UDAIPUR SOLAR OBSERVATORY GOLDEN JUBILEE INTERNATIONAL CONFERENCE

ABSTRACT BOOK

Topic – 1

Quiet-Sun Dynamics

USO50YR-ST-01-0001

Stereoscopic diagnostics of the solar granulation: Two components of the velocity field vector using Hinode and Solar Orbiter

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In the quiet region, various convection-related phenomena, such as supersonic flows, vortices, and flux tubes, form and evolve dynamically. Understanding these processes requires deriving the velocity and magnetic field vectors, particularly their horizontal components. A promising approach is to use stereoscopic observations, incorporating multiple LOS components obtained from different viewing angles. The joint use of the Solar Orbiter / Polarimetric Helioseismic Imager (SO/PHI) and Hinode / Spectropolari-meter (SP) is well-suited for studying small-scale features, thanks to their stable space-based observations and comparable high spatial resolution. We analyzed a quiet region, observed at cosine of heliocentric angles of 0.80 (Hinode) and 0.90 (Solar Orbiter), with a 63-degree separation angle between the Sun-Hinode and Sun-SO lines. Our newly developed coalignment algorithm, applicable to slit-based and filtergraph observations, generates a map that is coaligned in both space and time, with the same number of spatial pixels and a correlation coefficient of 0.91, enabling one-to-one pixel comparison. The velocity field vector is derived by decomposing the two LOS velocities into the vertical and horizontal flow components, based on their respective heliocentric angles. The resulting horizontal flow field reveals clear signatures of fountain-like divergent flow in granules. This behavior is naturally expected from convection theory, but it is the first observational validation using Doppler measurements. In addition, our method captures horizontal flows along intergranular lanes, which may contribute to shaping meso-scale distribution of magnetic fluxtubes beyond the granulation scale. This presentation explores the horizontal flow distribution, and discusses the potential of stereoscopic diagnostics for quiet regions.

USO50YR-ST-01-0002

Photospheric scattering polarization at high spatial resolution

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Diagnosing photospheric quiet Sun magnetic fields via polarimetric signatures of the Hanle effect in scattering polarization of spectral lines at high spatial resolution remains a formidable challenge due to achieving sub-arcsec resolution simultaneously with high polarimetric sensitivity. I present the first direct observations of structuring in the linear polarization of the photospheric Sr I 4607 Å line at 0.2 arcsec resolution, obtained with the Visible Spectro-Polarimeter (ViSP) at the Daniel K. Inouye Solar Telescope (DKIST). Using the adjacent Fe I line as a reference, which is more Zeeman-sensitive than the Sr I line, we can statistically determine the spatial dependence of the polarization strength. Sr I shows depolarization in pixels which we classify as intergranules, and has more polarization in granules and specifically in pixels which are as bright as granules, but show low line-of-sight velocities. However, we had only enough signal-to-noise in positions on the solar disk that were not at disk center, and oblique viewing angles make interpretation of such results difficult. Therefore, to fully leverage ViSP observations for high resolution Hanle diagnostics, future observations need sufficient signal-to-noise at disk center.

USO50YR-ST-01-0003

Understanding the Solar Chromosphere's Fine Structure: Bridging MURaM Simulations and Observations

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Spicules have long been suggested to contribute to coronal heating, with reports of an association with transition region (e.g. Si IV emission) and coronal emission. However, interpreting spicule observations remains challenging due to line-of-sight superposition, Doppler-dependent visibility, and the difficulty of inferring three-dimensional structure from two-dimensional diagnostics. Realistic 3D simulations now help overcome these limits. We present the first statistical analysis of synthetic spicules from MURaM-ChE simulations, which reproduce key features of chromospheric dynamics. The non-equilibrium hydrogen treatment enables examination of 3D spicule geometry. Using a new Hα proxy, we identify numerous off-limb spicules and their on-disk counterparts in an enhanced-network simulation.

We statistically analyze 58 spicules (types I and II) and compare them with earlier high-resolution studies using Ca II H and Hα observations. The synthetic spicules show morphological properties and lifetimes broadly consistent with observations. To probe the underlying structure, we examine selected spicules using the Hα-proxy opacity. One illustrative spicule, with an apparent 190 km/s velocity, shows a sheet-like morphology. We demonstrate that such extreme apparent speeds arise not from true mass motion but from a rippling plasma sheet seen along the line of sight. The sheet lies at a quasi-separatrix layer (QSL). Whether a spicule appears sheet- or tube-like depends strongly on the Doppler shift selected for observation, and their on-disk counterparts often exhibit structures distinct from the spicules themselves. We further investigate the transition-region response of these structures using synthetic Si IV emission.

By combining physically motivated synthetic diagnostics with MURaM-ChE simulations, this work provides a physically consistent framework for comparing observed and simulated spicule morphology and apparent dynamics, thereby substantially narrowing the gap between observations and models of the solar chromosphere.

USO50YR-ST-01-0004

Solar Atmospheric Modelling Suite: a next step towards accurate modelling of the solar atmosphere

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Numerical modelling of the solar atmosphere is crucial for understanding the energy transport that leads to heating of the chromosphere and corona, as well as to eruptions and flares. Such modelling must capture the fundamental physical, radiative, and ionisation properties of the Sun's highly stratified atmospheric layers, together with the complex coupling between them. At present, no single model can accurately represent all the key processes operating across the different regions of the solar atmosphere. Yet such a capability is essential for interpreting cutting-edge, high-resolution observations produced by new and established space-, balloon- and ground-based facilities (Solar Orbiter, Aditya-L1, SUNRISE, DKIST, SST), and for achieving a step change in our understanding of plasma processes in the solar atmosphere.

In this talk, I will present the Solar Atmospheric Modelling Suite (SAMS), a new software framework recently supported by STFC. We have secured funding to build a modular platform centred on an exascale-ready, GPU-accelerated magnetohydrodynamic engine, coupled to a broad suite of physics modules, including 3D radiative transfer, updated atomic models, and multi-fluid capabilities. SAMS will also feature an integrated pipeline for generating synthetic observables directly from the simulations. I will outline the structure and purpose of SAMS, our current development status, our longer-term vision, and our plans to actively engage the wider community in this project.

USO50YR-ST-01-0005

Modelling wave dynamics of the quiet Sun atmosphere driven by p-mode oscillations

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Recent observational studies have shown the presence of ubiquitous coronal Alfvénic fluctuations and a substantial fraction of the Alfvénic power is concentrated in the 3–5 mHz frequency range, which has been widely reported to correspond closely to photospheric p-mode oscillations. In our study, we investigate the wave dynamics of the solar atmosphere with p-mode oscillations as a driver in the quiet-Sun region. We employ a series of high-resolution 2.5D and 3D MHD simulations of a stratified atmosphere containing small-scale magnetic flux-tube structures characteristic of the quiet Sun region, in which a broadband photospheric driver (2–4 mHz) is imposed to examine wave excitation and propagation. We analyze the atmospheric response to this driving under different magnetic field inclinations. Mode decomposition and height-dependent frequency analysis show that, in predominantly vertical fields, most of the slow magnetohydrodynamic wave power remains confined below the transition region. In contrast, in inclined fields, it is enhanced in both slow and Alfvén modes. In addition, our simulations also show an enhancement of Alfvénic power at higher frequencies (5–7 mHz) that propagates to coronal heights, which is more profound with inclined fields. This enhanced Alfvénic activity is also accompanied by strong spatial gradients in wave amplitude along the magnetic fields, leading to spicule-like plasma motions at the transition region.

USO50YR-ST-01-0006

Enhanced Detection of Fainter and Smaller Events in Solar EUV images

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Small-scale brightenings, prevalent in chromospheric and coronal layers and observed in EUV/X-ray emissions, represent a largely unmapped class of events key to understanding solar atmospheric heating to $> 1\,\mathrm{MK}$. This study develops novel detection methods, combining established techniques and machine learning, to identify and characterise the faintest, smallest brightenings at instrumental resolution and noise limits in EUV image time-series from SDO/AIA (quiet Sun/upper transition region), DKIST, and EUI/Solar Orbiter, leveraging recent high-resolution imaging advances. Following the basic method of Humphries et al. (2021) and adapting automated techniques from Pillai et al. (2019) for fine-scale structures, we extend beyond current algorithms that primarily detect bright, large-scale events using binary mapping (Henriques et al. 2016), intensity trends (Mravcová & Švanda 2017), central median methods (Plowman 2016), and background corrections (Nelson et al. 2017a), using conventional baselines to train advanced models and reveal their role in coronal heating.

USO50YR-ST-01-0007

Relation between solar spicules and propagating coronal disturbances using radiative MHD simulations

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Spicules are ubiquitous, small-scale plasma jets that populate the lower solar atmosphere. They are seen prominently in chromospheric observations and also exhibit signatures in the transition region and lower corona. More recently, these highly dynamic spicular jets observed in the corona have been reported to be associated with upward-propagating EUV intensity perturbations. A similar link has been found in previous simulations. However, the physical origin and properties of these Propagating Coronal Disturbances (PCDs), and their spicular connection, are not yet fully understood. Here, we ask whether PCDs carry mass and momentum into the solar wind. In this work, we explore the connection of PCDs with spicules by performing radiative MHD simulations using the Pencil Code, where a forest of spicules is self-consistently produced in the solar atmosphere powered by the subsurface convective processes. The convection generates "acceleration fronts", which are regions of strong compression or slow MHD shocks in the lower atmosphere that propagate outward along magnetic field lines (Srivastava et al. 2025) and subsequently move into the corona. The passage of these fronts, formed through nonlinear wave steepening, successively through any point in the atmosphere, produces saw-toothed velocity profiles in time. We analyze wavelet power spectra for these modeled velocity signals sampled at several atmospheric heights in the simulations, along with other diagnostics, and use them to investigate how the slow MHD shock waves can be a common driver for both PCDs and spicules.

USO50YR-ST-01-0008

Properties of magnetic field lines in coronal holes and quiet Sun

V N Nived
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Coronal holes (CH) are indistinguishable from the surrounding quiet Sun (QS) in the transition region. However, they show differences when their properties are comparedfor the region with the same magnetic field strength. In this work, we compared the properties of the magnetic field lines in CHs and QS using potential field extrapolation. We find that the height and length of the closed loops are larger in QS compared to CHs. Moreover, the number of short closed loops is similar in both CHs and QS (in agreement with Weigmann and Solanki, 2004). By combining our extrapolation results with the transition region and chromospheric observations, we find that the Si iv lines are formed slightly higher in QS compared to CHs. Furthermore, the blueshift in Si IV and Mg II (k3,h3) lines increases with the cosine of the inclination of the field lines (Blueshift increasesas the field line becomes vertical). The height of maximum correlation in k3 and h3 with respect to the extrapolated field map is much lower than the optical depth of unity for those features.

