ABSTRACTS:

Invited talks

1. **Mihalis Mathioudakis, Queen's University Belfast**

   Title: The diagnostic potential of asymmetric flare line profiles

   Abstract: Asymmetric line profiles and associated Doppler shifts are a power diagnostic for estimating the temporal evolution of the flare velocity field. We will focus of spectral lines in the visible and show how the complex interplay between the temporal and spatial evolution of the flare velocity structure, combined with the properties of line formation, can alter the observed line profiles. The derived velocities should be treated with care especially for lines with formation heights that span across the photosphere and chromosphere. We will draw attention to the challenges associated with the current methods of estimating magnetic field variations and make some suggestions for improvements.

2. **Adam F Kowalski, National Solar Observatory and the University of Colorado**

   Title: Spectroscopic Signatures of Explosive Phenomena in the 3D Flaring Chromosphere (from Particles to Pixels to Point Sources)

   Abstract: Solar flares are remarkable phenomena that can occur over a large fraction of the volume of an active region. Yet, the individual brightenings in the chromosphere are highly localized in transient "kernels", from which much of the radiative energy is emitted. The near-ultraviolet and optical spectra of these kernels provide critical information about the distribution of heating from the low-density upper chromosphere into the deepest regions near the photosphere. In this talk, I review the spectral signatures of explosive phenomena within the 3D flaring chromosphere with an emphasis on high-time resolution model predictions of hydrogen emission line broadening. Soon, hydrogen Balmer and Paschen line spectra from the NSF's Daniel K. Inouye Solar Telescope will provide new tests of our knowledge of impulsive energy deposition as a function of depth in the chromosphere and along the flare ribbons. I discuss how high-resolution solar flare data of the hydrogen lines will provide urgently needed constraints on models of spatially unresolved stellar flare spectra, which are unavoidably affected by the full 3D nature of their flaring regions.

3. **Jiong Qiu, Montana State University**

   Title: Fine-scale Structure and Dynamics of Flare Ribbons in the Lower Atmosphere

   Abstract: The spectacular energy release in solar flares is governed by magnetic reconnection, which is believed to take place in the corona, at least for "major" flares. The lower atmosphere - the chromosphere and transition region, not only is the physical boundary of the corona, but also responds rapidly and prominently to flare energy release. In the past decade, flare observations in the lower atmosphere have been obtained in a broad spectral domain with sub-arcsecond resolutions and large dynamic ranges. The ample radiation signatures in the flaring chromosphere allow us to infer properties of the complex cross-scale physical process of magnetic reconnection, and provide diagnostics of the transport of the reconnection-released (and converted?) energy in plasmas and particles. With respect to the rich information the chromosphere flare observations promise to offer, this talk will give a narrow-scope review of some recent progress or effort trying to unravel the spatial, temporal, and spectral structure of chromosphere flare ribbons observed in the AIA-IRIS era. These studies attempt to probe the scales, and their indication of or association with essential physics that governs flare energetics. Questions are posed with regard to what the fundamental scales are, and how the 3D connection with the corona can be elucidated using current and future observations together with state-of-the-art models.

Contributed talks

4. **Paulo Simões, Mackenzie Presbyterian University**

   Title: Vertical structure of flare ribbons from AIA 1600 and 1700 Å images

   Abstract: The relative contribution of spectral lines into the SDO/AIA filters has been a subject of interest in the past years, especially in regard to differential emission measure analysis of solar features. However, such discussions have neglected AIA UV 1600 and 1700 Å filters, often used in flare analysis. We present our analysis of the main spectral features that contribute to both filters during solar flares. We employ spectroscopic data from Skylab NRL SB082 spectrograph observations of the flare SOL1973-09-07, folded through AIA's filters 1600 and 1700 Å to estimate the contributions of the several spectral lines and continua present in this wavelength range. The main contributions into the 1600 Å filter are C IV 1550 Å, Si II 1533 Å, C I 1560 Å and Si I 3P continuum. The 1700 Å filter is dominated by C I 1657 Å, He II 1640 Å and Al II 1670 Å. In the 1700 Å range, the large number of weaker lines enhanced during the flare makes it difficult to identify a contribution from Si I 1D continuum. These have formation temperatures between log T 4.1 and 5.1, therefore originating from the chromosphere. We use these estimates in the interpretation of AIA and STEREO observations of a limb flare ribbon. The vertical profile of the ribbon using both AIA UV filters indicate a formation height of the maximum emission about 1Mm above the photosphere. This is consistent with our findings that the AIA UV flare emission should arise from the chromosphere.

