



HINODE-17/IRIS-15/SPHERE-3

ABSTRACT BOOK

Montana State University
July 23–27, 2024

This year, our annual Hinode/IRIS science meeting is joined by the SPHERE(Solar Physics High Energy REsearch) group. This meeting focuses on the Sun's atmospheric ecosystem: studies of the multifaceted Sun from radio to hard X-rays. Emphases include connecting high energy activity with observations from Hinode, IRIS, and future missions; the physical mechanisms driving the solar atmosphere; and information services for collaborative data acquisition by multiple observatories.

Over 160 presentations (oral and poster) are discussed in the following science sessions:

- Energy Storage and Release: Flaring events from Jets to CMEs
- Energy Storage and Release: Non-Flaring regions
- Atmospheric coupling and energy transport from the Sun to Solar Wind
- New and upcoming observatories, methods, and collaborations
- Others

Oral Presentations

July 23, 2024

Session 1

Chair : Adam Kobelski

| ID | Time | Presenter | Title |
|-----|-------|----------------------|--|
| V01 | 08:30 | Piyali Chatterjee | Insights into the nature and dynamics of solar spicules |
| C01 | 08:50 | Kyuhyoung Cho | Relation between non-thermal broadening and magnetic field inclination at the transition region. |
| C02 | 09:05 | Salvo Guglielmino | Small-scale eruptive phenomena in active region NOAA 12585 |
| C03 | 09:20 | Juan Martinez-Sykora | Small-scale turbulence can heat the solar chromosphere in plage regions. |
| C04 | 09:35 | Samuel Evans | Multifluid and Kinetic 2D and 3D Simulations of Chromospheric Turbulence and Heating Due to the Thermal Farley-Buneman Instability |
| C05 | 09:50 | Akiko Tei | Comparison of coronal hole and quiet Sun chromosphere using IRIS Mg II h & k observations of polar off-limb regions |

Session 2

Chair : Lucia Kleint

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|-----|-------|---------------|--|
| V02 | 11:00 | Adam Kowalski | Near-Ultraviolet Spectra of Stellar Flares: First Results from Hubble Space Telescope Treasury Program "Fulcrum" |
| C06 | 11:20 | Shin Toriumi | Status and future of the atmospheric heating studies for the Sun and sun-like stars |
| C07 | 11:35 | Takato Otsu | Sun-as-a-star Analysis of the X1.6 Flare on 2023 August 5: Dynamics of Post-flare Loops in Spatially Integrated Observational Data |
| C08 | 11:50 | Crisel Suarez | Solar Flares X-ray Irradiance Observations from the Miniature X-ray Solar Spectrometer (MinXSS) CubeSats |

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|-----|-------|-------------|---|
| C09 | 12:05 | Xiaoyan Xie | Thermal diagnostics on an M-flare observed with Hinode/XRT, SDO/AIA, and MinXSS-1 |
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Session 3

Chair : Lucas Tarr

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|-----|-------|------------------|---|
| V03 | 13:30 | Maria Kazachenko | Solar Magnetic Fields Before and During Eruptions |
| C10 | 13:60 | Zhiyu Yin | Modeling Electron and Proton Acceleration in Macroscale Magnetic Reconnection |
| C11 | 14:05 | Bin Chen | Energetic Electrons Accelerated and Trapped in a Magnetic Bottle above a Solar Flare Arcade |
| C12 | 14:20 | Joel Dahlin | Decoding Three-Dimensional Reconnection Dynamics in Flare Ribbons |
| C13 | 14:35 | Viggo Hansteen | Small and large scale episodic events in smaller and larger scale numerical simulations spanning the convection zone to the corona. |
| C14 | 14:50 | Drake Osaben | Modeling the Shear Evolution of Post-Reconnection Flare Loops |

Session 4

Chair : Lindsay Fletcher

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|-----|-------|----------------|---|
| V04 | 16:00 | Daniel Ryan | 3D evolution of solar flare via X-rays |
| C15 | 16:20 | Joel Allred | First Steps in Comprehensive Flare Modeling |
| C16 | 16:35 | Tingyu Gou | An intense long-duration confined flare observed by Hinode, IRIS, and SDO |
| C17 | 16:50 | Ivan Oparin | Does the tip of the cusp in candle-flame-shaped flares trace the bottom of the reconnection current sheet? |
| C18 | 17:05 | Kouhei Teraoka | Observational Comparison of Coronal Magnetic Field Parameters Between Confined and Eruptive Flares in the Similar MFR Configuration |
| C19 | 17:20 | Chunming Zhu | Genesis of a Confined X6.4 Flare in a Quadrupolar Magnetic Configuration |

July 24, 2024

Session 5

Chair : Jiong Qiu

| ID | Time | Presenter | Title |
|-----|-------|-------------------|---|
| V05 | 08:30 | Karin Dissauer | Unveiling the uniqueness of solar flare precursors - do pre-event conditions of the upper solar atmosphere differ for flaring vs. non-flaring active regions? |
| C20 | 08:50 | Jonas Zbinden | Is the Mg II triplet emission a distinct flare precursor? |
| C21 | 09:05 | Lindsay Glesener | The First Solar Flare Rocket Campaign |
| V06 | 09:20 | Ryan Milligan | The Max Millennium Program of Solar Flare Research |
| C22 | 09:40 | Shane Maloney | Flare Forecasting and SolarMonitor 2 |
| C23 | 09:55 | Marianne Peterson | How Do We Know When to Launch? Statistical Basis for Sounding Rocket Flare Triggers |

Session 6

Chair : Paola Testa

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|-----|-------|------------------------|--|
| V07 | 11:00 | Jessie Duncan | Characterizing Hot Plasma in Solar Active Regions via HXR Differential Emission Measure Analysis |
| V08 | 11:20 | Teia Mihailescu | Plasma Composition and Wave Activity in a Solar Active Region |
| C24 | 11:40 | James McKeivitt | Full Sun Spectral Analysis of Hinode/EIS data using Machine Learning |
| C25 | 11:55 | Andy S.H. To | Identifying Plasma Fractionation Processes in the Chromosphere Using IRIS |
| C26 | 12:10 | NATALIA ZAMBRANA PRADO | Connecting the Sun and the Heliosphere through the FIP effect |

Session 7

Chair : Yukio Katsukawa

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|-----|-------|-----------------|--|
| V09 | 13:30 | David Brooks | Spectroscopic Observations of Coronal Rain Formation and Evolution Following an X2 Solar Flare |
| C27 | 13:50 | Luke McMullan | DeepFiltering: Utilising the Power of Generative Networks to Produce Quality Images of Coronal Rain |
| C28 | 14:05 | Patrick Antolin | Cool and hot emission disambiguation in instrument passbands |
| C29 | 14:20 | Seray Sahin | From Chromospheric Evaporation to Coronal Rain: An Investigation of the Mass and Energy Cycle of a Flare |
| C30 | 14:35 | Dana Longcope | Characterizing Chromospheric Condensation with High-cadence Si IV Observations from IRIS |
| C31 | 14:50 | Ryan French | Spectroscopic Observations of Supra-Arcade Downflows (SADs) |

Session 8

Chair : Kathy Reeves

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|-----|-------|-------------------|--|
| V10 | 16:00 | Sijie Yu | Probing Energetic Electrons in Solar Flares with Radio Observations |
| C32 | 16:20 | Xingyao Chen | Joint metric, microwave, and hard X-ray imaging spectroscopy observations of the 2023 December 31 X5 Flare |
| C33 | 16:35 | Natalia Bajnokova | Different X-ray views of solar flares with NuSTAR and Solar Orbiter/STIX |
| C34 | 16:50 | Yuqian Wei | Joint Microwave and X-ray Observations of Supra-Arcade Downflows Impacting the Loop-Top and Above-Loop-Top Regions |
| C35 | 17:05 | Meiqi Wang | Energy-Dependent Ejection in an Impulsive Solar Energetic Electron Event associated with an X-class Flare |

July 25, 2024

Session 9

Chair : Dana Longcope

| ID | Time | Presenter | Title |
|-----|-------|---------------------|--|
| V11 | 08:30 | Tomoko Kawate | Study on non-Maxwellian Electron Velocity Distribution in Laboratory Plasmas via high-resolution spectroscopy and spectropolarimetry |
| C36 | 08:50 | Meriem Alaoui | How much return current electric field mirroring occurs in solar flares? |
| C37 | 09:05 | Gordon Emslie | Evaluating the level of turbulence in the flaring transition region from IRIS spectral line observations |
| C38 | 09:20 | Mitsuo Oka | Evolution and effect of pre-existing non-thermal (PENT) particles in magnetic reconnection |
| C39 | 09:05 | Alberto Sainz Dalda | How significant is the role of turbulent motions in causing flares? |
| C40 | 09:50 | Jeongbhin Seo | Acceleration of Non-Thermal Electrons in Solar Flares |

Session 10

Chair : David Williams

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|-----|-------|------------------------|--|
| V12 | 11:00 | Lakshmi Pradeep Chitta | Multifaceted puzzles of the solar atmosphere in the era of high-resolution observations |
| C41 | 11:20 | Roy Smart | Inverting ESIS Observations of the Solar Transition Region using Convolutional Neural Networks |
| C42 | 11:35 | Will Barnes | How does the heating frequency on elemental strands change as a function of active region age? |
| C43 | 11:50 | Souvik Bose | Chromospheric and coronal heating in an active region plage by dissipation of currents from braiding |
| C44 | 12:05 | Alphonse Sterling | Solar Active Region Coronal Jets: Hidden-onset Jets |

Session 11

Chair : Graham Kerr

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| C45 | 13:30 | Ramada Sukarmadji | Nanojets as pointers to the flare energy release process |
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| C46 | 13:45 | Kristopher Cooper | Detecting thermal and non-thermal emission in solar microflares using nested sampling |
| C47 | 14:00 | Hidetaka Kuniyoshi | Small-scale coronal EUV brightening produced by a magnetic tornado |
| C48 | 14:15 | Sanjiv Tiwari | Solar Orbiter/EUI Observations and a Bifrost MHD Simulation of Fine-scale Bright Dots in Emerging Flux Regions |
| C49 | 14:30 | Sam Krucker | Insights from Solar Orbiter |
| C50 | 14:45 | Michalina Litwicka | Investigation of co-temporal IRIS and SoHO/STIX observations of the solar flare. |

Session 12

Chair : Chris Lowder

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|-----|-------|-----------------|--|
| V13 | 16:00 | Haruhisa Iijima | Linking solar magneto-convection and interplanetary space in realistic MHD simulations |
| C51 | 16:20 | Minami Yoshida | Evolution of the open flux extended from the sunspot groups during solar maximum |
| C52 | 16:35 | Roger Scott | Simulation of Thermal Nonequilibrium Cycles in the Solar Wind |
| C53 | 16:20 | James Drake | Interchange magnetic reconnection as the driver of the fast |

July 26, 2024

Session 13

Chair : Kathy Reeves

| ID | Time | Presenter | Title |
|-----|-------|------------------|---|
| V14 | 08:30 | Hisashi Hayakawa | Archival Investigations for the Extremity of the Solar Eruptions in the Past: Case Studies |
| V15 | 08:50 | Ying Li | The White-light Flares Observed by ASO-S/LST/WST, CHASE, and IRIS |
| C54 | 09:10 | Harry Greatorex | Observational Analysis of Lyman-alpha Emission in Equivalent Magnitude Solar Flares |
| C55 | 09:25 | Pranjali Sharma | Statistical study to classify the occurrence of Balmer continuum enhancements in white light flares |
| C56 | 09:40 | De-Chao Song | Spectral Observations and Modeling of a Solar White-light Flare Observed by CHASE |
| C57 | 09:55 | Peter Young | The Temperature and Density of a Solar Flare Kernel Measured from Extreme Ultraviolet Lines of O IV |

Session 14

Chair : Shin Toriumi

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|-----|-------|---------------|---|
| V16 | 11:00 | Daikou Shiota | Hinode observation of long-term variation of magnetic fields in the Sun |
| C58 | 11:20 | Nariaki Nitta | The Behavior of the Magnetic Field in Sun's High-latitude Regions |
| C59 | 11:35 | Kai Yang | A New Disambiguation Method Based on Physics-Informed Machine Learning |
| C60 | 11:50 | Tetsu Anan | Magnetic and electric field structures at the X point of an Ellerman bomb II |
| C61 | 12:05 | Harsh Mathur | Unraveling the stratification of the chromospheric magnetic field using the H α line |

Session 15

Chair : Vanessa Polito

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| V17 | 13:30 | Juraj Lorincik | High-cadence IRIS solar flare imaging and spectroscopy: recent advances and open questions |
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| C62 | 13:50 | Spencer Riley | Identification of chromospheric dynamical signatures in solar flares with the Daniel K. Inouye Solar Telescope |
| C63 | 14:05 | William Ashfield | A Multi-wavelength Investigation of Quasi-periodic Pulsations an M4.2 Flare: Insights from High-Cadence and High-Resolution Observations |
| C64 | 14:20 | Sargam Mulay | Investigation of Quasi-periodic pulsations (QPPs) in solar flares |
| C65 | 14:35 | Yang Su | The early results of ASO-S/HXI |

Session 16

Chair : Harry Warren

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|-----|-------|-------------------|--|
| V18 | 16:00 | Noriyuki Narukage | Initial results of solar flare observing sounding rocket FOXSI-4 |
| C66 | 16:15 | Sabrina Savage | First Results from the Hi-C Flare Sounding Rocket Flight |
| C67 | 16:30 | Amir Caspi | The CubeSat Imaging X-ray Solar Spectrometer (CubIXSS): science and current status of implementation for a new mission to understand heating of coronal plasma |
| V19 | 16:45 | Hirohisa Hara | The SOLAR-C Mission: a progress report of the design and development |
| V20 | 17:00 | Gianna Cauzzi | The Daniel K. Inouye Solar Telescope: update and first results |
| V21 | 17:15 | Bart De Pontieu | Status of MUSE |

Invited talks are highlighted in light yellow.

Poster Presentations

| ID | Presenter | Title |
|-----|------------------------|--|
| P01 | Abby High | Analysis of Longitudinal Spread of Suprathermal Ions Co-Located with Coronal Mass Ejections |
| P02 | Akie Moritsuka | Bisector velocities of the photospheric line near the limb observed with Hinode SOT/SP |
| P03 | Kathy Reeves | XRT Mission-Long Flare Statistics |
| P04 | Iain Hannah | Revisiting the RHESSI X-ray Microflare Statistics |
| P05 | Paola Testa | Coronal abundances in solar active regions and their relationship with underlying chromospheric and transition region properties |
| P06 | Andy S.H. To | Understanding Elemental Composition Across Solar Atmospheric Layers |
| P07 | Bart De Pontieu | An optically thin view of the solar chromosphere. IRIS observations of the O I 1355 spectral line |
| P08 | Changxue Chen | Hard X-ray imaging of slipping reconnection and quasi-periodic pulsations in a solar flare |
| P09 | Juliana Vievering | Investigating Energy Release During a Quiescent Region Hard X-ray Flare Observed by RHESSI |
| P10 | Daniela Lacatus | Evolution of Spectroscopic Characteristics of Solar Filaments |
| P11 | De-Chao Song | An Observational Study of the Relationship between H I Ly α and H α /He II λ 304 in an M2.0 Solar Flare |
| P12 | Graham Kerr | Exploring the effects of deep heating of the solar chromosphere during flares |
| P13 | Harry Greatorex | Examining the Driver of High Contrast Lyman-alpha Emission in Solar Flares using Spectroscopic Observations from RHESSI and Fermi. |
| P14 | Wensi Wang | Observations of photospheric signatures for pre-eruptive coronal structures |
| P15 | Hugh Hudson | HOPE Properties and Implications |
| P16 | Iain Hannah | NuSTAR observations of quiet Sun phenomena |
| P17 | Samer Alnussirat | Impulsive solar flare observations conducted by Parker Solar Probe |
| P18 | Isabella Kraus | Investigating Coronal Bright Points: Statistical Analysis and 3D MHD Simulation with Hinode and SDO |
| P19 | Mitsuo Oka | Maximum Attainable Energy of Particles in Solar Flares |
| P20 | James Crowley | Magnetic Insights and Implications from Hinode |
| P21 | Jiayi Liu | What Can DKIST/DL-NIRSP Tell Us About Quiet-Sun Magnetism? |
| P22 | Jiong Qiu | Tracking Magnetic Structures That Are Reconnecting or Expanding or Both |
| P23 | Lucas Tarr | A comparison of electric currents from a flux emergence MHD simulation and as reconstructed using a nonlinear force free field extrapolation |
| P24 | Lyndsay FLETCHER | Precise timing of solar flare footpoint sources from mid-infrared observations |
| P25 | Marcel Corchado-Albelo | Spatial Complexity of Flare Ribbon Boundaries |
| P26 | Meers Oppenheim | Growth, Saturation and Effects of the Thermal Farley Buneman Instability in the Coldest Region of the Chromosphere |

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| P27 | Meriem Alaoui | Constraints on solar flare accelerated electrons and their associated return current |
| P28 | Milan Gotic | Global impact of emerging internetwork fields on the low solar atmosphere |
| P29 | Ryan French | Doppler signature of a possible termination shock in an off-limb solar flare |
| P30 | Navdeep K. Panesar | The Magnetic Origin of Solar Coronal Jets and Campfires: SDO and Solar Orbiter Observations |
| P31 | Sophie Musset | What are the properties of energetic electrons associated with solar jets? |
| P32 | Qiang Hu | Analysis of Coronal Magnetic Field Topology from High-Resolution Embedded Magnetograms |
| P33 | Rahul Yadav | High-resolution Spectropolarimetric Observation of a C-class Flare Observed by DKIST/ViSP |
| P34 | Tingyu Gou | Imaging and Spectroscopic Observations of Hot Plasmas in the Loop-Top Region During a Limb Solar Flare |
| P35 | Salvo Guglielmino | Energy release phenomena observed at high-resolution with GREGOR and IRIS |
| P36 | Shane Atwood | Unresolved Fine Structure and the Conductive Transition Region |
| P37 | Shin Toriumi | Close interaction of turbulent convection and magnetic twist in sunspot formation and flare eruptions |
| P38 | Xu Yang | GST High-cadence Observations to Solar Lower Atmosphere Energy Release |
| P39 | Souvik Bose | On the million-degree signature of spicules |
| P40 | Toshifumi Shimizu | The energy transported by compressible magnetoacoustic waves into chromospheric plage regions: dependence on magnetic field properties |
| P41 | Vanessa Polito | Observations of AR outflows with IRIS, Hinode/EIS and VLA |
| P42 | Ying Li | The Chinese ASO-S and CHASE Missions and the Maximum Millennium Program |
| P43 | Alan Hsu | A Probabilistic Calibration Procedure for the CORSAIR Polarimeter |
| P44 | Juan Martinez-Sykora | Beyond density diagnostics: combining O IV 1399, 1401, Si IV |
| P45 | Neal Hurlburt | Recent enhancements to the Heliophysics Event Knowledgeable |
| P46 | Rhiannon Fleming | Understanding the Student Impacts of A Solar Physics/Astrophysics Research Experience for Undergraduates |
| P47 | Amir Caspi | Chasing the 2024 eclipse: results from coordinated ground and airborne missions -- Citizen CATE 2024 and NASA |
| P48 | Albert Shih | The Fundamentals of Impulsive Energy Release in the Corona Explorer (FIERCE) mission concept |
| P49 | Yukio Katsukawa | SUNRISE III SCIP: a balloon spectro-polarimeter for seamless diagnostics of photo- and chromospheres |
| P50 | William Setterberg | The Integrating Miniature Piggyback for Impulsive Solar Hard X-rays (IMPISH): a Low-Cost Spectrometer for the GRIPS-2 Balloon Campaign |
| P51 | Pascal Saint-Hilaire | The GRIPS Imaging Concept |
| P52 | Christopher Moore | Spectral Soft X-ray Measurement Improvements of the three Miniature X-ray Solar Spectrometer (MinXSS-1, -2, -3) CubeSats and New Instrumentation to Open New Parameter Space |

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| P53 | Christopher Entzel | BUBO: the student-Built Ultraviolet solar Burst Observer |
| P54 | Daniela Lacatus | CMEx: Chromospheric Magnetism Explorer |
| P55 | Sarah Matthews | EUV Image Slicers for Solar Physics |
| P56 | Jacob Parker | ESIS (EUV Snapshot Imaging Spectrograph) II |
| P57 | Kathy Reeves | ECCCO: The EUV CME and Coronal Connectivity Observatory |
| P58 | Patrick Dunn | Simulating a detector's response to solar flare polarization - Geant4 and the PADRE mission |
| P59 | Soumyaranjan Dash | Application of Ensemble Kalman Filter Data Assimilation Technique to Infer the Surface Flows with Surface Flux Transport model |
| P60 | Alisdair Davey | VSO 2.0: A VSO Towards Easier Data Source Collaboration and Many Other Improvements |
| P61 | William Setterberg | Sunkit-spex: A High-energy Spectral Analysis Tool in Python |
| P62 | Shane Maloney | stixpy: STIX data analysis in python |
| P63 | Joy Velasquez | XRTpy: A Comprehensive Python Solution for Analyzing Hinode X-Ray Telescope Data |
| P64 | Lucas Guliano | Calibration Methods and Data Products for Hinode |
| P65 | Robert Jarolim | Advancing solar magnetic field extrapolations with physics-informed neural networks |
| P66 | Robert Jarolim | Physics Informed Neural Networks for Spectropolarimetric Inversions |
| P67 | Joseph Plowman | Multi-instrument DEMs and the EMToolKit framework for DEMs in Python |
| P68 | Bin Chen | Owens Valley Solar Arrays: An Integrated Community Facility for Solar and Space Weather Research |
| P69 | Juliana Vievering | Real-Time Early Flare Alert System for Triggered Observations |
| P70 | Kristopher Cooper | The FOXSI-4 instrument |
| P71 | Yixian Zhang | Scientific predictions for FOXSI-4 and comparison with observed data |
| P72 | Shunsaku Nagasawa | First Direct Focusing Hard X-ray Imaging of M-Class Solar Flare from FOXSI-4 Sounding Rocket Experiment |
| P73 | Shunsaku Nagasawa | Wide-gap CdTe Double-Sided Strip Detectors for High-Resolution Imaging Spectroscopy of Solar Flares in Hard X-rays for FOXSI-4 |
| P74 | Sarah Pawlowski | CAPRI-SUN: High Cadence Low-energy Passband X-ray Detector with Integrated Full-sun Field of View |
| P75 | Christopher Moore | Projected Performance of the Swift Solar Activity X-ray Imager (SSAXI-Rocket) for the Hi-C Flare Rocket |
| P76 | Sabrina Savage | COOL-AID Experiment on the Hi-C Flare Mission |
| P77 | Philip Klaassen | Modelling the Creation of Switchbacks from Interchange Reconnection |
| P78 | Kelvin Scheurer | Relationship Between X-ray Luminosity and Magnetic Flux of Active Regions and X-ray Bright Points |
| P79 | Allison Snyder | Analyzing and Modeling Shear of Post-Reconnection Flare Loops |
| P80 | Simon Shepard | Quantifying the Heating Energy in Individual Post-Reconnection Flare Loops |

Session 1

July 23

8:30 – 10:05

Insights into the nature and dynamics of solar spicules

Piyali Chatterjee, Sahel Dey, Robert Erdelyi

Bunches of swaying plasma jets in the solar chromosphere - the spicules- exhibit a variety of complex dynamics that are clearly observed in the images of the solar limb in both Hinode/SOT/Ca II and also IRIS/Si IV data. Apart from the rotation, sometimes a spicule is seen splitting into multiple strands, and the reverse where several strands coalesce into a single spicule is also detected. We present a simultaneous explanation for both of the above observed phenomena, namely the spinning and the splitting of spicule strands with the help of a radiative MHD simulation of the solar atmosphere. Our 3D numerical simulations further indicate an interesting relationship between spicules and vortex tubes that we refer to as "coronal swirling conduits" or CoSCos. In contrast to spicules that fall back to the solar chromosphere, the CoSCos form by drawing energy from the thermal and magnetic energy reservoir of the chromospheric plasma. These CoSCos have the potential to carry the rotational energy pulses further upward than spicules at Alfvén speeds than the typical length of spicules seen in the Si IV emission lines even when spicules are falling Sun-ward.

Relation between non-thermal broadening and magnetic field inclination at the transition region.

Kyuhyoun Cho, Bart De Pontieu, and Paola Testa

The non-thermal broadening of spectral lines emitted in the solar atmosphere, an additional spectral broadening component beyond thermal and instrumental broadening, remains a poorly understood phenomenon in solar spectroscopy. In particular, its manifestation in the transition region has received significant attention as it holds the potential to elucidate the underlying physical mechanisms driving the heating and dynamics the solar atmosphere in the solar atmosphere. We investigate the relation between non-thermal broadening and magnetic field inclination in the transition region. Analyzing data acquired by the Interface Region Imaging Spectrograph (IRIS), we extracted spectral parameters from the Si IV 1403 Å line in a full-disk mosaic dataset. Magnetic field inclination at the transition region was determined through non-linear force-free field extrapolation (NLFFF), based on vector magnetic field data from the Helioseismic and Magnetic Imager (HMI) on board the Solar Dynamics Observatory (SDO). Our analysis focused on three distinct plage regions, revealing that the region's edge facing the solar disk center exhibited comparatively strong non-thermal velocities and downward flows. In addition, the NLFFF extrapolation demonstrated alignment of the magnetic field direction in this region with the line-of-sight direction, suggesting a connection between non-thermal broadening and unresolved plasma motions along magnetic fields. This finding implies that a portion of the observed non-thermal broadening may be caused by the deceleration of falling plasma along these magnetic field lines.

Salvo Guglielmino (INAF - Catania Astrophysical Observatory)

Small-scale eruptive phenomena in active region NOAA 12585

Salvo Guglielmino, Mariarita Murabito, Vincenzo Andretta, Fabiana Ferrente, Serena Lezzi, Daniele Spadaro, Paolo Romano, Ilaria Ermolli

Observations from the IRIS satellite have revealed small-scale eruptive phenomena, characterized by a significant increase in integrated line intensity (up to a factor of 100-1000 in Si IV lines) and line width (reaching up to ± 100 km/s). These spectral signatures are indicative of local heating and bi-directional plasma flows likely stemming from magnetic reconnection between opposite polarity patches at the photospheric level. Some of these events exhibit bright counterparts across all SDO/AIA channels.

In this study, we document a series of similar events observed during secondary flux emergence in an arch filament system and between moving magnetic features within active region NOAA 12585. High-resolution observations from SST/CRISP shed light on the photosphere and chromosphere, allowing for the characterization of magnetic field configuration and phenomena within the lower atmosphere. IRIS and SDO/AIA observations unveil the atmospheric response to magnetic flux dynamics and the presence of heating and plasma ejection activity in the upper atmosphere.

These scientific findings are compared to state-of-the-art numerical simulations of flux emergence and recent observations from remote-sensing instruments aboard Solar Orbiter, which corroborate a similar scenario. Additionally, they serve as an ideal platform for future observations by MUSE and SOLAR-C, highlighting the complementary capabilities of spectropolarimetric high-resolution observations in a multi-instrument analysis.

Small-scale turbulence can heat the solar chromosphere in plage regions.

Juan Martínez-Sykora, Sam Evans, Bart De Pontieu, Meer Oppenheim, Yakov Dimant, Mats Carlsson.

The chromosphere is the interface region between the solar surface and the multi-million-degree corona. It is critical to understand energy flows within and through this region. Yet, in the chromosphere, particularly in plage regions, radiative MHD models have difficulties reproducing chromospheric observables. In this study, we combine IRIS observations with radiative magnetohydrodynamic (MHD) numerical models and multi-fluid models to more accurately model energy flows in the chromosphere. Specifically, we observe that within plage regions, between flux concentrations, the optically thin O I chromospheric line observed by IRIS shows a large non-thermal broadening. Combining radiative MHD simulations with the linear theory behind the Thermal Farley Buneman instability (TFB), we show that TFB instability should occur in these regions. This will create small-scale (meter) turbulence, leading to heating and changes in the electric field, which, in turn, can explain the source of non-thermal broadening of the O I spectral line.

Samuel Evans (Boston University Center for Space Physics)

Multifluid and Kinetic 2D and 3D Simulations of Chromospheric Turbulence and Heating Due to the Thermal Farley-Buneman Instability

Samuel Evans, Meers Oppenheim, Juan Martínez-Sykora, Yakov Dimant

Models fail to reproduce observations of the coldest regions in the Sun's atmosphere, where interactions between multiple ionized and neutral species prevent an accurate MHD representation. A meter-scale electrostatic plasma instability develops in these regions, causing turbulence and heating. We refer to this instability as the Thermal Farley-Buneman Instability (TFBI). Here, we determine how TFBI turbulence and heating depend on simulation scheme, across multifluid 2D, kinetic 2D, and kinetic 3D simulations. This includes the first ever 3D simulations of the TFBI. These results will be crucial to future work aiming to quantify the TFBI contribution to discrepancies between observations and radiative MHD models, across the entire range of parameters in the solar chromosphere.

Akiko Tei (National Astronomical Observatory of Japan (JSPS Research Fellow))

Comparison of coronal hole and quiet Sun chromosphere using IRIS Mg II h & k observations of polar off-limb regions

Akiko Tei, Stanislav Gunar, Joten Okamoto

In the solar atmosphere, quiet regions are broadly divided into two categories, depending on the coronal brightness: quiet-Sun regions (QS, bright) and coronal hole regions (CH, dark). To understand how the solar atmosphere forms, it is interesting to compare these different regions. In the corona, it is known from observations that the temperature, pressure, and density in CH are lower than those in QS. In the chromosphere, jet-like structures that appear to connect the photosphere and the corona, called spicules, and the differences between CH and QS spicules have been investigated, especially by using high-resolution imaging observations with Hinode SOT as well as ground-based spectral-imaging observations. Then, we also have a huge amount of IRIS spectral now, and the differences between CH and QS chromospheres can be statistically investigated using its high-resolution, stable, spectroscopic observations. Hence, to reveal the differences between QS and CH in the chromosphere, from the entire IRIS catalog, we extracted all high-resolution spectral datasets of polar off-limb regions for which the spectral slit was fixed in the north-south direction and analyzed the Mg II h and k lines. Then, we obtained the integrated intensity, hk line ratio, line shift, and line width from the Mg II line profile at each time and height, and made distribution functions of these spectral features as a function of height from the solar limb. We found that the integrated intensities in the Mg II k line show a rapid decrease with the height in QS while they remain bright at higher altitudes in CH. Moreover, we found that the widths of the Mg II k line first increase and then decrease with height in both CH and QS, and are overall larger for CH than for QS. We conclude that the chromosphere is higher and exhibits faster motions than QS chromosphere. In addition, we showed that some chromospheric structures or motions exist in the lower chromosphere both in CH and QS regions.

Session 2

July 23

11:00 – 12:20

Adam Kowalski (University of Colorado, National Solar Observatory)

Near-Ultraviolet Spectra of Stellar Flares: First Results from Hubble Space Telescope Treasury Program “Fulcrum”

Adam Kowalski, Rachel Osten, Yuta Notsu, Isaiah Tristan, Clara Brasseur, Antigona Segura, Shun Inoue, Teruaki Enoto, Hiroyuki Maehara, Kosuke Namekata

We present the first results from a treasury project with the Hubble Space Telescope, which is observing a large sample of stellar flares with near-ultraviolet spectra and optical photometry. We give an overview of the treasury project goals from astrobiology to flare physics. We will show results from spectral analyses of a giant flare, which challenges the standard theoretical treatment of electron beam transport from the corona to the chromosphere. Potential connections to IRIS spectra of solar flares will be discussed.

