type magnetic configuration.

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4. Eruptions in the solar atmosphere

IRIS Ultraviolet Spectral Properties of a Sample of X-Class Solar Flares

E. Butler[1]

White-light (near-ultraviolet (NUV) and optical) continuum emission comprises the majority of the radiated energy in solar flares, but its physical origin is currently not well understood. Many different emission sources (e.g. blackbody or optically-thin hydrogen recombination) appear consistent with the white-light data, and modeling with electron beam heating has only recently been able to reproduce observations of high NUV continuum-to-line ratios along with the line profiles. Furthermore, there are rarely robust constraints on the time-resolved dynamics in the white-light emitting flare layers. We are conducting a statistical study of the properties of Fe II lines, Mg II lines, and NUV continuum intensity in bright flare kernels observed by the *Interface Region Imaging Spectrograph* (IRIS), in order to provide comprehensive constraints for radiative-hydrodynamic flare models. Here we present a new technique for identifying bright flare kernels and preliminary relationships among IRIS spectral properties for a sample of X-class solar flares.

Poster

4. Eruptions in the solar atmosphere

Quasi-simultaneous eruptions of multiple flux ropes in active region 12673 leading to the two largest flares in Solar Cycle 24

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Solar active region (AR) 12673 in 2017 September produced two largest flares in Solar Cycle 24: the X9.3 flare on September 06 and the X8.2 flare on September 10. We attempt to investigate the detailed evolutions of the two super flares and the associated magnetic fields. Before the X9.3 flare on September 06, one negative magnetic patch began to move along the polarity inversion line in AR core region and kept shearing with adjacent positive fields. The strong shearing motion contributed to the kink-instability of a flux rope, which subsequently erupted upward with a projected velocity of $\sim$280 km s^{-1}. Another two flux ropes beside the kink-unstable flux rope then were disturbed and successively erupted within 5 minutes like a chain reaction. Similarly, three flux ropes were detected to consecutively erupt during the X8.2 flare occurring in the same AR on September 10. We examine the evolution of the AR magnetic fields from September 03 to 06 and find that four dipoles emerged successively at the east of the main sunspot. The interactions between these dipoles took place continuously, accompanied by magnetic flux cancellations and strong shearing motions. In AR 12673, significant flux emergence and successive interactions between the different emerging dipoles resulted in a complex magnetic system, accompanied by the formations of multiple flux ropes. We first propose that the quasi-simultaneous eruptions of multiple flux ropes within several minutes resulted in the two largest flares in Solar Cycle 24.

Simultaneous Observations of p-mode Light Walls and Magnetic Reconnection Ejections above Sunspot Light Bridges

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Recent high-resolution observations from the Interface Region Imaging Spectrograph reveal bright wall-shaped structures in active regions (ARs), especially above sunspot light bridges. Their most prominent feature is the bright oscillating front in the 1400/1330 Å channel. These structures are named light walls and are often interpreted to be driven by p-mode waves. Above the light bridge of AR 12222 on 2014 December 06, we observed intermittent ejections superimposed on an oscillating light wall in the 1400 Å passband. At the base location of each ejection, the emission enhancement was detected in the Solar Dynamics Observatory 1600 Å channel. Thus, we suggest that in wall bases (light bridges), in addition to the leaked p-mode waves consistently driving the oscillating light wall, magnetic reconnection could happen intermittently at some locations and eject the heated plasma upward. Similarly, in the second event occurring in AR 12371 on 2015 June 16, a jet was simultaneously detected in addition to the light wall with a wave-shaped bright front above the light bridge. At the footpoint of this jet, lasting brightening was observed, implying magnetic reconnection at the base. We propose that in these events, two mechanisms, p-mode waves and magnetic reconnection, simultaneously play roles in the light bridge, and lead to the distinct kinetic features of the light walls and the ejection-like activities, respectively. To illustrate the two mechanisms and their resulting activities above light bridges, in this study we present a cartoon model.

Rare Solar Radio Burst and Falling EUV Blob

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At the beginning of the M3.7 flare that occurred on November, 4th, 2015, we observed a rare burst drifting with the frequency drift of 115 MHz.s^{-1} from 1300 to 2000 MHz. We analyzed the multi-spectral imaging data of the flare from H_α, EUV (IRIS, SDO/AIA) and soft X-rays (Hinode/XRT) and found that this slowly positively drifting burst was associated with a falling blob of plasma observed in EUV and soft X-rays. The blob moved with velocity of about 280 km.s^{-1} along a dark loop visible also in H_α. The H_α profile taken from the same position in the dark loop showed a change from absorption to a weak emission profile. Considering different possibilities, we propose that this slowly positively drifting burst was generated by the thermal conduction front formed in front of the falling hot EUV blob.