5. **Petr Heinzel, Czech Academy of Sciences and University of Wroclaw**

   Title: Off-limb observations and analysis of cool flare loops

   Abstract: I will present recent observations of cool flare loops in different spectral domains and show the results of the radiative-transfer diagnostics. Of particular interest are the new determinations of plasma densities. 2D and 3D non-LTE radiative-transfer modeling will be discussed.

6. **Sargam Mulay, University of Glasgow**

   Title: Evidence of chromospheric molecular hydrogen emission in a solar flare observed

   Abstract: We have carried out the first comprehensive investigation of enhanced line emission from molecular hydrogen, H2 at 1333.79 Å, observed at flare ribbons in SOL2014-04-18T13:03. The cool H2 emission is known to be fluorescently excited by Si IV 1402.77 Å UV radiation and provides a unique view of the temperature minimum region (TMR). Strong H2 emission was observed when the Si IV 1402.77 Å emission was bright during the flare impulsive phase and gradual decay phase, but it dimmed during the GOES peak. H2 line broadening showed non-thermal speeds in the range 7-18 km s^{-1}, possibly corresponding to turbulent plasma flows. Small red (blue) shifts, up to 1.8 (4.9) km s^{-1} were measured. The intensity ratio of Si IV 1393.76 Å and Si IV 1402.77 Å confirmed that plasma was optically thin to Si IV (where the ratio = 2) during the impulsive phase of the flare in locations where strong H2 emission was observed. In contrast, the ratio differs from the optically thin value of 2 in parts of ribbons, indicating a role for opacity effects. A strong spatial and temporal correlation between H2 and Si IV emission was evident supporting the notion that fluorescent excitation is responsible.

7. **Juraj Lorincik, Bay Area Environmental Research Institute, Lockheed Martin Solar and Astrophysics Laboratory**

   Title: Slipping flare kernels and the behavior of blue- and red-shifts of TR and chromospheric lines

   Abstract: We investigate the behavior of flare kernels in the chromosphere and TR using the high 1-s cadence IRIS observations of the 2015 June 22 M-class flare. Multiple slipping kernels appear during the beginning of the flare in the developing flare ribbons. Majority of these show redshifts and/or pronounced red wings. However, we detect an accelerating kernel that shows both blueshifts and enhanced blue wings at its leading edge in the Si IV 1402.77 line as well as chromospheric lines of Mg II and C II. We find that these blueshifts are extremely short-lived, and are soon replaced by the ""standard"" redshifted behavior of these lines. We discuss the implications of this finding in the framework of the 3D extensions of the Standard solar flare model, as well as from the viewpoint of chromospheric evaporation.

8. **Jaroslav Dudík (talk), Astronomical Institute of the CAS, Ondrejov**

   Title: Saddle-shaped solar flare arcades: A previously unnoticed 3D property

   Abstract: It is long accepted that in eruptive solar flares, the flare loops form as a consequence of magnetic reconnection. We show that five well-known flares show a common property of their flare arcades - all are saddle-shaped. This is despite the different magnetic environments and X-ray classes of the flares (C to X). The appearance of saddle occurs due to presence of relatively-longer loops at both peripheries of the saddle, which we term 'cantles'. Detailed investigation using stereoscopic data from SDO/AIA and STEREO-B shows that at least one case, the cantle loops occur due to the 3D 'ar-rf' reconnection between the erupting flux rope and the surrounding coronal arcades. The cantle loops are rooted in the hooked extensions of flare ribbons, which increases their length/height. These findings suggest that 3D reconnection involving the erupting flux rope itself plays a vital role in solar flares.