Shin Toriumi (Japan Aerospace Exploration Agency)

Status and future of the atmospheric heating studies for the Sun and sun-like stars

Shin Toriumi, Vladimir Airapetian, Kosuke Namekata, Yuta Notsu, Mai Yamashita

The Sun and sun-like stars commonly host extremely hot atmospheres, i.e., the corona, the chromosphere, and the transition region. It is widely believed that the magnetic field plays a central role in generating these atmospheres, although the exact heating mechanisms remain unclear. By analyzing the Sun-as-a-star multiwavelength observations over the last 10 yr, including SDO/EVE, SORCE, and Hinode/XRT, we derived the power-law scaling relations between the surface magnetic flux and irradiances of various wavelengths, which are sensitive to different temperatures from the corona to the chromosphere. We found that the derived power-law scalings for the current Sun are consistent with those for the sun-like G-type main-sequence stars with ages from 50 Myr to 4.5 Gyr, regardless of stellar age or activity level. This striking consistency is key evidence for the universal heating mechanism for the Sun and sun-like dwarf stars. In the presentation, we will show our recent attempts to expand the analysis to other types of stars (e.g., young stellar objects and M-type stars) and discuss future directions to utilize upcoming SOLAR-C and MUSE as well as new EUV space telescopes, such as LAPYUTA, a candidate for JAXA's 6th competitively-chosen M-class mission.

Sun-as-a-star Analysis of the X1.6 Flare on 2023 August 5: Dynamics of Post-flare Loops in Spatially Integrated Observational Data

Takato Otsu, Ayumi Asai, Kai Ikuta, and Kazunari Shibata

Post-flare loops are loop-like plasmas observed during the decay phase of typical solar flares. Recently, superflares, which emit energy more than 10^{33} erg, have been discovered in various stars (e.g., Maehara+ 2012), and many observations suggest that their basic mechanism is similar to that of solar flares. For example, filament/prominence eruptions, fundamental elements of standard solar flares as well as post-flare loops, have also been observed with superflares (Namekata+ 2022, 2023). These results are supported by the similarity with the spatially integrated solar data obtained by Sun-as-a-star analyses (Otsu+ 2022). However, the spatially integrated data of solar post-flare loops have not been fully investigated, and it is not yet clear how post-flare loops are observed in stellar cases.

To clarify behaviors of post-flare loops in spatially integrated data, we performed the Sun-as-a-star analysis of the X1.6 flare that occurred near the northwest limb on 2023 August 5 using GOES (soft X-rays, ~ 107 K), SDO/AIA (EUV, ≥ 105 K) and SMART/SDDI at Hida Observatory, Kyoto University ($H\alpha$, ~ 104 K), focusing on post-flare loops. As a result, this flare showed signatures corresponding to the important dynamics of the post-flare loops even in the spatially integrated data: (1) Cooling of post-flare loops was confirmed as peak time difference in soft X-rays, EUV, and $H\alpha$. Notably, the $H\alpha$ light curve showed two distinct peaks corresponding to the flare ribbons and the post-flare loops. (2) Downflows were confirmed as simultaneous red/blue-shifted absorptions in Sun-as-a-star $H\alpha$ spectra. (3) Apparent rise of post-flare loops was confirmed as the stop of the decay for the $H\alpha$ light curve. These results are keys to detect stellar post-flare loops in multiwavelength observations and grasp their dynamics with spatially integrated data. We also discuss the dependence of our results on flare locations and its possible applications to stellar observations.

Solar Flares X-ray Irradiance Observations from the Miniature X-ray Solar Spectrometer (MinXSS) CubeSats

Crisel Suarez^{1,2}, *Christopher S. Moore*², *Amir Caspi*³, *Phil Chamberlin*⁴, *Brendan D'Aquino*², *Anant Kumar*⁵, *James Mason*⁶, *Bennet Schwab*⁴, *Robert Sewell*⁴, *Tom Woods*⁴

1. Vanderbilt University

2. Center for Astrophysics | Harvard & Smithsonian

3. Southwest Research Institute

4. Laboratory for Atmospheric and Space Physics

5. University of Alberta

6. Johns Hopkins University Applied Physics Laboratory

The Miniature X-ray Solar Spectrometer (MinXSS) CubeSats were the first solar science-oriented CubeSat mission flown for the NASA Science Mission Directorate, with the main objective of measuring the absolute radiometrically calibrated energy distribution of solar soft X-ray emission over a large spectral bandpass at a moderate spectral resolution (nominal 0.15 keV energy resolution at 5.9 keV). The MinXSS CubeSats were successful in measuring the solar soft X-ray irradiance in the energy range of 0.8 - 12 keV. The first of the twin CubeSats, MinXSS-1, has observed over 30 solar flares from June 2016 to May 2017 over its 1-year mission lifetime. MinXSS-2 observed the quiescent Sun during December 2018-January 2019 and small B class flare. Since February 2022, the next generation MinXSS, the Dual Aperture X-ray Solar Spectrometer (DAXSS), has been conducting higher sensitivity and higher spectral resolution measurements. The spectral measurements and unique energy resolution at the time, provided by MinXSS can constrain solar flare and active region temperature structure, emission measure, and abundances of Fe, Ca, Si, and, S. We present the science results of the MinXSS-1 and MinXSS-2 measurements for flares. These results have proven to be consistent with numerous solar observations from GOES, Hinode/XRT, and SDO/AIA providing constraints in modeling and understanding solar flare phenomena, therefore proving the scientific capabilities of CubeSats.

Xiaoyan Xie (Center for Astrophysics | Harvard & Smithsonian)

Thermal diagnostics on an M-flare observed with Hinode/XRT, SDO/AIA, and MinXSS-1

Xiaoyan Xie, Anna Chen, Crisel Suarez, Katharine K. Reeves, Soumya Roy, Nishu Karna, Joy Velasquez, and Christopher S. Moore

On July 21, 2016, the X-ray Telescope (XRT) aboard Hinode, Atmospheric Imaging Assembly (AIA) aboard Solar Dynamics Observatory (SDO), and the Miniature X-ray Solar Spectrometer (MinXSS-1) CubeSat mission observed an M1.0 flare on the western limb of the Sun. The analysis of the flare from disk-integrated solar spectra of MinXSS-1 (Suarez & Moore 2023) shows an anomalous abundance evolution. In contrast to the usual abundance evolution consistent with the chromospheric evaporation model, where the elemental abundances are depleted from coronal toward photospheric values during the flare peaks in the events that are analyzed, the elemental abundances of this flare are near photospheric levels in the impulsive phase and reach coronal levels around the flare peak. By taking advantage of the spatial resolution abilities provided by XRT and AIA, we speculate that the coronal levels of the elemental abundances around the flare peak originate from a hot flux rope. Through the analysis of the differential emission measure (DEM) from AIA and XRT data, we present the thermal evolution of the flare with spatial resolution. The temperature and emission measure (EM) from the DEM are consistent with the values in Suarez & Moore (2023) that were derived from MinXSS-1 spectra. Finally, we discuss the improvements in thermal diagnostics by combining XRT with AIA channels and employing the appropriate abundance assumptions based on the elemental abundances determined by the spectra of MinXSS-1 for this flare.

Session 3

July 23

13:30 – 15:05

Solar Magnetic Fields Before and During Eruptions

Maria D. Kazachenko

Space weather is largely caused by the activity of our Sun. Invisible yet powerful magnetic fields, created within the Sun, determine when and where the next solar eruption will happen. In this talk, I will review how advances in solar observations and data-driven models allowed scientists to understand flare magnetism in a lot more detail than ever before. I will specifically focus on results of statistical analyses of SDO/HMI datasets and will show some new results from DKIST observations.

Modeling Electron and Proton Acceleration in Macroscale Magnetic Reconnection

Zhiyu Yin, James F. Drake, Marc Swisdak

Magnetic reconnection, the drive mechanism of solar flares, rapidly converts the stored magnetic energy in the Sun's corona into high speed flows and energetic electrons and ions. Simulations and models of reconnection suggest that plasma energization is controlled by Fermi acceleration during the growth and merger of macroscale magnetic flux ropes rather than acceleration in kinetic-scale boundary layers. The computational model *kglobal* is a hybrid MHD/particle model that eliminates all kinetic scales and has been developed to explore particle energization in macroscale reconnecting systems relevant to solar flare dynamics. The model, which initially only included non-thermal (energetic) electrons, has now been extended to include non-thermal ions. Reconnection simulations in macrosystems produce powerlaw spectra of electrons and protons that extend nearly three decades in energy with maximum energies of around an MeV for electrons and 5 MeV for protons. Particle energy gain is dominated by the growth and merger of large numbers of flux ropes. Protons typically gain more energy than electrons, with the powerlaw spectra of electrons reaching lower energies than that of protons. As in earlier electron-only *kglobal* simulations (Arnold et al 2021), the ambient guide field is the key factor that controls energization, with the strongest acceleration taking place with weak guide fields. The *kglobal* model is being benchmarked with in situ PSP observations of a reconnection event in the heliospheric current sheet that produced a powerlaw spectrum of protons extending up to 500 keV (Desai et al 2024) .

Bin Chen (New Jersey Institute of Technology)

Energetic Electrons Accelerated and Trapped in a Magnetic Bottle above a Solar Flare Arcade

Bin Chen, Xiangliang Kong, Sijie Yu, Chengcai Shen, Xiaocan Li, Fan Guo, Yixian Zhang, Lindsay Glesener, Säm Krucker

Where and how flares efficiently accelerate charged particles remains an unresolved question. Recent studies revealed that a "magnetic bottle" structure, which forms near the bottom of a large-scale reconnection current sheet above the flare arcade, is an excellent candidate for confining and accelerating charged particles. However, further understanding its role requires linking the various observational signatures to the underlying coupled plasma and particle processes. Here we present the first study combining multi-wavelength observations with data-informed macroscopic magnetohydrodynamics and particle modeling in a realistic eruptive flare geometry. The presence of an above-the-looptop magnetic bottle structure is strongly supported by the observations, which feature not only a local minimum of magnetic field strength but also abruptly slowing down plasma downflows. It also coincides with a compact hard X-ray source and an extended microwave source that bestrides above the flare arcade. Spatially resolved spectral analysis suggests that nonthermal electrons are highly concentrated in this region. Our model returns synthetic emission signatures that are well-matched to the observations. The results suggest that the energetic electrons are strongly trapped in the magnetic bottle region due to turbulence, with only a small fraction managing to escape. The electrons are primarily accelerated by plasma compression and facilitated by a fast-mode termination shock via the Fermi mechanism. Our results provide concrete support for the magnetic bottle as the primary electron acceleration site in eruptive solar flares. They also offer new insights into understanding the previously reported small population of flare-accelerated electrons entering interplanetary space.

Decoding Three-Dimensional Reconnection Dynamics in Flare Ribbons

J. T. Dahlin, J. Qiu, S. K. Antiochos, C. R. DeVore, P. F. Wyper

Solar flares are spectacular manifestations of explosive energy release powered by magnetic reconnection. While the standard CSHKP model has proven highly successful in explaining key features of flare observations in terms of magnetic reconnection, many aspects of the energy release are not yet understood. In particular, the complex three-dimensional structure of the flare current sheet is thought to play important roles in particle acceleration and bursty energy release. While direct diagnosis of the magnetic field dynamics in the corona is highly challenging, rich information may nevertheless be gleaned from flare ribbons, which represent the chromospheric imprints of reconnection in the corona. In particular, high-resolution observations by IRIS and BBSO/GST have revealed that ribbons frequently exhibit plentiful fine structure that hints at corresponding structures in the reconnection region - e.g., plasmoids or turbulence.

We present high-resolution MHD modeling of an eruptive flare and discuss our efforts to interpret flare ribbon features in terms of associated reconnection dynamics. We focus on field-line length maps which we employ to identify analogues of chromospheric transient brightenings associated with reconnection. Our model analogues of ribbon brightenings exhibit numerous fine-scale ‘spirals’. We show in detail how the evolution of the flare-ribbon spirals reveal the birth, propagation, and annihilation of coronal plasmoids formed in the flare current sheet. We show in detail how the evolution of fine-scale flare ribbon spirals reveal the birth, propagation, and annihilation of plasmoids. We discuss implications for interpretation of flare ribbon observations.

Viggo Hansteen (BAERI/LMSAL and RoCS/University of Oslo)

Small and large scale episodic events in smaller and larger scale numerical simulations spanning the convection zone to the corona.

Viggo Hansteen

Field stored just below or rising to the photosphere will break through the surface and enter the upper atmosphere once the gradient of the sub-photospheric field strength becomes sufficiently large. Driven by convective motions and the expansion of field in the chromosphere's low- β plasma, opposite polarity flux bundles will reconnect. Some of this emerging flux is likely due to a local dynamo, but also the emergence of larger scale magnetic structures from deeper layers is important, even in the quiet Sun. A significant proportion of this field likely reaches the chromosphere and leaves imprints on chromospheric and coronal dynamics and energetics. Using large scale numerical models, (72x72x60) Mm, the high resolution spectra and slit jaw images from IRIS, imaging data from SDO/AIA and Solar Orbiter's EUI/HRI, as well as ground based Ca II 854.2 and Ca II spectrograms, are synthesised and compared to observed data. We also synthesise observations from the upcoming MUSE and EUVST observatories in the context of episodic heating. The magnetic structure and dynamics of small scale events such as jets and dots, more energetic Ellerman bombs and a small C-class flare are discussed and analysed.

Modeling the Shear Evolution of Post-Reconnection Flare Loops

Drake Osaben, Jiong Qiu, Dana Longcope

Observations of solar flares suggest a strong-to-weak shear evolution of post-reconnection flare loops (PRFLs). We quantify magnetic shear as the complement of the angle formed between the PRFLs (projected in the image plane) and the photospheric magnetic polarity inversion line (PIL) where the radial magnetic field switches sign. Previous work uses the evolution of the flare ribbons to infer magnetic shear. In this work, we construct the 3D magnetic field of a PRFL arcade by fitting linear force free field (LFFF) lines to observed PRFLs. The two-ribbon flare SOL20141218T21:40 observed by the Solar Dynamics Observatory is investigated, for which we have identified more than 2500 PRFLs observed by the Atmosphere Imaging Assembly in EUV passbands. An optimal fitting is achieved by tracing field lines for a range of LFFF parameters and heights, then minimizing the distance between observed and modeled field lines projected in the image plane. The modeled field lines are further constrained by the flare ribbons observed in the UV 1600 passband, where they must be anchored. We successfully fit over 95% of the observed loops and find that the optimal force free parameter decreases in magnitude from over 0.1 to less than 0.01 Mm^{-1} during the flare. This indicates that later formed PRFLs are more potential-like. We also computed the shear angle of modeled loops projected in the image plane, finding the average shear decreasing from 50 degrees to under 20. This study confirms the strong-to-weak shear evolution in this flare and provides a method for modeling the 3D magnetic field after reconnection.

Session 4

July 23

16:00 – 17:35

3D evolution of solar flare via X-rays

Daniel Ryan

The 3-D locations and volumes of hot plasmas ($>5\text{MK}$) are crucial to understanding the evolution of solar flares. However to date, such observations have only ever been made in 2-D. Estimating source volumes from these measurements has relied on approximate area-to-volume scaling laws while estimating source locations has relied on assumptions about the sources' place within the magnetic field structure inferred from 2-D EUV images. In this presentation, we directly reconstruct the 3-D locations and volumes of hot flare plasma by leveraging the substantially different viewing angles offered by two X-ray imagers, SolO/STIX and Hinode/XRT. In addition, we discuss ongoing efforts to derive source topologies as a function of energy by enabling the first ever solar X-ray 3-D imaging spectroscopy with SolO/STIX and ASO-S/HXI. Such measurements promise to improve our understanding of solar flare evolution including energetics, cooling mechanisms, and the spatial relationship between the hottest plasmas and magnetically connected structures such as ribbons and footpoints.

First Steps in Comprehensive Flare Modeling

Joel Allred, Joel Dahlin, Rick DeVore, Silvina Guidoni, Judy Karpen, Graham Kerr, Marc Swisdak, and Valeriy Tenishev

Dominant processes occurring during solar flares range from global scale restructuring of magnetic field to particle acceleration and transport at the kinetic scale, some ten orders of magnitude smaller. Currently, no single model can resolve such disparate scales. Instead, distinct models have been developed, each tackling only some aspects of a complete solar flare. Here, we report on progress in developing a new composite flare model, which chains outputs from several well-tested codes. These were chosen to cover the range of physical processes dominating flares. The ARMS MHD code predicts the evolution of the global magnetic field and arcade structure and provides the conditions in which particles are accelerated. Particle acceleration is modeled kinematically by the AMPS code. The hybrid fluid/particle global code is used to simulate self-consistently the dynamic interplay between the MHD fluid and the accelerated nonthermal particles. We trace field lines in the ARMS arcade simulation and inject accelerated particles at looptops. Particle transport and the radiative-hydrodynamic response to these are modeled using the RADYN+FP code. We show the radiation predicted by our composite simulation with particular emphasis on X-rays and emission in the IRIS and Hinode bandpasses.

Tingyu Gou (Center for Astrophysics | Harvard & Smithsonian)

An intense long-duration confined flare observed by Hinode, IRIS, and SDO

Tingyu Gou and Katharine Reeves

We present observations of an intense and long-duration but confined flare that occurred on the southwest solar limb. The event was simultaneously observed by the Atmospheric Imaging Assembly (AIA) on the Solar Dynamics Observatory (SDO), the X-ray Telescope (XRT) on Hinode, and the Interface Region Imaging Spectrometer (IRIS). A prominence rises up at the onset of the flare, but finally fails to escape from the Sun with plenty of material falling back. A magnetic flux rope structure that rises together with the prominence contains high-temperature plasma as is evident in XRT and AIA hot channel images. Hot post-flare loops, evidenced in AIA, XRT, and IRIS SJI images, form in the wake of the rising flux rope, similar to the scenario of standard eruptive flares. IRIS detects strong Fe XXI emissions with excess line broadenings from the low-lying flare loops. Additionally, some less bright, high-lying loops appear above the prominence and flux rope, which become more prominent after the flare peak and are visible for more than 4 hours during the long-duration gradual phase. In the context of a multi-polar magnetic configuration in the active region, our results suggest a failed magnetic-breakout eruption that produces an intense long-duration flare.

Ivan Oparin (New Jersey Institute of Technology)

Does the tip of the cusp in candle-flame-shaped flares trace the bottom of the reconnection current sheet?

Ivan Oparin, Sabastian Fernandes, Bin Chen, Chengcai Shen, Xiaocan Li, Sijie Yu, Fan Guo

The bright cusp-shaped regions observed in candle-flame-shaped flares are generally accepted to be signatures of magnetic reconnection and subsequent plasma energization in solar flares (Tsuneta et al. 1992; Tsuneta 1996). Intense heating and compression in the cusp region can maintain the extreme ultraviolet (EUV) and Soft X-ray (SXR) emission in high-temperature channels for hours. However, it is still an open question whether the reconnection current sheet and associated plasma downflows extend below the tip of the observed cusp and directly energize the EUV and SXR sources. We utilize the multiwavelength observations in EUV and SXR data from SDO/AIA high-temperature channels (131, 94) and Hinode/XRT for two solar flares. By making use of a three-dimensional magnetohydrodynamic flare model by Shen et al. 2022, we localize the Y-points where the reconnection current sheet bifurcates and compare to the observed signatures. To confirm the geometry and orientation of the loops we also employ STEREO observations from a different viewing perspective. We find that although the observed cusp tip in EUV and SXR is the general manifestation of a series of Y points of freshly reconnected field lines projected to the plane of the sky, their spatial distribution is evolving during the gradual phase of the flare and can be located below the cusp tip.

Observational Comparison of Coronal Magnetic Field Parameters Between Confined and Eruptive Flares in the Similar MFR Configuration

Kouhei Teraoka, Toshifumi Shimizu, Daiki Yamasaki, Yusuke Kawabata, Shinsuke Imada

Solar flares are an explosive release of magnetic energy in the solar atmosphere. Magnetic flux ropes (MFRs) are a bundle of twisted magnetic field lines and are considered the energy source of flares. Some flares are associated with the eruption of MFRs and are called eruptive flares. Others fail to erupt and may be called confined flares. Eruptions are thought to be caused by magnetohydrodynamic instabilities such as the torus and kink instabilities. An experimental study by Myers et al. (2015) has shown that eruptive flares have MFRs both in torus and kink unstable states. Meanwhile, an observational study by Jing et al. (2018) has shown that eruptive flares have MFRs in the torus unstable state but are not characterized by the kink unstable state. The difference in the results may arise in that the former one compared MFRs in simple dipole configurations, whereas the latter one did in more complicated configurations. Therefore, making eruption conditions clearer by eliminating the influence of the configuration, we observationally investigated differences between the confined and eruptive flares in a similar MFR configuration. States of MFRs were identified by calculating coronal magnetic field parameters for each magnetic field line obtained by extrapolating the nonlinear force-free field from SDO/HMI data. We also focused on the magnetic field lines contributing to the energy release identified by flare ribbons in the SDO/AIA data. We examined confined and eruptive flares observed within 3 hours in AR 12673 on September 6, 2017. The results show that the magnetic field lines are more likely to be kinked unstable in the eruptive flare and less likely to be kinked unstable in the confined flare, but no difference is found in the torus instability between the flares. The presence of magnetic field lines becoming kinked unstable may make a difference in eruptivity.

Genesis of a Confined X6.4 Flare in a Quadrupolar Magnetic Configuration

Chunming Zhu, C. Richard DeVore, Joel T. Dahlin, Jiong Qiu, Maria D. Kazachenko, Vadim M. Uritsky

Both eruptive and confined flares – those having and lacking, respectively, an associated large-scale coronal mass ejection – are frequently observed in solar active regions (ARs). The physical mechanisms controlling the nature of these AR flares are poorly understood, and detailed investigation of both the magnetic environment and the dynamic flare production process within the source region is required. Here we study a confined X6.4 flare with a failed filament eruption in AR 13590 on 2024 February 22 that was observed by the SDO and HINODE spacecraft. AR 13590 had a quadrupolar magnetic configuration consisting of one central and two side arcades of low-lying loops, overlain by a fourth arcade of high-lying loops. A potential-field extrapolation contains a low-altitude null point at a height of about 5 Mm. This is a classic magnetic-breakout topology of the field, except that the rising filament lay under one of the side arcades. The confined flare generated four ribbons located in all four of the major polarities, and it proceeded in two steps. First, breakout reconnection in the null region between the fluxes in the two side arcades removed strapping field above the rising filament and initiated the formation of all four ribbons. Second, “anti-breakout” reconnection occurred at the null region between the high-lying arcade and the low-lying central arcade as those flux systems relaxed downward and upward, respectively, following the filament disruption. The two steps of breakout and “anti-breakout” reconnection are indicated by two successive stages of ribbon brightenings accompanied by forward, then reverse, motion of the brightenings along the interior ribbons. We discuss the physical mechanisms producing such strong confined flares while preventing much material from escaping from the Sun.

Session 5

July 24

8:30 – 10:10

Karin Dissauer (NorthWest Research Associates)

Unveiling the uniqueness of solar flare precursors - do pre-event conditions of the upper solar atmosphere differ for flaring vs. non-flaring active regions?

Karin Dissauer¹, KD Leka^{1,2}, Graham Barnes¹, Eric L. Wagner¹

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Observational case studies of the solar chromosphere and corona reveal increased levels of magnetic reorganization, dynamics, and temperature variation prior to solar energetic events. Here, we investigate whether parameters describing these activities can differentiate a region that will imminently produce a solar flare from one that will not.

We statistically analyze the coronal and chromospheric conditions of active regions prior to solar flares and during flare-quiet periods using a machine-learning ready dataset from the Atmospheric Imaging Assembly (AIA) onboard the Solar Dynamics Observatory (SDO) recently created by NWRA.

The AIA Active-Region Patches dataset (AARPs; Dissauer et al. 2023) comprises targeted extractions of AIA time-series data aligned with HMI active region patches (HARPs), downsampled spatially to active-region size and temporally to 13-minute intervals per hour at a 72-second cadence from 15:48-21:48 UT daily, enabling evaluation of short-lived features and long-term trends of pre-event dynamics and heating of the upper solar atmosphere using moment analysis of brightness images and running-difference images.

Temporal behavior is analyzed using linear regression on 6-hour time-series data for each parameter. The NWRA Classification Infrastructure (NCI), employing Non-Parametric Discriminant Analysis, is applied to over 32,000 samples across four flare-based event definitions to determine significant differences in pre-event conditions between flare-imminent and flare-quiet populations. We find top Brier Skill Scores in the 0.07 – 0.33 range, True Skill Statistics in the 0.68 – 0.82 range (both depending on event definition), and Receiver Operating Characteristic Skill Scores above 0.8.

Total emission can perform notably, although mean brightness measures do not, demonstrating the well-known active-region size/flare productivity relation. Once a

region is flare productive, active-region coronal plasma appears to stay hot. The 94 Å filter data provide the most parameters with discriminating power, with indications that it benefits from sampling multiple physical regimes. In particular, classification success using higher-order moments of running-difference images indicates a propensity for flare-imminent regions to display short-lived, small-scale brightening events.

Focusing on small-scale brightening events revealed a clustering tendency at future flare locations, compared to a random appearance of brightenings during flare-quiet epochs. Preliminary results show that these clusters also tend to occur predominantly at strong polarity inversion lines, fan traces of coronal null points, and magnetic bald patch locations.

Is the Mg II triplet emission a distinct flare precursor?*Jonas A. Zbinden, Lucia Kleint*

The trigger mechanism of solar flares is still unclear, and whether a trigger may exist in chromospheric layers. Brightenings, enhanced X-ray emission, and particular spectral properties, such as Mg II triplet emission were found before flare onset. Studies on flare precursors based on Mg II spectra were based on labeling full IRIS observations as either flaring or not, which has the drawback that no clear distinction between solar features within an observation is done. We aim to identify flare precursors in spectra, and in particular investigate the role of the chromospheric Mg II triplet as a flare precursor, because it was found in several studies as particularly distinctive. We use different machine learning methods, such as VAEs and CNNs, to establish a new spectra-based labeling scheme and train CNNs on the newly labeled data in Mg II h&k spectral line at identifying flare precursors. With a new triplet finding algorithm we track the appearance and strength of triplet emission before flares. We show a quantitative comparison of where the triplet emission appears before a flare and where it appears in non-flaring regions. Additionally, we compare the strength of the triplet emission with increases in intensity in the near-UV and far-UV. We find that the triplet emission is a distinct flare precursor in the IRIS spectral range and we speculate that this is because of chromospheric heating before flares.

Lindsay Glesener (University of Minnesota)

The First Solar Flare Rocket Campaign

*Lindsay Glesener and Sabrina Savage, on behalf of the FOXSI-4, Hi-C FLARE,
and early flare alert teams*

On 2024 April 17, two sounding rockets launched telescopes into space during a GOES class M1 solar flare. The FOXSI-4 and Hi-C experiments launched one minute apart and observed the Sun for approximately 5 minutes each with novel, high-resolution, high-sensitivity instrumentation, resulting in unprecedented X-ray and EUV coverage of a large flare. Although solar sounding rockets have been used for several decades to advance scientific investigations and technology, never before had an attempt been made to capture a large flare in progress. This successful endeavor relied on the combined efforts of the science teams of both experiments, a broad coalition of solar scientists eager to take on the problem of when to trigger a launch, and a great deal of development by NASA's Sounding Rocket Program office and the Poker Flat Research Range.

This presentation will give an overview of the solar flare campaign, including its goals and methodology. It is expected that triggered launches will become a more routine tool for solar sounding rockets, and we will touch on a few ways in which such launches could be used to advance science and technology.

Ryan Milligan (Queen's University Belfast)

The Max Millennium Program of Solar Flare Research

Ryan Milligan

The Max Millennium Program for Solar Flare Research has supported the solar flare community for over 25 years. Its goal is to help understand particle acceleration and explosive energy release during solar flares through coordinated observations, data analysis, and theory. In this talk I will give an overview of the history of the Max Millennium program, introduce the current Max Millennium Chief Observers, describe the various MM Observing Programs, Major Flare Watch criteria, and give a brief evaluation of how successful MFW calls have been over the past two solar cycles. I will also discuss how we propose to adapt the program as we look to Solar Cycle 25 and beyond.

Shane Maloney (Dublin Institute for Advanced Studies)

Flare Forecasting and SolarMonitor 2

Shane Maloney, Sophie Murray, Peter Gallagher, Paul Wright, Anna Massone, Michele Piana, Tamas Kiss, Gabriele Pierantoni, Gabor, Robert Lovas, Attila Farkas

The Sun is an enigmatic star that produces the most powerful explosive events in our solar system – solar flares and coronal mass ejections. Studying these phenomena can provide a unique opportunity to develop a deeper understanding of fundamental processes on the Sun, and critically, to better forecast space weather. The Active Region Classification and Flare Forecasting (ARCAFF) project will develop a beyond state-of-the-art flare forecasting system utilising end-to-end deep learning (DL) models to significantly improve upon traditional flare forecasting capabilities.

The five key objectives of ARCAFF are:

1. Active region classifications using magnetogram cutouts
2. Active region localisation and classification using full disk magnetograms
3. Point-in-time flare prediction using full disk magnetograms
4. Point-in-time flare prediction using full disk multimodal observations
5. Time series flare prediction based on time series of full disk multimodal observation

The huge amount of space-based solar observations are an ideal candidate for this type of analysis, given DL effectiveness in modelling complex relationships. DL has already been successfully developed and deployed in weather forecasting, financial services, and health care domains, but has not been fully exploited in the solar physics domain. The forecasts will be benchmarked against current systems using international community standards.

Benchmarking and intercomparison is a key challenge in solar flare forecasting and in particular machine learning based solutions. As part of the ARCAFF project and the ongoing SolarMonitor2 upgrade. SolarMonitor2 will run and store the results from the ARCAFF and other flare forecast models. Based on the results standard metrics will be computed and displayed - in particular on unseen data - allowing for fair and unbiased comparisons.

Marianne Peterson (University of Minnesota, Twin Cities)

How Do We Know When to Launch? Statistical Basis for Sounding Rocket Flare Triggers

Marianne Peterson, Juliana Vievering, Kristopher Cooper, Paolo Massa, Juan Camilo Buitrago-Casas, Philip Chamberlin, Gordon Emslie, Lindsay Glesener, Vicki Herde, Säm Krucker, Ryan O Milligan, Ndiefreke Okon Nyah, Subramania Athiray Panchapakesan, Athanasios Pantazides, Katharine Reeves, Orlando Romeo, Yoshiaki Sato, Sabrina Savage, Genevieve Vigil, Robert Walsh, Amy Winebarger, Yixian Zhang

In April 2024, the Focusing Optics X-Ray Solar Imager (FOXSI)-4 and the High Resolution Coronal Imager Flare Mission (Hi-C Flare) sounding rockets took part in NASA's first solar flare sounding rocket campaign. The two instruments performed a triggered launch, each having a 4-hour window daily over a two week period to trigger their launches, with the goal of observing the same large solar flare. However, the novel solar flare campaign was met with immediate challenges of performing a triggered launch—how will a solar flare of large magnitude be confidently predicted from its earliest signatures?