USO50YR-ST-01-0009

Influence of magnetic-field distribution on the spatio-temporal properties of EUV brightenings in the solar atmosphere

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The extreme-ultraviolet (EUV) brightenings identified by Solar Orbiter, commonly known as "campfires", are one of the fine-scale transient brightenings detected in the solar corona. Using closest-perihelion observations of Extreme-Ultraviolet Imager (EUI) onboard Solar Orbiter, recently we have reported the presence of smallest and shortest-lived EUV brightenings in the quiet-sun to date. We will present the spatio-temporal distribution of EUV brightenings over different magnetic environments of the solar atmosphere. By using various sets of quiet-sun and coronal-hole observations from HRIEUV/EUI we will present a comparative analysis of morphological and photometrical properties of EUV brightenings. We will discuss the interlinks of EUV brightenings to the photospheric dynamics and magnetic field distribution using HRT/PHI observations. Further their potential coupling through the solar atmosphere will be addressed using SPICE and IRIS observations.

Topic – 2

Magnetic & Velocity Fields in Active Regions

USO50YR-ST-02-0001

Magnetic field as the architect of active region morphology

Jan Jurčák
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For more than a century, it has been known that the appearance and structure of solar active regions are governed fundamentally by the magnetic field. I will review observations of both the global and the fine-scale properties of magnetic fields in active regions, with special emphasis on the influence of magnetism on convection. Observations, theory, and MHD simulations point to two critical field regimes: a critical value of the vertical magnetic field component that outlines the umbra–penumbra boundary, and the equipartition field strength that defines the outer penumbral edge, where magnetic and convective energy densities balance. Together, these thresholds describe how magnetic fields regulate the brightness and shape of convective cells. By connecting magnetic field strength to morphology, we can better understand how solar magnetism governs convective motions and thus the surface manifestations of magnetic activity.

USO50YR-ST-02-0002

Magnetic Field Variations Driven by Umbral Shocks in the Sunspot Chromosphere

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In the chromosphere above sunspots, magnetoacoustic shocks manifest as umbral flashes and running penumbral waves, producing clear signatures in spectrallines and their polarization profiles. Over the past decade, high-cadence spectropolarimetric observations combined with modern inversion techniques have revealed periodic variations in the inferred magnetic field during these events. Diagnostics such as the Ca II 8542 Å and He I 10830 Å lines suggest that shock-driven changes in line opacity and formation height can account for the observed variation in the apparent magnetic field. At the same time, growing evidence suggests that strong shocks can also produce real, though localized, changes in the magnetic field, including measurable variations in the transverse components linked to shock-driven expansion of magnetic field lines. Together, these results emphasize the close connection between wave propagation, radiative transfer effects, and magnetic field evolution in sunspot chromospheres.

USO50YR-ST-02-0003

On the link between penumbra formation and surrounding network

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Sunspots are the most prominent manifestion of solar magnetic fields. Their complex magnetic field structure and dynamics present an outstanding puzzle.In particular the formation of the sunspot penumbra and the associated creation of horizontal components of the magnetc field is still not fully understood. We willreview the current understanding and investigate the connectivity of the sunspot magnetic field with the surrounding network. Sunspot are known to be hosted withinsupergranular cells which are surrounded by the network. In mature sunspots the supergranular cell transforms into a stronger moat flow with velocities up to $1\,\mathrm{km\,s^{-1}}$. While the outwards directed moat flow is un-magnetic, individual magnetic elements are observed as Moving Magnetic Features (MMFs) to migrate from the spot tothe surrounding network. These MMFs connect the sunspot magnetic field with the network magnetic fields and could be linked to the horizontal component of themagnetic field in the penumbra. We present observational evidence using GREGOR data from June 28, 2022, that the rise of sea-serpent fields at the outer spot boundaryis observed as MMFs migrating away from the spot to eventually reach and reconnect with the network magnetic field. These findings indicate that the network magneticfields are, at least partially, rooted in the sub-photospheric magnetic sunspot trunk. Thus, the surrounding network is an ingral part sunspot formation, structureand dynamics, and the connecting MMFs in the photosphere may play a crucial role in the creation of the penumbra.

USO50YR-ST-02-0004

Penumbra formation in Sunspot simulations

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Despite being one of the most prominent features on the solar surface, the structure, formation mechanism and evolution of sunspots are still open questions. Radiative MHD simulations of sunspots that most closely resemble observations rely on a specific substructure model of the field configuration ('monolithic sunspot') and require an artificially forced ring current at the top boundary to promote the formation of a substantial penumbra. In this talk, we explore alternate mechanisms that self-consistently produce a sunspot penumbra without the upper boundary forcing and what they imply for subsurface flows and field configuration.

USO50YR-ST-02-0005

Granular light bridges

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We analyse five light bridges observed by the GREGOR telescope in the leading spot of AR 13014 on May 18, 2022. Spectropolarimetric observations of the lines Si I 1082.71 nm and Ca I 1083.90 nm were inverted using the code SIR to obtain thermal parameters, magnetic field vector, and line-of-sight velocity. Additionally, a sequence of 184 images in the TiO band was acquired during the spectral scan. The light bridges have a granular structure composed of grains with sizes from $0\farcs2$ to $1.4''$ and lifetimes around 6 minutes, as determined from the TiO sequence. The largest grains ($> 1''$) resemble photospheric granules and appear at the locations with upflows of $1\,\mathrm{km\,s^{-1}}$ and a weak inclined magnetic field, vertical component of which approaches the equipartition value. A statistical comparison shows that continuum intensities, standard deviations of the line-of-sight velocities, and effective diameters of the LB grains generally decrease with increasing magnetic field strength B and usually increase with increasing magnetic field inclination. These relations differ in individual light bridges depending on the large-scale magnetic field configuration.

USO50YR-ST-02-0006

New Insights into Low-Chromosphere Magnetic and Velocity Fields in Sunspots: Results from TuMag/SUNRISE III

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Active regions are among the most magnetically complex and dynamic structures on the solar surface, hosting processes such as flux emergence, magnetic reconnection, wave propagation, shock formation, chromospheric flashes and heating, systematic flows, supersonic transient events, strong magnetic field concentrations, and many more. Understanding how these phenomena behave and interact across different atmospheric layers is essential for constraining the physics of sunspots and their evolution.In sunspots, the interplay between magnetic fields and plasma flows governs key processes such as penumbral filament formation, energy transport, and the transition from photospheric to chromospheric structuring. Yet, direct diagnostics in the low chromosphere remain scarce, limiting our ability to track how magnetic fields expand, reorganize, and guide flows as they rise toward the chromosphere and higher layers.
In this talk, I will present recent advances in characterizing magnetic and velocity fields in sunspots, with a particular focus on the low chromosphere. The results are based on high-resolution spectropolarimetric observations of the Mg I b_2 line acquired with the TuMag instrument onboard the SUNRISE III balloon-borne mission. These novel observations provide new insights into the transition from photospheric to chromospheric large-scale penumbral flows, the structure of magnetic fields above sunspot penumbrae, and their expansion near the temperature-minimum region of the solar atmosphere.

USO50YR-ST-02-0010

Analysis of Doppler Velocity Power Spectra and Magnetic Fields in the Solar Active Region NOAA 13842

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The acoustic (p-mode) power distribution in solar active regions serves as a key diagnostic of how magnetic fields influence helioseismic oscillations. In this study, we investigate oscillatory power in NOAA Active Region 13842 using high-resolution Dopplergrams from the Helioseismic and Magnetic Imager (HMI) onboard the Solar Dynamics Observatory (SDO). Time–frequency analysis shows a distinct suppression of acoustic power in magnetically strong regions relative to the quiet Sun, indicating absorption and damping of p-modes by magnetic structures. These results highlight the complex interaction between magnetic topology and wave propagation in the solar atmosphere, contributing to a deeper understanding of helioseismic behavior in magnetized environments and its relevance to flare-related wave processes.

USO50YR-ST-02-0012

Exploring spatially highly resolved spectro-polarimetric scans

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High-resolution broad-band observations of the Sun reveal a multitude of small-scale structures, everywhere in the photosphere. Until recently spectro-polarimetric scans failed to attain the resolution exhibited by broad-band imagery. In this contribution we present first results from spatially highly resolved ($\sim 0\rlap{.}''07$) spectro-polarimetric slit-scanning observations utilizing the signal from many simultaneously observed spectral lines.
From a previous study on synthetical observations we expect many-line interpretations to show better robustness against noise and a better height coverage (in terms of optical depth). This is particularly important for Stokes Q and U (and partly V), especially in quiet Sun conditions. In this contribution we will discuss the performance of many-line interpretation applied to diffraction-limited solar observations. We further present first results on small-scale features which previously could not be characterized spectro-polarimetrically.

USO50YR-ST-02-0013

Evolution of Magnetic Energy, Helicity, and Twist in Active Regions Associated with Major Solar Flares

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Udaipur Solar Observatory, PRL, India

Solar flares and coronal mass ejections (CMEs) are major solar eruptions that significantly influence space weather. They are powered by the rapid release of magnetic energy that has been progressively stored in the corona. The sustained buildup of magnetic energy and magnetic helicity plays a crucial role in forming non-potential magnetic structures that may eventually become unstable, leading to eruption.

To better understand their roles, we analysed ten eruptive events associated with M- and X-class flares. Using vector magnetograms from the Helioseismic and Magnetic Imager (HMI), spanning several hours before and after each flare, we applied the Differential Affine Velocity Estimator for Vector Magnetograms (DAVE4VM) to derive the photospheric fluxes of magnetic energy and helicity. Our results show a clear decrease in both quantities following the eruptions, consistent with the release of stored magnetic stresses. We also examined the temporal evolution of the photospheric twist parameter. Most events exhibit a decrease in twist prior to the flare, while a significant enhancement is seen immediately after the eruption, indicating post-flare reconfiguration of the magnetic field. These findings highlight distinct photospheric signatures of magnetic restructuring associated with major solar eruptions and reveal clear patterns in the pre- and post-flare evolution of active-region magnetic fields.