9. **Shaun McLaughlin, Queen's University Belfast**

   Title: Radiative Hydrodynamic Modelling of The Lyman Continuum During Solar Flares

   Abstract: The Lyman Continuum (LyC; <912Å) forms at the base of the transition region in the quiet-Sun, as a result of a free-bound transition, making LyC a powerful tool for probing the chromospheric plasma conditions (e.g. stratification of electron density, ionisation, and temperature) during solar flares. By fitting the LyC spectrum applying an Eddington-Barbier approximation, the departure coefficient of hydrogen, b1, and the colour temperature, Tc, can be determined. The departure coefficient measures the degree to which the plasma departs from local thermodynamic equilibrium (LTE) and has been observed to approach unity during flares, indicating a strong coupling to local conditions. When b1 approaches unity, Tc is reflective of the electron temperature of the plasma. To understand the effects of nonthermal energy deposition in the chromosphere during solar flares, we have been analysing LyC profiles from a grid of 1D field-aligned radiative hydrodynamic RADYN models hosted at Queen's University Belfast, which were generated as part of the F-CHROMA project. We have investigated the spectral response of LyC, and the temporal evolution of b1 and Tc in response to a range of nonthermal heating functions, based on characteristic electron fluxes, spectral indices, and low-energy cutoffs. The LyC intensity was seen to increase by 3-4 orders of magnitude during solar flares, responding strongly to the electron flux of the beam. The spectral index had a less significant effect on the LyC intensity. Generally, b1 decreased from 102-3 to approximately 1 during solar flares, while Tc increased from ~8000K to ~12000K. By generating continuum contribution functions, we found that there are both optically thick and optically thin components of LyC, in agreement with recent observations. The optically thick layer forms nearly 1000km deeper in the chromosphere during a flare compared to the quiet-Sun, and is strongly coupled to local conditions. The optically thin layers form at higher altitudes due to chromospheric evaporation. Whether the evaporation is explosive or gentle affects the number of optically thin layers formed. Our analysis paves the way for an interpretation of the wealth of solar LyC observations taken by the Extreme Ultraviolet Experiment onboard the Solar Dynamics Observatory over Solar Cycle 24.

10. **Alberto Sainz Dalda, Bay Area Environmental Research Institute/Lockheed-Martin Solar and Astrophysics Laboratory**

    Title: Better-constrained thermodynamics of a flare in the chromosphere as a consequence of fitting its challenging spectra

    Abstract: The Interface Region Imaging Spectrograph (IRIS) has become one of the most successful observers of flares. Its spectral capability to observe (mostly) from the chromosphere to the corona, together with the context information provided from the slit-jaw images, provides us with knowledge of the flares in the upper solar atmosphere. However, the physical interpretation of the spectral signatures observed by IRIS in the chromosphere during flares remains elusive, both from a theoretical and numerical approach as well as from the observations. While the flare signatures in IRIS spectra are easily identifiable, a successful explanation of how they are formed - and therefore the physics encoded in them - has not been given yet. We will present the results of the inversion of these challenging spectral flare profiles and the thermodynamics associated with them: from the early stage of the flare to its maximum. These observational results, which have a higher degree of accuracy than the ones currently available, shed light on the behavior of the flares in the chromosphere and they provide new observation-driven constraints to the theoretical and numerical models.

11. **Christoph Kuckein, Instituto de Astrofísica de Canarias**

    Title: Deciphering an M3.2 flare using multiwavelength observations

    Abstract: An M3.2 flare was observed in active region NOAA 11748 on 2013 May 17 with the Vacuum Tower Telescope (VTT) at Observatorio del Teide, Tenerife, Spain. Several hours of observations covered the entire flare, including the pre-flare, impulsive, gradual, and post-flare phases. Spectropolarimetric raster scans of the four Stokes parameters in the upper chromosphere (He I triplet at 1083.0 nm) and in the underlying photosphere (Si I line at 1082.7 nm) were obtained with the Tenerife Infrared Polarimeter (TIP-II). In addition, co-temporal spectroscopic raster scans of another chromospheric spectral line (Ca II at 854.2 nm) and H-alpha filtergrams were acquired with the Echelle spectrograph. A summary of the obtained results so far will be presented. This includes inversions of the photospheric Si I line to infer information of the magnetic field. Furthermore, we inspect and follow the time evolution of the chromospheric He I Stokes profiles and the Ca II intensity spectra during the different stages of the flare.