We developed an early-onset flare trigger system, based on a statistical study of historical GOES X-ray Sensor (XRS) data, in order to provide actionable realtime trigger values for upcoming flares with a low false-alarm rate. Both long- and short-wavelength GOES XRS flux channels are utilized for such triggers, with parameters of interest including their flux levels and derivatives, as well as temperature and emission measure. Specific combinations of such parameters were tested as triggers and refined on historical data, as well as in trials which simulated the two week launch campaign. We then integrated finalized triggers into an operational tool alongside context GOES XRS and EVE Extreme Ultraviolet Spectrophotometer (ESP) data, which was utilized during the flare campaign. We present results from the historical flare trigger analysis, as well as its successful implementation in the April 2024 launch campaign.

Session 6

July 24

11:00 – 12:25

Jessie Duncan (NASA Postdoctoral Program/Goddard Space Flight Center)

Characterizing Hot Plasma in Solar Active Regions via HXR Differential Emission Measure Analysis

Jessie Duncan, Reed B. Masek, Albert Y. Shih, Lindsay Glesener, Will Barnes, Katharine K. Reeves, Iain G. Hannah

Solar active regions (ARs) contain plasma across a broad range of temperatures, with the thermal distribution often observed to peak in the few millions of kelvin. Hard x-ray observations are uniquely sensitive to extremely hot (>10 MK) material, and are therefore essential for diagnosing the very hottest components of ARs. At quiet times, constraining this ultra-hot material is a crucial diagnostic of the frequency of heat input leading to the elevated temperature of the corona. Differential emission measure (DEM) analysis uses observations by instruments sensitive to thermal plasma to estimate the amount of material present as a function of temperature. DEMs with HXR constraints are so far fairly limited in the literature, but represent an exciting opportunity to investigate hot AR plasma. The Nuclear Spectroscopic Telescope ARray (NuSTAR) is a sensitive HXR observatory which makes periodic observations of the Sun. Combining NuSTAR's HXR coverage with other instruments (AIA, XRT), we perform time-resolved DEMs to characterize the thermal evolution of ARs. We discuss initial results from these NuSTAR DEMs, in conjunction with future prospects for gaining further insight about active region heating using HXR observation.

Teia Mihailescu (UCL Mullard Space Science Laboratory)

Plasma Composition and Wave Activity in a Solar Active Region

T. Mihailescu, D. Brooks, M. Laming, D. Baker, L. Green, A. James, D. Long, L. van Driel-Gesztelyi, M. Stangalini

The plasma composition of the solar corona exhibits an overabundance of elements with a low first ionization potential (FIP) compared to those with a high FIP. This enhancement of low-FIP elements is believed to take place in the chromosphere and is characterised by the FIP bias parameter. Typically, the strongest enhancement is observed in active regions and is believed to be a result of wave activity within the active region. In this work, we study the plasma composition in an active region following an episode of significant new flux emergence into the pre-existing active region, which separates it into two loop populations with different ages and properties. We use Hinode EIS data to estimate the FIP bias using two diagnostics: Si X 258.375 Å/S X 264.233 Å (temperature of approximately 1.5 MK) and Ca XIV 193.874 Å/Ar XIV 194.396 Å (temperature of approximately 4 MK). The preexisting loops (those that had formed before the flux emergence) show significantly higher FIP bias values in the Ca/Ar diagnostic than the Si/S one, but this pattern is not observed in the emerging loops (those created by the flux emergence). This result can be interpreted in the context of the ponderomotive force model, which proposes that the plasma fractionation is generally driven by Alfvén waves. Matching spectroscopic observations with predictions from simulations of the ponderomotive force suggests that the different plasma composition patterns observed in the two sets of loops depend on the properties of the Alfvén waves driving the enhancement - in particular, on whether the waves are resonant or not resonant with the loop and the chromospheric height at which they deposit their energy.

Full Sun Spectral Analysis of Hinode/EIS data using Machine Learning

James McKeivitt, Sarah Matthews, Deborah Baker, Hamish Reid

Throughout its mission, Hinode/EIS has performed over 20 full disk observations, capturing a wide range of active regions at multiple wavelengths. This provides a large dataset from which many observables like intensity, and fitted parameters like non-thermal velocity, can be derived. As the physical origins of non-thermal velocity remain ambiguous, these full disk observations are a valuable resource, useful to help us better understand the statistical behaviour of non-thermal velocity in active regions alongside other key parameters.

In this study, we analyse three Hinode/EIS full-disk observations from January 2013, April 2015 and October 2015, and use machine learning techniques to analyse the relationship between intensity, Doppler velocity and non-thermal velocity at multiple wavelengths, and FIP, in the quiet Sun and different active region types. In addition to considering these parameters alongside one another, we systematically apply clustering algorithms and use the result to characterise the significance of each parameter to each active region type and plasma condition (e.g. quiet Sun or coronal hole). We also apply machine learning techniques to capture the importance of the non-linear relationships between the parameters.

We use this study to consider known models of solar physics (e.g. FIP and I-FIP) alongside large sets of data, to demonstrate the usefulness of machine learning techniques in this data's analysis, and to pave the way for an extended analysis of the other full disks observed by Hinode/EIS during its mission.

Andy S.H. To (European Space Agency (ESTEC))

Identifying Plasma Fractionation Processes in the Chromosphere Using IRIS

David M. Long, Deborah Baker, Andy S.H. To, Lidia van Driel-Gesztelyi, David H. Brooks, Marco Stangalini, Mariarita Murabito, Alexander W. James, Mihalis Mathioudakis, Paola Testa

The composition of the solar corona differs from that of the photosphere, with the plasma thought to fractionate in the solar chromosphere according to the first ionization potential (FIP) of the different elements. This produces a FIP bias, wherein elements with a low FIP are preferentially enhanced in the corona compared to their photospheric abundance, but direct observations of this process remain elusive. Here, we use a series of spectroscopic observations of active region AR 12759 as it transited the solar disk over a period of 6 days from 2020 April 2–7 taken using the Hinode Extreme ultraviolet Imaging Spectrometer and Interface Region Imaging Spectrograph (IRIS) instruments to look for signatures of plasma fractionation in the solar chromosphere. Using the Si X/S X and Ca XIV/Ar XIV diagnostics, we find distinct differences between the FIP bias of the leading and following polarities of the active region. The widths of the IRIS Si IV lines exhibited clear differences between the leading and following polarity regions, indicating increased unresolved wave activity in the following polarity region compared to the leading polarity region, with the chromospheric velocities derived using the Mg II lines exhibiting comparable, albeit much weaker, behavior. These results are consistent with plasma fractionation via resonant/nonresonant waves at different locations in the solar chromosphere following the ponderomotive force model, and indicate that IRIS could be used to further study this fundamental physical process.

Connecting the Sun and the Heliosphere through the FIP effect

*Natalia Zambrana Prado, Samantha Wallace, Irena Gershkovich, Nicholeen Viall,
Therese Kucera, Peter Young, Stephanie Yardley*

Linking solar activity in the photosphere and corona to the inner heliosphere is one of the main objectives of ESA and NASA's Solar Orbiter mission. Establishing a link between an event on the Sun and its repercussions in the heliosphere is no trivial matter, especially in the case of small structures that are often below the resolution of current heliospheric imagers. Fortunately, for these small events, it is possible to find a link between the Sun and the heliosphere by diagnosing the elemental composition of the plasma thanks to the FIP effect (for first ionization potential), an increase in the abundance of low-FIP elements usually present in closed magnetic field zones.

Solar Orbiter was designed to narrow the gap between in situ and remote sensing measurements, approaching the Sun as close as 0.28 AU. Its unique combination of in situ and remote sensing instruments can be used to shed light on this difficult task. We present an analysis in which we have established such a connection through observations and modeling. The SPICE EUV spectrometer can observe the source regions of the Sun that will be sampled a few days later by the SWA-HIS in-situ instrument. Thanks to modeling, we have determined the trajectory followed by the solar wind and established where the various plasma parcels measured in situ originated.

We analyzed an event that took place in March 2022 where the in situ composition showed an overall decrease in the Fe/O ratio with periodic structures in the composition and determined whether the general trend we observed in situ was reflected in remote sensing data when measuring relative sulfur/nitrogen abundances.

Session 7

July 24

13:30 – 15:05

Spectroscopic Observations of Coronal Rain Formation and Evolution Following an X2 Solar Flare

*David H. Brooks, Jeffrey W. Reep, Ignacio Ugarte-Urra, John E. Unverferth,
Harry P. Warren*

A significant impediment to solving the coronal heating problem is that we currently only observe active region loops in their cooling phase. Previous studies showed that the evolution of cooling loop densities and apex temperatures is insensitive to the magnitude, duration, and location of energy deposition. Still, potential clues to how energy is released are encoded in the properties of the cooling phase. The appearance of coronal rain, one of the most spectacular phenomena of the cooling phase, occurs when plasma has cooled below 1 MK, which sets constraints on the heating frequency, for example. Most observations of coronal rain have been made by imaging instruments. Here we report rare Hinode/EUV Imaging Spectrometer (EIS) observations of a loop arcade where coronal rain forms following an X2.1 limb flare. A bifurcation in plasma composition measurements between photospheric at 1.5 MK and coronal at 3.5 MK suggests that we are observing postflare-driven coronal rain. Increases in nonthermal velocities and densities with decreasing temperature (2.7–0.6 MK) suggest that we are observing the formation and subsequent evolution of the condensations. Doppler velocity measurements imply that a 10% correction of apparent flows in imaging data is reasonable. Emission measure analysis at 0.7 MK shows narrow temperature distributions, indicating coherent behavior reminiscent of that observed in coronal loops. The limitations on spatio-temporal resolution of EIS suggest that we are observing the largest features or rain showers. These observations provide insights into the heating rate, source, turbulence, and collective behavior of coronal rain from observations of the loop cooling phase.

DeepFiltering: Utilising the Power of Generative Networks to Produce Quality Images of Coronal Rain

Luke McMullan, Dr Patrick Antolin, Dr Brandon Panos, Prof. Lucia Kleint

Coronal rain can be a key indicator of coronal heating taking place. If the coronal heating problem is going to be resolved it behoves us to fully investigate this link across the full disk of the Sun. There is no lack of observational data, but currently this data is inadequate for a complete analysis of the phenomenon to be carried out. The AIA 304 channel provides the best dataset for coronal rain observations. However, besides the cool component at 10^5 K from He II emission, the passband also includes hotter coronal emission from other ions. The contribution of this hotter emission can become comparable to that of the cool emission in off-limb observations, leading to ambiguity when determining the temperature of structures. Conversely, IRIS/SJI 1400 dominated by Si IV emission at $10^{4.8}$ K provides higher resolution images with far less ambiguity between hot and cool emission, and therefore higher contrast between both the rain and the surrounding corona. Unfortunately, the small field-of-view of the satellite makes it ill-suited for large scale statistical analysis of the phenomenon.

We present a novel approach to this problem by training a CycleGAN based algorithm to undertake a style translation between AIA 304 images and those belonging to IRIS 1400. This produces a model which can optimally, and without the need of additional data, convert AIA 304 images into those unhampered by the large temperature ambiguity. The structures in these images are then compared to the original IRIS 1400 images, as well as those produced from alternative methods, to show the reliability of this method going forwards. This method opens the path for large-scale statistical analysis of coronal rain, and a greater understanding of the phenomenon and its relation to coronal heating.

Cool and hot emission disambiguation in instrument passbands

P. Antolin, F. Auchère, E. Winch, E. Soubrié, R. Oliver

Narrowband ultraviolet (UV) or extreme ultraviolet (EUV) imagers, despite being relatively narrow, typically include significant contribution from more than one ion, thus leading to uncertainty regarding the temperature of the observed plasma. This is particularly limiting for diagnostic purposes of very hot or cool plasmas, whose sole presence in the solar corona can be attributed to specific physical mechanisms such as magnetic reconnection or thermal instability. The ambiguity is particularly large when observing off-limb, where line-of-sight superposition is maximal and the diffuse, hot emission becomes comparable in intensity to that of clumpy, cool structures such as spicules, coronal rain and prominences. In this work we investigate 3 methods based on temperature and morphology that are able to distinguish the cool and hot emission, and apply them to the AIA 304, SJI 1330 and SJI 1440 passbands. The methods are based on the Differential Emission Measure (DEM), a linear decomposition of the AIA response functions (RFit) and the Blind Source Separation (BSS) technique. All three methods are found to produce satisfactory results in both quiescent and flaring conditions, decomposing each image into a pair, one with the hot diffuse corona and another with the cool material off-limb in sharp contrast with the background. For AIA 304 we compare our results with co-aligned IRIS data in the SJI 1400 and 2796 channels, and find the RFit method to best match the quantity and evolution of the cool material detected with IRIS. These methods are in principle applicable to any passband from any instrument suffering from similar cool and hot emission ambiguity as long as there is good coverage of the hot temperature range.

From Chromospheric Evaporation to Coronal Rain: An Investigation of the Mass and Energy Cycle of a Flare

Seray Sahin¹ & Patrick Antolin¹
1. Northumbria University

Chromospheric evaporation (CE) and coronal rain (CR) represent two crucial phenomena encompassing the circulation of mass and energy during solar flares. While CE marks the start of the hot inflow into the flaring loop, CR marks the end, indicating the outflow in the form of cool and dense condensations. With the Interface Region Imaging Spectrograph (IRIS) and the Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics Observatory (SDO), we examine and compare the evolution, dynamics, morphology, and energetics of the CR and CE during a C2.1 flare. The CE is directly observed in imaging and spectra in the Fe XXI line with IRIS and the Fe XVIII line of AIA, with upward average total speeds of $[138+35]$ km s⁻¹ and a temperature of $[9.03+3.28]\times 10^6$ K. An explosive to gentle CE transition is observed, with an apparent reduction in turbulence. From quiescent to gradual flare phase, the amount and density of CR increases by a factor of ~ 4.4 and 6, respectively. The rain's velocity increases by 1.4, in agreement with gas pressure drag. In contrast, the clump width variation is negligible. The location and morphology of CE closely match those of the rain showers, with a similar CE sub-structure to the rain strands, reflecting fundamental scales of mass and energy transport. We obtain a CR outflow mass three times larger than the CE inflow mass, suggesting the presence of unresolved CE, perhaps at higher temperatures. The CR energy corresponds to half that of the CE. These results suggest an essential role of coronal rain in the mass-energy cycle of a flare.

Dana Longcope (Montana State University)

Characterizing Chromospheric Condensation with High-cadence SiIV Observations from IRIS

Dana Longcope, Chunming Zhu, Willow Reed, Alysa Derks

Chromospheric flare ribbons are believed to result from coronal magnetic energy released by reconnection and propagating down to the cooler, lower atmosphere. They offer an opportunity to study flare reconnection using chromospheric observations at a spatial and temporal resolution higher than typically available by direct coronal observation. Transient downflows, known as chromospheric condensations, often occur at the leading edge of a ribbon as a prompt response to the energy input. These have properties that have recently been shown to relate to the coronal energy release process driving them. We use a set of IRIS observations of flare ribbons, made at high cadence in the sit-and-stare mode, to identify and analyze a sample of 134 chromospheric condensation episodes. Quantitative analysis of this large sample shows the distribution of pre-flare chromospheric scale heights and flare energy fluxes. Scale heights fall primarily between 200 - 1,500 km. Clear chromospheric condensation appears to occur in only about one fifth of all ribbon pixels. This indicates that flare energy release is necessary but not sufficient for producing the characteristic form of chromospheric condensation. We find that condensation pixels form clusters averaging one arcsecond in extent, all undergoing similar and concurrent time evolution. This suggests that coronal reconnection, and associated energy release, occur in localized patches whose spatial extent maps to around one arcsecond in the chromosphere.

Ryan French (National Solar Observatory (NSO, Boulder))

Spectroscopic Observations of Supra-Arcade Downflows (SADs)

Ryan French, Maria Kazachenko, Katharine Reeves, Teodora Mihailescu

Despite their somewhat-frequent appearance in EUV imaging of off-limb flares, the origins of Supra-Arcade Downflows (SADs) remain a mystery. Appearing as dark, tendril-like downflows above growing flare loop arcades, SADs themselves are yet to be tied into the standard model of solar flares. The uncertainty of their origin is, in part, due to a lack of spectral observations, with the last published SAD spectral observations dating back to the SOHO/SUMER era. In this work, we present new observations of Supra-Arcade Downflows within an M-class solar flare, observed by the Hinode EUV Imaging Spectrometer (EIS) and Solar Orbiter's Spectrometer Telescope for Imaging X-rays (STIX). We measure Fe XXIV Doppler downflows and non-thermal velocities exceeding those of the surrounding hot flare fan, with evidence of diverging SAD flows above the flare arcade. Finally, we find evidence of fast downflow components within the line-of-sight, albeit far slower than the 1000 km/s downflows reported from the SUMER era.

Session 8

July 24

16:00 – 17:20

Probing Energetic Electrons in Solar Flares with Radio Observations

Sijie Yu

Radio emissions offer a unique window into the dynamics of non-thermal electrons accelerated during solar flares. These emissions, generated through coherent and incoherent mechanisms, serve as comprehensive probes into energy release, particle acceleration, and transport within flares. Recent advancements in solar radio observation techniques, transitioning from traditional imaging at limited spectral channels or total-power dynamic spectroscopy towards dynamic imaging spectroscopy, have been spurred by the arrival of new instruments. Notable developments include the Expanded Owens Valley Solar Array (EOVSA) and the upgraded Very Large Array (VLA), among others. In conjunction with X-ray imaging spectroscopic data from the RHESSI and SolO/STIX, these radio observations have yielded new insights into flare physics. This presentation will highlight the recent results from radio observations in probing energetic electrons in solar flares, and discuss future scientific opportunities/challenges in radio observations.

Xingyao Chen (New Jersey Institute of Technology)

Joint metric, microwave, and hard X-ray imaging spectroscopy observations of the 2023 December 31 X5 Flare

Xingyao Chen, Bin Chen, Sijie Yu, Surajit Mondal, Dale Gary, Sam Krucker

Joint radio and hard X-ray studies of solar flares provide abundant information about the properties of accelerated electrons, magnetic fields, and flare dynamics. The relevant diagnostic techniques include nonthermal gyrosynchrotron emission at microwave wavelengths, coherent emission at metric-decametric wavelengths, and bremsstrahlung in hard X-rays. However, studies that employ simultaneous imaging spectroscopy observations with all three techniques on a single flare event have been elusive. Here we present multi-wavelength imaging spectroscopy observations of the X5.0-class eruptive solar flare that occurred on December 31, 2023 using microwave data obtained by EOVS in 1–18 GHz, meter-decameter-wavelength radio data across 30–80 MHz via OVRO-LWA, and X-ray data from the STIX instrument onboard the Solar Orbiter. We apply various spectral imaging diagnostics to provide a detailed investigation of the filament eruption, flare dynamics, and energy conversion processes.

Different X-ray views of solar flares with NuSTAR and Solar Orbiter/STIX

Natalia Bajnokova, Iain G. Hannah, Kristopher Cooper, Säm Krucker, Brian W. Grefenstette, David M. Smith, Natasha L. S. Jeffrey, Jessie Duncan

We present analysis of the X-ray emission from small solar flares jointly observed with the Nuclear Spectroscopic Telescope Array (NuSTAR) and the Spectrometer Telescope for Imaging X-rays (STIX) on Solar Orbiter, providing different viewing angles of each event. NuSTAR is a highly sensitive X-ray imaging spectrometer that can directly image the Sun from 2.5 keV using focusing optics. STIX is an imaging spectrometer which instead uses indirect optics but has detectors capable of handling a wide range of solar X-ray fluxes from 4 to 150 keV. NuSTAR is in Earth orbit, whereas STIX is orbiting the Sun, so the two instruments combined can give different viewing angles of solar X-ray emission, providing a clearer picture of the flare's structure. By combining analysis of NuSTAR and STIX's X-ray spectra, we can take advantage of their different strengths, gaining a better understanding of the energy release in solar flares. We present observations of flares from June 2020 (on-disk for both instruments) and September 2022 (occulted for NuSTAR but on-disk for STIX - allowing us to probe a possible non-thermal coronal source with NuSTAR and bright lower atmosphere emission with STIX). We also consider these X-ray observations within the context of EUV emission seen by the SDO/AIA and softer X-ray with Hinode/XRT.

Yuqian Wei (New Jersey Institute of Technology)

Joint Microwave and X-ray Observations of Supra-Arcade Downflows Impacting the Loop-Top and Above-Loop-Top Regions

Yuqian Wei Bin Chen Sijie Yu Xiaoyan Xie Yixian Zhang

Supra-arcade downflows (SADs) are dynamic, sunward-moving plasma voids observed in the solar corona above flare arcades. Despite frequent observations, the mechanisms driving SADs and their impact on the flaring corona remain subjects of debate. In this study, we present joint microwave and X-ray observations of an M2.2 west limb flare on May 11, 2022. This event featured two episodes of SADs, with the relatively rare occurrence during the main impulsive phase and the more common post-impulsive phase. We present four key findings from our study on the interaction between the supra-arcade downflows (SADs) and the flare arcades:

1. The interaction between SADs and the flare arcade results in the transverse displacement of both microwave and Extreme Ultraviolet (EUV) emissions.
2. We note a correlation between the arrival of SADs and enhancements in the microwave light curve from 5-13 GHz, accompanied by thermal X-ray emissions in the loop-top region with an average 35-second delay relative to the microwave emissions.
3. In certain instances observed in (2), spectral hardening on the optically thin side of the microwave spectrum occurs as SADs reach a certain height.
4. The frequency of SADs throughout the flare's main and post-impulsive phases correlates with periodic enhancements in microwave and soft X-ray emissions.

These findings highlight the significant influence of SADs on the dynamics and electron population in the loop-top and above-loop-top regions of solar flares.

Meiqi Wang (New Jersey Institute of Technology)

Energy-Dependent Ejection in an Impulsive Solar Energetic Electron Event associated with an X-class Flare

Meiqi Wang, Bin Chen, Sijie Yu, Dale Gary, Jeongwoo Lee, Christina Cohen, Trevor Knuth

Impulsive solar energetic electron events are commonly associated with the magnetic reconnection processes during the solar flares. However, identifying when they are released during the flare and how they escape from the flare region persist as open questions. In this study, we report an impulsive solar energetic particle event associated with an X-class eruptive flare on July 3, 2021, using a combination of remote sensing and in situ measurements. The in situ energetic electrons over a wide energy range from tens of keV to \sim MeV were recorded by multiple spacecraft. Meanwhile, the joint observations in microwaves and hard X-rays provide diagnostics of this broad spectrum of energetic electrons near the source region. The release time of electrons showed that the lower energy electrons were released during the early impulsive phase, while those at higher energies were released during the later stage of the impulsive phase. We suggest that lower energy electrons were initially accelerated and released during the magnetic reconnection that triggered the eruption, while the higher energy electrons were produced during the magnetic reconnection processes in the above-the-looptop region.

Session 9

July 25

8:30 – 10:05

Study on non-Maxwellian Electron Velocity Distribution in Laboratory Plasmas via high-resolution spectroscopy and spectropolarimetry

T. Kawate, M. Goto, T. Oishi, Y. Kawamoto, I. Yamada, H. Funaba, H. Takahashi

The electron velocity distribution function (EVDF) represents the nature of energy transfer and dissipation processes in solar, space, and thermonuclear fusion plasmas. Non-Maxwellian/anisotropic electrons often interact with electromagnetic waves and excite kinetic instabilities. In fusion plasmas, non-Maxwellian EVDF is expected during electron cyclotron resonance heating (ECRH), lower hybrid heating, and DC heating operations. Such heating processes create anisotropic EVDF as well. Thus, high-temperature plasmas created and maintained by these heating methods are good for studying the role of non-thermal electrons in high-energy astrophysical plasmas.

One method to measure EVDF is population kinetics of ions, i.e., line spectra. X-ray lines emitted from helium-like ions and their satellite lines have been used as temperature diagnostics, and intensities of lines that are formed by inner-shell excitation and ionization are affected by high-energy electrons as reported from observations by Hinotori satellite (Kato & Masai 1992). In addition, ions colliding with anisotropic electrons are excited with population alignment and emit polarized light when de-excitation. X-ray crystal spectrometers behave as polarizers and are potentially used for the diagnostics of anisotropic EVDF (Akita et al. 1983). Therefore, X-ray line spectroscopy with crystal spectrometers can be a good diagnostics of nonthermal electrons.

We performed X-ray measurements of ECRH plasmas in the Large Helical Device at the National Institute for Fusion Science. Thomson scattering and electron cyclotron emission are also used to measure electron temperatures. Argon gas was injected for the x-ray diagnostics of high-temperature plasmas. In the low electron density conditions, Ar XII and the satellite lines at around 3.95-4.00 Å show some signs of suprathermal/anisotropic electrons. In the presentation, we introduce the results of the experiment of nonthermal electrons and ongoing projects on the interaction between nonthermal electrons and bulk plasmas via spectroscopy/spectropolarimetry.

How much return current electric field mirroring occurs in solar flares?

Meriem Alaoui, Gordon Holman, Marc Swisdak

High energy solar flare electrons carry a substantial fraction of the flare's energy. Estimating this energy flux, usually at the chromosphere, involves analyzing X-ray spectra, hydrodynamic models, and chromospheric and coronal line emissions. Therefore, understanding changes in electron distributions during the beam propagation is crucial. A key focus of this talk is how the co-spatial return current reduces the accelerated non-thermal energy flux and the extent of this reduction both in the fully beamed case, and when the pitch-angle distribution of the injected beam is isotropic in the forward direction.

We systematically compute this reduction for various beam and plasma parameters relevant to solar flares. Our model accounts for collisions between beam and plasma electrons, return current electric-field deceleration, thermalization in a warm target approximation, and runaway electron contributions. The results focus on the classical regime, offering a valuable benchmark for energy flux reduction and its extent.

Evaluating the level of turbulence in the flaring transition region from IRIS spectral line observations

*Gordon Emslie, Simon Shepard (WKU), Graham Kerr (CUA), Joel Allred (GSFC),
Stephen Bradshaw (Rice)*

It is well established that spectral line profiles in the EUV are significantly broadened compared to their thermal widths, and this has been taken as evidence for turbulent nonthermal motions of the emitting ions. The excess line width is typically evaluated by fitting a Gaussian profile and comparing its standard deviation σ with the thermal width $\sqrt{(kT/m_i)}$. However, several studies have shown that turbulent motions can result in a line profile that is intrinsically non-Gaussian in shape. In particular, several authors have modeled the turbulent mean free path as a two-parameter function, with one parameter (R) measuring the ratio of the turbulent and collisional mean free paths at the thermal speed, and another parameter (α) measuring the velocity dependence of the turbulent mean free path (compared to $\alpha = 4$ for collisions). Predicted line profiles for various values of R and α show not only excess widths (i.e., standard deviations σ), but also significantly non-Gaussian wings, parametrized by the reduced kurtosis K , a quantity determined by the ratio of the fourth normalized moment and the fourth power of σ . The two-parameter physical parameter set (R, α) may therefore be mapped onto a two-parameter observational set (σ, K) . We report on the analysis of the profiles of several spectral lines observed by IRIS during flares, and on the behavior of σ and K with position along the slit and with time. In this way we shed light on the variation of R and α throughout the observed area, and hence on the role of turbulence in the flare transition region.

Evolution and effect of pre-existing non-thermal (PENT) particles in magnetic reconnection

Mitsuo Oka, Fan Guo, and Xiaocan Li

Solar flares produce a significant number of high-energy, non-thermal particles. Earlier observations suggested that non-thermal electrons alone carry up to 50% of the released magnetic energy, and recent observations reported that nearly all electrons are accelerated to form a power-law. These observations may lead to the idea that particles, once accelerated, might replenish the acceleration region to receive further acceleration. However, it is not clear what happens to magnetic reconnection when it is replenished with non-thermal particles and if reconnection can sustain the energy conversion process. Here we show, using 2D particle-in-cell (PIC) simulations, that pre-existing non-thermal (PENT) particles do not experience significant re-acceleration by magnetic reconnection, and the reconnection process itself also does not receive substantial feedback from the PENT population, unless plasma beta is increased. While the result needs to be further tested in 3D, we anticipate that the problem of particle acceleration in solar flares remains challenging and requires breakthroughs in future observational studies.

Alberto Sainz Dalda (Lockheed Martin Solar and Astrophysics Lab/Bay Area Environmental Research Institute)

How significant is the role of turbulent motions in causing flares?

A. Sainz Dalda

Turbulent motions have long been associated with flares, but were generally thought to be a result of the energy released by the flare. In a recent study, we analyzed the velocity of turbulent motions in the chromosphere and transition region recovered from the spectral lines observed by IRIS before the X-class flare SOL2014-03-29-17:48 onset. Our findings clearly indicate that the non-thermal velocity (or micro-turbulence) in the flare's ribbon increased about 2 hours before the flare's maximum. This suggests that turbulent motions in the lower atmosphere may play a role in triggering some flares. We discuss possible scenarios that may be consistent with these results.

Acceleration of Non-Thermal Electrons in Solar Flares

Jeongbhin Seo, Fan Guo, and Xiaocan Li

During the impulsive phase of a solar flare, notable emissions include strong hard X-rays, as well as intense UV and white-light emissions. However, traditional studies encounter what is known as the 'number problem' that a discrepancy between the high count of non-thermal electrons required to explain energy deposition in solar flares and the lower observed numbers in the solar corona. Our study aims to comprehend the generation and role of non-thermal particles through numerical simulations. We have developed a new method for MHD, including feedback from non-thermal particles, to better understand generation and transport of non-thermal electrons in flares. In this talk, we will discuss our recent results, demonstrating that non-thermal energetic particles are generated through magnetic reconnection, and we will present the distribution and energy budget of the non-thermal electrons above the looptop, which are related to the hard X-ray emission.

Session 10

July 25

11:00 – 12:20

**Multifaceted puzzles of the solar atmosphere in the era of
high-resolution observations***Lakshmi Pradeep Chitta*

The solar atmosphere is created by an interplay between the magnetic field and multi-thermal plasma. High-resolution imaging and spectroscopic data continue to shed light on the truly complex nature of this interplay. Observations from the SST, IRIS and RHESSI have substantially contributed to improving our understanding of the lower atmospheric dynamics ranging from 10000 K Ellerman bombs to 0.01 MK ultraviolet bursts to multimillion-Kelvin hard X-ray flares. In this talk I will discuss data acquired by these telescopes that highlight the puzzling nature of small-scale energy transport through the solar lower atmosphere and plasma heating. I will present an outlook on how the upcoming solar telescopes will play a crucial role in resolving these issues.

Inverting ESIS Observations of the Solar Transition Region using Convolutional Neural Networks

Roy T. Smart, Charles C. Kankelborg, Jacob D. Parker

The EUV Snapshot Imaging Spectrograph (ESIS) is a sounding rocket instrument designed to capture a hyperspectral image of the solar transition region over a wide field of view in a single exposure. ESIS achieves this by using four identical slitless spectrographs, each oriented with a different dispersion direction, to capture four different "overlappograms" of the solar atmosphere. These overlappograms are then inverted (in a process analogous to computed tomography) to retrieve a hyperspectral image of the solar atmosphere.