USO50YR-ST-02-0014

Beyond Intensity: Linear Polarization as a Proxy for Solar Vortices

Nitin Yadav
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Vortex flows drive key processes in the solar atmosphere, but detecting them observationally has mostly relied on intensity images. This work introduces wavelength-integrated linear polarization as a powerful new indicator for spotting these structures in both the photosphere and chromosphere.

Using advanced computer simulations of solar magnetic activity, we demonstrate that polarization maps clearly reveal vortex locations, outperforming traditional methods by highlighting spatial patterns across the solar surface.

This simple yet effective approach promises to enhance vortex studies with upcoming solar telescopes, providing fresh insights into solar turbulence and energy transport.

USO50YR-ST-02-0016

On the connectivity of sunspots and surrounding network

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While stable sunspots have been extensively studied and their global surface properties are well understood, their formation process and connectivity with their surroundings continue to elude definitive explanation. Here, we present further advancements on the mechanism(s) responsible for sunspot development through a comprehensive analysis spanning from observations of the photosphere and chromosphere to magnetic field extrapolation and magneto-hydrodynamic simulations. Our findings provide clear evidence that penumbra formation begins with the emergence of sunspot magnetic flux through the solar surface, giving rise to transient penumbral filaments. As this magnetic flux continues to ascend through the solar atmosphere, a stable, low-lying magnetic canopy eventually forms. Once a sufficient amount of flux has emerged, its further rise is inhibited at the photospheric level, leading to the formation of stable penumbrae. This process is also accompanied by the formation of an enhanced magnetic network surrounding the spot, the nature of which will be further discussed.

USO50YR-ST-02-0017

Magnetic jerk driven acoustic emissions in the sunspots associated with major solar flares

Brajesh Kumar
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The Udaipur Solar Observatory has the genesis of working in the research areas of solar flares and eruptions (hence space weather studies), solar magnetic fields and helioseismology since its inception. This led to our interest in working on flare induced global and local oscillations in the Sun, motivated with the examples of the discovery of solar quakes seen during flares in SOHO/MDI observations. While working on these problems using the observations from GONG, SOHO/MDI/GOLF/VIRGO, and SDO/HMI, we have found some important results related to flare driven global waves in the Sun as well as magnetic jerk driven acoustic emissions in the sunspots associated with major flares. These acoustic emissions can travel upward in the solar atmopshere and contribute to the heating of active region atmopsheres. Here, we will present some of our impotant results related to magnetic jerk driven acoustic emissions in the sunspots during major flares.

USO50YR-ST-02-0018

Multi-line Spectropolarimetric Observations of a Flaring Active Region with DKIST

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Solar flares, driven by magnetic reconnection in the corona, release immense amounts of energy throughout the solar atmosphere. Observations show that flares influence multiple atmospheric layers almost simultaneously. To achieve a comprehensive understanding of flare dynamics, multi-line spectropolarimetric observations that probe different atmospheric heights are essential. In this presentation, we will show multi-line observations of a flaring active region obtained with the ViSP (Fe I 630.1 nm, Na I D1, and Ca II 854.2 nm) and VBI instruments at the NSF's DKIST. These high-resolution, high-cadence observations reveal rotation of two small-scale pores both before and during the flare. Additionally, in the red wing of the Ca II line, we identified multiple compact, roundish, and quasi-equally spaced bright "blob-like" structures within the flare ribbon. We performed multi-line inversion of ViSP Spectra to infer the stratification of physical parameters across the flare ribbon. In this talk, I will discuss potential physical mechanisms responsible for the pore rotation in the photosphere, and using multi-line spectropolarimetric inversions, I will explore plausible mechanisms underlying the small-scale flare ribbon structures in the chromosphere.

USO50YR-ST-02-0019

Surface flows near the leading polarity of emerging active regions consistent with tilt angle

Asha Lakshmi Kizhakkekunnathara Venu
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In some solar dynamo models the tilt angle of the polarity pair in magnetic active regions away from an east-west alignment (known as Joy's Law) is a critical component. It is thought that the Coriolis force is responsible for Joy's Law, but it is not clear what flows the Coriolis force is acting on. It has been shown that Joy's law sets in during the emergence process, which suggests that the tilt angle is generated near the surface. Our goal is to track the evolution of Joy's Law to understand the relationship between the surface flows and the motion of the polarities.By studying a statistical sample of 100s of active regions included in the Solar Dynamics Observatory Helioseismic Emerging Active Region (SDO/HEAR) survey (Schunker et al. 2016), we refined the emergence time and location of active regions and then tracked the location of each of the polarities as the active regions emerges on the surface of the Sun .By averaging samples of active regions that follow Joy's law and anti-Joys law separately, we found that the flows on the upstream side of the leading polarity are in the direction of motion. Our results suggests that surface flows contribute to the observed tilt evolution, providing new constraints on the mechanisms underlying Joy's Law.

USO50YR-ST-02-0020

Height Extent of Umbral Dots: Photospheric and Chromospheric Signatures from High-Resolution Spectropolarimetry

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Umbral dots (UDs) are small, bright features embedded in the dark umbrae of sunspots and are widely interpreted as the photospheric manifestation of magnetoconvection withinstrong magnetic fields in monolythic sunspot models. In case of aggregate flux bundel model, they represent the field free gap between flux bundles. While the thermodynamic and kinematic properties of UDs in the photosphere are well established, their vertical extent and influence on the chromosphere remain poorly constrained.

We investigate the thermal and dynamic signatures of UDs from the photosphere to the chromosphere using high-resolution spectropolarimetric data acquired with the Interferometric BIdimensional Spectrometer (IBIS) at the Dunn Solar Telescope. The observations target a round, isolated leading sunspot in NOAA AR 12519 at a heliocentric angle of 32°.

Local thermodynamic equilibrium (LTE) inversions of the Fe I 6302.5 Å Stokes profiles using the SIR code provide photospheric temperature and magnetic field stratifications. Non-LTE (NLTE) inversions of Ca II IR with the CAISAR code deliver chromospheric temperature stratifications, while bisector analyses of the Hα 6563 Å and Ca II IR lines yield line-of-sight (LOS) velocity stratifications from the upper photosphere into the chromosphere. A set of intensity-based masks is used to isolate umbra, penumbra, UDs, and quiet-umbra reference regions.

In the chromosphere, the direct UD footprint becomes less distinct, but localized temperature enhancements at $\log\tau \approx -3.5$ and strong, spatially offset downflows in Ca II IR (3–5 km s^{-1}) are observed near many UDs. The Hα and Ca II IR velocity fields show a characteristic pattern: upflows in Hα tend to correlate spatially with nearby downflows in Ca II IR, and large chromospheric redshifts in Ca II IR spectra occur preferentially where such downflow patches are present.

Our results indicate that UDs influence the solar atmosphere well beyond the deep photosphere, producing vertically extended perturbations that become laterally displaced and highly structured in the lower chromosphere. We interpret these signatures in terms of magnetoconvective plumes, mass drainage along inclined magnetic flux tubes, and possibly magnetoacoustic wave propagation. These findings provide new constraints on the vertical coupling between umbral fine structure and the overlying atmosphere.

USO50YR-ST-02-0022

The Nature of Convective Intrusions in Sunspots and the Associated Heating of the Chromosphere and Transition Region

Rohan Eugene Louis

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Sunspots are sites of extremely strong magnetic fields where the photospheric field strength is in excess of 2.5 kG in the dark umbral core. Despite the presence of strong magnetic fields, convective flows are not entirely suppressed, as evidenced by the observations of umbral dots and light bridges, which correspond to hot, weakly magnetised plasma emerging within the strongly magnetised umbral environment. Light-bridges are large-scale, convective intrusions that are typically seen at various stages of a sunspot's lifetime, particularly in the early phase of sunspot formation and in the late stages of spot decay. They are also sites where a host of dynamic phenomena, such as surges, jets, flares, etc, occur. In this talk, I will describe our current understanding of the nature of sunspot light bridges and the possible processes that could supply the necessary energy to maintain the elevated temperatures across a large height range, spanning the chromosphere to the corona.

USO50YR-ST-02-0023

Evershed-Flow: A new look through stereoscopic means

David Lykke Ivens
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The orbit of the ESA/NASA Solar Orbiter space mission allows for simultaneous observation of sunspots from different viewpoints. Combining data from the SO/PHI instrument with those obtained from Earth's viewpoint can be used to study the properties of sunspots through stereoscopic means. In this project we combine line-of-sight Doppler velocities in the penumbra of a sunspot obtained by SO/PHI and SDO/HMI from two highly offset vantage points. We reconstruct the velocity vectors of the penumbral Evershed-flow under different assumptions including magnetic field data in the analysis. The temporal evolution of the Evershed-flow can then be studied with a time series of 6 hour duration and one minute cadence. Comparing the reconstructed velocity vector with the magnetic field vectors allows for a validation of the obtained results and gives new insights in the structure of sunspot penumbrae.

USO50YR-ST-02-0025

Structure of Light Bridges in AR 13889 mapped across multiple heights in Solar Atmosphere

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Light bridges are known to be bright, elongated structures surrounded by umbrae within a sunspot. Light bridges have been studied extensively for their properties, and various types of light bridges have been identified. While light bridges are generally observed at photospheric heights, some have also been observed at chromospheric heights. Ground-based spectro-polarimetric data, along with inversion of the Stokes vectors, reveal various magnetic parameters of magnetic features around sunspots. In this study, we use simultaneous observations of the photosphere and chromosphere using the Si I 10827 Å and Ca II 8542 Å lines, obtained with the GREGOR Infrared Spectrometer (GRIS) . Using the DeSIRe inversion code, we perform inversions of the Stokes vectors to estimate the magnetic field, velocity, and other parameters across multiple heights in the solar atmosphere for light bridges observed within AR 13889. We present a three-dimensional magnetic field topology of the observed light bridge, mapped across multiple heights.