Poster

4. Eruptions in the solar atmosphere

Multi-instrument observations of a failed flare eruption associated with MHD waves in a loop bundle

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We present multi-instrument observations of a B7.9-class flare occurred on January 24th, 2015, using SDO/AIA, Hinode/EIS and XRT. The flare heats the local plasma up to temperatures of ~ 8 MK, and triggers the eruption of a dense blob, which is unable to expands completely, and remains confined within the local bundle of active region loops. During this process, vertically polarised kink oscillations of the loop threads with a period of 3.5–4 min and an amplitude of 5 Mm are driven by the blob, which diffuses and descends along each loop strand causing variations in density. In addition, a co-existing longitudinal slow MHD wave propagates along the hot loop bundle with a period of 10 min, and a phase speed of ~ 430 km s^{-1}. We show that the evolution of these waves are determined by the temporal variations of the local plasma parameters (e.g. density, temperature), caused by the flare heating and the consequent cooling. Furthermore, the correct interpretation of the nature of both the observed fast and slow magneto-acoustic waves is exploited to determine better the plasma-β and the adiabatic index γ of the coronal plasma.

Poster

6. Science together with future facilities

Simulating observations of the corona/inner heliosphere with Parker Solar Probe/WISPR

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The Wide-Field Imager for Parker Solar Probe (WISPR) consists of two cameras designated to observe the Thomson-scattered emission of the corona/inner heliosphere. The overall field-of-view is offset from the Sun's centre, and covering 13.5–108 deg of elongation angles. Thanks to the highly-eccentric orbits of Parker Solar Probe (PSP), which will achieve the closest perihelion below 10 solar radii in 2024, the WISPR images will be taken from unprecedented points of observation at high temporal (0.05–60 min) and spatial resolution (plate scale of 1.2-1.7 arcmin per pixel). Therefore, it is important to understand how WISPR images will look during the perihelion phases and when PSP will eventually fly throughout various coronal structures (e.g. streamers, expanding flux ropes, and jets). Here, we present simulations of WISPR images for different coronal structures by using the raytracing tools available with the SolarSoftWare package. We will discuss the effects due to the varying radial distance and the high orbital speed (200 km/s) of PSP on the WISPR images, including the possibility of 3D reconstruction and the determination of the correct kinematics for expanding flux ropes and/or jets. Future joint observations between PSP/WISPR and other facilities like IRIS will provide new insights on the complex processes occurring in the solar atmosphere.

Poster

6. Science together with future facilities

IRISpy: Expanding IRIS Data Analysis into Python and Upgrading the Data Analysis Paradigm for a New Generation

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As IRIS becomes a mature mission, it continues to seek new ways to expand its user base and foster science collaborations with new instruments, thus ensuring it remains a valuable member of the solar satellite fleet. One such strategy is to develop IRIS data analysis tools in the Python programming language which is becoming increasingly prevalent in solar physics. Open-source packages such as SunPy have made the analysis of solar images and timeseries in Python far more common. A new generation of students is arriving in the field increasingly proficient in Python relative to IDL. And new ground-based facilities, like DKIST, increasingly prefer to implement their data analysis tools in Python. To help IRIS keep pace with this changing demand, a new open-source Python package, IRISpy, is currently being developed to read, manipulate, and visualise IRIS slit-jaw and spectrograph data. In this presentation, we outline the current capabilities and future direction of the IRISpy package as well as the benefits of developing and using Python-based IRIS analysis tools. These include, but are not limited to: increasing the longevity of IRIS data analysis by providing tools in a language increasingly preferred by a new generation of scientists; facilitating cross-instrument collaborations by reducing the need to switch languages; increasing the size and geographic diversity of IRIS's user base by providing free analysis tools in a free language; and access to a range of scientific data analysis tools not available in IDL, e.g. for machine learning (scikit-learn). In addition, the use of sophisticated version control and package distribution tools (git, github and anaconda) make it simple to cite and revert to an exact historical version of IRISpy and its dependencies. This makes it easier to ensure IRIS science results are transparent and reproducible. IRISpy is a community-driven effort and encourages contributions from anyone interested in IRIS science and in keeping IRIS a highly utilized member of the solar satellite fleet.

Poster

6. Science together with future facilities

Merging GST, DKIST and IRIS Capabilities to Maximize Their Scientific Output

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The 1.6-m clear aperture Goode Solar Telescope (GST) in Big Bear benefits from the long periods of local excellent seeing, is equipped with high-order adaptive optics (AO), and routinely collects diffraction-limited spatial resolution (0.1") photometric, spectroscopic and/or polarimetric data with a high cadence (¡ 40 s), across the spectrum from 0.4 - 5.0 μm.
Joint observing campaigns between IRIS, DKIST and GST will maximize their scientific output, while minimizing the risk of failing to acquire observing data due to bad weather or instruments glitches. Science topics that could be addressed with these unique data sets range from small-scale magnetism and its role in coronal heating to the fine structure of large-scale energy release events such as flares. GST has complementary to DKIST suite of instruments (e.g. NIRIS vs DL-NIRSP, CYRA vs Cryo-NIRSP, VIS vs VTF, FISS vs ViSP, BFI vs VBI), which sample similar parts of the solar spectrum. Moreover, observations at BBSO precede DKIST by 2-3 hours and observing time overlap more than 4-5 hours each day.
Currently, the GST instruments (Cao et al. 2010) include: BFI (Broad-band Filter Imager), VIS (Visible Imaging Spectrometer), NIRIS (Near-InfraRed Imaging Spectropolarimeter), FISS (Fast Imaging Solar Spectrograph, and CYRA (CrYogenic solar spectrogRAph). All aforementioned instruments have been put into regular operation after system commissioning, calibration and optimization, which can fully meet with observations requested by the proposed scientific research.