In this work, we present a convolutional neural network (CNN) that has been trained to invert ESIS overlappograms using Si IV 1394 Å observations from the Interface Region Imaging Spectrograph (IRIS) as a proxy for the O V 630 Å spectral line observed by ESIS. We will use this CNN to invert observations gathered during the 2019 flight of ESIS and investigate the nature of small-scale dynamic events observed in the quiet solar transition region.

Will Barnes (American University, NASA Goddard Space Flight Center)

How does the heating frequency on elemental strands change as a function of active region age?

Will Barnes, Stephen Bradshaw, Nicholeen Viall, Emily Mason

The evolution of active regions over their lifetime, from initial emergence to the eventual complete dispersal of magnetic flux, has been well studied. However, how this evolution is connected to the detailed heating processes within an active region has been largely unexplored. In particular, it is not well known how the heating frequency on individual elemental strands within an active region is connected to the large-scale evolution of the active region.

To address this question, we study two active regions, NOAA 11190 and 11339, over two rotations using observations from SDO/AIA, Hinode/EIS, and Hinode/XRT. We compute both the emission measure distribution and the time lag in order to diagnose the underlying heating frequency and its spatial distribution over the whole active region. Additionally, we make comparisons to forward-modeled observables from synthetic images composed of ensembles of field-aligned hydrodynamic models for several different heating frequencies.

We also assess the ability of soft x-ray measurements from future observatories to diagnose these heating properties. In doing so, we are able to quantitatively assess how the spatial distribution of heating frequency over these active regions changes as they evolve and how this is connected to bulk properties of the active region such as the total unsigned magnetic flux.

Souvik Bose (Lockheed Martin Solar & Astrophysics Lab)

Chromospheric and coronal heating in an active region plage by dissipation of currents from braiding

Souvik Bose

The question of what heats the outer solar atmosphere remains one of the long-standing mysteries in astrophysics. Statistical studies of Sun-like stars reveal a correlation between global chromospheric and coronal emissions, constraining theoretical models of potential heating mechanisms. However, spatially resolved observations of the Sun have surprisingly failed to show a similar correlation on small spatial scales. Here we use unique coordinated observations of the chromosphere (from the IRIS satellite) and the low corona (from the Hi-C 2.1 sounding rocket), and machine-learning-based inversion techniques, to show a strong correlation on spatial scales of a few hundred kilometres between heating in the chromosphere and emission in the upper transition region in strong magnetic field regions ('plage'). Our observations are compatible with an advanced three-dimensional magnetohydrodynamic simulation in which the dissipation of current sheets caused by magnetic field braiding is responsible for heating the plasma simultaneously to chromospheric and coronal temperatures. Our results provide deep insight into the nature of the heating mechanism in solar active regions.

Solar Active Region Coronal Jets: Hidden-onset Jets

Alphonse C. Sterling, Ronald L. Moore, & Navdeep K. Panesar

Solar quiet- and coronal-hole region coronal jets frequently clearly originate from erupting minifilaments, but active-region jets often lack an obvious erupting-minifilament source. We observe a coronal-jet-productive active region (AR), AR12824, over 2021 May 22 0–8 UT, primarily using Solar Dynamics Observatory (SDO) Atmospheric Imaging Array (AIA) EUV images and SDO/Heliioseismic and Magnetic Imager magnetograms. Jets were concentrated in two locations in the AR: on the south side and on the northwest side of the AR's lone large sunspot. The south-location jets are oriented so that we have a clear view of the jets' origin low in the atmosphere: their source is clearly minifilaments erupting from locations showing magnetic flux changes/cancelations. After erupting a projected distance $\sim 5''$ away from their origin site, the minifilaments erupt outward onto far-reaching field as part of the jet's spire, quickly losing their minifilament character. In contrast, the northwest-location jets show no clear erupting minifilament, but the source site of those jets are obscured along our line of sight by absorbing chromospheric material. EUV and magnetic data indicate that the likely source sites were $\sim 15''$ from where we first see the jet spire; thus, an erupting minifilament would likely lose its minifilament character before we first see the spire. We conclude that such AR jets could work like non-AR jets, but the erupting-minifilament jet source is often hidden by obscuring material. Another factor is that magnetic eruptions making some AR jets carry only a harder-to-detect comparatively thin ($\sim 1''$ – $2''$) minifilament "strand." A full report appears in Sterling et al. (2024, ApJ, 960, 109). This work was supported by the NASA Science Mission Directorate's HSR and HGI programs, and through the NASA/MSFC Hinode Project.

Session 11

July 25

13:30 – 15:00

Nanojets as pointers to the flare energy release process

Ramada Sukarmadji, Patrick Antolin, James McLaughlin, Stephane Regnier

The discovery of nanojets by Antolin et al. (2021) represents magnetic reconnection in a braided field, thus clearly identifying the reconnection-driven nanoflares from similar intensity bursts produced by other mechanisms. Nanojets have since been found in multiple coronal structures, namely in a coronal loop powered by a blowout jet and in coronal loops with coronal rain (Sukarmadji et al. 2022). In these cases, the reconnection at their origin is due to dynamic instabilities (Kelvin-Helmholtz or Rayleigh-Taylor) in a braided field. The variety of structures and environments where they are found support nanojets as a general result of small-angle component reconnection. However, it is still unclear how pervasive nanojets are in the solar corona and whether they play a role in heating within large-scale heating events such as flares. In this talk, we present IRIS and SDO observations of nanojets found in a C-class flare. In agreement with previous findings, we observe that nanojets are accompanied by small nanoflare-like intensity bursts in the (E)UV, have fast velocities over $\sim 150 \text{ km s}^{-1}$, and occur transversely to the field line of origin. However, the number of nanojets found in this flare event greatly exceeds the previous cases, and the nanojets have larger energy releases up to the microflare range individually, both suggesting a correlation with the energy release of the event. The occurrence of the nanojets also coincides with the timing of the peaks in the GOES X-rays derivative, meaning that the heating signatures from the nanojets may be identifiable in the GOES X-rays. Such small and short-lived energy releases from nanojets that can only be detected with high-resolution observations indicate that there may still be many unresolved small-scale reconnection events that can potentially contribute significantly to the heating of the structure.

Detecting thermal and non-thermal emission in solar microflares using nested sampling

Kristopher Cooper, Iain Hannah, Lindsay Glesener, Brian Grefenstette

We use the Nuclear Spectroscopic Telescope Array (NuSTAR) to investigate very weak and highly frequent X-ray microflares that occur in active regions (ARs). NuSTAR is an astrophysical direct imaging X-ray telescope capable of observing the Sun with a unique sensitivity to emission >2.2 keV. Determining the emission mechanisms present in flares at weak scales can be difficult. We commonly find a weak but significant emission excess at higher energies after fitting an isothermal model to the spectrum, and it is sometimes unclear whether this excess is due to accelerated particles or flare-heated plasma. We employ a nested sampling algorithm to compute the parameter posterior distributions and the evidence of one model representing the excess with thermal emission and another with non-thermal emission. Calculating Bayes factor from these evidences, we are able to assess which emission mechanism is more likely to be responsible for the high-energy count excess visible in the isothermal spectral fit. We present spectral, spatial, and temporal analysis performed on several sub-A GOES class equivalent microflares that were observed with NuSTAR in November 2021. Along with EUV observations from the Solar Dynamics Observatory's Atmospheric Imaging Assembly, we utilise a Python spectral fitting tool, Sunkit-spex, to perform nested sampling analysis on the X-ray microflare spectra. In at least one example, we show there is significantly stronger evidence for the high energy count excess to be represented by non-thermal emission from flare accelerated electrons than by an additional hot thermal source (Cooper et al. 2024 MNRAS 529 1). Other 2021 November NuSTAR microflares at similar small scales either indicate the presence of particle acceleration as well or plasma temperatures up to ~ 10 MK.

Small-scale coronal EUV brightening produced by a magnetic tornado

Hidetaka Kuniyoshi, Souvik Bose, Takaaki Yokoyama

Alfvén waves are considered a promising mechanism for transferring magnetic energy for the solar coronal heating. Recent high-resolution simulations have revealed that impulsive Alfvén waves originating from intergranular lanes, commonly known as magnetic tornadoes, can contribute significantly to the energy transfer processes. Observationally, imprints of magnetic tornadoes, commonly referred to as swirls, are commonly observed between the photosphere and chromosphere, theoretically supported by magneto-convection simulations. However, understanding their response in the corona is still challenging due to a lack of robust theoretical support. Therefore, this study aims to synthesize the coronal emission from a magnetic tornado, as observed by the EUV 174A and AIA 171A channels, using a three-dimensional magneto-convection simulation modeling an entire coronal loop. Consequently, a small-scale (1,500 km) brightening occurs within a magnetic tornado located near the base of the corona (6,000 km above the surface). This brightening occurs independently of any interaction with other magnetic fields and is positioned just above a chromospheric swirl. This result shows an alternative candidate mechanism to produce the EUV small-scale brightenings called campfires.

Solar Orbiter/EUI Observations and a Bifrost MHD Simulation of Fine-scale Bright Dots in Emerging Flux Regions

Sanjiv K. Tiwari^{1,2}, *Viggo H. Hansteen*^{1,2,3,4}, *Bart De Pontieu*^{3,4}, *Navdeep K. Panesar*^{1,2}, *David Berghmans*⁵

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Observations with Solar Orbiter’s EUI/HRI of an emerging flux region (a coronal bright point) in 174Å, emitted by the coronal plasma at ~ 1 MK, reveals the presence of numerous tiny bright dots with a diameter of 675 ± 300 km, a lifetime of 50 ± 35 seconds, and an intensity enhancement of $30 \pm 10\%$ from their immediate surroundings. About half of the dots remain isolated during their evolution and move randomly and slowly (< 10 km/s). The other half show extensions, appearing as a small loop or surge/jet, with intensity propagations below 30 km/s.

Many of the bigger and brighter HRI dots are discernible in SDO/AIA 171 Å channel, have significant EM in the temperature range of 1–2 MK, and are often located at polarity inversion lines observed in HMI LOS magnetograms. Bifrost MHD simulations of an emerging flux region do show dots in synthetic Fe IX/X images, although dots in simulations are not as pervasive as in observations. The dots in simulations show distinct Doppler signatures – blueshifts and redshifts coexist, or a redshift of the order of 10 km/s is followed by a blueshift of similar or higher magnitude. We synthesized O V/VI lines [because these lines are covered in EUI/HRI passband] and Si IV line [to see how these dots would appear in IRIS observations], which both form in the transition region. These synthetic images also show the dots that are observed in Fe IX/X images, often expanded in size, or extended as a loop, and always with stronger Doppler velocities (up to 100 km/s) than that in Fe IX/X lines. Our results, together with the field geometry of dots in the simulations, suggest that most dots in emerging flux regions form in the lower solar atmosphere (at ~ 1 Mm) by magnetic reconnection between emerging and pre-existing/emerged

magnetic field. The dots are smaller in Fe IX/X images (than in O V/VI, and Si IV lines) most likely because only the hottest counterpart of the magnetic reconnection events is visible in the hotter emission. Some dots might be manifestations of magneto-acoustic shocks (driven from the lower atmosphere) through the line formation region of Fe IX/X emission.

Insights from Solar Orbiter's first Major Flare Watch

Sam Krucker Daniel Ryan Laura Hayes David Berghmans Cis Verbeeck

The Solar Orbiter Major Flare Watch executed around the perihelion in spring 2024 resulted in unprecedented observations of several M class flares with strong non-thermal components detected by Solar Orbiter/STIX. Solar Orbiter EUV/HRI captured these flares with the EUV 174A filter at a very fast time cadence of 2 s. The extremely short exposure time (0.04 s) made it possible avoiding saturation even in the brightest flare kernels. Besides the high time cadence, the HRI images provide information on spatial scales of a few hundred km revealing astonishing details not only from the main flare site, but also remote from the flaring active region. We will present results combining EUV and HXR images with soft X-ray imaging from Hinode/XRT focusing on the flare ribbon evolution. These new observations clearly demonstrate the importance of fast cadence for flare observation making it a key requirement for future space instrumentation.

Michalina Litwicka (University of Wrocław, Centre of Scientific Excellence – Solar and Stellar Activity)

Investigation of co-temporal IRIS and SolO/STIX observations of the solar flare.

Michalina Litwicka, Arkadiusz Berlicki, Petr Heinzel

STIX onboard Solar Orbiter (SolO) continuous observation since 2020 gives us access to high quality X-ray data. Together with IRIS UV spectrograph we are able to see solar flares in very broad spectral range which allows us to test some physics behind this events. One of the STIX's advantage is orbit around the Sun with distance much less than 1 AU for most of the time. At the same time it is challenging to find common flare observation with Earth-orbiting satellites. Since 2020 there was only a few months during which SolO observed the Sun from close-to-Earth perspective. We found couple of flares observed by SolO and IRIS, from which we chose two for further analysis. Using data from STIX, Full Sun Imager (FSI) from Extreme-UV Imager (EUI) onboard SolO, AIA (SDO) and IRIS we were able to study and compare emission during flare time in near-UV spectral range (Mg II h and k, IRIS), far-UV (Si IV, C II, IRIS), in extreme UV channels (SDO, FSI) and in X-ray emission (SolO, STIX), in the range of 4-150 keV. We located X-ray source on IRIS slit-jaw images, specified source size and its other parameters. Using OSPEX software we made spectral fitting using a standard combination of thermal (f_vth) and non-thermal (f_thick2) functions, in order to determine parameters referring to thermal and non-thermal spectrum component. Finally, we make first step in flare modeling using hybrid radiation-hydrodynamical, numerical code FLARIX, in order to calculate synthetic Mg II h and k spectra evolution and make comparison with IRIS Mg II h and k observation.

Session 12

July 25

16:00 – 17:05

Haruhisa Iijima (Institute for Space-Earth Environmental Research,
Nagoya University)

Linking solar magneto-convection and interplanetary space in realistic MHD simulations

Haruhisa Iijima

We will show recent advancements and related scientific topics of our comprehensive MHD simulations from the upper convection zone to the solar wind acceleration region. The supersonic plasma stream of solar wind is one of the steady backgrounds in interplanetary space. Although the small-scale dynamo and resultant MHD waves by the near-surface thermal convection have been believed to be a primary energetic origin of the solar wind, vast parameter space in the magnetic structure and the wave excitation/transport processes prevented us from understanding a quantitative picture of the Sun-to-Solar-Wind coupling. We have recently performed the first radiative MHD simulation that links solar near-surface magneto-convection and the formation and properties of resultant solar wind, using the numerical code RAMENS (Iijima et al., 2023, ApJL, 951, L47). This approach, which uses realistic simulation with minimum empirical parameters, is one of the possible ways to avoid the curse of dimensionality in modeling solar atmosphere. In this talk, we will present the latest findings on this topic, including the formation of solar coronal holes. We will also discuss a potential collaboration with the state-of-the-art and future instruments.

Evolution of the open flux extended from the sunspot groups during solar maximum

Minami Yoshida, Toshifumi Shimizu, Shin Toriumi, Haruhisa Iijima

The open magnetic flux extended from the photosphere produces the interplanetary magnetic field (IMF), and that of global structure changes over the solar cycle. The coronal magnetic field is mainly extended from the polar regions during the solar minimum, while complicated due to locally closed magnetic fields during the solar maximum. Understanding the evolution of open flux leads to understanding the structure of the background magnetic field in the heliosphere. One of the serious problems is the "open flux problem," in which the near-Earth magnetic field estimated from photospheric magnetic field observations is underestimated by a factor of 2-5 compared with in-situ observations in interplanetary space. The systematic bias in the polarimetric magnetic field observation was focused as one of the causes of this. As another idea, Yoshida et al. (2023) suggest that the low-latitude magnetic field in the photosphere is a main component of producing the IMF evolution.

In this study, we investigate how low-latitude active regions during the solar maximum contribute to the evolution of the open flux. We simulate the time evolution of photospheric and coronal magnetic structure from a bipolar magnetic group, using the surface flux transport model and the potential field source surface model. After inserting a new bipolar magnetic group, the open flux increases until 3-4 months later, depending on the sunspot tilt angle and the latitude of emergence. Further analysis shows that the simulated increase in open flux is produced by the equatorial magnetic dipoles, which are in turn formed by a largely tilted sunspot group sheared by the differential rotation. Further analysis is needed to understand the evolution of the sunspot as a primary source of the open flux.

Roger Scott (US Naval Research Laboratory)

Simulation of Thermal Nonequilibrium Cycles in the Solar Wind

Roger B. Scott; Jeffrey W. Reep; Mark G. Linton; Stephen J. Bradshaw

Thermal nonequilibrium (TNE) is a condition of the plasma in the solar corona in which the local rate of energy loss due to radiation increases to the point that it cannot be sustained by the various heating terms acting on the plasma, precluding the existence of a steady state. The limit cycles of precipitation and evaporation that result from TNE have been simulated in 1D models of coronal loops, as well as 2D and 3D models of the solar chromosphere and lower corona. However, a careful study of TNE in the solar wind has not been performed until now. Here we demonstrate that for suitable combinations of local and global heating rates it is possible for the plasma to exhibit a TNE condition, even in the context of a transonic solar wind with appreciable mass and energy fluxes. This implies limits on the amount of foot-point heating that can be withstood under steady-state conditions in the solar wind, and may help to explain the variability of solar wind streams that emanate from regions of highly concentrated magnetic flux on the solar surface. The implications of this finding pertain to various sources of high-density solar wind, including plumes that form above regions of mixed magnetic polarity in polar coronal holes and the slow solar wind (SSW) that emanates from coronal hole boundaries.

James Drake (University of Maryland, College Park)

Interchange magnetic reconnection as the driver of the fast solar wind

J. F. Drake, S. D. Bale, M. Swisdak and the PSP Science Team

The mechanism that drives the solar wind has been a topic of extensive scientific debate since the 1960's when the existence of the solar wind was confirmed with spacecraft observations. In its recent closest approaches to the sun the Parker Solar Probe (PSP) spacecraft is revealing wind structure not seen by spacecraft at 1AU. The bursty radial flows and associated local reversals of the radial magnetic field (switchbacks) exhibit a spatial periodicity that is linked to that of network magnetic field near the solar surface (Bale et al, 2021, 2023). The observations point to magnetic reconnection between open and closed magnetic flux in coronal holes (interchange reconnection) as the driver of these bursts. The corresponding enhancements in plasma pressure, wind speed, and energetic ions further suggest that interchange reconnection is the fundamental source of energy that drives the fast solar wind. We use the PSP data along with the basic characteristics of reconnection to deduce the local properties of interchange reconnection near the solar surface, including the characteristic strength of the reconnecting magnetic, the ambient density, the rate of reconnection and associated rate of energy release. An important conclusion of the analysis is that coronal interchange reconnection is in the collisionless regime and that the energy released by interchange reconnection is sufficient to drive the wind. Analytical estimates are supported by particle-in-cell simulations of interchange reconnection that establish that the structure of reconnection exhausts match PSP measurements. The spectra of energetic protons and alpha particles from the simulations, which take the form of powerlaws at high energy, also match the observations by the PSP. The bursty nature of interchange reconnection has implications for the development of the turbulence, including switchbacks, in the solar wind.

Session 13

July 26

8:30 – 10:10

Archival Investigations for the Extremity of the Solar Eruptions in the Past: Case Studies

Hisashi Hayakawa

Solar eruptions occasionally release considerable energy, launch geo-effective interplanetary coronal mass ejections, and trigger intense geomagnetic storms. It is important to study their extremity, as the modern civilization has accelerated dependency on technological infrastructure and vulnerability to such intense solar eruptions. However, it is challenging to quantify their extremity such as once-a-century events or once-a-millennium events, as our modern database covers only several decades. This presentation aims at improving this difficulty on the basis of archival investigations for historical records upon extreme solar storms in the past. This presentation first quantify the Carrington storm in 1859 to contextualize this storm with the modern studies in multiple aspects. This presentation also shows another extreme storm in 1872 and compares this with the Carrington storm. This presentation shows a potential for archival investigations to extend our scientific discussions to the extremity of the solar eruptions.

Ying Li (Purple Mountain Observatory)

The White-light Flares Observed by ASO-S/LST/WST, CHASE, and IRIS

Ying Li and the ASO-S team

Solar white-light flares (WLFs) are a special kind of flares showing an enhancement in the optical continuum. Since the first WLF (i.e., the Carrington event) reported in 1859, there have been a large number of studies on WLFs by using the observational data from ground- and space-based telescopes. In the presentation, I will talk about the very recent two-year studies of WLFs observed by two Chinese space missions — the Advanced Space-based Solar Observatory (ASO-S) and the Chinese H α Solar Explorer (CHASE). Their joint observations with IRIS and some preliminary analyses on WLFs are also presented.

Observational Analysis of Lyman-alpha Emission in Equivalent Magnitude Solar Flares

Harry J. Grotorex, Ryan O. Milligan, Phillip C. Chamberlin

The significant intensity of Lyman-alpha ($\text{Ly}\alpha$; 1216 Å) emission in the solar spectrum makes it a crucial component to our understanding of the energy transport processes in solar flares. Despite this, observations of short-term variability in the Sun's irradiance at $\text{Ly}\alpha$ wavelengths have been scarce until relatively recently. Milligan et al. (2020) and Milligan (2021) showed that the energy radiated in $\text{Ly}\alpha$ and the corresponding flux enhancement both tend to increase with flare magnitude, respectively. However, we hypothesise that a more fundamental driver may be responsible for the variability in $\text{Ly}\alpha$ flux rather than the flare magnitude alone. Here we present observational analysis of three M3 flares that were co-observed by RHESSI, GOES, and SDO, which despite their equivalent magnitudes showed distinctly different $\text{Ly}\alpha$ responses. The peak $\text{Ly}\alpha$ enhancements above quiescent background for these flares were 1.5%, 3.3%, and 6.4%. However, the predicted $\text{Ly}\alpha$ enhancements from FISM2 were consistently $<2.5\%$. Deriving the properties of the nonthermal electrons from HXR spectroscopy, it was found that flares with a 'harder' spectral index tended to produce a greater enhancement in $\text{Ly}\alpha$. The percentage of nonthermal energy radiated by the $\text{Ly}\alpha$ line during the impulsive phase was found to range from 2.0–7.9%. Comparatively, the radiative losses in He II (304 Å) were found to range from 0.6–1.4% of the nonthermal energy while displaying enhancements above the background of 7.3–10.8%. FISM2 was also found to underestimate the level of He II emission in two out of the three flares. With new generation $\text{Ly}\alpha$ instruments onboard present and upcoming missions, the results from this study may guide the interpretation of future $\text{Ly}\alpha$ observations of flares in Solar Cycle 25.

Statistical study to classify the occurrence of Balmer continuum enhancements in white light flares

Pranjali Sharma, Lucia Kleint, Jonas Zbinden

So-called White Light Flares (WLFs) show enhancements in the visible spectrum with respect to the black-body curve. IRIS has also found enhancements in the NUV spectral region, indicating an enhanced Balmer continuum. Statistical studies using imaging instruments have shown such enhancements to occur commonly, but what causes these enhancements is still a matter of debate, despite significant efforts in the field. Although simulations of individual flare events may offer a valuable understanding of particle energy and penetration depth, the examination of numerous flares can provide better constraints and probe the energy transfer process.

We perform a statistical study using IRIS NUV spectral data to classify the occurrence of Balmer continuum enhancements. We use Gaussian process regression (GPR) to detect continuum intensities that are more than 4 sigma above the mean level. These “outliers” are then marked as NUV continuum enhancements. Our findings indicate that most of the enhanced pixels are located on the flare ribbon. Higher energy flares exhibit greater enhancement and a larger enhancement area. Our next step will be to simulate the NUV spectra of flares using the RH code (Uitenbroek 2001) and to provide constraints on the energy transport mechanism for WLFs.

Spectral Observations and Modeling of a Solar White-light Flare Observed by CHASE

De-Chao Song, Jun Tian, Y. Li, M. D. Ding, Yang Su, Sijie Yu, Jie Hong, Ye Qiu, Shihao Rao, Xiaofeng Liu, Qiao Li, Xingyao Chen, Chuan Li, and Cheng Fang

The heating mechanisms of solar white-light flares remain unclear. We present an X1.0 white-light flare on 2022 October 2 (SOL2022-10-02T20:25) observed by the Chinese H α Solar Explorer that provides two-dimensional spectra in the visible light for the full solar disk with a seeing-free condition. The flare shows a prominent enhancement of $\sim 40\%$ in the photospheric Fe I line at 6569.2 Å, and the nearby continuum also exhibits a maximum enhancement of $\sim 40\%$. For the continuum near the Fe I line at 6173 Å from the Helioseismic and Magnetic Imager on board the Solar Dynamics Observatory, it is enhanced up to $\sim 20\%$. At the white-light kernels, the Fe I line at 6569.2 Å has a symmetric Gaussian profile that is still in absorption and the H α line at 6562.8 Å displays a very broad emission profile with a central reversal plus a red or blue asymmetry. The white-light kernels are cospatial with the microwave footpoint sources observed by the Expanded Owens Valley Solar Array and the time profile of the white-light emission matches that of the hard X-ray emission above 30 keV from the Gamma-ray Burst Monitor (GBM) on Fermi. These facts indicate that the white-light emission is qualitatively related to a nonthermal electron beam. We also perform a radiative hydrodynamic simulation with the electron-beam parameters constrained by the hard X-ray observations from Fermi/GBM. The result reveals that the white-light enhancement cannot be well explained by a pure electron-beam heating together with its induced radiative backwarming but may need additional heating sources such as Alfvén waves.

Peter Young (NASA Goddard Space Flight Center)

The Temperature and Density of a Solar Flare Kernel Measured from Extreme Ultraviolet Lines of O IV

Peter R. Young

Previously-unexplored diagnostics of O IV in the extreme ultraviolet region 260-280 Å are used to derive a temperature and density for a solar flare kernel observed on 2012 March 9 with the Extreme ultraviolet Imaging Spectrometer on the Hinode satellite. Seven lines from the $2s\ 2p^2 - 2s\ 2p\ 3s$ transition array between 271.99 and 272.31 Å are both temperature and density sensitive relative to the line at 279.93 Å. The temperature, T , is constrained with the 268.02/279.93 ratio, giving a value of $\log(T/K) = 5.10 \pm 0.03$. The ratio 272.13/279.93 then yields an electron number density, N_e , of $\log(N_e/\text{cm}^{-3}) = 12.55$ with a lower limit of 11.91, and an upper limit of 14.40. The O IV emitting volume is estimated to be 0.4 arcsec (300 km) across. Additional O IV lines at 196, 207 and 260 Å are consistent with the derived temperature and density but have larger uncertainties from the radiometric calibration and blending. Density diagnostics of O V and Mg VII from the same spectrum are consistent with a constant pressure of $10^{17.0}$ K cm^{-3} through the transition region. The temperature derived from O IV supports recent results that O IV is formed around 0.15 dex lower at high densities compared to standard "zero-density" ionization balance calculations. The possibility for observing the O IV diagnostics with the Multi-Slit Solar Explorer (MUSE) will be discussed.

Session 14

July 26

11:00 – 12:20

Daikou Shiota (National Institute of Information and Communications
Technology (NICT))

Hinode observation of long-term variation of magnetic fields in the Sun's polar regions during Cycle 24-25

D. Shiota^{1,2} *M. Kubo*³ *Y. Katsukawa*³ *M. Shimojo*³ *H. Iijima*² *T. Matsumoto*² *S.
Masuda*²

- 1. National Institute of Information and Communications Technology, Japan*
- 2. Institute for Space-Earth Environmental Research, Nagoya University, Japan*
- 3. National Astronomical Observatory of Japan, Japan*

Observations of the magnetic fields in the Sun's polar regions are known to be very important for understanding the long-term variation of the solar magnetism. Furthermore fast solar wind emanates from the large coronal holes formed in polar regions around solar minima. The understanding the fluctuation of the solar polar magnetic field is also an important element for improving the accuracy of space weather forecasts.

The first Hinode observation of the polar region reveals the fine structure of photospheric vector magnetic fields of the polar areas: the existence of many patchy magnetic concentrations with intrinsic field strengths of over 1 kG distributed across the entire polar region (Tsuneta et al. 2008) around the solar minimum. Following the first polar observation, the monitoring of the polar regions has been continued for 17 years. Since 2012, the monitoring of the whole polar regions has begun as HOP 206: Periodic SP observations during a month at the proper timing (March for the south pole and September for the north pole). The monitoring covers the period longer than one solar cycle and revealed that the distributions of large magnetic patches show variations associated with the solar activity cycle while small magnetic patches do not change as shown in the previous study (Shiota et al 2012).

In this study, we present Hinode observation of long-term variation of magnetic fields in both Sun's polar regions. Since the beginning of Cycle 25 in December 2019, the Sun becomes more active toward the maximum, which is expected to reach in 2025. At the same time, the polarity reversal of the magnetic fields of both the Sun's polar regions seems to rapidly proceed in HMI observation. Hinode observation revealed that in the South polar region magnetic fields also are rapidly weakening but still keep the same negative polarity in March 2024 and therefore the polarity reversal process has not yet finished.

Nariaki Nitta (Lockheed Martin Advanced Technology Center)

The Behavior of the Magnetic Field in Sun's High-latitude Regions

Nariaki Nitta, Rebecca Centeno, Yang Liu, Jon Linker

The line-of-sight magnetograms from SDO/HMI suggest the difficulty of determining if and when the polar magnetic field has reversed or will reverse during solar cycle 25, depending on the definition of the polar regions. We compare vector magnetic field measurements of the polar regions by Hinode/SOT and HMI over a period that encompasses solar cycles 24 and 25 and discuss the realistic uncertainties in the magnetic flux from the polar regions. In addition, using SDO/AIA data, the frequency of brightenings is studied in various latitudinal zones above 60 degrees up to the poles. A large subset of these brightenings, which may or may not accompany coronal jets, are thought to result from reconnection of magnetic field elements of prevailing polarity of either pole with those of the opposite polarity that are expected to increase as we approach the solar maximum. We discuss implications of this study in the so-called open magnetic flux problem and possible improvement of heliospheric numerical models.

Kai Yang (University of Hawaii at Manoa)

A New Disambiguation Method Based on Physics-Informed Machine Learning

Kai E. Yang, Lucas A. Tarr, Matthias Rempel, Curt Dodds, Sarah A. Jaeggli, Peter Sadowski, Thomas A. Schad, Xudong Sun, Ian Cunnyngham, Jiayi Liu, Yannik Glaser

The spectropolarimetric inversion of vector magnetic fields faces a well-known problem of 180-degree ambiguity in the azimuth angle. Traditionally, this challenge is tackled by minimizing a target function, such as the divergence of the magnetic field within a single layer. We introduce a novel approach using Physics-Informed Machine Learning to solve the divergence-free equation of the magnetic field across multiple optical depth layers, while simultaneously estimating the geometric heights of these layers. Our approach has been tested on magnetohydrodynamic simulations of both quiet-Sun and plage regions, effectively recovering the horizontal field orientation on pixels with strong magnetic fields. By integrating the vector magnetic field with the estimated geometric heights, our method can reconstruct the three-dimensional vector electric currents in the solar photosphere.