USO50YR-ST-02-0026

Revealing the Invisible Sun through Doppler Observations of the Visible Photosphere

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National Solar Observatory, USA

Understanding and monitoring active regions on the Sun's surface are crucial components of space weather forecasting and sola dynamo modeling. While routine observations of the visible hemisphere have long been available from both ground- and space-based instruments, coverage of the invisible hemisphere became possible only with NASA's STEREO mission and, more recently, ESA's Solar Orbiter. These missions, however, do not continuously observe the entire far hemisphere. Helioseismology offers an indirect but powerful alternative by inferring far-side maps, highlighting medium-to-large active regions using Doppler observations of the front hemisphere. In this presentation, we will discuss recent advances in far-side mapping and how these inferred maps help close the critical gap in achieving full 360° monitoring of the Sun.

USO50YR-ST-02-0027

An Investigation of the Spatial Distribution of Sunspot Umbral Dots

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Umbral dots (UDs), observed in the highly magnetized sunspot umbra, are understood to be signatures of small-scale magnetoconvection. UDs are typically classified as peripheral and central,depending on their relative proximity to the umbra-penumbra boundary, withthe former being brigher and larger than the latter. However, this classical categorisation does not take into account the localised spatial distribution of UDs that depends on the lifetime of the sunspot, the morphology of the sunspot, the physical conditions outside the sunspot, etc. Our work aims to determine the spatial distributions of UDs and how it is affected by the changes in sunspots's morphology, as well as the presence of large-scale convective structures such as light bridges. We utilize blue continuum filtergrams of 10 sunspots observed between 2006 and 2015 by the Solar Optical Telescope (SOT) onboard the Japanese satellite Hinode. We adopt a multi-level tracking (MLT) scheme to identify the UDs and incorporate a density based clustering algorithm in order to determine localizations in the UD population. Our initial results show that the UD fill-fraction is enhanced in sectors with a highly constricted umbra which simulatneously elevates the local intensity. On the other hand, the average effective diameter do not show any discernible pattern. We also describe the similarities and differences between UDs located near the umbra-penumbra boundary with those forming a large-scale, coherent light bridge. We discuss our findings and their relevance to exisiting sunspot models.

Topic – 3

Upper Atmospheric Heating

USO50YR-ST-03-0001

Coronal structure and dynamics — New insights from Solar Orbiter

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The outer solar atmosphere, the million-Kelvin degree hot corona, is intricately governed by the magnetic field. The diverse magnetic landscape in the solar surface results in an equally diverse and complex coronal features. Magnetic structures in the corona range from $\sim$100 km sized tiny brightenings with lifetimes of at most a few seconds to regions on scales of tens of megameters with minimal temporal variations. Understanding the origin and dynamics of this coronal magnetic field is a central theme of the Solar Orbiter mission. The Polarimetric and Helioseismic Imager and the Extreme Ultraviolet Imager, two of the remote-sensing instruments on board Solar Orbiter, capture surface magnetic structures and coronal features at almost exactly the same high spatial resolution of 200 km. These unprecedented observations are providing new insights into the photosphere-corona connection and are refining our understanding of fundamental processes in the magnetized plasma including reconnection and magnetohydrodynamic waves. I will review the recent progress on coronal structure and dynamics with an emphasis on the open questions and possible future directions.

USO50YR-ST-03-0004

High-Resolution Ground–Space Synergies for Probing Small-Scale Magnetic Reconnection in the Solar Atmosphere

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Small-scale magnetic reconnection is a fundamental mechanism for energy release in the solar atmosphere. However, observational characterization of this process requires resolving the coupling between magnetic drivers in the photosphere and the resulting plasma response in the upper atmosphere. Here, we present results from coordinated campaigns, combining high-resolution ground-based spectro-polarimetry at SST and GREGOR with space-based UV and coronal diagnostics from IRIS, SDO, and Hinode. We use these datasets to track sub-arcsecond magnetic evolution at the photospheric level—specifically flux emergence and cancellation events—and correlate these dynamics with impulsive energy release in the transition region and corona. The analysis focuses on reconnection-driven phenomena such as UV bursts and compact brightenings. These events are characterized by Si IV and O IV emission enhancements (factors of 100–1000), pronounced non-thermal line broadening, and high-speed bi-directional flows. We observe a strict temporal and spatial correspondence between photospheric magnetic restructuring and multi-thermal signatures in the chromosphere and corona. This suggests a bottom-to-top process in which lower-atmospheric magnetic activity directly drives heating across multiple layers. These observations provide quantitative constraints for numerical models by establishing realistic magnetic boundary conditions and diagnostics of energy conversion. Furthermore, the results validate the utility of combining ground- and space-based instrumentation to isolate the physical mechanisms of reconnection, serving as a baseline for future investigations with IBIS2.0, MUSE, and Solar-C, as well as for the development of EST.

USO50YR-ST-03-0005

Exploring small-scale coronal loop structures using ultra high resolution observations from HiC-Flare

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This work takes advantage of new observational data collected by the High-resolution Coronal imager (Hi-C) at the highest spatial and temporal resolutions available. This most recent Hi-C dataset is the first to make use of the hot 129Å channel and the first to consist of targeted observations of a solar flare, rather than the quiescent corona. Images from Hi-C are analysed and compared with complementary EUV observations from SDO/AIA. The widths of the loop strands are measured, and the resulting populations analysed. Preliminary results suggest the majority of loop strands have a width in the range 500-2,000 km, but there is some variation in the loop strand widths observed in plasma at different temperatures. There is some evidence that there are smaller structures present which are partially resolved by Hi-C, with the very smallest smallest loop strands of a similar order of magnitude to the spatial resolution of the Hi-C images. Further results will be presented, as well as a discussion of future work, investigating individual events within the Hi-C observations, making use of the high cadence available to track the dynamic behaviour of the corona.

USO50YR-ST-03-0006

Automatic Detection of Solar Spicules and their Role in Coupling the Chromosphere and Corona

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Spicules are among the most dynamic and ubiquitous features of the solar atmosphere. They exhibit rapid upward and downward motions and are prominently observed in the wings of chromospheric spectral lines. Despite decades of research, the mechanisms responsible for their formation and their potential contribution to heating the transition region and corona remain open questions. In this study, we perform an automated detection of spicules in Hα and Ca II 8542 Å spectral observations and investigate their statistical properties. Our analysis reveals that spicule lengths follow a power–law distribution, whereas their average widths are represented by a Gaussian distribution. Using coordinated high–resolution observations from the Swedish 1-m Solar Telescope (SST) and the Solar Dynamics Observatory (SDO), we further explore possible driving mechanisms of spicule formation and their influence on the upper solar atmosphere.Our results suggest that a subset of spicules may be generated by shock waves, which manifest as distinct sawtooth patterns in λ–t (lambda–time) diagrams. These shocks appear to propagate upward and may be visible as propagating disturbances in coronal channels, indicating a potential link between chromospheric dynamics and coronal activity.

USO50YR-ST-03-0007

Plasma diagnostics of coronal fan loops using AIA/SDO and EIS/Hinode

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We utilize the spectroscopic and imaging data from the Extreme-ultraviolet Imaging Spectrometer (EIS) onboard Hinode and the Atmospheric Imaging Assembly (AIA) onboard Solar Dynamics Observatory (SDO) to investigate plasma parameters along coronal fan loops. The fan-loop system is clearly visible in several spectral lines formed in the temperature range of 0.3–2.5 MK. We derive the electron number density and temperature along several fan loops using the line ratio and emission measure-loci (EM-loci) method, respectively, from EIS spectroscopic data. We also derive the electron number density and temperature using differential emission measure (DEM) analysis from AIA imaging data. The density scale heights derived from Fe XII spectral line pairs are larger than expected scale heights as per the hydrostatic equilibrium model, suggesting an over-dense nature of these fan loops. We also found the existence of two temperature plasma components along the loops, ranging from 0.8–1.05 MK and 1.6–1.8 MK, along with an average temperature varying between 1.2–1.4 MK. Our results highlight the dual temperature component of these loops, which can be well-resolved with EIS spectroscopic data. This can be due to the presence of multiple thin strands having uniform but different temperatures, which are subsets of the individual traced fan loops. However, the DEM results using AIA imaging data are unable to resolve these findings after a few pixels. The low temperature dominates near the loop footpoints, while the high temperature dominates further away. We also deduced the nonthermal velocity along the various fan loops using the strongest isolated Fe XII spectral line profile. The obtained nonthermal velocities remain almost constant along the loop lengths. Using the obtained parameters, we further calculate Alfvén wave energy flux using the recently estimated magnetic field strengths along coronal fan loops. We find significantly higher Alfvén wave energy fluxes at the coronal loop footpoints $\approx 2 \times 10^7$ erg cm^{-2} s^{-1}, which are sufficient to heat the active region corona.

USO50YR-ST-03-0008

Probing the magnetic field and plasma-β along individual umbral fan loops using 3-min slow waves

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Coronal fan loops rooted in sunspot umbra constantly show 3-min period propagating slow magnetoacoustic waves (SMAWs) in the corona. However, the origin of these waves in the lower solar atmosphere is still unclear. Here, we present the results of our study of these waves along a clean fan loop system using multi-wavelength imaging observations from IRIS and SDO. We demonstrate a novel observational technique to trace the origin of these waves at the photosphere by utilizing amplitude and frequency modulations of 3-min waves from the corona to the photosphere via the transition region and chromosphere. These modulation periods are in the range of 20–35 min at all the heights. Tracing of these loops also provides observational evidence of cross-sectional area expansion of the loops from the photosphere to the corona. We utilized this information to estimate the magnetic field strength and plasma-β along isolated individual loops emanating from the sunspot umbra. We find the RMS magnetic field strengths in the range 1596-2269 G at the photospheric footpoints of the fan loops decrease rapidly to 158-225 G at the coronal footpoints. We estimated the plasma-β at the photospheric and coronal footpoints in the range 0.2-0.5 and 0.0002-0.0008, respectively. We found plasma-β<1 along the whole loop, whereas the plasma-β $\approx$1 layer is found to be at sub-photospheric heights. We compared our findings for isolated individual fan loops with a previously established model for active regions and found an almost similar pattern in variations with height, but with different plasma-β values. Our results demonstrate the seismological potential of 3-min slow waves omnipresent in the umbral sunspot atmosphere to probe and map isolated loops along with their cross-sectional area and determine the magnetic field and plasma-β along these loops.