12. **Julius Koza, Astronomical Institute, Slovak Academy of Sciences, Tatranska Lomnica**

    Title: Spectral Diagnostics of Cool Flare Loops Observed by the SST

    Abstract: Flare loops form an integral part of eruptive events, being detected in the range of temperatures from X-rays down to cool chromospheric-like plasmas. While hot loops are routinely observed by the Solar Dynamics Observatory's Atmospheric Imaging Assembly, cool loops seen off-limb are rare. We employ unique observations of the SOL2017-09-10T16:06 X8.2-class flare which produced an extended arcade of loops. The Swedish 1 m Solar Telescope made a series of spectral images of the cool off-limb loops in the Ca II 8542 Å and the hydrogen Hβ lines. Our focus is on the loop apices. Non-local thermal equilibrium (non-LTE; i.e., departures from LTE) spectral inversion is achieved through the construction of extended grids of models covering a realistic range of plasma parameters. The Multilevel Accelerated Lambda Iterations code solves the non-LTE radiative-transfer problem in a 1D externally illuminated slab, approximating the studied loop segment. Inversion of the Ca II 8542 Å and Hβ lines yields two similar solutions, both indicating high electron densities around 2×10^{12} cm^{-3} and relatively large microturbulence around 25 km s^{-1}. These are in reasonable agreement with other independent studies of the same or similar events. In particular, the high electron densities in the range 10^{12}-10^{13} cm^{-3} are consistent with those derived from the Solar Dynamics Observatory's Helioseismic and Magnetic Imager continuum observations. The presence of such high densities in solar eruptive flares supports the loop interpretation of the optical continuum emission of stars which manifest superflares. This contribution is a result of collaboration with D. Kuridze, P. Heinzel, S. Jejčič, H. Morgan, and M. Zapiór

13. **Aaron Monson, Queen's University Belfast**

    Title: Solar Flare-Induced Photospheric Velocity Diagnostics and Stellar Applications

    Abstract: We present radiative-hydrodynamic simulations of solar flares generated by the RADYN and RH codes to study the perturbations induced in photospheric Fe I lines by electron beam heating. We investigate the induced line-of-sight velocities by various electron beam parameter combinations, and the primary energy transport mechanisms responsible for heating the lower solar atmosphere. From these models, we synthesize several deep forming Fe I spectral lines and study the Doppler velocity information retrievable during the flare. It is shown that throughout the period of beam heating a significant proportion of the line intensity is contributed from the chromosphere, leading to erroneous Doppler shifts not reflective in the photospheric LOS velocities. The apparent m/s Doppler shifts can even indicate false downflows in the photosphere, making their study vital for correctly considering momentum transfer throughout the lower solar atmosphere. We have expanded our analysis to stellar flare scenarios, where the m/s scales created become relevant for consideration compared to the radial velocities induced by orbiting exoplanets on their host star.

14. **Tetsu Anan, National Solar Observatory**

    Title: Structure of the flare chromosphere investigated with magnetic field measurements

    Abstract: A flare kernel associated with a C4 class flare was observed in a spectral window including the He I triplet 1083.0 nm and Si I 1082.7 nm with a spectro-polarimeter on the Domeless Solar Telescope at Hida Observatory on 2015 August 9. The observed Stokes profiles of the He I triplet in the flare kernel are well reproduced through inversions considering the Zeeman and the Paschen-Back effects with a three-slab model of the flare kernel. One slab of them produces an absorption, while the others produce emissions with upward and downward velocities. The magnetic field strength inferred from the emission components of the He I line was 1400 G, which is significantly stronger than 690 G that was observed at the same location in the same line 6.5 hr before the flare. In addition, the photospheric magnetic field vector derived from the Si I10827 Å was similar to those of the He I emissions. To explain this result, we suggest that bombardment of non-thermal electrons leaded to the formation of a coronal temperature plasma around a formation layer of the photospheric Si I line, and then the emission in the He I triplet was produced in the deep layer.