Magnetic and electric field structures at the X point of an Ellerman bomb II

Tetsu Anan (NSO), Roberto Casini (HAO), Han Uitenbroek (NSO), Héctor Socas-Navarro (IAC), Tom Schad (NSO), Jeffrey Reep (UH), Sanjiv Tiwari (LMSAL), Jiong Qiu (Montana State U.), Kiyoshi Ichimoto (Ritsumeikan U.), Sarah Jaeggli (NSO), Yukio Katsukawa (NAOJ), Ayumi Asai (Kyoto U.), Kevin Reardon (NSO), Alexandra Tritschler (NSO), Friedrich Wöger (NSO), Thomas Rimmele (NSO)

Magnetic reconnection in the solar atmosphere can release stored magnetic energy efficiently into the solar atmosphere and the heliosphere. In order to explain the high efficiency, various reconnection models have been proposed. Direct measurements of magnetic and electric field structures at or around a reconnection X point where the magnetic fields reconnect would enable us to determine which reconnection models work. Using the newly commissioned National Science Foundation's Daniel K. Inouye Solar Telescope (DKIST), we observed NOAA active region 12995 on February 23rd, 2022, in the Ca II H 397 nm, Fe I 630.15 nm, Fe I 630.25 nm, and Ca II 854 nm lines using the Visible SpectroPolarimeter (ViSP) together with blue continuum imaging with the Visible Broadband Imager (VBI). We successfully obtained Stokes spectra of Ellerman bombs, which are brightenings in the lower chromosphere and are thought to be associated with magnetic reconnection. We applied Departure coefficient aided Stokes Inversion based on Response function (DeSIRe, Ruiz Cobo et al. 2022) to the Stokes spectra of the four lines at the Ellerman bomb. As a result, it is revealed that the inferred line-of-sight component of the magnetic field strongly varies along the line-of-sight, so that It has at least 3 or 4 peaks. Moreover, at the Ellerman bomb, we discovered a broadband circular polarization in a Balmer line of the neutral hydrogen at 397 nm, H epsilon, that can only be explained by the presence of an external electric field. In this presentation, we will discuss the magnetic diffusivity derived from the measured electric field and the electric current.

Unraveling the stratification of the chromospheric magnetic field using the H α line

Harsh Mathur¹, K. Nagaraju¹, Rahul Yadav², Jayant Joshi¹

1. Indian Institute of Astrophysics, II Block, Koramangala, Bengaluru 560 034, India

2. Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80303, USA

The H α line is widely utilized for studying the solar chromosphere, but there is a scarcity of polarimetric studies aimed at inferring magnetic fields. One of the many reasons could be that there are no theoretical polarimetric studies of the H α line utilizing 3-D radiative transfer, and earlier 1-D radiative transfer studies suggested a significant contribution of the photospheric fields in the Stokes V profiles. In our recently published work, Mathur et al. 2023, using spectropolarimetric data of a pore simultaneously recorded in the H α and Ca II 8542 Å lines, we investigated the potential of H α Stokes V profiles in determining chromospheric magnetic fields. Our findings suggested that the line core of the H α line probes the chromospheric magnetic field. However, the previous study was limited to a small pore. In this study, we inferred the stratification of the chromospheric magnetic field by using spectropolarimetric observations of an active region recorded simultaneously in the H α and Ca II 8662 Å lines. The sunspot exhibits multiple structures, viz., four umbras, a lightbridge, and a region where Ca II 8662 Å line core is in emission. The H α line core image also displays brightening in the emission region, a signature of localized heating, with the spectral profiles showing elevated line cores. Consistent with Mathur et al. 2023, we found that the magnetic field inferred from the H α line core is consistently smaller than that inferred from inversions of the Ca II 8662 Å line at $\log \tau_{500} = -4.5$; however, in contrast with Mathur et al. 2023, uncorrelated. The field strength and morphology inferred in the heating region from the inversions at $\log \tau_{500} = -4.5$ is comparable to that at $\log \tau_{500} = -1$. There is also a good agreement with the field strengths at $\log \tau_{500} = -1$ with that inferred from WFA over H α full spectral range, except in the heating region. In addition, the fields inferred in the heating region from the WFA over H α line core and full spectral range are similar in strengths and morphology. Thus, we suggest that the line core of the H α line consistently probes the chromospheric magnetic field at higher heights than that

probed by the Ca II IR triplet. In heating events, the full H α line becomes sensitive to the chromospheric magnetic field instead of just the line core. Consequently, the H α line spectropolarimetry is a valuable diagnostic for studying the chromosphere, especially in regions with localized heating, where the Ca II IR triplet lines probe deeper layers of the solar atmosphere.

Session 15

July 26

13:30 – 14:50

High-cadence IRIS solar flare imaging and spectroscopy: recent advances and open questions

Juraj Lorincik

High cadence flare campaigns of the Interface Region Imaging Spectrograph (IRIS) opened new windows for studying rapid processes characteristic for flare energy release. Prime example of instrument's capabilities has been recently set in our imaging and spectroscopic analyses of a confined C4-class flare from 2022 September 25. Using < 2 s cadence imagery from the Slit Jaw Imager, we for the first time revealed flare ribbon kernels exhibiting motions at speeds reaching thousands of kilometers per second. These dynamics are consistent with the slip-running reconnection in quasi-separatrix layers, a phenomenon elusive in observations for nearly two decades. Emission of these kernels was further investigated in our follow-up spectroscopic study focused on the response of the chromospheric and transition region plasma to the energy deposition at sub-second timescales. Intensities of Si IV, C II, and Mg II k lines exhibited enhancements with varying peak times across the ions, with the transition region Si IV enhancements typically preceding those in Mg II by a few seconds. In order to replicate these delays, we investigated a grid of RADYN flare simulations heated by electron beams, thermal conduction, and Alfvén waves. Electron beam parameters were constrained by non-thermal hard X-ray observations of the Gamma-ray Burst Monitor (GBM) of the Fermi spacecraft. Our imaging and spectroscopic studies provide comprehensive insights into the dynamics and energetics of solar flares, validating long-unaddressed theoretical predictions as well as challenging current generation of flare emission models.

Identification of chromospheric dynamical signatures in solar flares with the Daniel K. Inouye Solar Telescope

Spencer Riley

With the emergence of new high-resolution, high-cadence spectral data from the Daniel K. Inouye Solar Telescope, we can probe solar flare energetics and dynamics in the chromosphere on unprecedented small scales. We utilize available Ca II 854.2 nm spectral data to diagnose the dynamics of the flaring chromosphere. In addition, we co-aligned AIA 1600 with DKIST observations to provide a history of localized heating in the vicinity of the spectral measurements. The aim is to characterize tens of thousands of spectra from a 27 December 2022 C4 solar flare into groups of similar spectral features via a hierarchical k-means algorithm and investigate how the spectral features vary during different stages of the localized heating events defined by AIA 1600 lightcurves. We find that within a sixty-minute interval centered on the spectral observations, there are strong populations of double-peaked spectral groups in the early gradual phase of the localized heating. While red-enhanced asymmetric spectral groups have strong populations in the later gradual phase and the pre-heating phase.

A Multi-wavelength Investigation of Quasi-periodic Pulsations an M4.2 Flare: Insights from High-Cadence and High-Resolution Observations

William Ashfield, Vanessa Polito, Souvik Bose, Jonas Thoen Faber, Reetika Joshi, Juraj Lörinčík, and Alberto Sainz Dalda

The response of the lower solar atmosphere during flares is fundamental to understanding flare energy release. As ribbon emission ultimately stems from energy transported from the reconnection site, the characteristic signatures of spectral lines in the chromosphere and transition region offer insight into the energy release process. Here, we present an analysis of such signatures during the 05-03-2023 M4.2-class flare, the first in a series of rapid flares produced from AR13293. Utilizing very high-cadence (1s) observations from the Interface Region Imaging Spectrograph (IRIS), we detect quasi-periodic pulsations (QPPs) in the Si IV and Mg II spectral lines on the order of 20s. A similar periodicity was found in the GOES SXR light curve derivative and HXRs measured by Fermi/GBM, indicating a common driver between the responses. Coordinated observations taken with the CHROMospheric Imaging Spectrometer (CHROMIS) at the Swedish 1m Solar Telescope (SST) provided complimentary, high-spatial-resolution images and spectra of Ca II K ($\sim 0.038''/\text{px}$), where the overall response was found to be similar to that of the IRIS spectra. The multi-wavelength probe of flare ribbon dynamics in this work reveals oscillatory behavior across several atmospheric layers, ranging from the photosphere to the corona, providing a unique insight into the interrelation between energy release signatures.

Investigation of Quasi-periodic pulsations (QPPs) in solar flares

Sargam Mulay, Lyndsay Fletcher, Rahul Sharma

Solar flares are explosive energetic events that produce radiative signatures at all layers of the solar atmosphere. Quasi-periodic pulsations (QPPs) are the most commonly observed phenomena in solar flares exhibiting periodic fluctuations in the observed radiation. Our research aims to carry out a systematic investigation of quasi-periodic pulsations in M7.3 class solar flare ribbons and study their height-wise distribution using various low and high-temperature UV spectral lines observed by the Interface Region Imaging Spectrograph (IRIS). The time series analysis of GOES soft X-rays and RHESSI hard X-rays revealed multiple conspicuous oscillatory patterns during the impulsive phase of the flare. At the same time, the IRIS UV spectral images showed sawtooth pattern intensity fluctuations in space as the ribbon sweeps the slit with time. Small-scale substructures at various locations within the ribbon are tracked in Slit-Jaw images and the time series analysis showed the oscillatory patterns with characteristic periods. The non-linear and non-stationary properties of QPPs observed along the flare ribbons in various time series were studied thoroughly using the Empirical Mode Decomposition (EMD) and the results confirmed the existence of multi-periodic regimes. Combining data from various observatories facilitated us to study the role of QPPs in flare energy release at various heights in the solar atmosphere and study their relationship with the plasma properties such as Doppler and Non-thermal velocities obtained for the stationary and moving components of spectral lines.

Yang Su (Purple Mountain Observatory, Chinese Academy of Sciences,
China)

The early results of ASO-S/HXI

Yang Su et al.

The Hard X-ray Imager (HXI) on board the Advanced Space-based Solar Observatory (ASO-S) has observed more than 500 solar X-ray bursts in the energy range of ~ 15 -300 keV, with a spatial resolution as high as 3.1 arcsec and a time resolution as high as 0.125 s in burst mode. The reconstructed images reveal interesting features of hard X-ray sources in flares. In this talk, a brief introduction on HXI will be presented first, followed by some early results, including (1) origin of flare QPPs revealed by detailed HXR source motions; (2) the possible coronal origin of flare-related SEP electron event revealed by joint observations of HXI, Solar Orbiter/STIX, and WIND; (3) new details of acceleration process in flares HXR fine structures above the looptop; (4) 3D HXR imaging with HXI and STIX. More related studies will also be briefly introduced.

Session 16

July 26

16:00 – 17:30

Noriyuki Narukage (National Astronomical Observatory of Japan)

Initial results of solar flare observing sounding rocket FOXSI-4

Noriyuki Narukage, Lindsay Glesener, Kazuki Ampuku, Yumi Bamba, Wayne Baumgartner, Stephen Bongiorno, Juan Camilo Buitrago-Casas, Patrick R. Champey, Steven Christe, Kristopher Cooper, Sasha Courtade, Tamar Ervin, Ryuto Fujii, Tadashi Hirose, Hunter Kanninen, Sota Kashima, Sam Krucker, Kanya Kusano, Juan Carlos Martinez Oliveros, Takahiro Minami, Ikuyuki Mitsuishi, Shunsaku Nagasawa, Athanasios Pantazides, Eliad Peretz, Savannah Perez Piel, Orlando Romeo, Taro Sakao, Koki Sakuta, Yoshiaki Sato, Sabrina Savage, Riko Shimizu, Daniel Ryan, Tadayuki Takahashi, Juliana Therese Vievering, Shin Watanabe, Yusuke Yoshida, Yixian Zhang, Flare Campaign Team and Hi-C FLARE team

On April 17, 2024, two sounding rockets, FOXSI-4 and Hi-C FLARE, were launched and successfully observed an M-class solar flare.

FOXSI-4 (4th flight of the Focusing Optics X-ray Solar Imager) has realized the world's first X-ray focusing imaging spectroscopic observation of a solar flare with seven pairs of high-precision electroformed Wolter type I mirrors and high-speed X-ray cameras, which enable photon-counting type measurements from soft to hard X-ray ranges. In this observation, each X-ray photon emitted from a solar flare was individually measured. Thus, the entire solar flare region can be investigated with spatial, temporal, and energy resolution. FOXSI-4 has detected at least 10 million photons in the soft X-ray range (up to 10 keV), from which we can investigate the spatial distribution and temporal evolution of the temperature and density of the flaring plasmas. In the hard X-ray range (up to 20 keV), at least 10 thousand photons have been detected, which is expected to enable the investigation of the behavior of high-energy electrons.

For this solar flare observation with sounding rockets whose observation time is limited to 5 minutes (called a "Solar Flare Sounding Rocket Campaign"), we have established a method of launching rockets shortly after the onset of a large flare using real-time monitoring of solar activity in X-rays and EUV light and flare size prediction based on the photospheric magnetic field data and a kappa-scheme.

Coordinating observation with the Hinode satellite was also conducted in this solar flare campaign.

In this talk, the initial results of FOXSI-4 will be introduced, along with a brief summary of FOXSI-4 instruments, flare campaign, and coordinate observation with Hi-C FLARE and Hinode satellite.

First Results from the Hi-C Flare Sounding Rocket Flight

Sabrina Savage, on behalf of the Hi-C Flare team

The Hi-resolution Coronal imager Flare (Hi-C Flare) sounding rocket mission launched on 2024 April 17 from the Poker Flat Research Range in Alaska. Hi-C Flare launched within 60s of the Focusing Optics Solar X-ray Imager (FOXSI-4) launch as part of the pioneering solar flare sounding rocket campaign. The two payloads captured observations of an M1.6 flaring event in progress. Hi-C Flare observed the extended phase of the event with a high-resolution, low-noise extreme ultraviolet (12.9 nm) imager and EUV slitless spectrometer combined with soft X-ray imaging and high cadence flux measurements. Previous flights of Hi-C have provided groundbreaking insights into small-scale energetics occurring in the corona. The flare campaign provided the unique opportunity to test Hi-C configured for high-temperature observations along with newly-developed, flare-optimized instrumentation to probe flare energy release. We will present the first results from this payload suite in conjunction with coordinated observations from the companion FOXSI-4 flight.

Amir Caspi (Southwest Research Institute)

The CubeSat Imaging X-ray Solar Spectrometer (CubIXSS): science and current status of implementation for a new mission to understand heating of coronal plasma

Amir Caspi, P.S. Athiray, Will Barnes, Mark Cheung, Craig DeForest, Szymon Gburek, J. Marcus Hughes, Viliam Klein, James A. Klimchuk, Mirosław Kowaliński, Glenn T. Laurent, James P. Mason, Biswajit Mondal, Tomasz Mrozek, Scott E. Palo, Jacob D. Parker, Bennet Schwab, Mark Schattenburg, Daniel B. Seaton, Albert Y. Shih, Marek Steślicki, Janusz Sylwester, Harry P. Warren, Thomas N. Woods, and the CubIXSS Team

The CubeSat Imaging X-ray Solar Spectrometer (CubIXSS) is a 16U CubeSat funded under NASA H-FORT. CubIXSS is motivated by a compelling overarching science question: what are the origins of hot plasma in solar flares and active regions? CubIXSS addresses its science question through sensitive, precise measurements of abundances of key trace ion species, which are a unique diagnostic of how mass and energy flow into and within the corona, and whose spectral signatures thus reveal the chromospheric or coronal origins of heated plasma across the entire temperature range from ~ 1 to >30 MK. CubIXSS measurements of the coronal temperature distribution and elemental abundances directly address longstanding inconsistencies from prior studies using instruments with limited, differing temperature and composition sensitivities.

CubIXSS comprises two co-optimized and cross-calibrated instruments that fill a critical observational gap:

- * MOXSI, a novel diffractive spectral imager using a pinhole camera and X-ray transmission diffraction grating for spectroscopy of flares and active regions over an unprecedented spectral range of 1 to >70 Å; and

- * SASS, a suite of four spatially-integrated off-the-shelf spectrometers for high-cadence, high-sensitivity X-ray spectra of lines and continuum from 0.5 to >30 keV.

CubIXSS is currently in Phase C/D (implementation) and plans to launch in late 2025 to observe intense solar flares and active regions during the peak of the solar cycle. Its 1-year prime mission is well timed with perihelia of Parker Solar Probe and Solar Orbiter, and with the launches of complementary missions such as SunCET and

PUNCH. CubIXSS is a pathfinder for the next generation of Explorer-class missions with improved capabilities for SXR imaging spectroscopy.

We present the CubIXSS motivating science background, its suite of instruments and expected performances, and its current implementation status and projected outlook for the mission, as well as additional planned developments including novel analysis techniques to fully exploit the rich data set of CubIXSS spectral observations.

Hirohisa Hara (National Astronomical Observatory of Japan)

The SOLAR-C Mission: a progress report of the design and development

H. Hara (NAOJ) and the SOLAR-C team

This talk will provide a brief overview of the progress of the SOLAR-C mission. SOLAR-C is a JAXA-led mission in collaboration with multiple organizations of NASA, ASI, CNES, DLR, SSO, and ESA for launch in FY2028. Since March 2024, the SOLAR-C program has become a JAXA Project, upgraded from Phase A in the Pre-Project status and is in Phase B. The satellite carries the EUV high-throughput Spectroscopic Telescope (EUVST), which consists of an EUV imaging spectrograph and a slit-jaw imager. The high-sensitivity spectrograph with a field of view of 280 arcsec squares will observe the solar atmosphere from the chromosphere up to the corona with a seamless temperature coverage by multiple EUV bands in the wavelength range of 17–123 nm and a high spatial resolution of 0.4". The slit-jaw imager will provide similar high-resolution photospheric/chromospheric imaging data not only for playing a role in locating the spectrograph's slit position on the Sun for the co-alignment to the other dataset but also for monitoring and investigating the photospheric/chromospheric solar activity. An EUV spectral irradiance monitor assembled to the EUVST external surface will monitor the whole Sun in two EUVST wavelength bands to watch the solar activity influencing the Earth's atmosphere and cross-calibrate the spectrograph throughput. The SOLAR-C spectral and imaging diagnostics will provide powerful tools to access the fundamental physical processes for achieving the primary SOLAR-C science goals. Coordinating with the MUSE to enable high-cadence spatial coverage, in addition to large-aperture ground-based observatories to include high-resolution magnetic fields, will synergistically enhance the SOLAR-C scientific outcomes.

The Daniel K. Inouye Solar Telescope: update and first results

G. Cauzzi on behalf of the DKIST Team

The 4-m, National Science Foundation Daniel K. Inouye Solar Telescope (DKIST) is the most advanced and largest solar telescope currently operating, opening new diagnostic windows into solar magnetism at unprecedented resolutions. Science operation started in 2022, providing observations for both PI-led proposals and community programs; much of this data is now publicly available through the DKIST Data Center.

In this talk, I will present a brief update on the status of the telescope and its instruments, as well as current science operations and first results, with an emphasis on investigations of magnetism and structure of the outer solar atmosphere.

Bart De Pontieu (Lockheed Martin Solar & Astrophysics Laboratory)

Status of MUSE

B. De Pontieu and MUSE team

In this talk I will provide a status update of the development of the upcoming Multi-slit Solar Explorer (MUSE) mission, which is scheduled for launch in 2027. MUSE is a NASA MIDEX mission, composed of a multi-slit EUV spectrograph (in three narrow spectral bands centered around 171Å, 284Å, and 108Å) and an EUV context imager (in two narrow passbands around 195Å and 304Å). MUSE will provide spectral and imaging diagnostics of the solar corona at high spatial (~ 0.5 arcseconds), and temporal resolution (down to ~ 0.5 seconds) thanks to its innovative multi-slit design. By obtaining spectra in 4 bright EUV lines (Fe IX 171Å, Fe XV 284Å, Fe XIX-XXI 108Å) covering a wide range of transition region and coronal temperatures along 35 slits simultaneously, MUSE will be able to “freeze” (at a cadence as short as 10 seconds) with a spectroscopic raster the evolution of the dynamic coronal plasma over a wide range of scales: from the spatial scales on which energy is released (< 0.5 arcsec) to the large-scale often active-region size (~ 170 arcsec x 170 arcsec) atmospheric response. The MUSE science investigation is highly synergistic with that of Solar-C/EUVST and coordination with EUVST will be a key priority for MUSE. I will provide an update on the status of MUSE including the preliminary design review (PDR) in March 2024 and the key-decision point (KDP-C) review in May 2024.

Poster Presentations

Analysis of Longitudinal Spread of Suprathermal Ions Co-Located with Coronal Mass Ejections

Abby High, Rachael J. Filwett, Robert Allen, Maher A. Dayeh, Gang Li.

The IS \odot IS instrument onboard the Parker Solar Probe is a vital tool being used to analyze the energies and abundances of solar energetic particles (SEPs) as well as their characteristics and behavior. In this study, we examine hydrogen, carbon, oxygen, and iron ions. The dates being studied are Event 2020-335, 2021-148, 2021-325, 2022-266. This investigation, analyzing gradual SEP events, aims to observe the evolution and dynamics of these distinct solar particle events. In addition to the observations from the Parker Solar Probe, the investigation will incorporate data from complementary missions. The ACE Ultra-Low Energy Isotope Spectrometer (ULEIS) instrument and STEREO-A's Suprathermal Ion Telescope (SIT) package will aid in combining data from multiple sources to seek a comprehensive insight into these events. The data acquired from these missions will provide insight into the complex processes governing gradual SEP events. Our focus during this study will be the examination of the time-intensity profiles for these heavy ions, showing their relative intensity and arrival time similarities and disparities. This analysis will highlight the transport and acceleration phenomena experienced by these ions.

Akie Moritsuka (The University of Tokyo/National Astronomy
Observatory of Japan)

Bisector velocities of the photospheric line near the limb observed with Hinode SOT/SP

Akie Moritsuka, Yukio Katsukawa, Ryohtaroh T. Ishikawa

Bisector velocities of photospheric lines show significant center-to-limb variation: they have a C-shape with a blueshift at the line core while they become a shape with a redshift at the line core toward the limb. Although the bisector velocities are known to reflect the corrugated 3-dimensional structure of the granular convection, it is poorly known how the bisector velocities change very close to the limb because it has been difficult to achieve high spectral resolution with spatial resolution enough to resolve the granular convection. The purpose of this study is to improve our understanding of the 3-dimensional structure of the granular convection based on bisector analysis of high-resolution spectroscopic data obtained with Hinode SOT/SP. We analyzed the bisector velocities of the Fe I 630.15 nm line very close to the limb in the polar regions and found that the bisector velocities of granules show changes from a shape with a blueshift to an I-shape with a redshift from 60 degrees to 89 degrees in the heliocentric angles. On the other hand, the bisector velocities of intergranules remained an I-shape with a redshift at the line core. The shape of the granules can be interpreted as a large velocity gradient in a thicker line formation height, while the I-shape of the intergranules is due to a thinner formation height. Because bright areas in the photosphere were considered as the granules in our analysis, the decrease of the blueshift in the granules toward the limb may be caused by the redshifts of the horizontal flow appearing brighter.

Kathy Reeves (Harvard-Smithsonian Center for Astrophysics)

XRT Mission-Long Flare Statistics

Kathy Reeves and Joy Velasquez

In this presentation, we will explore the mission-long flare observations by Hinode XRT. We use the data in the XRT flare catalog (https://xrt.cfa.harvard.edu/flare_catalog/) and provide statistics for how many C, M, and X flares were captured by XRT. We will also explore which locations on the Sun are most likely to produce flares imaged by XRT, and document the reasons for missing flares. These results will be useful for planning XRT observations as we move into the maximum of solar cycle 25.

Revisiting the RHESSI X-ray Microflare Statistics

Iain Hannah, Kate Barton

RHESSI observed 10,000s of X-ray microflares (i.e. A, B-class flares) finding similar behaviour as found in larger flares: active region flares with hard X-rays from accelerated non-thermal electrons as well as hot thermal X-ray emission (Christe et al. 2008, Hannah et al. 2008). Spectral analysis of these events (covering 2005-2007) managed to determine the thermal and non-thermal energetics of each microflare, how their properties related and the overall flare frequency distributions. Here we revisit the spectral analysis of those RHESSI microflares, investigating their X-ray spectra in the context of updated models - non-thermal (using thick and warm target models instead of photon-space broken power-laws) and thermal (using CHIANTI v10.1, instead of v5.2) - determining the properties and energetics of these microflares. This has been done not only using OSPEX/SSWIDL (as was done in the original analysis) but also in the new Python package `sunkit-spex` (<https://github.com/sunpy/sunkit-spex>), with comparison made between the two. This work is also put in the context of more recent X-ray microflare observations from instruments like NuSTAR and STIX on Solar Orbiter.

Paola Testa (Smithsonian Astrophysical Observatory)

**Coronal abundances in solar active regions and their
relationship with underlying chromospheric and transition
region properties**

*P. Testa (SAO), J. Martinez-Sykora (BAERI/LMSAL), B. De Pontieu (LMSAL),
D. Brooks (GMU)*

The element abundances in the solar corona and solar wind are often different from those of the solar photosphere, and the fractionation mechanisms are thought to be intimately tied to the physical processes leading to coronal heating. We have recently applied a new spectral inversion method, developed for the MUSE investigation, to Hinode/EIS spectral observations of active regions to derive maps of coronal abundances, and analyzed coordinated IRIS observations to investigate the footprints of the chemical fractionation in the lower atmosphere. We discuss the interesting correlations we find between coronal abundances and underlying chromospheric and transition region properties.

Andy S.H. To (European Space Agency (ESTEC))

Understanding Elemental Composition Across Solar Atmospheric Layers

Andy S.H. To, Miho Janvier, Slimane Mzerguat, David M. Long, Deborah Baker, David H. Brooks, Stephanie Yardley, Natalia Zambrana Prado

Elemental abundances provide a unique tracer of the origin of plasma in the solar atmosphere, with a particular dependence on the first ionisation potential (FIP) of elements. Low-FIP elements often show enhanced abundances in the corona in active regions and slow solar wind source regions - a phenomenon known as the FIP effect. Current theories suggest that fractionation of elements occurs in the upper chromosphere/transition region, with composition signatures “frozen” into corona. However, composition variability across atmospheric layers is poorly understood, and has never before been observed. We present results linking, for the first time, spatially resolved composition measurements from Hinode/EIS and Solar Orbiter/SPICE. Utilising the March 2023 composition mosaic SOOP that scans a big area of the solar disk, we track abundance variations of elements with across the chromosphere to the corona in different solar structures.

Bart De Pontieu (Lockheed Martin Solar & Astrophysics Laboratory)

An optically thin view of the solar chromosphere. IRIS observations of the O I 1355 spectral line

B. De Pontieu (LMSAL, RoCS), M. Carlsson (RoCS)

The O I 1355 A spectral line is one of the only optically thin lines that are both routinely observed and thought to be formed in the chromosphere. We present analysis of a variety of observations of this line with the Interface Region Imaging Spectrograph

(IRIS), and compare it with other IRIS diagnostics as well as diagnostics of the photospheric magnetic field. We utilize special deep exposure modes on IRIS and provide an overview of the statistical properties of this spectral line for several different regions on the Sun. We analyze the spatio-temporal variations of the line intensity, and find that it is often significantly enhanced when and where magnetic flux of opposite polarities cancel. Significant emission occurs in association with chromospheric spicules. Because of the optically thin nature of the O I line, the non-thermal broadening can provide insight into unresolved small-scale motions. We find that the non-thermal broadening is modest, with typical values of 5-10 km/s, and shows some center-to-limb variation, with a modest increase towards the limb. The dependence with height of the intensity and line broadening off-limb is compatible with the line broadening being dominated by the superposition of Alfvén waves on different structures. The non-thermal broadening shows a modest but significant enhancement above locations that are in between photospheric magnetic flux concentrations in plage, i.e., where the magnetic field is likely to be more inclined with respect to the line-of-sight. Our measurements provide strict constraints on future theoretical models of the chromosphere.

Changxue Chen (Purple Mountain Observatory, Chinese Academy of Sciences)

Hard X-ray imaging of slipping reconnection and quasi-periodic pulsations in a solar flare

Changxue Chen, Yang Su, Yang Guo, Dong Li, Wei Chen, Fu Yu, Yu Huang, Zhe Zhang, Jian Wu, Xiankai Jiang, Fanxiaoyu Xia, Zhentong Li, Wei Liu, Dengyi Chen, Yan Zhang, Yiming Hu, Yongqiang Zhang, Astrid Veronig, Zhao Wu, Julia Shamsutdinova, Larisa Kashapova, Hui Li1, Li Feng, Hui Liu, Ying Li, Youping Li and Weiqun Gan

Quasi-periodic pulsations (QPPs) widely exist in solar and stellar flares and other celestial activities. They are deeply related to the basic physical processes behind and therefore have attracted great attentions. However, the physical mechanism responsible for QPPs remains a controversial topic. Here we present observation and simulation evidence of spatially resolved hard X-ray (HXR) QPPs associated with slipping magnetic reconnection during an M6.5-class solar flare. The high cadence HXR images reconstructed by ASO-S/HXI revealed two clearly separated footpoint sources in 30-50 keV that show significant slipping motion along the flare ribbons. The locations and motion of HXR sources are in good line with the sequential brightening along the same ribbons seen in the UV images. The fluxes of the two sources change synchronously and quasi-periodically with a period of approximately 23 seconds, and the same period is simultaneously identified in full-disk microwave emissions. Moreover, the magnetic field strength and flux along the path of the footpoint sources follow a spatial quasi-periodic distribution that has almost the same period of 26 seconds when the variations are converted from space to time. In addition, the flare process was successfully reproduced and represented by our magnetohydrodynamic simulation, where the overall evolution and the slipping motion of magnetic field along the ribbons are found to be consistent with the observations. Based on these findings we propose a new QPP mechanism that is associated with energetic electrons accelerated by quasi-periodic energy release from a slipping reconnection process with quasi-periodic magnetic flux input.

Juliana Vievering (Johns Hopkins Applied Physics Laboratory)

Investigating Energy Release During a Quiescent Region Hard X-ray Flare Observed by RHESSI

*Juliana Vievering, Angelos Vourlidas, Chunming Zhu, Jiong Qiu, Laura
Balmaceda, and Lindsay Glesener*

Hard X-rays (HXR) provide a key diagnostic for energy release during a solar flare, as HXR are emitted from flare-accelerated electrons and strongly heated flare plasma. Years of observations and studies have indicated that RHESSI HXR flares, including microflares, only occur in active regions, with only one instance in the published literature of a quiescent region RHESSI HXR flare to date. Through our work studying the evolution of solar eruptive events, we have identified an additional quiescent region HXR flare observed by RHESSI on 2013 February 6, associated with a filament eruption. Here we investigate the nature of energy release for this rarely-studied type of event through timing, spectral, imaging, and energetics analyses using data from RHESSI, STEREO, and SDO. We examine “bursts” in the HXR, reconnection rate, and CME acceleration profiles, representing distinct episodes of energy release, to explore how intermittent energy release impacts the evolution of the event. Furthermore, we trace the energetics and spatial evolution of the event, discussing how this eruption compares to standard active region eruptions and the previously published quiescent region RHESSI HXR flare.