USO50YR-ST-03-0009

Multimode Quasi-Periodic Pulsations in Extreme-Ultraviolet Emissions Associated with an X-Class Solar Flare

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We investigate quasi-periodic pulsations (QPPs) in EUV emission during the peak phase of an X-class solar flare using wavelet analysis, EEMD, Hilbert–Huang spectra, and Fourier-based reconstruction. All methods consistently reveal oscillatory power with periods of roughly 2–3 minutes in both the AIA 171 Åand 335 Åchannels. These periodicities appear in the second and third intrinsic mode functions, show clear non-stationarity, and reproduce the original light curves with high fidelity. The results indicate that multi-minute oscillations are intrinsic to the flare emission and likely reflect multimode processes in coronal energy release.

USO50YR-ST-03-0010

Characterizing small-scale transient chromospheric brightenings using data from MAST and SDO

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The solar atmosphere is dominated by intense magnetic activities, where strong heating events occur throughout the different layers of the atmosphere. Small-scale transient events, such as Ellerman bombs and UV bursts, are thought to play a crucial role in transferring energy from the Sun's lower atmosphere to its outer layers. When observed in Ca II filters, the solar chromosphere consistently exhibits several small-scale, compact brightening events in sunspot plage regions, which are not well understood. Here, we present an analysis of narrow-band images of Ca II 8542 Å data observed by the Multi Application Solar Telescope (MAST). These observations are complemented by multi-channel data from the Atmospheric Imaging Assembly (AIA) and Helioseismic and Magnetic Imager (HMI), both onboard the Solar Dynamics Observatory (SDO). We detected some of these brightening events using our algorithm, which is based on the intensity of their surroundings. We detected 62 bright points from the AIA 1700 Å passband and characterized them using various factors, such as occurrence, lifetime, area, and magnetic field. We utilized time-lag analysis to study their origin and evolution. We found that most of these bright points have a lifetime of less than 6 minutes and are associated with flux cancellation/emergence. We found that more than 50% of these brightenings reach the transition region temperature during their lifetime. 24% show their signature in MAST Ca II 8542 Å observations. We also studied their spatial distribution around the active region to find any possible relation with their occurrence. In this presentation, we will present a detailed statistical investigation of such compact brightenings with their origin and thermal evolution.

USO50YR-ST-03-0011

Multi-Sigmoidal Structure's Impact on an Active Region Flare

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Forward or inverse S-shaped magnetic structures are known as sigmoid, which are typically observed in the solar corona. For the study of magnetic topology and magnetic instability, which can result in eruptive events like solar flares and coronal mass ejections, the formation of a sigmoid in an active zone is essential. Using multi-wavelength observational data sets from the Extreme Ultraviolet Imager (EUVI) from the Solar Terrestrial Relations Observatory (STEREO) and the Atmospheric Imaging Assembly (AIA) onboard the Solar Dynamic Observatory (SDO), we present observations and analysis of the subsequent formation of sigmoidal structures and eruption of a sigmoid, associated jet formation, coronal wave generation and propagation, and related M-class solar flare. First, we address potential reasons why forward and inverse S-shapes arise simultaneously in adjacent areas of the active region. Additionally, we examine the possible function of the sigmoid eruption in initiating the flare along with parallel and circular flare ribbons, where multi-stage subsequent magnetic reconnection and significant twist or shear may be crucial. In addition, we calculate the coronal wave's propagation speed and the erupting jet's velocity during the sigmoid generation and eruption time.

USO50YR-ST-03-0012

A unified picture of swirl-driven solar coronal heating: magnetic energy supply and dissipation

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The outermost layer of the solar atmosphere is referred to as corona, of which temperature is hundred times hotter than the surface while the ultimate heat source locates at the inner core. The solar coronal heating problem is one of the most critical challenges in solar physics. Recent advancements in observational accuracy have revealed numerous facts that cannot be explained by the classical model of solar coronal heating. Among these, small-scale swirls, whose diameters are comparable to the current instrumental limits, are ubiquitously observed in the quiet-Sun photosphere and chromosphere. They have been highlighted as a potential new source of magnetic energy supply to the corona. However, the overall contribution of swirls to the total magnetic energy supply to the corona remains uncertain. Additionally, theoretical model capable of deriving the swirl-driven magnetic energy dissipation has yet to be established. To address this, we conducted statistical analyses using a three dimensional radiative magnetohydrodynamic simulation that self-consistently solves the system from the convection zone to the corona. We investigated the statistical properties of magnetic energy supply and dissipation caused by swirls in a unified framework. Our results reveal that swirls account for approximately half of the total magnetic energy supplied to the corona and can trigger magnetic reconnection, achieving magnetic energy dissipation consistent with observed heating signatures.

USO50YR-ST-03-0013

Sloshing Oscillations in coronal loops excited by successive M- and C-Class flares

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Loops associated with flares often exhibit plasma oscillations, where a disturbance moves back and forth between the loop footpoints. These oscillations are known as "sloshing oscillations". Current understanding suggests that they are triggered by flares; however, they do not appear after every flare. The connection between flare strength and the occurrence of oscillations is still not well understood. To investigate this, we compare the properties of sloshing oscillations occurring during M- and C-class flares in a single loop. Our sample includes seven such loops observed by AIA onboard SDO. Since these loops are very hot, we primarily analysed the oscillations in the AIA 131 Å and 94 Å channels. We find that loops hosting oscillations during M-class flares generally have higher temperatures than those associated with C-class flares. In most cases, the damping time of oscillations during M-class flares is longer than that during C-class flares. However, the damping time shows no clear correlation with temperature, suggesting that thermal conduction may not be the dominant damping mechanism in all cases. Additionally, in some events the damping time is shorter in the cooler 94 Å channel, which is not expected from previous observational studies. These results therefore suggest that the dominant damping mechanism may vary with every event, rather than being governed solely by thermal conduction. Furthermore, we find an approximately linear relationship between the damping time and the oscillation period in the 131 Å channel, with an exponent close to unity, while the exponent is larger in the 94 Å channel.

USO50YR-ST-03-0014

Effect of Geometry on Dissipative High-Frequency Leaky MHD Waves in Coronal Loops

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The study of MHD waves in coronal loops is important for understanding both coronal heating and coronal seismology. In the present work we compare the characteristics of high-frequency leaky standing fast magnetoacoustic waves mimicking the loop geometry as a magnetic slab and a cylindrical flux tube under the assumption of low-β plasma. A number of studies have been done concerning the leaky mode waves, under the assumption of ideal plasma conditions. However, the solar coronal plasma is not ideal thus in our study we include compressive viscosity as the damping mechanism. The major finding of our work is that for the long wavelength limit, the period of leaky mode waves is independent of loop length and depends only on the radius of the loop. While for short wavelength limit the period of modes depends on both radius and length of the loop. We found that the general trends in wave periods and damping time are qualitatively similar for both slab and cylindrical geometries; however, there are quantitative differences. Cylindrical loops exhibit shorter periods and stronger damping than their slab counterparts. This shows the significance of geometry in describing the energy dissipation and wave dynamics in the coronal loops. Our findings highlight the importance of geometry on wave properties and demonstrate that cylindrical model provides more accurate representation of coronal loops.

USO50YR-ST-03-0015

Magnetic edges dominate heating in the solar atmosphere

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At the interface between the Sun's million-degree corona and its surface lies the chromosphere: cooler and far denser than the corona, yet it processes essentially all of the magnetoconvective energy that ultimately powers the outer atmosphere. How and where that energy is converted into heat remains a central open question in astrophysics. Here we combine high-resolution observations from IRIS, Hinode and SDO with a state-of-the-art 3D radiative-MHD simulation to show that the key sites of energy release in active-region plage are not the familiar strong-field cores, but their magnetic edges. Machine-learning-assisted chromospheric inversions (IRIS^{2+}) reveal that radiative losses per unit magnetic flux sharply peak in weak-to-intermediate fields at the expanding rims of plage flux tubes, whereas kG cores are comparatively "dark", carrying most of the flux yet contributing only a minor fraction of the losses. The simulation reproduces this rim-bright, core-dim pattern and indicates that magnetic geometry—rather than field strength alone—governs atmospheric heating. These results identify flux-tube boundaries as primary sites of energy conversion in active regions and provide a new observational constraint for models of chromospheric and coronal heating, with clear, testable predictions for upcoming facilities such as MUSE, Solar-C and next-generation ground-based observatories.

USO50YR-ST-03-0016

Ubiquitous Decayless Kink Oscillations in Solar Coronal loops observed by Solar Orbiter/EUI

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Decayless oscillations are a class of persistent transverse wave motions frequently observed in solar coronal loops. Unlike large-amplitude loop oscillations that undergo rapid damping, decayless oscillations maintain nearly constant amplitudes over multiple cycles, suggesting the presence of a continuous energy input that counteracts dissipative losses in the coronal plasma.

In this study, we performed a detailed analysis of decayless kink oscillations with extreme-ultraviolet observations using instrument HRIEUV on-board Solar Orbiter Satellite and identified events exhibiting both short and long-period oscillations in different coronal loops. The observed oscillation periods span from a few minutes up to approximately 35 minutes. Using time–distance analysis and wavelet transforms, we independently confirmed the periodic behavior and found that the oscillations persist over multiple cycles without significant decay. The existence of short and long-period decayless oscillations in different loop structures indicates that these phenomena are widespread and scale-independent, likely driven by continuous small-scale motions or quasi-periodic disturbances in the lower solar atmosphere.

Our results emphasize the ubiquity and persistence of decayless kink oscillations across various coronal environments and strengthen their significance in understanding wave-based energy transport and heating processes in the solar corona.

USO50YR-ST-03-0017

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

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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 $\sim 10^{18}\,\mathrm{Mx\,hr^{-1}}$ (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 magneticreconnection 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.

Topic – 4

Solar Transients & Space Weather

USO50YR-ST-04-0002

Flare-productive active regions: key observational features and how numerical models explain them

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Solar flares, particularly the most powerful ones, tend to occur in large, complex, and dynamically evolving active regions. Yet, the detailed processes by which these regions emerge from the convection zone, store magnetic energy, and ultimately release it remain poorly understood. Such flare-productive active regions exhibit key magnetic features, including sheared polarity inversion lines, sunspot rotations, and flux ropes. To fully understand these phenomena and physical mechanisms behind them, it is essential to integrate high-resolution observations from both ground-based and space-borne telescopes. In this presentation, we will review observational advances on active regions prone to major flares, highlight insights from state-of-the-art numerical simulations, and discuss future directions.