15. **Chris Osborne, University of Glasgow**

    Title: 2D Modelling of the Radiative Effects of Flare Energy on Adjacent Chromosphere

    Abstract: The fine structure and high variability of the flaring chromosphere has been repeatedly shown by modern ground-based observations; however, the commonly used radiation hydrodynamic models of flares are by necessity one-dimensional and stratified along the magnetic field. These models do not consider the effects of the flare's radiation on adjacent plasma despite this occurring naturally in observations. The radiation field in line-forming regions of flares can present strong angular and spatial anisotropies that will affect neighbouring plasma. We present detailed time-dependent two-dimensional radiative models of a slab of quiet Sun atmosphere responding to the radiation from adjacent flare models. The thermodynamic evolution of the flares is simulated with RADYN, and the Lightweaver radiative transfer framework is used to reprocess these and compute the two-dimensional transfer effects. We find that radiative effects alone can drive significant changes in the line profiles of the Halpha and Ca II 8542 Å chromospheric lines visible at distances over 1 Mm from the flaring boundary, but this incoming radiation is not sufficient to affect the atomic level populations deeper in the atmosphere where the continuum forms. The enhancement in chromospheric lines observed from the slab is strongly wavelength dependent which both qualitatively agrees with observations and has possible implications when considering filling factors. This "horizontal" transfer effect has been rarely considered but may have a significant impact on observations of flare kernels.

16. **Brandon Panos, The University of Geneva**

    Title: Spectral characteristics of flare ribbons using machine learning

    Abstract: A unique three-dimensional picture of the thermodynamics of the solar atmosphere can only be obtained by jointly analyzing the characteristics of multiple spectral lines over a variety of formation hights. We used unsupervised machine-learning techniques to build statistical models based on IRIS transition region, chromospheric, and photospheric lines, allowing us to analyze the flare ribbon from a multithermal perspective. The models were based on several million spectra derived from 21 large M- and X-class flares. We found that blue-shifted central reversals occur simultaneously in Mg II, C II, and Si IV, with the latter possibly displaying optical depth effects. The reversals in Mg II migrate away from line center before relaxing back into single peak formations over a time window of 1-3 minutes. Fe II appears to go into emission during the impulsive phase, indicating deep early atmospheric heating, while emission in the 10 MK coronal line (Fe XXI) shows a delay between downflows in the chromosphere and large coronal upflows. These statistical models provide useful diagnostics as well as a comprehensive set of multithermal benchmarks for simulations.

Posters

17. **Hugh Hudson, UC Berkeley / U of Glasgow**

    Title: IR and mm-wave observations of flare footpoints

    Abstract: The opacity of the solar atmosphere grows steadily from the near infrared (1.6 microns) into the submm, mm, and microwave regions. We thus cannot directly observe flare footpoint regions in the microwaves. We have explored this numerically via RADYN simulations and find that one can observe the altitudes of elecron beam penetration in the mm region, for example at 100 GHz. This may make it possible to gain useful observations of the continuum at ALMA. In the meanwhile, new observations in the far infrared (30 THz/10 microns) show that even C-class flares can readily be detected. We discuss the relationship of these observations to the white-light flare phenomenon.