Daniela Lacatus (High Altitude Observatory (HAO) | NSF National
Center for Atmospheric Research (NSF NCAR))

Evolution of Spectroscopic Characteristics of Solar Filaments

Daniela Lacatus

Solar filaments are structures of cool and dense material suspended at coronal heights by the magnetic field. We present a detailed investigation of characteristics of solar filaments derived from the chromospheric emission captured by the Mg II resonance lines from the Interface Region Imaging Spectrograph (IRIS) and their relation to the surrounding solar atmosphere. Despite being long-lived structures, filaments show a dynamic evolution of their morphology and properties on both spatial and temporal scales. Given the Mg II lines formation spans the whole chromosphere, these lines can capture changes within the larger structure, corresponding to individually evolving strands. Additional derived characteristics provide information on the emitting region as well as reveal flows and hints of potential destabilization. We present our exploration for finding the best set of parameters for filament identification and pinpointing the loss of confinement.

De-Chao Song (Purple Mountain Observatory)

An Observational Study of the Relationship between H I Ly α and H α /He II λ 304 in an M2.0 Solar Flare

De-Chao Song, Qiao Li, Y. Li, Gen Li, Jun Tian, Hui Li, Weiqun Gan, M. D. Ding, L. Harra, L. Teriaca, R. Aznar Cuadrado, S. Parenti, K. Barczynski, A. N. Zhukov, P. J. Smith, F. Auchere, and D. Berghmans

The H I Ly α at 1216 angstrom, H α at 6563 angstrom, and He II Ly α at 304 angstrom are some of the stronger spectral lines observable in the solar atmosphere at, respectively, ultraviolet, optical, and extreme-ultraviolet wavelengths. However, their relationships have not been fully understood especially during flares due to the substantial lack of imaging observations of H I Ly α until recently. In this work, we analyse the temporal and spatial relationships between the H I Ly α and H α /He II λ 304 emissions in an M2.0 solar flare (SOL2022-03-02T17:39) observed by the Extreme Ultraviolet Imager (EUI) onboard the Solar Orbiter spacecraft, the Global Oscillation Network Group at Big Bear Solar Observatory, and the Atmospheric Imaging Assembly (AIA) on the Solar Dynamics Observatory. The correlations between these emissions in a flaring region, in flare ribbons and in loops are presented for the first time, together with the relationships between the Sun-as-a-star irradiances for the different lines. It is found that the H I Ly α emission has a positive correlation with the He II λ 304 emission in both full-disk and for targeted solar regions. By contrast, the H I Ly α and H α correlations are different for these cases. The relationship between H I Ly α and AIA 1600 angstrom is also analysed and this shows similar behaviour to H I Ly α and H α . These results improve our understanding of the formation and properties of these important lines in solar flares and provide some insights for studying the flaring atmospheres of Sun-like stars.

Graham Kerr (Catholic University of America / NASA GSFC)

Exploring the effects of deep heating of the solar chromosphere during flares

Graham S. Kerr, Adam F. Kowalski, Joel C. Allred

Radiation hydrodynamic (RHD) modelling of solar flares using standard non-thermal electron beams typically heat the mid-upper chromosphere, and have been largely successful in reproducing the broadly observed features. However, with high spatial and spectral resolution afforded by modern observatories (both ground and space-based, i.e. IRIS) it is clear that there are details of flare emission that these RHD models have been unable to explain. There are hints that heating to greater depths than standard electron beams can achieve are required. Here we explore deep heating of the solar chromosphere in two ways, and discuss the impacts on the resulting synthetic spectra and continua, with particular focus on line widths, that have been observed to be extremely broad in observations. First, we produce a set of adhoc models with a range of temperature gradients between the height of chromospheric condensations and the temperature minimum region. Second, we explore a particular case of an electron beam driven flare in which re-acceleration of particles results in a harder, more deeply penetrating energy spectra. Lines relevant for both IRIS (Mg II h & k, Mg II subordinate, O I, and C II) as well as ground based observatories (H Balmer series, Ca II H, Ca II 8542A) are explored.

Examining the Driver of High Contrast Lyman-alpha Emission in Solar Flares using Spectroscopic Observations from RHESSI and Fermi.

H. J. Greatorex, R. O. Milligan, and P. J. A. Simões

Recent advances in observing capabilities mean that we are now more capable than ever to regularly observe flare-related Lyman-alpha ($\text{Ly}\alpha$; 1216 Å) emission. However, there are still a number of unanswered questions surrounding the energy transport processes associated with the emission of this significantly intense line. Milligan et al. (2020) found that $\sim 95\%$ of M and X-class flares had an associated $\text{Ly}\alpha$ contrast of $< 10\%$, however contrasts of $> 10\%$ were in fact possible with some unique cases achieving contrasts of 25-30%. The physical explanation for these uniquely high contrasts is not yet fully understood. Greatorex et al. (2023) found that nonthermal electron parameters, namely the spectral index, may be linked to the associated $\text{Ly}\alpha$ contrast seen in solar flares independent of their GOES magnitude. Here, we postulate that the properties of the nonthermal electron distribution may also explain the uniquely high $\text{Ly}\alpha$ contrasts found for some flares. To examine this, a sample of 15 flares from Solar Cycle 24 were employed, each with an associated $\text{Ly}\alpha$ contrast of $> 10\%$. For each flare, Hard X-Ray data from RHESSI and/or Fermi were used to derive the properties of the nonthermal electrons at the peak of the $\text{Ly}\alpha$ emission. Where co-observations from RHESSI and Fermi are available for a single flare, we attempt to find a scaling relationship between these observations such that a more accurate comparison can be made between flares independent of the observing instrument. It is hoped that a unique set of parameters can be discerned that drive uniquely high contrasts in $\text{Ly}\alpha$ emission, which may in future be validated with Radiative-Hydrodynamic flare simulations. Ultimately, this will advance our understanding of energy transport processes during solar flares and the interpretation of data from current and upcoming missions with $\text{Ly}\alpha$ observing capability.

Wensi Wang (University of Science and Technology of China)

Observations of photospheric signatures for pre-eruptive coronal structures

Wensi Wang, Rui Liu and Jiong Qiu

Solar eruptions are powered by free magnetic energy stored in the corona. The free energy is believed to be gradually accumulated through photospheric motions and emergence of magnetic fluxes from below the photosphere into the corona. The buildup of the pre-eruptive coronal structure and the eruption onset mechanism are the two most critical yet poorly understood problems. Coronal structures like sigmoids and filaments have been identified as pre-eruptive structures; their associated pre-flare motions as well as pre-flare brightenings have been identified as precursor signatures, yet none of these definitively leads to eruptions, and the cause and effect is always questionable. Most importantly, the associated photospheric magnetic field dynamics are elusive. Here we report the development of pre-flare ribbons of electric currents associated with the buildup of a pre-eruptive structure observed as a bundle of hot low-lying coronal loops collectively taking a sigmoidal shape, implying the presence of a magnetic flux rope (MFR). Two ribbons of strong vertical electric current densities at two sides of the major polarity inversion line (PIL) of the host active region are observed several hours ahead of the appearance of the pre-eruptive structure. More impressively, the buildup of the pre-eruptive structure in the corona is simultaneous with the gradual extension of the current ribbons in the photosphere. Continuous brightening were observed along the MFR in the corona when the extension of current ribbon ended in the photosphere, implying the onset of magnetic reconnection. The brightening lasted for 4 hours until the MFR and erupted. Quantitative measurements indicate that the MFR's feet, which were well identified by conjugate coronal dimmings occurred during the eruption, possess significant non-neutralized current. It is reminiscent of the current-carrying MFR in the previous simulations. Our observations provide a new definitive photospheric signature for the buildup of pre-eruptive structures and imminent eruptions.

HOPE Properties and Implications

Hugh Hudson

Hot Onset Precursor Events (HOPEs) generally precede flares, as detected by the [EM,T] diagnostic diagram (Jakimiec) in GOES/XRS soft X-ray data. We show here that filament eruptions also have this property, but that some classic cases of polar-crown filament eruptions (e.g., SOL1994-04-14 as originally observed by K. Shibata, which featured in the "solar flare myth" debate) may not. This is despite their possibly high geoeffectiveness (McAllister et al., 1997). We argue that GOES misses these events simply because their HOPE phases have undetectably small emission measures.

Because a HOPE phase almost always occurs, it seems likely that this process itself - the loading of the corona with slowly injected hot plasma, containing relatively little mass - actually is the fundamental instability of the flare process, and that everything else (particle acceleration, CME ejection, reconnection, and all of CSHKP) occurs as secondary effects enabled by the development of this initial instability.

NuSTAR observations of quiet Sun phenomena

Sarah Paterson, Iain Hannah, Brian Grefenstette, Kristopher Cooper, Hugh Hudson, Sam Krucker, Lindsay Glesener, David Smith, Stephen White⁷

We present a unique set of observations from the recent solar minimum (2018-2020) of the quiet-Sun using The Nuclear Spectroscopic Telescope Array, NuSTAR. This sensitive hard X-ray telescope provides for the first-time imaging spectroscopy $> 2\text{keV}$ of quiet Sun phenomena like bright points (in a quiescent and flaring states), emerging flux regions, jet, minifilament eruptions and network/quiet Sun "flares". These types of features have previously been studied in softer X-rays and EUV, typically finding 1-3MK emission. NuSTAR X-ray spectra enables investigation of hotter ($> 5\text{MK}$) and possible non-thermal emission, which are expected if these small impulsive releases of energy are "flare-like" and contribute significantly to heating the Sun's atmosphere. Combining the NuSTAR X-ray data with softer X-ray images from Hinode/XRT and EUV observations from SDO/AIA we can investigate the spatial and temporal evolution of these faint features and calculate the differential emission measure to study their multi-thermal behaviour. We present an overview of some of the quiet Sun features detected by NuSTAR from different campaigns during solar minimum. This work has so far been published in Paterson et al. Sol Phy 298 (2023) and Paterson et al. MNRAS 528 (2024).

Impulsive solar flare observations conducted by Parker Solar Probe

Samer Alnussirat

Multiple instruments onboard Parker Solar Probe have detected 10 impulsive ion and electron beam events. All events are characterized by non-power law energy spectra and a characteristic peak that descends down in energy and merges with the bulk of the solar wind. The majority of the events are well associated with GOES X-ray flares. These events are important for understanding particle acceleration and transport as well as the energy partitioning between electrons and ions in impulsive solar flares. In this talk, we present an analysis of the first catalog of these events.

Investigating Coronal Bright Points: Statistical Analysis and 3D MHD Simulation with Hinode and SDO

Isabella Kraus & Philippe-A. Bourdin

Understanding the precise mechanism behind coronal heating remains a fundamental challenge in solar physics. Smaller-scale bipolar regions, extending up to 10 Mm, show extreme UV emission in the form of coronal bright points (CBPs). In this study, we show a comprehensive analysis of CBPs using continuous data from the Solar Dynamics Observatory (SDO) spacecraft to track their lifetimes. Our investigation aims to validate the co-rotation of the lower corona with the photosphere through CBP tracking data. For the statistics we use 346 CBPs and analyze their lifetime, shape, polarity, merging behavior, flux emergence, and magnetic evolution. 80% of CBPs magnetic field approach during their lifetime, merge, and annihilate in the end of their lifecycle. Then we see in all AIA channels how the CBPs are fading out and finally disappear. The analysis demonstrates that most of the CBPs have mixed polarities. The hottest and brightest ones show bipolar structure and a significantly longer lifetime. Only one-third of the CBP show a merging behavior with another CBP. Our findings reveal that loop-like CBPs mostly originate from bipolar regions, with weaker magnetic polarities giving rise to fainter and cooler CBPs. Additionally, we observe that typical CPBs with lifetimes exceed 6 hours, supporting the hypothesis that CBP heating primarily stems from magnetic energy dissipation via a relatively steady and gradual magnetic reconnection process. Moreover, we aim to replicate an isolated CBP in a 3D MHD simulation. To achieve this, we rely on observational data from both SDO/HMI and Hinode/NFI instruments. As a result of different FOV and resolutions of SDO's and Hinode's instruments, combining their data requires careful alignment to maintain consistency in the simulated photospheric magnetic fields. To achieve this, we use a sophisticated multi-scale overlaying technique to enhance the Hinode observations with SDO data, enabling the creation of adequate input for the MHD simulation. In our simulation setup, the bottom and top boundaries are treated as fully closed to mass and heat flows. The ensuing simulation output enables the computation of synthetic UV emission maps, which can be directly compared to observations from SDO and Hinode. With our model,

we will be able to distinguish different heating mechanisms that act in the corona. This allows us to tell if the heating of CBPs is substantially different from the one in coronal loops above active regions.

Maximum Attainable Energy of Particles in Solar Flares

Mitsuo Oka

Particles are accelerated to very high, non-thermal energies in solar and space plasmas. While various mechanisms of particle acceleration have been proposed, it remains unclear what limits the maximum energy of particles in each plasma environment. Here we show the observed maximum energy of particles in solar and space plasmas roughly aligns with the energy predicted by the Hillas limit, a concept often invoked in astrophysics. However, this correlation depends on certain assumptions, and in some cases, the observed maximum energy exceeds or falls short of the predicted energy. We hope that this study serves as a starting point for more detailed discussions of a possible scaling law and offers a fresh perspective on particle acceleration in solar flares.

James Crowley (National Solar Observatory; University of Colorado,
Boulder)

Magnetic Insights and Implications from Hinode

James Crowley, Don Schmit, Cooper Downs, Caroline Evans

Over the past few years, a new wave of high-resolution solar telescopes and in-situ observations have revealed complicated and dynamic interactions between the Sun's surface, magnetic field, and the inner heliosphere. To probe these connections, we drive Predictive Science Inc.'s state of the art global MHD simulation with time-dependent lower boundary conditions supplied by high-resolution Hinode/SP vector magnetograms. In this project, I have produced and validated Hinode/SP magnetograms and carefully aligned them using HMI magnetograms. I present our process for creating and some interesting findings from the retrieved magnetograms, such as the open magnetic flux between Hinode/SP and HMI vector magnetograms. Finally, I present conclusions from the simulated Corona and Solar Wind when driving the MHD model with different resolutions of magnetic boundary conditions.

Jiayi Liu (Institute for Astronomy, University of Hawaii)

What Can DKIST/DL-NIRSP Tell Us About Quiet-Sun Magnetism?

Jiayi Liu, Xudong Sun, Peter W. Schuck, and Sarah A. Jaeggli

Quiet-Sun regions cover most of the Sun's surface; its magnetic fields contribute significantly to the solar chromospheric and coronal heating. However, characterizing the magnetic fields of the quiet Sun is challenging due to their weak polarization signal. The 4-m Daniel K. Inouye Solar Telescope (DKIST) is expected to improve our understanding of the quiet-Sun magnetism. In this paper, we assess the diagnostic capability of the Diffraction-Limited Near Infrared Spectropolarimeter (DL-NIRSP) instrument on DKIST on the energy transport processes in the quiet-Sun photosphere. To this end, we synthesize high-resolution, high-cadence Stokes profiles of the Fe I 630 nm lines using a realistic magnetohydrodynamic simulation, degrade them to emulate the DKIST/DL-NIRSP observations, and subsequently infer the vector magnetic and velocity fields. For the assessment, we first verify that a widely used flow-tracking algorithm, Differential Affine Velocity Estimator for Vector Magnetograms, works well for estimating the large-scale (> 200 km) photospheric velocity fields with these high-resolution data. We then examine how the accuracy of inferred velocity depends on the temporal resolution. Finally, we investigate the reliability of the Poynting flux estimate and its dependence on the model assumptions. The results suggest that the unsigned Poynting flux, estimated with existing schemes, can account for about 71.4% and 52.6% of the reference ground truth at $\log \tau = 0.0$ and $\log \tau = -1$. However, the net Poynting flux tends to be significantly underestimated. The error mainly arises from the underestimated contribution of the horizontal motion. We discuss the implications on DKIST observations.

Tracking Magnetic Structures That Are Reconnecting or Expanding or Both

J. Qiu, D. Longcope, D. Osaben

Explosive energy release in the solar atmosphere is driven magnetically, but mechanisms triggering the onset of the eruption remain in debate. In the case of flares and CMEs, ideal or non-ideal instabilities usually occur in the corona, but direct observations and diagnostics there are difficult to obtain. To overcome this difficulty, we analyze observational signatures in the upper chromosphere or transition region, in particular, brightenings and dimmings at the feet of coronal magnetic structures. In this study, we examine the time evolution of spatially resolved light curves in several eruptive flares, and identify a variety of tempo-spatial sequences of brightenings and dimmings, such as dimming followed by brightening, and dimming preceded by brightening. These brightening-dimming sequences are indicative of the configuration of energy release in the form of plasma heating or bulk motion, either or both of which may result from reconnection. We demonstrate the potential of using these analyses to diagnose properties of magnetic reconnection and plasma expansion in the corona, and to infer magnetic configuration of the corona prior to eruption, and during the early phase of eruption.

**A comparison of electric currents from a flux emergence
MHD simulation and as reconstructed using a nonlinear force
free field extrapolation**

Lucas A. Tarr (NSO) Kalman J. Knizhnik (NRL) Mark G. Linton (NRL)

The formation and distribution of electric currents in the solar atmosphere is a key physical process for heating the solar plasma and producing eruptions. Direct inference of currents from observations is extremely challenging, so one typically must rely on some method to reconstruct the 3D magnetic field from limited observations. This is usually accomplished by extrapolating the field into the coronal volume from a well-observed 2D boundary layer in the solar photosphere under the assumption that the plasma beta is very low and the field is “[Lorentz] force free,” meaning that the currents are aligned with the magnetic field. We demonstrate the dubious nature of these assumptions for an MHD simulation of an emerging flux rope but go on to explore the results of extrapolations that are applied to simulation anyway.

Lyndsay FLETCHER (University of Glasgow)

Precise timing of solar flare footpoint sources from mid-infrared observations

Paulo J. A. Simoes, Lyndsay Fletcher, Hugh. S. Hudson, Graham S. Kerr, Matt Penn, Karla F. Lopez

Solar flares are powerful particle accelerators, and in the accepted standard flare model most of the flare energy is transported from a coronal energy-release region by accelerated electrons which stop collisionally in the chromosphere, heating and ionising the plasma, producing a broadband enhancement to the solar radiative output. We present a time-delay analysis of the infrared emission from the two main chromospheric sources in the circular ribbon flare SOL2014-09-24T17:50 taken at the McMath-Pierce telescope. By cross-correlating the intensity signals, measured with 1s cadence, from the two spatially resolved infrared sources we find a delay of 0.75 ± 0.07 s at 8.2 microns, where the uncertainties are quantified by a Monte Carlo analysis. The sources correlate well in brightness but have a time lag larger than can be reasonably explained by the energy transport dominated by non-thermal electrons precipitating from a single acceleration site in the corona. If interpreted as a time-of-flight difference between electrons traveling to each footpoint, we estimate time delays would be between 0.14 s and 0.42 s, for a reconnection site at the interior quasi-separatrix layer or at the null-point of the spine-fan topology inferred for this event. We employed modelling of electron transport via time-dependent Fokker-Planck and radiative hydrodynamic simulations to evaluate other possible sources of time-delay in the generation of the IR emission, such as differing ionisation timescales under different chromospheric conditions. Our results demonstrate that they are also unable to account for this discrepancy. This flare appears to require energy transport by some means other than electron beams originating in the corona.

Marcel Corchado-Albelo (University of Colorado Boulder)

Spatial Complexity of Flare Ribbon Boundaries

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We use high-resolution Interface Region Imaging Spectrograph (IRIS) 1330 and 1400 Å Slit-Jaw Imager (SJI) observations of several flares to quantify the fractal properties of “fine-structures” in the flare ribbon boundary for the first time. Our working hypothesis is that these structures could serve as an indirect proxy to processes in the flare current sheet, as has been suggested by previous studies (e.g. Wyper & Pontin 2021). We compute the spatial fractal dimension over the ribbons’ boundary using the correlation dimension mapping (CDM) method. We then quantify how this fractal dimension evolves during the flare and compare it with other observed flare properties, including reconnection rate and particle acceleration proxies.

Growth, Saturation and Effects of the Thermal Farley Buneman Instability in the Coldest Region of the Chromosphere

Meers Oppenheim, Samuel Evans, Juan Martínez-Sykora, Yakov Dimant

In the coldest regions of the solar chromosphere electrons and ions will decouple due to high collision rates, and, in the presence of cross-B-field flows, can lead to the development plasma waves and turbulence. We will discuss a set of simulations and analytical theory that show how solar atmospheric currents can drive a thermal plasma instability that rapidly develops into turbulence. Though this turbulence is small scale (centimeters to a few meters), it will modify the conductivity, temperatures, and energy flows through much of the chromosphere. Incorporating the effects of this turbulence, and other small-scale turbulence, into large-scale models of solar and stellar atmospheres should improve physicists' ability to model energy flows with important consequences for the predicted temperatures and radiation patterns.

Constraints on solar flare accelerated electrons and their associated return current

Meriem Alaoui, Gordon Holman, Marc Swisdak

Accelerated electron beams in solar flares stream both toward the interplanetary medium and toward lower layers of the solar atmosphere where they are usually most easily observed through their hard X-ray emission. These beams constitute a current which is neutralized by a co-spatial return current, which effectively decelerates the nonthermal electron beam.

We systematically compute the electron energy distribution along the legs of a flare loop for various beam and plasma parameters relevant to solar flares, and show that interpretation of a number of flares observed with RHESSI needs to be reviewed to account for effects of return currents.

Our 1D steady-state model accounts for collisions between beam and plasma electrons, return current electric-field deceleration, thermalization in a warm target approximation, and runaway electron contributions. The results focus on the classical regime, offering a valuable benchmark for energy flux reduction and its extent.

We calculate a number of thresholds which become significant for higher nonthermal flux densities in the following order: (1) the threshold for return current losses to become energetically significant, (2) where runaway electrons become significant, and (3) where current-driven instabilities become significant, requiring a model that self-consistently accounts for them. The threshold for generating current instabilities is increased in the presence of runaway electrons. All results are dependent on beam and co-spatial plasma parameters.

Global impact of emerging internetwork fields on the low solar atmosphere

Milan Gosic, Bart De Pontieu, Alberto Sainz Dalda

Small-scale internetwork (IN) magnetic fields have been considered as potential sources of energy and mass for the solar chromosphere and corona. Several studies show that single instances of emerging fields can cause localized heating in the low solar atmosphere by interacting with the preexisting ambient field lines. However, the global impact of the newly emerging IN fields on the solar atmosphere is still unknown. In this work we analyze the spatiotemporal evolution of IN bipolar flux features and their impact on the energetics and dynamics of the quiet Sun atmosphere. We used high-resolution, multi-wavelength, coordinated observations from the Interface Region Imaging Spectrograph (IRIS), Hinode, and the Solar Dynamics Observatory (SDO) to identify emerging IN magnetic fields and track their spatial and temporal evolution. Our observations suggest that only the largest IN bipoles are capable of locally heating the solar atmosphere, while the global contribution of these bipoles appears to be minimal, i.e., the newly emerging IN bipoles cannot globally maintain the chromospheric heating directly through interaction with the ambient overlying magnetic fields. However, it should be noted that the sensitivity level, spatial resolution, and duration of our observations limit the total number of IN bipoles detected, as well as their estimated impact. To detect smaller and weaker IN fields that maintain basal flux, and examine their contribution to the chromospheric heating, a higher resolution, sensitivity, and longer time series would be necessary.

Ryan French (National Solar Observatory (NSO, Boulder))

Doppler signature of a possible termination shock in an off-limb solar flare

Ryan French, Sijie Yu, Bin Chen, Chengcai Shen, Sarah Matthews

We report striking Doppler velocity gradients observed during the well-observed 2017 September 10 solar flare, and argue that they are consistent with the presence of an above-the-looptop termination shock beneath the flare current sheet. Observations from the Hinode Extreme-ultraviolet Imaging Spectrometer measure plasma sheet Doppler shifts up to 35 km/s during the late-phase of the event. By comparing these line-of-sight flows with plane-of-sky (POS) measurements, we calculate total velocity downflows of 200+ km/s, orientated $\approx 6-10^\circ$ out of the POS. The observed velocities drop rapidly at the base of the hot plasma sheet seen in extreme ultraviolet, consistent with simulated velocity profiles predicted by our 2.5D magnetohydrodynamics model that features a termination shock at the same location. Finally, the striking velocity deceleration aligns spatially with the suppression of Fe XXIV non-thermal velocities, and a 35-50 keV hard X-ray looptop source observed by the Reuven Ramaty High Energy Solar Spectroscopic Imager. Together, these observations are consistent with the presence of a possible termination shock within the X8.2-class solar flare.

The Magnetic Origin of Solar Coronal Jets and Campfires: SDO and Solar Orbiter Observations

*Navdeep K. Panesar, Alphonse C. Sterling, Ronald L. Moore, Sanjiv K. Tiwari,
Viggo H. Hansteen, David Berghmans, Mark Cheung, Daniel Müller, Frederic
Auchere, and Andrei Zhukov*

Here we present the magnetic origin of different types of campfires and coronal jets, using line-of-sight magnetograms from Solar Dynamics Observatory (SDO)/Helioseismic and Magnetic Imager together with extreme ultraviolet images from Solar Orbiter/Extreme Ultraviolet Imager and SDO/Atmospheric Imaging Assembly. We find that (i) both campfires and coronal jets reside above neutral lines and they often appear at sites of magnetic flux cancelation between the majority-polarity magnetic flux patch and a merging minority-polarity flux patch, with a flux cancelation rate of $\sim 10^{18}$ Mx hr $^{-1}$ (ii) majority of campfires are preceded by a cool-plasma structure, analogous to minifilaments in coronal jets. Our observations suggest that (a) the presence of magnetic flux ropes may be ubiquitous in the solar atmosphere and not limited to coronal jets and larger-scale eruptions that make CMEs, and (b) magnetic flux cancelation, most likely accompanied with magnetic reconnection in the lower solar atmosphere, is the fundamental process for the formation and triggering of most solar campfires and coronal jets. Finally, we compare fine-scale jets with those found in a Bifrost MHD simulation.

What are the properties of energetic electrons associated with solar jets?

Sophie Musset and the Solar Jet Hunter team

Solar flares are one of the sources of energetic particles that fill the heliosphere. With the launch of recent missions such as Parker Solar Probe and Solar Orbiter, we aim to understand both how particles get accelerated during flares, and how they escape the flare site in the solar corona, to reach the interplanetary medium and fill the heliosphere. Coronal jets are one of the features often observed when flare-accelerated particles escape the solar atmosphere. I will present a statistical approach to the study of this phenomena using the new catalogue of solar jets resulting from the citizen science Solar Jet Hunter, in which hundreds of jets have been reported in the 304 A AIA observations. A description of the jets in this catalogue will be followed by a focus on the properties of the accelerated particles in flare-associated jets. I will also present preliminary results on the detection of solar jets using machine learning, which will be used to enhance our data sets in combination with citizen science.

Qiang Hu (The University of Alabama in Huntsville)

Analysis of Coronal Magnetic Field Topology from High-Resolution Embedded Magnetograms

Wen He, and Qiang Hu (presenting author)

High-resolution (up to $\sim < 0.1$ arcsec) photospheric vector magnetograms have become increasingly available from Hinode, and more recently the ground-based GST and DKIST observations. We present an approach for the extrapolation of the coronal magnetic field by combining both the (ultra) high-resolution magnetogram and the routine HMI magnetogram for the same event study. This allows for maintaining the native resolutions of both sets of the magnetograms, while achieving a desirable field of view with reasonable computational efficiency. We demonstrate a few event studies for the magnetic field topological analysis associated with multiple observations of pre-flare morphology near a major polarity inversion line in an active region and one small-scale recurring jet.

High-resolution Spectropolarimetric Observation of a C-class Flare Observed by DKIST/ViSP

Rahul Yadav and Maria Kazachenko

We present spectropolarimetric observations of a C4-class solar flare from the ViSP instrument at DKIST. This unprecedented high-cadence, resolution, and polarimetric-sensitive data provides a unique opportunity to quantify properties of small-scale photospheric magnetic fields before and during the flare. Specifically, we inferred the magnetic field vector in the photosphere from the Fe I 6302 line using Milne-Eddington inversion. From the inverted data, we find two pores of opposite polarities rotate before and during the flare. The observed anti-clockwise rotation of up to 60 degrees suggests a connection between the flare and photospheric dynamics. From the analysis of the Lorentz force in the photosphere, we conclude that the change in its horizontal component is most likely responsible for the observed pores rotation. Our findings are in agreement with previous findings for larger flares.

Tingyu Gou (Center for Astrophysics | Harvard & Smithsonian)

Imaging and Spectroscopic Observations of Hot Plasmas in the Loop-Top Region During a Limb Solar Flare

Tingyu Gou, Katharine Reeves

Solar flares are explosive and energetic phenomena in the solar atmosphere accompanied by a rapid release of magnetic energy. Flaring plasmas can be heated up to above 10 MK, forming bright flare loops on the solar surface. We study the dynamics of flare plasmas by focusing on the high-temperature emissions, using high-resolution imaging and spectroscopic observations. We present results of the investigation on an X-class flare occurring near the east limb, observed by SDO/AIA and IRIS. AIA reveals highest temperatures at the reconnection current sheet region above the flare arcade, where supra-arcade spikes and downflows are observed. IRIS captures the flare loop-top region and detects Fe XXI 1354.08 Å spectral line emissions from the bottom of current sheet and loop top under the slit. Spectral line fittings are performed to diagnose the Doppler motion and nonthermal broadening of hot flare plasmas, at different locations and during different evolution stages. The spectroscopic results are also compared with thermal properties and the thermodynamic evolution of flare loops.

Salvo Guglielmino (INAF - Catania Astrophysical Observatory)

Energy release phenomena observed at high-resolution with GREGOR and IRIS

Salvo Guglielmino, Fabiana Ferrente, Serena Lezzi, Mariarita Murabito, Vincenzo Andretta, Daniele Spadaro, Ilaria Ermolli, Paolo Romano, Francesca Zuccarello

We present observation of energy release events occurring in the solar atmosphere, observed during a 10-day observing campaign conducted in August 2023 at GREGOR telescope (1.5 m diameter, located on Tenerife island), using the High-resolution Fast Imager (HiFI) and GREGOR Infrared Spectrograph (GRIS) in spectropolarimetric mode. The campaign was also coordinated with IRIS and Hinode observations. IRIS carried out observations during the early morning hours (local time at GREGOR), acquiring medium dense rasters (0".32 slit) and simultaneous slit-jaw images.

Data analysis has been limited to specific dates so far. On August 5th, IRIS captured a footpoint of a C-class flare within the leading sunspot of the active region. The following day, August 6th, IRIS detected a small-scale reconnection event (consisting of a UV burst and surge ejection) within the moat region surrounding the leading sunspot. We have conducted an initial examination of the evolution of the latter event. Noteworthy, observations from GREGOR's HiFI exhibit analogous brightenings and ejections within the same area.