USO50YR-ST-04-0003

First Results from the Solar Ultraviolet Imaging Telescope

Durgesh Tripathi with SUIT Team
Inter-University Centre for Astronomy and Astrophysics (IUCAA), India

The Solar Ultraviolet Imaging Telescope (SUIT) onboard Aditya-L1 mission provides the unique opportunity yo study the Sun in the wavelength range of 200-400 nm, covering near and mid ultraviolet region in the solar spectrum. Since the insertion in the halo orbit and subsequent payload verification phase, SUIT has been continuously recording the observations in all its 11 channels. All the data taken are made science ready and is made available through PRADAN. This talk will highlight the quality of data and some first results which are obtained using SUIT observations.

Data-constrained magnetohydrodynamic simulation of solar coronal transients

Ramit Bhattacharyya
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The solar coronal transients are events which are sudden and can vary from coronal jets to large solar flares giving rise to coronal mass ejections. The magnetic reconnection is believed to be the underlying mechanism for these transients. A workflow can be developed to explore the mechanisms of these reconnections by extrapolating the coronal magnetic field using photospheric magnetograms and subsequently use the extrapolated field for magnetohydrodynamic simulations. These are often called data-constrained simulations which, have open a new avenue to understand magnetic reconnection at the solar corona and consequently, the coronal transients. The presentation will explore these simulations in terms of their objectives, outputs and limitations.

USO50YR-ST-04-0008

Statistical Signatures of Solar Activity in Near-Sun Switchbacks

Sneha Pandit
Inter-University Centre for Astronomy and Astrophysics (IUCAA), India

Switchbacks are sudden deflections of the magnetic field that are uniquitous in the inner Heliosphere and have been primarily observed by Parker Solar Probe (PSP). However, there is no consensus on their origin, with proposed sources ranging from local in-situ processes to deeper coronal dynamics. The key question we address here is whether the properties of switchbacks carry the signature of the ∼11 year solar Schwabe cycle, which would indeed provide constraints on their possible causes. To do so, we consider a large statistical ensemble of switchbacks and evaluate the cycle-dependence of their physical properties, including deflection amplitude, duration, waiting time, and related parameters to the observing conditions.

USO50YR-ST-04-0010

Sun to Earth propagation of 21 April 2023 CME and its space weather impact

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We analysed the CME of 21 April 2023, which triggered the first severe geomagnetic storm of Solar Cycle 25. By combining advanced modellingtechniques with multi-point observations, the propagation of the CME from the Sun to Earth was reconstructed, yielding forecasts that closely matchedthe observed geomagnetic storm profiles. The study highlights the importance of heliospheric imaging and multi-vantage data in improving the accuracy of CME arrival and impact predictions.

USO50YR-ST-04-0011

Interpretable Dst Modeling from Solar Wind Energy via Symbolic Regression

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Space weather, driven by solar phenomena such as solar flares, coronal mass ejections (CMEs), and stream interaction regions (SIRs), strongly influences the coupled magnetosphere–ionosphere–thermosphere (MIT) system. Disturbances in this system can disrupt communication and navigation networks (e.g., GPS, NaVIC), impair satellite operations, and pose risks to ground-based infrastructure. The intensity of geomagnetic storms is commonly characterized by the Disturbance Storm Time (Dst) index, which measures global magnetic field variations.

In this work, we model the Dst response to solar wind kinetic energy using a physics-informed, data-driven framework. Symbolic regression is applied to derive analytical expressions describing the temporal evolution of the Dst index, while convolutional neural networks (CNNs) are employed to estimate the coefficients of the governing differential equation. This hybrid approach provides an interpretable and physically grounded linkage between solar wind energy input and geomagnetic storm intensity, overcoming the nonlinear challenges associated with direct coefficient estimation. Inputs to the model include solar wind parameters from the Aditya-L1 ASPEX payload, interplanetary magnetic field (IMF) data, and remote indicators of solar activity, enabling the capture of both precursor signatures and direct solar wind drivers of geomagnetic disturbances.

An improved coefficient formulation of the Newell coupling function for Dst prediction is introduced. Using the PySR symbolic regression framework, a suite of mathematical expressions linking dDst/dt to key solar wind parameters is identified. The resulting models span multiple complexity levels and are benchmarked against established empirical formulations such as the Burton–McPherron–Russell and O'Brien–McPherron models. Performance evaluation across 50 geomagnetic storm events demonstrates that the proposed models achieve superior accuracy, particularly during moderate storms, while maintaining physical interpretability. Overall, the results provide closed-form expressions that capture nonlinear dependencies and threshold effects governing the evolution of the Dst index.

USO50YR-ST-04-0012

Merging flux ropes and nanojet ejections: Insights from MHD modeling and synthetic observations

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Forced magnetic reconnection can be triggered by external perturbations, which plays a crucial role in the energy release during solar transient events, that are often associated with the disintegration of electric current sheets (CSs) through tearing instability. We demonstrate through a resistive-magnetohydrodynamic (MHD) simulation, how the instability in the CS is triggered by imposing impulsive localized perturbations in the CS plane. This leads to the formation of flux ropes and their later coalescence. We demonstrate how this coalescence process lead to the ejections of small-scale jet like structures with nanoflare energy range. Furthermore, we use forward modeling to generate the synthetic observations (imaging and line profiles) in the Extreme-ultraviolet wavelengths compatible with existing instruments such as SDO/AIA and Hinode/EIS, and upcoming missions including MUSE and Solar-C/EUVST, and compare them with an existing observation of nanojets. The synthetic diagnostics of the emissivity maps, Doppler velocity, thermal, and non-thermal line broadenings produce key observational properties, suggesting a plausible scenario for nanojet generation where tiny flux ropes reconnect within loops. Our results also provide predictions for the detectability of nanojets with current and future spectroscopic facilities, and establish a bridge between theory and observations.

USO50YR-ST-04-0013

Analysing an A-class flare using XSM, SDO/HMI, and SDO/AIA

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Solar flares are one of the most fascinating solar activities, releasing free magnetic energy in the form of electromagnetic radiation, heat, and acceleration of charged particles. Energetically large flares (like X, M, C), which are easily detected and have significant impacts on space weather, are studied more. Whereas the small-scale energy release events or energetically small flares play an important role in the continuous heating of the solar corona, and their detection requires more sensitive observations. Relevantly, the solar X-ray monitor (XSM) on board Chandrayaan-2 has detected many energetically small flares, enabling the exploration of their properties as well as the magnetic topologies associated with them. Focusing on the latter, in this study, we are analysing an A-class flare, detected by the solar X-ray monitor (XSM) on board Chandrayaan-2. In addition to that, a corresponding rise in intensity is observed in multiple AIA channels. Furthermore, non force-free field extrapolation (NFFF) of the flaring region has been carried out using the HMI vector magnetogram. The dynamics of this extrapolated magnetic field is then explored using data-constrained EULAG-MHD simulation.

USO50YR-ST-04-0014

A high-frequency type II radio burst associated with a X2.3 class flare

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Radio observations provide access to the corona, heliosphere, and ionosphere, and are thought to be an excellent indicator of disturbances in the solar atmosphere. An immediate indicator of solar transients, such as solar flares and coronal mass ejections, is solar radio bursts, especially in the inner and middle corona. We studied a rare type II high frequency (start freq: ~ 750 MHz), fast drifting (~ 0.5 MHz/s) type II radio burst on Nov 6, 2024. The active region source location for this burst was S08E14 (AR13883). There was an X2.3 class flare associated with this burst, which started at $13:24$ UT, peaked at $13:40$ UT, and ended at $13:46$ UT. The duration of the X-ray flare was ~ 22 min. There was an EUV wave seen just after the flare at $\sim 13:55$ UT in the SDO-AIA field of view (fov). Several ground-based radio spectrographs had recorded this type II radio burst at $13:50$ and $13:56$ UT, spanning frequencies from. Radio imaging observations with the Nancay radio heliograph (NRH) in the frequency range of 444-150 MHz, corresponding to a height range of 1.01-1.29 R_0, reveal that the radio sources were moving in the east direction. We used the High Energy L1 Orbiting X-Ray Spectrometer (HELIOS) on-board Aditya-L1 data for spectroscopy to find the cut-off energy range for non-thermal emission. We used the Spectrometer Telescope for Imaging X-rays (STIX) on board Solar Orbiter (SoLO) to locate the hard X-ray emission region at the eruption footpoints. Our preliminary analysis suggests that the type II bursts were not associated with any whitelight CME, as it was not sufficient to give rise to the shock in the inner corona. This Type II radio burst was associated with the flare blast wave generated due to the strong X2.3-class flare.

USO50YR-ST-04-0015

Radio Diagnostics of Particle Acceleration

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Radio observations to probe particle acceleration in solar energetic particle events Abstract: Solar radio bursts (SRBs) are intense emissions observed in radio wavelengths during solar transients, such as coronal mass ejections (CMEs) and flares. SRBs are direct signatures of accelerated electrons in the solar atmosphere. These solar transients have a direct impact on the near-Earth atmosphere. SRBs serve as key diagnostic tools for plasma processes, particle accelerations, magnetic field dynamics in the solar corona and the heliosphere, which are the root cause of these solar transients. We present two case studies on solar energetic particle (SEP) events involving type III storms and type II bursts in metric and decameter-hectometric (DH) wavelengths. In one case, a type III storm was disrupted by an eruption, while in the other, the storm remained unaffected. Both events featured fast and wide coronal mass ejections (CMEs) and regular type III bursts. Analysing Nancay Radioheliograph (NRH) data, we found that in the high-intensity SEP event, the source locations of the type III storm and type II bursts were the same, indicating storm disruption. In contrast, the weak SEP event displayed spatial separation between the type III storm and type II bursts. These findings support the hypothesis that type III storm sources can accelerate ions, providing seed particles to SEP events.