18. **Alex Pietrow, Stockholm university**

    Title: Physical properties of a Fan-Shaped jet backlit by an X9.3 flare

    Abstract: Fan-shaped jets can be observed above light bridges and are driven by reconnection of the vertical umbral field with the more horizontal field above the light bridges. Because these jets are not fully opaque in chromospheric lines, one cannot study their spectra without the highly complex considerations of radiative transfer in spectral lines from the atmosphere behind the fan. We take advantage of a unique set of polarimetric observations of the Halpha line along with the Ca II 8542 Å and Ca II K lines obtained with the CRISP instrument of the Swedish 1-m Solar Telescope to study the physical properties of a fan-shaped jet that was backlit by an X9.3 flare. The Halpha flare ribbon emission profiles from behind the fan are highly broadened and flattened, allowing us to investigate the fan with a single slab via Beckers' cloud model, as if it were backlit principally by continuous emission. Using this model we derived the opacity and velocity of material in the jet. For what we believe to be the first time, we can report an estimate of the mass and density of material in a fan-shaped jet. Using inversions of Ca II 8542 Å emission via STiC (STockholm inversion Code), we were also able to estimate temperature and cross-check the velocity of material in the jet. Finally, we use the masses, plane of sky and line of sight velocities as functions of time to investigate the supply of momentum to the photosphere in the collapse of this jet, and evaluate it as a potential driver for a Sunquake beneath

19. **Marianna Korsos, Aberystwyth University**

    Title: Different atmospheric oscillatory behaviour of the magnetic helicity fluxes in flaring and non-flaring Ars

    Abstract: The magnetic helicity slowly and continuously accumulates in response to plasma flows tangential to the photosphere and magnetic flux emergence normal to it, it into the solar atmosphere. Analyzing the evolution of magnetic helicity flux at different atmospheric heights is key for identifying its role in the dynamics of ARs. The 3D magnetic field is obtained from PF extrapolations in order to derive the emergence, shearing and total magnetic helicity components at different atmospheric heights. In this presentation, we show results obtained by analysing the evolution of the three magnetic helicity components in flaring and non-flaring ARs. The evolution of the three components reveals significant periodicities of them. In the flaring ARs, we found that the emergence, shearing and total helicity fluxes have common long periods as a function height in the solar atmosphere. In the case of non-flaring ARs, we do not find such common long oscillatory periods. This case study suggests that the presence of common significant long periodicities could help for a better understanding of the physics of the lower solar atmosphere, and, this oscillatory behaviour may even serve as a valuable precursor for flares.

20. **Aabha Monga, Aryabhatta Research Institute, India**

    Title: Investigation of solar photospheric magnetic parameters contributing to the post-flare rotation

    Abstract: Recent studies (Bi et al., Nature Comm, 2016; Xu et al., Nature Comm, 2018) have shown an abrupt post-flare rotational motion in the sunspot structures associated with flaring active regions. These motions are believed to be driven by Lorentz forces associated with the gradient in the rotational parameters from the photosphere to the corona. These parameters generally include helicity, shear and photospheric twist parameter (α) estimates that provide an insight into the rotational component associated with the magnetic fields. Furthermore, this dynamic phenomenon is assisted by other photospheric magnetic parameters, such as flux distribution, emergence, etc. Here, we present a systematic study to quantify the role of photospheric magnetic parameters in association with the induced rotation in post-flare active regions. Spaceweather HMI Active Region Patch (SHARP) magnetic field and derived estimates are investigated to identify their mutual relationships prior to large-scale reconnection events associated with rotated active regions. Distinct periodicities in some pre-flare parameters are also examined and compared for cases with different flare magnitudes to assess any impact of oscillatory behavior in facilitating the rotation and/or flare intensities.

21. **Jonas Zbinden, Université de Genève**

    Preprocessing solar spectra with a variational autoencoder to obtain the optimal dataset

    Title: for solar flare prediction

Abstract: Solar flares are the most energetic events in our solar system. Interacting with Earth's magnetic field they may cause beautiful aurora or damage our modern infrastructure, but so far they cannot be reliably predicted. Novel methods such as neural networks allow us to cluster data, find rare events, or train models to attempt the prediction of solar flares. It is crucial to pre-process data such that the model can learn the relevant aspects of a solar flare. A problem of flare data sets is that they always also contain non-flaring pixels, which may negatively affect any prediction models. We present a method using a variational autoencoder VAE to pre-process solar spectra and clean observations from Quiet Sun spectra which have no predictive power for solar flares.