Shane Atwood (Montana State University)

Unresolved Fine Structure and the Conductive Transition Region

Shane Atwood Charles Kankelborg

Transition region (TR) emission below 100,000 K is brighter than can be explained by heat conduction alone, with brightness increasing as temperature declines. Consequently, the ratio of C II (formed around 20,000 K) emission to Si IV (about 80,000 K) is brighter than expected. We employ large, dense, 400-step IRIS rasters on 7 quiet sun (QS) observations to obtain statistics on emission in these lines. In all observations, we find widespread, bright C II emission even where there is little or no Si IV. There is a near-linear average trend in C II intensity as a function of Si IV, but this trend very clearly passes above the origin. We interpret the data as a two-component atmosphere: a sparse, classical TR anchors coronal structures among a cool background dominated by unresolved fine structure.

Shin Toriumi (Japan Aerospace Exploration Agency)

Close interaction of turbulent convection and magnetic twist in sunspot formation and flare eruptions

Shin Toriumi, Hideyuki Hotta, Kanya Kusano

Magnetic flux emergence from the deep convection zone is a key piece of the global magnetism of the Sun and crucial for the generation of active regions and triggering of jets, flares, and coronal mass ejections. To investigate the effect of thermal convection and magnetic twist to the emergence, we performed radiative magnetohydrodynamic simulations of flux tube emergence from the deep, realistic convection zone, where we controlled the twist strength of the initial flux tube. Contrary to one's intuition, even in the case of an untwisted flux tube, the generated sunspots inject finite (non-zero) magnetic helicity into the upper atmosphere, because the strong background turbulence rotates the magnetic flux. The amount of total injected helicity due to the turbulence is significant and even explains the medium-sized solar eruptions. We also revealed that the emergence of strongly-twisted flux tube, unstable to the kink instability, produces sunspots with magnetic helicity far exceeding the observed values. Although the kink instability has long been regarded as a prominent candidate for the massively-flaring delta-type sunspots, this result suggests that it is less likely, which calls for further study combining numerical modeling and observational data to better understand the genesis of flare-productive active regions.

Xu Yang (Big Bear Solar Observatory, New Jersey Institute of Technology)

GST High-cadence Observations to Solar Lower Atmosphere Energy Release

Xu Yang, Wenda Cao, Vasyl Yurchyshyn, Yi-Min Huang, Meiqi Wang, Jiong Qiu, Kaifan Ji

High-spatial-resolution imaging is highly valued within the solar physics community. However, ground-based observations face challenges as the telescope diffraction limit approaches the photon mean-free-path. Meanwhile, elucidating the energy release mechanisms in the lower solar atmosphere could benefit from high-temporal-resolution observations. We conducted a series of case studies using GST high-cadence imaging spectroscopy observation to offer a distinctive perspective. In a study of a small-scale X-point reconnection event, our observations resolved a 2 Mm reconnection current sheet with a width of 80–120 km in $H\alpha$ line center images. Corresponding features, including current sheet counterparts and outflows, were detected in DUV slit-jaw images from IRIS and across all EUV wavelengths of SDO/AIA. Plasmoids were discerned within the fine structures of the heated current sheet in $H\alpha$ images. In another observation of an X-1 white light flare, GST captured the dispersal motion of two white-light kernels in the visible spectrum for the first time. Analysis of the light curves from these kernels aligned with FERMI HXR time profiles, revealing the flare's rapid evolution. This finding suggests that the energy source of the white light emission in this flare originates from the direct heating of energetic particles.

On the million-degree signature of spicules

Souvik Bose

Spicules have often been proposed as substantial contributors toward the mass and energy balance of the solar corona. While their transition region (TR) counterpart has unequivocally been established over the past decade or so, the observations concerning the coronal contribution of spicules have often been contested. This is mainly attributed to the lack of adequate coordinated observations, their small spatial scales, their highly dynamic nature, and complex multi-thermal evolution, which are often observed at the limit of our current observational facilities. Therefore, it remains unclear how much spicular plasma is heated to coronal temperatures. In this study, we use coordinated high-resolution observations of the solar chromosphere, TR, and corona of a quiet-sun network region with the Interface Region Imaging Spectrograph (IRIS) and the Atmospheric Imaging Assembly (AIA) to investigate the (lower) coronal ($\sim 1\text{MK}$) emission associated with spicules. We perform differential emission measure (DEM) analysis on the AIA passbands using the basis pursuit and a newly developed technique based on Tikhonov regularization to probe the thermal structure of the spicular corona for the first time. We find that the EM maps at 1 MK reveal the presence of ubiquitous, small-scale jets that have a clear spatio-temporal coherence with the spicules observed in the IRIS/TR passband. Detailed space-time analysis of the chromospheric, TR, and EM maps show unambiguous evidence of rapidly outward propagating spicules with strong emission (2–3 times higher than the background) at 1MK. Our findings are consistent with existing MHD simulation that shows heating to coronal temperatures in spicules.

The energy transported by compressible magnetoacoustic waves into chromospheric plage regions: dependence on magnetic field properties

Shimizu, T. and Koyama, M.

A proposed mechanism for solar chromospheric heating is magnetohydrodynamic waves propagating upward along magnetic field lines and dissipating their energy in the chromosphere. In particular, compressible magnetoacoustic waves may contribute to the heating. Theoretically, the components below the cutoff frequency cannot propagate into the chromosphere; however, the cutoff frequency depends on the inclination of the magnetic field lines. Using high-temporal cadence spectral data of IRIS and Hinode Solar Optical Telescope spectropolarimeter in solar plages (IHOP 341), we investigated the dependence of the low-frequency waves on magnetic field properties and quantitatively estimated the amount of energy dissipation in the chromosphere. The following results were obtained: (a) The amount of energy dissipated by the low-frequency component (3–6 mHz) increases with the inclination of the field below 40 deg, whereas it decreases as a function of the inclination of the field above 40 deg. (b) The amount of the energy is enhanced toward 10^4 W/m², which is the energy required for heating in the chromospheric plage regions when the magnetic field is higher than 600 G and inclined more than 40 deg. (c) In the photosphere, the low-frequency component has much more power in the magnetic field inclined more and weaker than 400 G. The results suggest that the observed low-frequency components can bring the energy along the magnetic field lines and that only a specific range of the inclination angles of the field and the strength of the field may allow the low-frequency component to bring a sufficient amount of the energy into the chromosphere. This presentation is based on the article published recently in the *Astrophysical Journal* (Koyama & Shimizu 2024, ApJ 965, 136).

Vanessa Polito (Lockheed Martin Solar and Astrophysics Laboratory)

Observations of AR outflows with IRIS, Hinode/EIS and VLA

V. Polito (LMSAL)

High-temperature plasma upflows at the edges of active regions (AR outflows) have often been invoked as a candidate source of mass and energy to the slow solar wind (SW). AR outflows have been studied in detail since the launch of Hinode/EIS, and interchange reconnection in the corona between closed and open magnetic field loops has been suggested as a possible candidate mechanism to explain AR outflows and their connection to the solar wind. A key signature of interchange reconnection is the detection of type III bursts in radio data. Using IRIS observations, recent work has also revealed the presence of peculiar spectral signatures in the chromosphere and transition region underneath the AR outflows, which are not seen elsewhere in the AR. The underlying physical cause for these unique signatures is still unclear, but these results suggest that the corona and lower atmosphere are not separate environments and must be studied together. In this work we present a follow up study combining different ARs observed by EIS and IRIS in the ultraviolet and VLA in radio wavelengths. Using these multi-wavelength observations, we investigate the response of the plasma throughout different layers of the atmosphere from chromosphere to corona, and compare our results with predictions from theoretical models.

Ying Li (Purple Mountain Observatory)

The Chinese ASO-S and CHASE Missions and the Maximum Millennium Program

Ying Li

The Chinese missions of the Advanced Space-based Solar Observatory (ASO-S) and the Chinese H α Solar Explorer (CHASE), launched on 2022 October 9 and 2021 October 14, respectively, provide full-disk images and two-dimensional spectra in multiple wavelengths. These can be served as references in selection of a target region for solar observers, which is the goal of the Maximum Millennium Program. In this poster, I will present the instruments and quick-look images from these two Chinese space missions, as well as how to use these near-real-time images to help select the flaring target region for coordination observations.

A Probabilistic Calibration Procedure for the CORSAIR Polarimeter

Alan Hsu, Jenna Samra, Steven Tomczyk

The Coronal Spectropolarimeter for Airborne Infrared Research (CORSAIR) is a balloon-based coronagraph that will make spectropolarimetric observations of the 3.9 micron Si IX emission line. Its 2025 commissioning flight will be followed by a long-duration Antarctic science mission in 2028. CORSAIR is a pathfinder for making routine, continuous, high-sensitivity measurements of the global coronal magnetic field from high altitudes. CORSAIR uses a rotating-waveplate polarimeter to measure the full Stokes polarization state of the emission line, which includes the Stokes Q, U signals that encode the plane-of-sky direction of the magnetic field, and the Stokes V signal that encodes the line-of-sight magnetic field strength. To accurately measure the faint polarization signals, however, requires a comprehensive understanding of the systematic and random errors in our polarimeter. We present a novel, robust calibration routine that computes the posterior distribution of systematic random variables in our polarimeter, which subsequently allows us to compute downstream distributions of the demodulation matrix and thus Stokes Q, U, V from observations. In our setup, we use calibration optics to generate representative Stokes inputs that are fed into the polarimeter, which are subsequently modulated by a rotating waveplate. We build upon the calibration procedure used in the Upgraded Coronal Multi-channel Polarimeter (UCoMP) by extending the theoretical model to account for more systematic errors, and utilize the calibration data to compute posterior distributions instead of point-estimates of these errors. This allows us to perform Bayesian inference on the Stokes signals and propagate uncertainties in an end-to-end manner.

Beyond density diagnostics: combining O IV 1399, 1401, Si IV

Juan Martinez-Sykora, Paola Testa, Vanessa Polito, Bart De Pontieu

Previous studies revealed the complexity of using Si IV and O IV as diagnostics when considering non-equilibrium ionization (NEQ). For this research, we combine IRIS, EIS observations, and 2.5D radiative MHD models where the oxygen and silicon ionization are computed in non-equilibrium ionization and compare them to the case assuming statistical equilibrium (SE). We use these results to provide new insights into interpreting O IV and Si IV observations of an active region with IRIS, including the nature of the transition region emission. The NEQ effects lead to a similar column depth for all the transitions. The O IV 1399 and 1401 ratio can provide the column depth, which can be used to calculate the density from the Si IV intensity. We also analyze column depth properties. The differences may provide transition region abundance diagnostics using IRIS, and we aim to compare these abundances derived from IRIS with those derived from Hinode/EIS data at higher temperatures.

Recent enhancements to the Heliophysics Event Knowledgeable

Neal Hurlburt, Ryan Timmons, Justin Cheng, Matthew Greenhaw and Steve Petrinec

Improvements in our understanding of heliophysics phenomena requires tools for conducting surveys of data and metadata to discern trends, correlations, and causation. The Heliophysics Events Knowledgebase (HEK) provides a system for collecting and presenting heliophysical data based on the Virtual Observatory (VOEvent) format and other standards. The HEK incorporates entries from distributed ground and space based solar observatories and event descriptions generated by automated algorithms, detailed data analysis and citizen scientists (while storing contact information and links to websites and papers for attribution purposes). This makes it possible to carry out integrated studies that span the full range of heliophysics and these resources are available to any interested researcher.

The HEK is transitioning to an infrastructure model to ensure that the archive persists beyond the life of the missions that shaped its development. We present features of the HEK that support construction of detailed workflows to conduct research involving fusion of multiple data and event sources via search tools that compute spatial and temporal overlaps between entries. We also outline improvements and new features planned and in development for the coming years, which include better tools and outreach to receive submissions from many more event lists and instruments to the HEK as well as improved support for coordinated, multi-instrument campaigns. In particular, we discuss improvements in the HEK API, expansion to support off-axis and in-situ events and possible extensions to support geospace missions.

Rhiannon Fleming (Montana State University)

Understanding the Student Impacts of A Solar Physics/Astrophysics Research Experience for Undergraduates

Rhiannon Fleming

During the summer, Montana State University (MSU) located in Bozeman, Montana hosts a number of research experience for undergraduates (REU) programs. There are various benefits to entering an REU program as a sophomore or junior year undergraduate student: increased knowledge of specific subject matter, introduction to research, and entry into a larger scientific community. Undergraduates who are already in a science, technology, engineering, and mathematics (STEM) program are increasingly likely to graduate with a STEM degree and continue to graduate school. The Physics Department at MSU has one such program focused on Solar physics/Astrophysics which has run for 23 years. In 2024, the program received 7 students from around the United States. This REU is structured as a course-based research program where students have class two days out of the week with the rest of the time devoted to research. Classes are physics-based, with a solar/astrophysics focus, at the start of the REU and then shift toward professional development. The future of solar physics needs new minds and an REU can be a great introduction to the field. For this year, I built and implemented formative assessments to track student progress over their time at the MSU solar physics/astrophysics REU. Formative assessments are a new classroom-based technique to check student understanding. These assessments are not traditional exams and focus on deeper knowledge gained over memorization. Additionally, I reintroduced an outreach component after a hiatus caused by the COVID 19 pandemic. Students were taught different facets of public outreach and had help to develop a collaborative program which focused from the Sun and beyond to present to teenagers at the Bozeman Young Men's Christian Association (YMCA). Anticipated results are feedback on course-work understanding, integrating formative assessments for future summers, and possibly sparking an interest in public outreach.

Amir Caspi (Southwest Research Institute)

Chasing the 2024 eclipse: results from coordinated ground and airborne missions – Citizen CATE 2024 and NASA’s WB-57s

Amir Caspi, Sarah A. Kovac, Daniel B. Seaton, Paul Bryans, Craig E. DeForest, Cooper Downs, Daniel W. Zietlow, Carey Scott, Matthew J. West, Padma A. Yanamandra-Fisher, Amelia Bettati, Fred Bruenjes, John Carini, Sarah Davis, Ed DeLuca, David F. Elmore, Charlie Gardner, Sanjay Gosain, Rebecca Haacker, Jason Jackiewicz, Viliam Klein, Shawn Laatsch, Julie Maldonado, Valentin Martínez Pillet, Jorge Perez-Gallego, Ritesh Patel, Kevin Reardon, Willow Reed, Patricia H. Reiff, Nikita Saini, Jenna Samra, Steven Tomczyk, Anna Tosolini, Andrei Ursache, Rachael L. Weir, John K. Williams, Jen Winter, and the Citizen CATE 2024 and NASA WB-57 2024 Eclipse Teams

Total solar eclipses are spectacular astronomical phenomena that allow unique studies of the solar corona. While observing windows at fixed sites are only a few minutes long, "chasing" the Moon's shadow enables longer observing periods, enhancing scientific return and mitigating the risk of bad observing conditions in any one location. Here, we discuss two successful expeditions to chase the 2024 eclipse: Citizen CATE 2024, a distributed ground network of uniform stationary sites deployed along the length of the eclipse path to observe in series, jointly funded by NSF and NASA; and a NASA-funded WB-57 campaign, with two airplanes flying along the shadow path to extend observing time from particular instruments.

CATE 2024 deployed 35+ near-identical stations along the eclipse path from Texas to Maine to observe the corona in polarized light out to ~ 3 solar radii, over more than an hour of totality. Each station was run by trained local community volunteers and observed with identical procedures, achieving high-dynamic-range (HDR) images of the corona every 2 seconds; images are calibrated, co-aligned, and stacked from all stations to produce observations of coronal dynamics (flows, waves, etc.). A pathfinding expedition to the 20 April 2023 Australian eclipse provided a beta-test of equipment and procedures. In addition to its science, CATE 2024 encompassed an enormous outreach opportunity.

NASA's WB-57 aircraft offer observations from nose-mounted 2-axis gimballed telescopes flying at 50 kft and 400 knots, for $\sim 40\%$ longer duration in totality per plane compared to a stationary ground site, and access to near-infrared (NIR: $0.8\text{--}1.2\ \mu\text{m}$), shortwave infrared (SWIR: $1.2\text{--}2\ \mu\text{m}$), and midwave infrared (MWIR: $2\text{--}5\ \mu\text{m}$) wavelengths. On one WB-57, we flew a new photometrically-calibrated multispectral imaging suite for high-speed, high-resolution images in multiple MWIR passbands to study emission from solar features – prominences, streamers, polar plumes, and active regions – opening new discovery space for this under-observed region of the coronal spectrum.

We discuss the CATE and WB-57 2024 missions, lessons learned and results from the pioneering experiments in 2017 and 2023, the first results these next-generation 2024 missions, and plans for the next eclipse in 2026.

Albert Shih (NASA Goddard Space Flight Center)

The Fundamentals of Impulsive Energy Release in the Corona Explorer (FIERCE) mission concept

Albert Y. Shih and the FIERCE team

Understanding how energy is released suddenly and transformed at the Sun requires breakthrough observations that reveal the whole picture of the initiation and evolution of flares and solar eruptive events. The Fundamentals of Impulsive Energy Release in the Corona Explorer (FIERCE) MIDEX mission concept leverages X-ray focusing optics for the unprecedented capability to characterize both particle acceleration and plasma heating in the tenuous corona and to trace the flow of energy down to the chromosphere without being blinded by bright sources. FIERCE performs imaging spectroscopy at hard X-ray energies to measure energetic electrons and at soft X-ray energies to measure hot (>2 MK) plasmas. FIERCE is the culmination of many years of instrument development – including multiple FOXSI sounding-rocket flights – with ready-to-go technologies and designs. FIERCE not only fills a critical gap in the Heliophysics System Observatory, but would also launch at the best time of the next cycle of solar activity.

Yukio Katsukawa (National Astronomical Observatory of Japan)

SUNRISE III SCIP: a balloon spectro-polarimeter for seamless diagnostics of photo- and chromospheres

Y. Katsukawa¹, M. Kubo¹, H. Hara¹, Y. Kawabata¹, T. Oba², T. Shimizu³, T. Matsumoto⁴, R. T. Ishikawa⁵, Y. Naito⁶, D. Orozco Suárez⁷, J. C. del Toro Iniesta⁷, C. Quintero Noda⁸, S. Solanki²

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6. SOKENDAI, NAOJ

7. Instituto de Astrofísica de Andalucía

8. Instituto de Astrofísica de Canarias

SUNRISE III to be flown in 2024 is the third flight of the international balloon project Sunrise. The team led by NAOJ provided the near-infrared spectro-polarimeter SCIP through international collaboration with the Spanish and German teams. By combining the 1-meter aperture telescope, SCIP will simultaneously observe many spectral lines in near-IR including two of the chromospheric Ca II infrared triplet lines, upper photospheric K I D1 and D2 lines, and multiple photospheric Fe I lines with a resolution of 0.2'' which is higher than that of the HINODE Solar Optical Telescope. The observation provides height-dependent magnetic and velocity structures and their time evolution from the photosphere to the chromosphere and clarifies the transport and dissipation processes of magnetic energies. By synthesizing the spectrum lines observed with SCIP, we demonstrated that we could aim to measure polarization signals from twisted magnetic fields driving a chromospheric jet. The other target is an Ellerman bomb to detect reconnection jets and their relationship with surrounding magnetic fields. We present here the capability of SCIP and its science cases.

William Setterberg (University of Minnesota)

The Integrating Miniature Piggyback for Impulsive Solar Hard X-rays (IMPISH): a Low-Cost Spectrometer for the GRIPS-2 Balloon Campaign

*William Setterberg Reed Masek Phillip Williams Christopher Guo Lestat Clemmer
Qianping Kuang Lindsay Glesener*

The Integrating Miniature Piggyback for Impulsive Solar Hard X-rays (IMPISH) is a low-cost solar spectrometer that will fly aboard the second Gamma Ray Imager/Polarimeter for Solar flares Antarctic balloon campaign (GRIPS-2). IMPISH is a collaboration between University of Minnesota, Montana State University, Space Science Research Lab, and Southwest Research Institute. Our spectrometer is optimized to measure fast variations in nonthermal X-rays from solar flares. Sub-second spikes in the X-ray flux offer a probe into particle acceleration mechanisms in solar flares through their periodicity, duration, and timing differences across energy bands.

The IMPISH payload features silicon photomultipliers coupled to LYSO or GAGG scintillators to achieve the desired sub-second (tens of milliseconds) measurements. The detectors boast a 64cm² geometric area and an energy range of at least 20 to 300 keV. We present our payload design and development, including lab tests justifying our choice of scintillator material and electronics readout.

Pascal Saint-Hilaire (University of California Berkeley)

The GRIPS Imaging Concept

Pascal Saint-Hilaire Albert Shih Gordon Hurford Meredith Wieber

The Gamma-Ray Imager/Polarimeter for Solar flares (GRIPS) project in its current form is a NASA high altitude balloon payload that first flew from Antarctica in January 2016. GRIPS observes the Sun from 20 keV to 10 MeV with germanium strip detectors (few keV resolution). It has a single imaging grid yielding 12.5" angular resolution over the full sun and over its whole energy band. GRIPS is particularly well-suited to observing gamma-ray lines emitted by flare-accelerated ions, one of the few existing diagnostic of such. After a brief overview of the GRIPS, we present its novel imaging technique (monogrid imaging with pixelized detectors), and in particular how to compute back-projected images and Fourier components of the source image (visibilities).

Christopher Moore (Center for Astrophysics | Harvard & Smithsonian)

Spectral Soft X-ray Measurement Improvements of the three Miniature X-ray Solar Spectrometer (MinXSS-1, -2, -3) CubeSats and New Instrumentation to Open New Parameter Space

Christopher S. Moore¹, Amir Caspi², Phil Chamberlin³, Brendan D'Aquino¹, Anant Kumar⁴, James Mason⁵, Bennet Schwab³, Robert Sewell³, Crisel Suarez^{1,6}, Tom Woods³

1. Center for Astrophysics | Harvard & Smithsonian

2. Southwest Research Institute

3. Laboratory for Atmospheric and Space Physics

4. University of Alberta

5. Johns Hopkins University Applied Physics Laboratory

6. Vanderbilt University

The three Miniature X-ray Solar Spectrometer (MinXSS-1, -2, -3) CubeSats measured the absolute radiometric energy distribution of solar soft X-ray emission from 0.5 – 20 keV at moderate (0.15 keV at 5.9 keV) energy resolution. The intermittent MinXSS solar flare, active region and quiet Sun measurements spanning 2015 – present have provided improved constraints on low-FIP elemental abundance plus temperature distribution over previous full-Sun soft X-ray spectrometers. This talk will discuss the quality of those observations and the improvement over the three versions of MinXSS due to instrument design/capability changes. Even with these improvements, there are limitations to the plasma temperature, abundance, and dynamics inferred from spatially integrated soft X-ray spectra. Thus, is a fundamental limitation due to the instrument type and measurement method. This talk will highlight how new detectors and imaging optics can open a new parameter space in overcoming these limitations with spatial soft X-ray observations. This talk will also discuss the efforts by the Center for Astrophysics | Harvard & Smithsonian and collaborators to bring make these measurements a reality soon.

Christopher Entzel (Montana State University)

BUBO: the student-Built Ultraviolet solar Burst Observer

Christopher Entzel, Sarah Pawlowski, Charles Kankelborg

Solar flares are among the most powerful events in the solar system, releasing up to 10^{32} ergs of energy. Although these events are well studied by numerous instruments, much remains to be learned about flare behavior at sub-second timescales. BUBO, the Student-Built Ultraviolet Solar Burst Observer, will help us better understand the behavior of solar plasma during these energetic events.

BUBO is a six-channel radiometer sensitive to extreme ultraviolet (EUV), soft X-ray (SXR), and hard X-ray (HXR) emissions. The instrument will measure disk-integrated solar flare emissions at a 0.01 s cadence with SXR source locating capability. Quasi-periodic pulsations (QPPs) with periods greater than a second have been observed in many wavelength bands (Van Doorselaere et al. 2016). Tan et al. (2010) observed numerous sub-second microwave QPPs during a solar flare, and CORONAS/IRIS observations found HXR pulses with superfine time structure during a flare (Charikov et al. 2004). We therefore ask, are sub-second QPPs occurring in the EUV and SXR energy bands? With BUBO's 0.01 s cadence, such QPPs could be observed. Due to the comparatively long exposure times of imagers, sub-second movement of SXR hot spots have not been investigated. We hypothesize that rapid, local movements in the hot spot's location occur during the evolution of a solar flare. With BUBO's high cadence and sensitive SXR source location capability, these hypothesized movements could be observed. Additionally, BUBO will examine the late-phase thermal evolution of solar flares on a centi-second timescale. Temperatures will be derived from BUBO's measurements in overlapping EUV, SXR, and HXR passbands.

BUBO will be part of the Multi-Slit Solar Explorer (MUSE), a satellite mission scheduled to launch in 2027. BUBO will augment the MUSE mission by measuring high temperature thermal emissions from flares at a rapid cadence.

Daniela Lacatus (High Altitude Observatory (HAO) | NSF National Center for Atmospheric Research (NSF NCAR))

CMEx: Chromospheric Magnetism Explorer

Holly Gilbert, Alfred de Wijn, Rebecca Centeno, Paul Bryans, Donald Schmit, Roberto Casini, Matthias Rempel, Giuliana de Toma, Daniela Lacatus, and the CMEx team

CMEx is a SMEX mission selected for Phase-A concept study in NASA's Heliophysics program. CMEx uses ultraviolet spectropolarimetry to diagnose magnetism from the solar photosphere to the transition region, leveraging the heritage of the Hinode and IRIS missions, and the CLASP sounding rockets. CMEx explores how the magnetic field evolves from the high- β photosphere (i.e., plasma pressure greatly exceeds magnetic pressure) to the low- β magnetically-dominated corona to form twisted non-potential flux ropes that are the energy storage devices for magnetic eruptions. This key β transition happens in the chromosphere. Recent advances in the understanding of the polarization chromospheric lines in the near-UV, which are not observable from the ground, have primed a space-based mission like CMEx for success. CMEx observes many near-UV spectral lines, including the well-known Mg II h and k lines as well as a series of Fe II lines, with full-Stokes polarimetry to provide quantitative diagnostics of plasma parameters densely sampling the 9 pressure scale heights in the chromosphere, thus enabling studies of how the magnetic field in and around active regions gets reconfigured leading up to the eruption process, how flares lead to persistent changes in photospheric and chromospheric magnetic fields, and what the large-scale magnetic structure is of prominences in their stable phase, and how it changes in the transition from equilibrium to eruption. If selected for implementation, CMEx will fly in 2029, concurrently with SOLAR-C EUVST and MUSE, to largely fulfill the recommendations from the joint NASA/ESA/JAXA Next-Generation Solar Physics Mission report.

Sarah Matthews (UCL Mullard Space Science Laboratory)

EUV Image Slicers for Solar Physics

Sarah Matthews, Ariadna Calcines and Hamish Reid

Image slicer technology has been used as an Integral Field Unit (IFU) for ground-based telescopes in night-time astronomy for several years, but only relatively recently proposed for solar physics, first for the European Solar Telescope, and later GRIS on GREGOR and DL-NIRSP on DKIST. Image slicers have several advantages which make them an excellent choice for space Integral Field Spectroscopy (IFS): they are compact, lightweight, robust to in-flight effects and highly efficient. They facilitate coupling between telescope and instrument with minimum light losses and offer the possibility to produce a magnification without additional components, enabling optimal imaging performance. With no polarisation effects and no focal-ratio degradation, image slicers are the best IFU alternative for solar IFS.

Despite their obvious technical and scientific advantages – they offer 2-D imaging spectroscopy without the need to raster, making them ideal for flare observations – the technology has not so far been applied to the EUV. In this presentation we discuss the results of a pilot study addressing some of the critical points for EUV applications, including the narrowest width achievable in powered slicer mirrors in different substrates, and the minimum surface roughness that can be achieved in glass. We outline next steps for development and potential applications for future solar physics space missions.

ESIS (EUV Snapshot Imaging Spectrograph) II

*Jacob Parker, Charles Kankelborg, Roy Smart, Amy Winebarger, Genevieve Vigil,
Will Barnes, Adrian Daw*

The Extreme-Ultraviolet Snapshot Imaging Spectrograph (ESIS) sounding rocket was launched for the first time on September 30th, 2019 from White Sands Missile Range. ESIS captures images in four slitless spectrograph channels, each with a unique dispersion direction. Images from each channel can be combined, and inverted, to measure spectral line profiles over its entire octagonal field of view (11.5 arcminute) at every exposure. During the 2019 launch, ESIS observed the evolution of dozens of small eruptive events, in the O V 630 angstrom spectral line, at a ten second cadence.

The recently proposed ESIS II will be expanded to six channels, and target the Ne VII 465 A and Si XII 500 A spectral lines formed at 0.5 MK and 3 MK respectively. For the second launch we will target an active region with the aim of measuring transient velocities at active region foot points and along connected loops that can be used to constrain loop heating models.

Kathy Reeves (Harvard-Smithsonian Center for Astrophysics)

ECCCO: The EUV CME and Coronal Connectivity Observatory

Kathy Reeves, Dan Seaton, Leon Golub, Peter Cheimets, Ed DeLuca, Craig DeForest, Giulio Del Zanna, Cooper Downs, Nishu Karna, Wei Liu, Chad Madsen, Chris Moore, Athiray Panchapakesan, Joe Plowman, Yeimy Rivera, Jenna Samra, Sabrina Savage, Paola Testa, Matt West, Amy Winebarger

The EUV corona is highly structured and dynamic out to $\sim 3R_s$, but observations in this region are limited. To fill this gap, we introduce The EUV CME and Coronal Connectivity Observatory (ECCCO), which will be proposed for the upcoming NASA Heliophysics SMEX call. ECCCO consists of two instruments: an imager that views the Sun out to 3 R_s and a spectrograph that produces spectrally pure, overlapped images of the Sun (overlappograms). Both instruments will have two channels, a long channel ranging from 171 — 205 Å to capture plasma in the 1-2.5 MK range, and a short channel ranging from 125 — 135 Å to capture hot plasma in the 8-12 MK range. The science goals of ECCCO are two-fold: 1. To understand the genesis and evolution of coronal energy storage and the solar wind, and 2. To understand the symbiotic relationship between eruptive solar events and large scale coronal structure.

Patrick Dunn (Space Sciences Lab, University of California, Berkeley)

Simulating a detector's response to solar flare polarization - Geant4 and the PADRE mission

*Patrick Dunn, Pascale Sainte-Hilaire, Juan Carlos Martinez, and the PADRE
Team*

Geant4 simulations were used to assist in the design (geometry and shielding) of the SHARP (Solar HARd X-ray Polarimeter) instrument of the PADRE (solar PolARization and Directivity X-Ray Experiment) mission. SHARP will determine the degree of polarization of solar flare non-thermal X-rays. Calculations resulting from the simulations include valuable characteristics of the detector such as effective area and μ_{100} . We also determined the overall detector response (geometric factor) to photons, electrons, and protons at a range of energies. Validation of the simulations included comparisons with scattering theory, mainly using the Klein-Nishina formula; this formula gives the theoretical distribution of the scattering angle of photons scattered from a single electron.