USO50YR-ST-04-0019

Understanding the role of compressibilty using multi-spacecraft in situ observations of ICME-ICME merging on March 3, 2024 event that led to a major geomagnetic storm

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Earth-directed solar coronal mass ejections (CMEs) are the primary drivers of the space weather impacts on the Earth. Therefore, a good understanding of the physics of these events is crucial to better predict their arrival times and speeds at the Earth. The interplanetary counterparts of CMEs are called interplanetary coronal mass ejections or ICMEs. In this study, we are tracking down the CME/ICMEs that may have caused the a major (D_{st} = - 112 nT) geomagnetic storm on March 3, 2024. Using the in situ observations from Bepi Colombo (0.48 AU), STEREO A (0.96 AU), Aditya L1 (0.99 AU), DISCOVR (0.99 AU), and Wind (0.99 AU) we have quantified the plasma and magnetic field compressibility of ICME plasma at various scales. The in situ signatures show a potential ICME-ICME interaction at STEREO A. The outcomes show that at STEREO A, the magnetic field compressibilities of different regions of the ICME structure have higher magnitudes (as compared to the magnitudes at the other spacecraft), which are indistinguishable for the different sub-structures of the event and fall under the same range of magnitudes, from around 0.03 at smaller scales to around 0.9, at larger scales. At STEREO A the magnitudes of plasma compressibility for different sub-structures, also remain indistinguishable and fall under the range between around 0.02 at smaller scales and around 0.4 at larger scales. These, therefore, suggest that during the ICME-ICME interaction, both plasma and magnetic fields of the two ICMEs tend to mix with each other at all scales in a similar fashion. We have also found that the compressibility features as well as magnitudes are different before the ICME-ICME interaction (at Bepi Colombo) and after the interaction (at Aditya L1, Wind, and DISCOVR). These findings can be important to better understand the turbulent structures at various scales, morphology, and overall cross-sectional coherence of Earth-directed ICMEs.

USO50YR-ST-04-0020

X-ray Spectroscopic Diagnostics of Confined and Eruptive Flares Using SoLEXS/Aditya-L1

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Solar flares and coronal mass ejections (CMEs) are the Sun's most energetic eruptions, but what determines whether a flare is "confined" or "eruptive" remains unclear. A key factor is how magnetic energy is divided among plasma heating, particle acceleration, and eruption kinetic energy.

In this study, we investigate the thermal evolution of eruptive and confined flares by comparing high-cadence soft X-ray (SXR) spectral data from the Solar Low-energy X-ray Spectrometer (SoLEXS) aboard Aditya-L1. We analyze a sample of flares spanning different GOES classes (C, M, and X), including both CME-associated (eruptive) and non-eruptive (confined) events. For each flare, we perform time-resolved spectroscopic analysis to derive key plasma parameters: temperature (T), emission measure (EM), and elemental abundances. By examining the temporal evolution of T and EM across flare phases, we aim to identify systematic differences in heating and cooling of the two event types. We hypothesize that the energy required to initiate a CME may result in observable differences in the peak thermal properties or decay timescales of the flare plasma.

Furthermore, we investigate whether the large-scale magnetic restructuring in eruptive events leads to distinct elemental abundance signatures, potentially indicating different plasma source regions or supply mechanisms compared to their confined counterparts. This work provides new observational constraints on the thermodynamics of solar flares and offers insights into the fundamental processes governing the flare-CME relationship.

USO50YR-ST-04-0023

On the Chromospheric dynamics associated with the X-class flare of 11th November 2025

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Solar flares are impulsive events in which the magnetic field undergoes reconnection, converting magnetic energy into radiation and particle acceleration. The flares radiate energy across the entire electromagnetic spectrum, with a significant fraction of the released energy originating from thermal sources. A considerable fraction of the released energy is deposited in the chromosphere.

In this work, we analyze the chromospheric response to the strongest X-class flare (X5.2) of 2025 to date, which occurred in active region NOAA 14274 and peaked at 10:04 UT on November 11th. We acquired the Ca II 8542Å line scans of the decay phase of the flare over a 50-minute period at a cadence of 30 seconds, starting at 10:23 UT. The line scans were acquired using the narrowband imager of the Multi-Application Solar Telescope (MAST), and were complemented with observations from IRIS and SDO. The active region exhibited a complex magnetic field distribution with the flare ribbons resembling a semi-circular shape. We applied k-means clustering to the Ca II 8542Å spectra spanning over the entire flare kernel and over 50 minutes of the observation time window. The clusters exhibited different types of emission spectra, ranging from single to double-peaked profiles with varying contributions in the red and blue wings. In localized patches within the flare kernel, we observed spectra with extreme broadening and strong downflows ($\sim$20 km s^{-1}), which vanished within the first few minutes of the observation window. We selected 20 representative clusters and investigated their spatio-temporal distribution over the flare kernel. The cluster distributions reveal a complex chromospheric dynamics, characterized by upflows and downflows of the order of 10 km s^{-1}, which are separated by a few arcseconds. In this meeting, I will present the analysis and results of this study.

USO50YR-ST-04-0024

Aditya-L1 and Solar Dynamics Observatory Observations of Prolonged Emission Phases during a Confined X-class Flare: Heating, Large-scale Dynamics, and Flux Rope Confinement

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Solar flares are energetic explosions, releasing immense energies up to 10^{32}–10^{33} ergs in 10–1000 seconds. They are either *eruptive*, expelling material into space, or *confined*, failing to erupt. This study presents a comprehensive multi-wavelength analysis of two distinct episodes of hard X-ray (HXR) emission in a confined X2.0 solar flare, followed by a decay thermal peak. The investigation utilises data from a suite of instruments connected by the triggering and rapid coronal expansion of a magnetic flux rope (MFR) that ultimately failed to erupt. A key aspect of this research involves a detailed investigation of data from the X-ray spectrometers (XRSs) on board the *Aditya-L1* mission, where a joint fitting of data from the low- and high-energy X-ray spectrometers, SoLEXS and HEL1OS, respectively, is performed. Simultaneously, extreme ultraviolet (EUV) imaging data from the Atmospheric Imaging Assembly (AIA) on board the *Solar Dynamics Observatory* (SDO) are utilized to gain insights into the spatial and temporal evolution of this confined X-class event, along with its preceding but connected M4.6 event. Analysis of the soft X-ray and EUV light curves, along with EUV multi-channel imaging, reveals that the two events essentially represent a single failed flux rope eruption with a two-stage energy release, separated by a time gap of approximately 10 minutes. Interestingly, the hard X-ray light curve exhibits a well-resolved dual phase of non-thermal emission, suggesting two distinct episodes of particle acceleration, separated by about 8 minutes. The first stage is associated with the activation of an MFR, revealed by the brightening of an EUV hot channel. During this phase, the plasma reaches a peak temperature of $\sim$20 MK, while in the second phase, a peak temperature of $\sim$28 MK and in decay thermal peak of $\sim$18 MK is observed. A particularly important aspect of this analysis focuses on the HEL1OS observation. A photon spectral index of $\sim$5 is observed, with maximum HXR energy of $\sim$50 keV above the background during the first phase, dropping to $\sim$3.2 with peak HXR energy up to $\sim$150 keV above the background during the second phase. Despite these energetic signatures, two stages of heating and particle acceleration, and the successful activation of the hot channel, the MFR ultimately failed to erupt, resulting in this high-energy confined solar flare.

USO50YR-ST-04-0025

PFSS Source Surface Height optimisation for improved WSA Solar Wind Velocity forecasting Across Solar Cycle 23 , 24 and 25

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Several studies have aimed at optimizing the source surface (SS) height in the potential field source surface (PFSS) model using different data sets and over different periods of time. Most of the earlier studies focused on improving predictions of the open magnetic flux in the heliosphere, by optimising the SS height in the PFSS model. In our recent work (Kumar et al. 2025), we demonstrated that optimizing the SS height significantly enhances the performance of the widely used solar wind velocity prediction model, i.e., WSA. The study tested the approach using two types of GONG magnetograms over selected intervals of solar cycles (SCs) 24 and 25. In the present study, we extend this analysis by incorporating all the available GONG data from SCs 23 to 25. We also evaluate all available HMI data for SCs 24 and 25, comparing its performance with both zero-point–corrected (ZPC) and standard GONG magnetograms. Our results show that HMI and ZPC maps consistently outperform the standard GONG maps.

Our results strongly support optimizing the SS height in the PFSS model to improve WSA model performance, rather than using the conventional fixed SS height, i.e., 2.5 $R_{\odot}$. We found that, during the solar maximum, a lower SS height ($\leq 2.5\ R_{\odot}$) provides better WSA solar-wind speed predictions at L1. During low-activity periods, the opposite is true.We also found that the absolute values of the optimised SS height might differ in different SCs although the trend in the distribution of the optimised SS height remains the same. Our results suggest a global pattern linking SS height to the phase of the solar cycle on a longer time-scale. The study reveals that SS height optimisation improves the existing background solar wind velocity prediction models in the heliosphere and hence the overall space weather prediction.

USO50YR-ST-04-0026

White-Light Continuum Observations across the Balmer Jump for SOL2024-10-03T12:18

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Solar flares release large amounts of energy into the solar atmosphere, often producing strong enhancements in the visible and near-ultraviolet (NUV) continuum. The physical origin of this white-light (WL) emission remains less understood. Some flares show Hydrogen recombination continuum with a Balmer jump (Type I), while others originate from deep photospheric heating that produces a blackbody-like spectrum (Type II).

The X9 WL flare of 2024 October 3 provides one of the best chances to investigate this problem. SUIT observed the event across the Balmer jump, with several other instruments capturing it simultaneously. SUIT delivered full-disk NUV images tracing ribbon evolution and continuum brightening. IRIS supplied high-resolution spectra and slit-jaw images. AIA monitored the upper-chromospheric and coronal response, while HEL1OS measured hard X-ray spectra that constrained the injected nonthermal electron spectrum.

By comparing the timing of hard X-ray bursts with peaks in WL and NUV emission, we directly infer the effect of accelerated electrons on the continuum. Together, the SUIT, IRIS, AIA, and HEL1OS observations offer a comprehensive view of how flare energy propagates from the corona into the lower atmosphere, providing new details on how deep layers respond during an extreme white-light flare.