Application of Ensemble Kalman Filter Data Assimilation Technique to Infer the Surface Flows with Surface Flux Transport model

Soumyaranjan Dash¹, Marc DeRosa², Mausumi Dikpati³, Xudong Sun¹, Sushant Mahajan⁴, and Yang Liu⁴

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Constraining solar surface flows is crucial to understanding solar magnetic activity at different time scales. Accurate global solar surface magnetic flux distribution is essential for modelling coronal magnetic fields, solar wind dynamics, open flux distribution and solar cycle predictions. However, routine and direct observation of the whole photospheric magnetic field is still challenging due to our limited field of view and high projection effects. Data-driven numerical models play an important role in estimating the distribution of magnetic field distribution including polar fields more accurately. The north-south component of the Sun's global flow, i.e. the meridional circulation that transports the flux from low latitudes and helps build up the polar field is utilized in surface flux transport (SFT) models to simulate photospheric magnetic field distribution. Since forecasting polar fields requires the forecast of the flow at a future time, it is necessary to reconstruct the flow behavior at the current time, so that future flow-patterns can be estimated. Data assimilation techniques like Ensemble Kalman Filter (EnKF) which utilizes observational data points to constrain the time advancement of a set of equations that govern the evolution of the physical system, has been adopted to reconstruct the meridional flow speed with solar dynamo modeling. In this study, show how such EnKF methods, when used with a surface-flux transport model that captures the evolution of the solar photospheric magnetic field, can be used to make ensemble estimates of flow into the future that will be used to drive the model forward to forecast solar surface magnetic field distribution.

Alisdair Davey (National Solar Observatory)

VSO 2.0: A VSO Towards Easier Data Source Collaboration and Many Other Improvements

Davey, A., Ireland, J., Inglis, A., Mansky, E., Millard, P., and Spencer, J.

The Virtual Solar Observatory (VSO) is undergoing a complete rewrite, which includes moving to the Python language and close collaboration with SunPy. This poster details some of the many improvements that will take place in this rewrite. In particular we draw attention to new tools to allow users to more easily find coincident observations beyond overlapping time windows which is already possible, and new plans to put much more metadata in users hands allowing them to better select datasets they are interested in. VSO 2.0 has the ambitious timeline of being available by June 2025.

Sunkit-spex: A High-energy Spectral Analysis Tool in Python

Kris Cooper (UMN), Daniel Ryan (FHNW), Shane Maloney (DIAS), Laura Hayes (ESA), Stuart Mumford (Aperio Software), Iain Hannah (UoG), Albert Shih (NASA GSFC), Will Barnes (NRL), Natalia Bajnokova (UoG), Lindsay Glesener (UMN), William Setterberg (UMN)

Sunkit-spex is a Python tool under development for the high-energy solar community to analyse observed spectroscopic data through forward-fitting and other methods as well as provide easy-to-use, relevant spectral models. High-energy spectroscopic analysis involving forward-fitting has unique complications not faced in other fitting environments. The process includes using physically driven models and a non-diagonal instrument-specific spectral response matrix to convert plasma parameters to an emitted photon spectrum then to an instrument-modelled count spectrum. The resulting modelled count spectrum can then be compared to the observed count spectrum. Therefore, converting from plasma parameters to modelled data is not a trivial process, being dependent on a number of instrument- and observation-specific qualities, and requires a dedicated software package. The community utilises several different spectral fitting tools (e.g., OSPEX and XSPEC); however, none can fit multiple high-energy spectra simultaneously with different fitting metrics while providing necessary models, being optimised for solar data products, and having a simple installation process. Software providing these features is desirable due to the increasing availability of simultaneous solar observations from multiple instruments with the opportunity to investigate flares and other phenomena ranging over several orders of magnitude. Sunkit-spex tackles these elements with a focus on community-led development and is already being used in solar flare investigations. Sunkit-spex also aims to be agnostic to a wide range of data products from past, present, and future instruments as well as different formats where the spectral data may be created from proprietary software, other Python packages, or within the package itself. Sunkit-spex is also able to facilitate the inclusion of custom analytical tools and techniques which can be applied to the spectral data, such as MCMC analysis or other Bayesian methods.

Shane Maloney (Dublin Institute for Advanced Studies)

stixpy: STIX data analysis in python

Shane Maloney and the STIX Team

Stixpy is a Python-based tool tailored for analysing STIX data, integrating with the scientific Python ecosystem. Leveraging popular libraries like NumPy, Matplotlib, Astropy, and SunPy, stixpy offers a user-friendly interface for accessing and manipulating STIX data, utilising familiar data containers and types such as sunpy Map, & TimeSeries and astropy Quantity and Time. The current version of stixpy supports various essential features including data search and download facilitated by the SunPy Fido interface, data visualisation using Matplotlib, and basic data manipulation operations such as detector selection and summation of counts over time/energy indices.

stixpy provides imaging capabilities through count-based techniques like Expectation Maximization and visibility-based methods such as Clean, Multi-scale Clean, and MEM via xrayvision. In its upcoming iterations, stixpy aims to introduce spectroscopy functionalities with sunkit-spex integration, enabling advanced data manipulation operations based on timesa & quantities. Additionally, enhancements in imaging will include visibility-based techniques like visforward_fit and visforward_fit_pso via xrayvision, along with the incorporation of regularised photon and electron visibilities.

Currently supported features

- * Data search and download - via sunpy Fido interface
- * Data visualisation - via matplotlib
- * Basic data manipulation - sum, slice, detector/pixel selection
- * Imaging
- * Count based - Expectation Maximisation
- * Visibility based - Clean, Multi-scale Clean and MEM - via xrayvision

Upcoming features

- * Spectroscopy - via sunkit-spex
- * Advanced data manipulation - sum, slice, subselect by quantities etc
- * Imaging
- * Visibility based - visforward_fit, visforward_fit_pso - via xrayvision

* Regularised photon and electron visibilities

This abstract encapsulates the core functionalities and future roadmap of stixpy, showcasing its utility as a comprehensive tool for STIX data analysis within the Python environment.

Joy Velasquez (Harvard Smithsonian Center for Astrophysics)

XRTpy: A Comprehensive Python Solution for Analyzing Hinode X-Ray Telescope Data

Joy Velasquez, Katharine Reeves, Nicholas Murphy, Jonathan Slavin, Mark Weber

XRTpy is a Python package specifically developed for the analysis of observations from the X-Ray Telescope (XRT) on the Hinode solar spacecraft, a key instrument for studying solar dynamics and phenomena through high-resolution soft X-ray images. This package provides comprehensive tools for XRT data analysis, including object-oriented representation of instrument configurations, effective area calculations, temperature response computations, light leak subtraction, and image sharpening. It also facilitates the derivation of electron temperature and emission measure, offering various abundance model options. Additionally, XRTpy includes snippet code functions for quick access to data, with filtering options and tools for working with image and movie files. As an open-source tool, XRTpy supports a growing community of users, enhancing the transition from traditional IDL routines to Python, which is increasingly preferred in the scientific community. By streamlining data processing, XRTpy has proven essential in several key research projects, furthering our understanding of solar activities.

Lucas Guliano (Harvard-Smithsonian Center for Astrophysics)

Calibration Methods and Data Products for Hinode's X-Ray Telescope (XRT)

L. Guliano, K. Reeves, P. Testa, S. Saar, J. Velasquez, C. Suarez, A. Takeda, K. Yoshimura, R. Fleming

Hinode's X-Ray Telescope (XRT) has been collecting X-ray solar data since 2006. Since launch, XRT's calibration team has employed a series of data calibration techniques to ensure that data products released to the public are of high scientific quality. These calibration methods have been modified and improved over the lifetime of the mission to reflect the changing conditions of the instrument hardware. Techniques addressed here include work on the temperature response function, contamination sources including dust maps, and scattered light analysis and intensity variations due to a stray light leak. This poster summarizes modifications and improvements to the methodology used in the calibration processes of XRT data and confirms the continued integrity of XRT data products.

Robert Jarolim (High Altitude Observatory, NCAR)

Advancing solar magnetic field extrapolations with physics-informed neural networks

R. Jarolim, B. Tremblay, J. K. Thalmann, M. Rempel, A. M. Veronig, M. Molnar, T. Podladchikova

While the photospheric magnetic field of our Sun is routinely measured, its extent into the upper atmosphere is typically not accessible by direct observations.

In this presentation, we introduce Physics-Informed Neural Networks (PINNs) for solar magnetic field extrapolations. Our method integrates observational data and the physical force-free magnetic field model to estimate the 3D topology of coronal magnetic fields based on photospheric vector magnetograms.

We demonstrate that our method can provide realistic coronal magnetic field estimates in quasi real-time. The systematic analysis of the time evolution of free magnetic energy and magnetic helicity in the coronal volume, as well as comparison to EUV observations demonstrates the unambiguous relation to the observed flare activity.

We further outline our recent advances where we apply this approach to magnetograms from Hinode/SP, perform multi-height extrapolations with chromospheric magnetograms from the Swedish Solar Telescope, and obtain global force-free extrapolations from SDO/HMI full-disk observations.

PINNs enable realistic magnetic field extrapolations in quasi real-time and have the potential to greatly advance the field of data-driven simulations, accelerate scientific research, and improve our understanding of the solar magnetic field.

Robert Jarolim (High Altitude Observatory, NCAR)

Physics Informed Neural Networks for Spectropolarimetric Inversions

R. Jarolim, M. Molnar, B. Tremblay, R. Centeno

Spectropolarimetric inversions of solar observations are fundamental for the estimation of the magnetic field in the solar atmosphere. To expedite solar inversions, a reasonable assumption for photospheric spectral lines is that they form under the Milne-Eddington (ME) approximation, where the source function is posed to vary linearly with optical depth, describing the atmosphere with a few (nine) free parameters. Despite the simplifications in current inversions, observational data typically exhibits noise and instrumental effects, which limits the success of estimating the solar plasma parameters.

We present a novel method for spectropolarimetric inversions of solar data under the ME approximation with a Physics Informed Neural Network (PINN) to estimate the solar magnetic field. Building on synthetic spectral line profiles, we demonstrate that our approach can reliably solve complex configurations in a computationally-efficient way. Our method intrinsically enables spatial and temporal coupled inversions that can overcome limitations of noise, directly provides uncertainty estimates, and is straight-forward to extend to different instrument configurations. Our method also accounts for the instrumental point-spread-function, further informing the spatial coupling.

Finally, we apply our method to observations from Hinode SOT/SP and compare our results to other state-of-the-art ME inversion codes. Our method operates with minimal memory requirements, makes efficient use of spatio-temporal relations, and is adjustable to observations from new instruments. This study provides a first step to utilize PINNs for spectropolarimetric inversions, and demonstrates the potential to address long standing challenges.

Multi-instrument DEMs and the EMToolKit framework for DEMs in Python

Joseph Plowman, Gilly Gilbert

We will present new work that allows seamless multi-instrument DEMs in Python, which can be done with, for example Hinode XRT and SDO/AIA simultaneously, compromising neither the spatial resolution of AIA or the extended temperature coverage of XRT. The method uses sparse matrix to take into account the differing sampling resolution of the instruments and can even correct for instrument PSFs in the same step. The same methodology can also be applied to even more heterogeneous observations such as AIA together with RHESSI or Solar Orbiter STIX. This new methodology, along with established DEM methods is integrated with our Python EMToolKit DEM analysis and visualization framework (<https://github.com/jeplowman/EMToolKit>) which we will also demonstrate. Some of these new developments have interesting parallels with work in coronal 3D reconstruction which we may touch on if time allows.

Bin Chen (New Jersey Institute of Technology)

Owens Valley Solar Arrays: An Integrated Community Facility for Solar and Space Weather Research

Bin Chen, Dale Gary, Gelu Nita, Sijie Yu, Pascal Saint-Hilaire, Gregg Hallinan, and the EOVSA and OVRO-LWA teams

We introduce the Owens Valley Solar Arrays (OVSAs) as an integrated facility to serve the solar and space weather community. OVSAs consist of two state-of-the-art radio telescopes located in the Owens Valley Radio Observatory (OVRO), namely the Expanded Owens Valley Solar Array (EOVSA) and the OVRO Long Wavelength Array (OVRO-LWA), which work in complementary wavelength regimes (EOVSA: microwaves in 1-18 GHz; OVRO-LWA: meter waves in 15-88 MHz). Together, they work in concert to probe a wide range of altitudes in the solar atmosphere from the upper chromosphere to the low corona as well as eruptions to ~ 6 solar radii (i.e., the “middle” corona). OVSAs provide unique and unprecedented spatial, temporal, and spectral imaging of a wide range of coronal heights to advance the study of various key solar phenomena, including solar flares, active regions, jets, filaments, and coronal holes. Equally importantly, they inaugurate a new means of studying coronal mass ejections (CMEs) via near-real-time spectral imaging from their birth near the solar surface to their development in the middle corona. We will provide an overview of the broad science topics that OVSAs address, the status of the instrumentation (including the NSF-funded EOVSA upgrade project), the observing modes, the data processing pipeline, and the spectral imaging data products we provide to the community. We will also discuss our efforts to broaden and strengthen our support for both expert and general users of the facility.

Juliana Vievering (Johns Hopkins Applied Physics Laboratory)

Real-Time Early Flare Alert System for Triggered Observations

Juliana Vievering, P. S. Athiray, Juan Camilo Buitrago-Casas, Phillip Chamberlin, Kristopher Cooper, Gordon Emslie, Lindsay Glesener, Vicki Herde, Hugh Hudson, Paolo Massa, Marianne Peterson, Katharine K. Reeves, Sabrina Savage, Amy Winebarger

Understanding when and where a flare will occur continues to be an important goal for the heliophysics community, relevant to fundamental research, coordinated flare observations, and space weather applications. Currently available flare forecasts typically fall into one of two categories: 1) long-term probabilistic forecasts (e.g., probability that an M-class flare will occur in the next 24 hours), or 2) flare alerts (e.g., notification when the flare flux reaches a high level). For a wide variety of research and operational purposes, there is an additional need for an early flare alert system to anticipate large and long-lasting flares that is more actionable than long-term forecasts and provides earlier notice than current flare alerts do. Such a tool would enable triggered observations of the early stages of solar flares, a crucial capability for demonstrating novel instrumentation optimized for solar flares via sounding rockets and other observing campaigns aimed at flares. With this goal in mind, a collection of tools was developed and implemented for the first solar sounding rocket flare campaign in April 2024, featuring the FOXSI-4 and Hi-C Flare experiments. Here we present on the real-time early flare alert system which supported these sounding rocket teams through a successful and unprecedented solar-flare-triggered sounding rocket launch and plans for continued development of these tools.

Kristopher Cooper (University of Minnesota)

The FOXSI-4 instrument

Kris Cooper, Athanasios Pantazides, Yixian Zhang, Shunsaku Nagasawa, Takahiro Minami, Savannah Piel, Riko Shimizu, Sota Kashima, Yoshiaki Sato, Koki Sakuta, Kazuki Ampuku, Ryuto Fujii, Tetsuo Kano, Naoki Ishida, Wayne Baumgartner, Stephen Bongiorno, Milo Buitrago-Casas, Patrick Champey, Steven Christe, Sasha Courtade, Jessie Duncan, Lindsay Glesener, Hunter Kanninen, Säm Krucker, Ikuyuki Mitsuishi, Sophie Musset, Noriyuki Narukage, Juan Carlos Martinez Oliveros, Subramania Athiray Panchapakesan, Eliad Peretz, Taro Sakao, Tadayuki Takahashi, Juliana Vievering, Shin Watanabe

We present an overview of the Focusing Optics Solar X-ray Imager (FOXSI-4) sounding rocket instrumentation and the capabilities that are enabled by its novel observation. The FOXSI sounding rocket utilises direct-focusing optics and has observed the quiet Sun, active region emission, and microflares in hard X-rays (HXR) during three previous flights. Direct imaging HXR telescopes are used regularly to observe astrophysical sources and, even though not solar-optimised, are occasionally able to observe the Sun if conditions are sufficiently quiet (e.g., with NuSTAR). Using direct-focusing optics allows for greater image quality achieving higher sensitivity and dynamic range when compared to indirect imaging techniques; therefore, detailed simultaneous measurements become possible between relatively weak and bright sources. FOXSI is the first solar-optimised direct-focusing HXR instrument capable of observing emission from a range of solar phenomena at different scales. FOXSI-4, the fourth sounding rocket mission flown on 2024 April 17 from Poker Flat in Alaska, took part in NASA's first solar flare campaign with Hi-C Flare where an M1 GOES class flare was near-simultaneously observed by both experiments. Throughout the flight, in addition to the M1 flare, FOXSI-4 also observed weaker flares within its field of view as well as quiescent active region emission. The FOXSI-4 instrument incorporated new hardware compared to previous flights with upgrades including high-resolution Wolter-I optics from Nagoya University and Marshall Space Flight Center, improved CMOS soft X-ray detectors, a new Timepix detector, and variable-pitch double-sided CdTe HXR strip detectors. Additionally, two microfabricated pixelated attenuators from Goddard Space Flight Center were also included.

Using the improved hardware, observations from FOXSI-4 will provide an unprecedented view into energy deposition throughout the solar atmosphere and flare particle acceleration via high-resolution images and spectra.

Scientific predictions for FOXSI-4 and comparison with observed data

Yixian Zhang, Lindsay Glesener, Athanasios Pantazides, Kristopher Cooper, Shunsaku Nagasawa, Takahiro Minami, Savannah Perez-Piel, Riko Shimizu, Koki Sakuta, Kazuki Ampuku, Ryuto Fujii, Sota Kashima, Yoshiaki Sato, Tetsuo Kano, Naoki Ishida, Tamar Ervin, Orlando Romeo, Juan Camilo Buitrago-Casas, Sophie Musset, Juliana Vievering, Wayne Baumgartner, Stephen Bongiorno, Patrick Champey, Steven Christe, Sasha Courtade, Hunter Kannianen, Säm Krucker, Juan Carlos Martinez Oliveros, Ikuyuki Mitsuishi, Noriyuki Narukage, Eliad Peretz, Dan Ryan, Tadayuki Takahashi, Shin Watanabe

The FOXSI-4 sounding rocket experiment aimed to observe medium-to-large solar flares using direct-focusing X-rays and successfully observed an M-class flare during its flight on April 17, 2024. For a flare-triggered rocket launch with only six minutes of observation time, there were large uncertainties in the photon fluxes that FOXSI-4 might encounter. Therefore, FOXSI-4 incorporated insertable attenuators for hard X-ray detectors and enabled different exposure times for soft X-ray detectors to accommodate a wide range of flare classes. Here we present the scientific predictions for FOXSI-4 for various flare classes as a demonstration of the capability of the instrument. In addition, we compare those predictions with the initial results from the flare observed during the actual flight.

Shunsaku Nagasawa (Space Sciences Laboratory, University of California, Berkeley)

First Direct Focusing Hard X-ray Imaging of M-Class Solar Flare from FOXSI-4 Sounding Rocket Experiment

Shunsaku Nagasawa, Takahiro Minami, Yixian Zhang, Athanasios Pantazides, Kristopher Cooper, Koki Sakuta, Kazuki Ampuku, Ryuto Fujii, Yusuke Yoshida, Riko Shimizu, Yoshiaki Sato, Sota Kashima, Savannah Perez-Piel, Tamar Ervin, Orlando Romeo, Juan Camilo Buitrago-Casas, Juliana Vievering, Wayne Baumgartner, Stephen Bongiorno, Patrick Champey, Steven Christe, Sasha Courtade, Lindsay Glesener, Hunter Kannianen, Säm Krucker, Juan Carlos Martinez Oliveros, Ikuyuki Mitsuishi, Noriyuki Narukage, Eliad Peretz, Dan Ryan, Shin Watanabe, Tadayuki Takahashi, Mitsuo Oka and FOXSI-4 team

The Focusing Optics X-ray Solar Imager (FOXSI) is the Solar-dedicated sounding rocket mission to realize the direct imaging method combined with Wolter-I X-ray focusing optics and fine-pitch focal plane detectors. FOXSI has been successfully launched three times so far, in 2012, 2014, and 2018, targetting the quiet Sun, active regions, and microflares. By contrast, the fourth launch, FOXSI-4, was conducted as part of NASA's first "Flare campaign," in which the rocket will be kept ready for immediate launch in two weeks to target mid-large class solar flares. To separate thermal and non-thermal emissions, separate intense hard X-ray (HXR) emission from the flaring loop footpoint and weak HXR emission in the corona, and perform photon measurement observations even at high count rates in flares, both focusing optic mirrors and focal plane detectors are upgraded. For the optics modules, new high-resolution optics have been developed by MSFC/NASA and Nagoya University, in addition to the heritage FOXSI-3 10-shell optics. For the focal plane detectors covering the hard X-ray range up to 20 keV, new CdTe double-sided strip detectors (CdTe-DSDs), developed by Kavli IPMU/The University of Tokyo, are installed in four of the seven telescopes, in addition to Si CMOS detectors and a new Timepix3 detector.

On 2024 April 17, FOXSI-4 successfully launched from Poker Flat Research Range/Alaska and obtained the first direct-focusing images of the GOES M1.8 class

solar flare. All four CdTe-DSDs successfully acquired data, totaling over 40000 photons in the 4-20 keV range. These data demonstrate the technological readiness of a space-borne mission to observe HXRs from solar flares through direct focusing optics.

We report an introduction to the FOXSI-4 instrument and present the first direct-focusing image of a solar flare, focusing on the HXR range.

Shunsaku Nagasawa (Space Sciences Laboratory, University of California, Berkeley)

Wide-gap CdTe Double-Sided Strip Detectors for High-Resolution Imaging Spectroscopy of Solar Flares in Hard X-rays for FOXSI-4

Shunsaku Nagasawa, Takahiro Minami, Shin Watanabe, Tadayuki Takahashi, Yixian Zhang, Kristopher Cooper, Athanasios Pantazides, Lindsay Glesener and FOXSI-4 team

We develop a new configuration CdTe double-sided strip detector as “Wide-gap CdTe-DSD,” in which a gap between strips is much wider than strips, as focal plane detectors in hard X-ray band (4-20 keV) for direct-focusing imaging spectroscopy observation of solar flares for FOXSI-4. The detector has 128 strip electrodes on both cathode and anode sides varied from 60 μm strip pitch (30 μm strip and 30 μm gap width) to 100 μm strip pitch (30 μm strip and 70 μm gap width). By widening the gap between the strips, the percentage of charge sharing events between adjacent strips is enhanced, and a sub-strip position resolution could be achieved by utilizing the information on the sharing energies.

To confirm this concept, we conducted an evaluation test by uniformly irradiated X-rays using ^{241}Am .

By developing a new energy reconstruction method to compensate for the charge loss of wider gaps and the depth of interaction effects, an energy resolution of 0.9 keV is obtained using all single and double strip events. We also conducted fine beam scanning experiments at SPring-8 to study the spatial dependence of the response. The beam size is collimated to 10 μm squared, and the beam energy is changed from 7 to 35 keV. From these experiments, the sub-strip position resolution has been demonstrated, especially for the anode side, with a precision of 10 μm in the gap region. Finally, we constructed an onboard data processing network using a standard communication interface of SpaceWire and new FPGA board SPMU-001.

We succeeded in developing the CdTe-DSD Data Encoder software to control and acquire data from four CdTe-DSDs simultaneously, which can withstand the high count rate and large data volume of solar flares observed by FOXSI-4.

Sarah Pawlowski (Montana State University)

CAPRI-SUN: High Cadence Low-energy Passband X-ray Detector with Integrated Full-sun Field of View

Sarah Pawlowski, Chris Entzel, Charles Kankelborg, Cole Arthur, Mila Kissinger, Reed Lando, Jackson Novak

Solar flares are incredibly powerful events that release up to 10^{32} ergs of energy. Numerous instruments in many wavelengths have studied solar flares, yet many unknowns remain about the spatial and temporal distribution of energy, the mechanisms of particle acceleration, and coronal plasma heating. CAPRI-SUN is a soft X-ray (SXR) radiometer designed and built by Montana State University (MSU) students, that takes measurements of SXR (1-8Å) flux released during a solar flare at an unprecedented cadence of 1kHz. Sub-second to centi-second fluctuations in microwave (Tan et al. 2010) and hard X-ray (Charikov et al. 2004) have been observed. We hypothesize that similar fluctuations may be observed in SXR, however there has yet to be an instrument with a rapid enough cadence for these fluctuations to be directly observed. The detection of these fluctuations is significant because they provide essential clues to determining the mechanisms driving coronal heating, energy transport, and particle acceleration.

CAPRI-SUN, the High Cadence Low-energy Passband X-ray Detector with Integrated Full-sun Field of View, flew as part of the High-Resolution Coronal Imager (HI-C) Flare campaign, a sounding rocket mission launched from Poker Flat Research Range on April, 17, 2024 during an M1.6 solar flare. The event was a two-ribbon flare, starting at 21:55 UTC and lasting approximately 30 minutes. The observational window of the sounding rocket was nominally five minutes above the atmosphere.

The rocket was recovered, and CAPRI-SUN was returned to MSU. Our poster will focus on instrument design and preliminary data analysis results. As the first sounding rocket mission purposefully launched during a solar flare this campaign provides a unique opportunity and essential data for studying solar flares.

Christopher Moore (Harvard-Smithsonian Center for Astrophysics)

Projected Performance of the Swift Solar Activity X-ray Imager (SSAXI-Rocket) for the Hi-C Flare Rocket

Christopher Moore, Elias Aguirre-Contreras, Isaac Anderson, David Caldwell, Gabriel Dubinsky, Tom Gauron, Leon Golub, Laura Hayes, Ed Hertz, Johnny Ho, JaeSub Hong, Andrew Inglis, Almus Kenter, Adam Kobelski, Jeffrey Reep, Suzanne Romaine, Sophia Sánchez-Maes ; Sabrina Savage, Nicholas Thomas, Amy Winebarger

The Swift Solar Activity X-ray Imager (SSAXI-Rocket) Instrument is a ride along instrument to the Hi-C Flare Rocket Launch campaign in April 2024. In the short 5-minute NASA Sounding Rocket flight, SSAXI-Rocket will measure the soft X-ray near-peak emission phase of a GOES C-class or greater solar flare. The SSAXI-Rocket instrument has peak sensitivity to 10 MK solar plasma, similar to the current Hi-C flare instruments, providing the exploration of the variability in heating and energy transport of Solar flares. SSAXI-Rocket combines small X-ray focusing optics (Wolter-1) with on-axis imaging resolution less than 10 arcseconds and high speed readout detector (CMOS), to image the flare soft X-rays at 5 hertz or faster, with minimized image saturation and pixel signal blooming. These high time cadence measurements can help uncover the soft X-ray intensity variations which can provide constraints on the intermittent heating processes in the magnetic loops.

The COOL-AID Experiment on the Hi-C Flare Mission

Sabrina Savage, Hi-C Team

The High-resolution Coronal Imager (Hi-C) Flare sounding rocket was launched during an M1.6 solar flare on April 17, 2024. Along with the primary Hi-C telescope, re-coated with a narrowband coating around 129 Angstroms, the payload carried the COOronal OverLapogram - Ancillary Imaging Diagnostics (COOL- AID) instrument. COOL- AID is a slitless spectrograph centered around the 129 Angstrom wavelength range to capture the Fe XXI 128.5 spectral line in first order. COOL-AID successfully observed the flare and, for the first time, captured spectrally pure data of the Fe XXI with a cadence of 1.3 s. This poster will show the optical design of COOL-AID and a preliminary analysis of the data. This instrument is a successful prototype for the spectrographs on the proposed ECCCO mission.

Modelling the Creation of Switchbacks from Interchange Reconnection

Philip Klaassen Dana Longcope

Interchange reconnection in the very low solar corona exchanges the foot points of open and closed field lines. This process has been invoked to explain brief reversals observed in the solar wind's magnetic fields and called switchbacks. Dynamical simulations of interchange reconnection have not, so far, shown the interchange reconnection regularly leading to instances of magnetic field reversals. To model such reversals, we conducted thin flux tube simulations of a magnetic flux tube after an interchange reconnection event. In the simulations, we observed the formation and persistence of a nonlinear wave in the flux tube. Under certain initial conditions, the geometric properties of these waves exhibit a reversal in magnetic field direction, constituting a switchback. We also perform calculations to show that a wave with the observed properties is a time-independent solution to the MHD equations used in the model. Further investigation of the factors influencing the specific geometry of the wave is required. The results of this work provide additional evidence supporting Interchange Reconnection as the process responsible for the creation of Switchbacks.

Kelvin Scheurer (Montana State University)

Relationship Between X-ray Luminosity and Magnetic Flux of Active Regions and X-ray Bright Points

Kelvin Scheurer

Dr. Keiji Yoshimura

Studying the relationship between magnetic fields and coronal emission is one way to approach the coronal heating problem. A clear power-law relationship between total unsigned magnetic flux and X-ray spectral luminosity over 12 orders of magnitude was reported in Pevtsov et al. (2003). In a recent study, Yoshimura et al. (2024) identified the cutoff magnetic field strength as a key parameter in influencing the power-law relationship. While Yoshimura et al. (2024) focused only on full sun data, we will expand the dataset to include XBPs and ARs. Utilizing data from Hinode/XRT and SDO/HMI, we successfully covered 5 orders of magnitude ranging between the lower XBP and upper AR. We will discuss the parameter dependency of the power-law relationship.

Allison Snyder (Montana State University)

Analyzing and Modeling Shear of Post-Reconnection Flare Loops

Allison Snyder, Jiong Qiu

Solar flares are events of increased radiation caused by heated plasmas confined in magnetic loops formed by magnetic reconnection. Astronomers have been attempting to observe and model flare loops for many decades. Previous investigations of solar flare loops have observed strong to weak shear as a phenomenon. Shear is the complementary angle between the projected flare loop and the polarity inversion line that divides the positive and negative magnetic fields on the surface of the Sun. However, 2D magnetic models of flare loops cannot account for shear. This necessitates a quantitative analysis of shear over time and a comparison of loop observations to 3D magnetic models. In this project, working with AIA's observations of the X1.0 flare on October 28th, 2021 in three different bandpasses, many thousands of flare loops were tracked to calculate the shear over time. These observations confirm the trend of strong to weak shear in this flare as the flare progresses. Additionally, these observed loops were compared to a potential field and linear force free models which did not align with all the observed loops. This suggests that the magnetic field model must be further advanced to match the observed flare loops and explain the phenomenon of shear.

Simon Shepard (Montana State University Solar Physics REU)

Quantifying the Heating Energy in Individual Post-Reconnection Flare Loops

Simon Shepard, Jiong Qiu, Drake Osaben

A solar flare releases a significant amount of energy. It has been known for a long time that magnetic reconnection drives the energy release and forms a large number of flare loops, where plasmas are heated. However, quantifying the energy used to heat flare loops is a challenging task, and what this study aims to tackle. Using data from the Solar Dynamics Observatory's (SDO) Atmospheric Imaging Assembly (AIA) and Helioseismic and Magnetic Imager (HMI), the M6.6 flare occurring on June 22, 2015, at approximately 18 UT was analyzed and modeled. The feet of flare loops were identified from the flare UV emission in the transition region, and the lengths of these loops were estimated using a potential field extrapolation. Furthermore, the heating rate of each individual loop was estimated using the UV Footpoint Calorimeter (UFC) method. The heating rates and loop lengths were input into the Enthalpy-Based Thermal Evolution of Loops (EBTEL) model to compute temperatures and densities of thousands of flare loops, which are used to synthesize coronal radiation from these loops. A few free parameters of the model can be optimized by matching the model's synthetic coronal radiation to the observed fluxes from GOES and AIA. With optimal parameters, the model produced emission in different passbands that agree with observed data within an order of magnitude, especially for higher temperature bands such as by GOES (>10 MK) and the AIA passbands characterized by plasma temperature 3 - 10MK, but it fails to accurately reproduce the observed long decay phase.