USO50YR-ST-04-0028

Investigation of magnetic topology and triggering mechanisms of a C-class flare and active-region blowout jet

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Coronal jets are collimated, beam-like plasma ejections and are ubiquitous in the solar atmosphere. They are govern by magnetic reconnection and play a crucial role in understanding solar activity at different scales, including chromospheric/coronal heating, and particle acceleration. The jet onset mechanism is yet to be fully understood and remain an open problem. In this work, we explore the onset of a blowout jet associated with SPoCA 29093, which produced a C1.1-class flare on 10 November 2022, using data-constrained magnetohydrodynamic simulations. The simulation is initialized with an extrapolated magnetic field obtained from a non-force-free field (NFFF) extrapolation of photospheric vector magnetogram data just before the jet onset , and the non-zero Lorentz force initiates plasma dynamics. The initial extrapolated magnetic field reveals the presence of a 3D null and a flux rope co-located with the jet activity region. The simulation shows that initial brightening is because of slip-reconnection of fan field lines and 3D null-point reconnection leading to a C class circular flare. The flux rope approaches and erupts its one leg through null point reconnection, launching near simultaneous blowout jet. Furthermore, the evolution also shows the spontaneous creation and annihilation of 3D null pairs via magnetic reconnection near flare and jet region. The presence of these additional in the simulations is also confirmed in the NFFF extrapolations at 03:12 UT. Such a reconnection driven study can be helpful in understanding in chromospheric/coronal heating and spontaneous generation nulls opens up an avenue to explore the contributions from these newly generated nulls in the jet and flares.

USO50YR-ST-04-0030

Large-scale Coronal Waves during 2010 – 2025 observed by SDO/AIA

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The wave-like large-scale disturbances in the corona belong to a distinct observable in EUV images. They occasionally accompany solar flares and more often coronal mass ejections (CMEs). Different scientists call them differently but here we call them large-scale coronal waves. The Atmospheric Imaging Assembly (AIA) on the Solar Dynamics Observatory has observed $\sim$1000 of them during 2010 – 2025. Here we discuss their basic properties and their relation with other phenomena including flares, CMEs, coronal dimmings, type II bursts, and solar energetic particles.

USO50YR-ST-04-0032

Solar Flares in Near and Mid UV

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Solar Flares are one of the most energetic phenomena in the heliosphere with strong relevance to space weather impacts. While they have been observed and studied for centuries, the physics of their origin is far from full comprehension. More so, their properties in near and mid UV are not known. The Solar Ultraviolet Imaging Telescope (SUIT) on board Aditya-L1, launched on Sep 02, 2023 and subsequently put into a halo orbit around L1, is the only instrument that provides spatially resolved observations of flares in the near and mid UV – covering a wavelength range of 200-400 nm. It carries 11 different filters – including Mg II h & k and Ca II H to cover different heights in the photosphere and chromosphere.

Since the start of the operation, SUIT has observed more than 650 flares. Out of those, it has localised 144 flares, including 18 X-class and 126 M-class flares. In this work, we present the catalogues of all these localised X-class flares and their properties as observed in near and mid-UV.

USO50YR-ST-04-0033

Detection of Filaments in Hα Solar Image using Bradley-Roth Inspired Adaptive Fuzzy C-Mean Algorithm

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Solar filament is a thin, long elongated rope like structures found on the solar surface. These filaments are formed in the solar chromospheric region and extend outward into the solar corona. These features are closed bipolar magnetic regions on the solar surface characterized by high plasma density and low temperatures compared to the surrounding regions. The destabilization of the magnetic field forces the filaments to erupt as flares and coronal mass ejections (CMEs) result in releasing stored plasma into space. These eruptions in turn contribute to the space weather activities. All these activities and phenomena ultimately lead to the proper and accurate localization of the filaments regions for studying the solar magnetic field and predicting space weather events. These filaments regions can be observed as dark structure in solar images captured through both space and ground - based solar observatories. This work focuses on the detection of the filaments structures in Hα full-disk solar images captured at the 656.3 nm spectral line from from the GONG telescope operational at Big Bear Solar Observatory during 2013. From the computer vision point of view the filaments detection is basically a task of identifying thin long elongated dark structures in Hα full-disk solar images. For the task a Bradley-Roth inspired adaptive fuzzy c-mean (FCM) algorithm has been proposed. The algorithm first implements the Bradley - Roth adaptive thresholding method to extract the dark pixels from solar image with non-homogeneous intensity level. Later, adaptive FCM clustering scheme, where the fuzziness parameter is dynamically updated using membership entropy, is applied to separate regions of similar gray-level intensities. The final dark structures are then extracted by intersecting the masks obtained using Bradley Roth thresholding technique and adaptive FCM, resulting in robust and noise-resistant segmentation. At the final stage connected component analysis has been performed to remove the redundant regions from the resultant image to obtain the accurate filaments regions. The proposed approach of filaments detection achieves an accuracy rate of approximately 99% for most solar images under consideration, outperforming traditional object detection algorithms.

USO50YR-ST-04-0034

A sudden fine-scale bright kernel captured by *Hi-C Flare* in Fe XXI 129 Å emission during an M1.6-class solar flare's post-maximum phase

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The third successful Hi-C sounding rocket flight, *Hi-C Flare*, recorded coronal images in Fe XXI 129 Å emission from 11 MK plasma during the post-maximum phase of an M1.6-class solar flare on April 17, 2024, achieving unprecedented spatial (∼300 km) and temporal (1.3 s) resolutions. The flare started at 21:55UT, peaked at 22:08UT, and lasted ∼40 minutes. Hi-C observed for over five minutes (22:15:45 to 22:21:25), starting roughly eight minutes after flare maximum. A sudden compact bright burst—875±25 km wide, lasting 90±1.3 s, exhibiting a proper motion of ∼50 $\mathrm{km\,s^{-1}}$, and splitting into two toward the end—occurs near the foot of some post-flare loops. Its size and brightness are reminiscent of flare-ribbon kernels during a flare's rapid rise phase, kernels marking sites of sudden heating and hot plasma upflow, making its occurrence during the late phase surprising. Such isolated brightenings in a flare's post-maximum phase are rare, and have not been previously reported. The kernel was detected in all SDO/AIA channels. Its 1600 Å light curve peaked ∼50 s earlier than its 131 Å light curve, similar to that of flare-ribbon kernels, albeit with a smaller delay of ∼25 s, during the impulsive phase of the flare. In SDO/HMI magnetograms, the kernel sits in unipolar positive magnetic flux near an embedded clump of negative flux. Although localized magnetic reconnection within the kernel (a microflare) cannot be ruled out for its cause, the observations favor the localized brightening being an isolated, exceptionally late flare-ribbon kernel, resulting from an exceptionally late burst of the flare's coronal reconnection.

USO50YR-ST-04-0035

Hybrid Machine Learning enabled Solar Flare Forecasting from Super-Resolved Magnetic Fields

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Reliable solar flare prediction requires both high-quality magnetic field observations and models capable of capturing the multiscale complexity of active regions. This work presents a two-stage framework in which low-resolution SOHO/MDI magnetograms are first enhanced using SDO/HMI observations as the high-resolution reference, enabling restoration of fine-scale magnetic complexity that are otherwise unresolved. These super-resolved magnetograms are then used to develop a hybrid machine-learning forecasting model that integrates feature extraction and global context modeling to learn discriminative signatures of flare-productive regions. Performance is quantified using the True Skill Statistic (TSS) and Heidke Skill Score (HSS), providing unbiased evaluation under strong class imbalance. The hybrid model trained on enhanced MDI data achieves substantially higher skill scores compared to predictions using raw MDI alone, demonstrating that super-resolved magnetic fields significantly strengthen flare-discrimination capability. This study establishes a unified path from magnetogram enhancement to operational flare forecasting and highlights the scientific and forecasting advantages of combining physics-aware super-resolution with advanced machine-learning architectures.

USO50YR-ST-04-0036

Magnetic Topology and Three-Ribbon Structure of an X4.0 Solar Flare Associated with a Fast CME

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We present a detailed observational and topological analysis of an X4.0 solar flare that occurred in an active region NOAA AR 13664 on 10th May 2024, starting at 06:27 UT, peaking at 06:54 UT, and ending at 07:13 UT, followed by a fast coronal mass ejection (CME) with a linear speed of approximately 953 $\mathrm{km\,s^{-1}}$. Multi-wavelength observations from SDO/AIA reveal a distinct three-ribbon flare morphology, consisting of two parallel ribbons located along the polarity inversion line and an additional semi-circular ribbon surrounding the core region, indicative of a complex three-dimensional magnetic reconnection scenario.

To investigate the underlying magnetic topology, we perform non-force-free field (NFFF) extrapolation of the photospheric magnetic field. The extrapolated coronal field reveals a fan–spine configuration associated with a single coronal magnetic null point. Beneath the null, a hyperbolic flux tube (HFT) is identified through the distribution of the squashing factor Q, indicating the presence of strong quasi-separatrix layers where magnetic reconnection can occur in the absence of additional null points. The footprints of high-Q regions show good spatial correspondence with the observed flare ribbons.

No coherent magnetic flux rope is identified in the extrapolated coronal field during the early and peak phases of the flare (e.g., at 06:36 UT), suggesting that the flare is not driven by the eruption of a pre-existing flux rope. However, significant large-scale coronal restructuring is inferred from the subsequent appearance of the fast CME near 07:12 UT and the associated coronal dimming observed in EUV channels, which is indicative of plasma evacuation and magnetic field opening.

These results suggest that the X4.0 flare is initiated by reconnection at the HFT and null-point topology, while the eruptive structure responsible for the CME is formed dynamically during the later stages of the flare or the early post-flare phase. Our study demonstrates that intense multi-ribbon flares and fast CMEs may occur without a pre-existing flux rope, with the eruptive magnetic structure being generated through sustained three-dimensional reconnection.

USO50YR-ST-04-0037

Kink-Driven Eruption of a Hot-Channel–Prominence System: Thermal and Structural Analysis of a Three-Part CME

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The morphology and evolution of three-part CMEs remain a topic of debate. Traditionally, the CME core was attributed to prominence material, but recent studies show that some active-region CMEs instead contain hot-channel structures in their bright cores. These hot channels, observed in Atmospheric Imaging Assembly (AIA) hot passbands (e.g., 94 Å, 131 Å), have temperatures of order 10 MK and are often interpreted as magnetic flux ropes. We analyze a rare CME on 2014 February 11 involving the simultaneous eruption of a prominence and two hot channels. Using differential emission measure (DEM) analysis from the AIA onboard the Solar Dynamics Observatory (SDO), we study their thermal properties and compare them with the CME core observed in white light by the K-Coronagraph (K-Cor). We identify their counterparts in the Extreme Ultraviolet Imager (EUVI) onboard STEREO-A and STEREO-B and trace their evolution into the outer corona using the COR1 coronagraph and the Large Angle and Spectrometric Coronagraph (LASCO/C2). Our results show that the CME eruption is associated with kink instability. We find the K-Cor CME core brightness is dominated by hot-channel emission rather than prominence material, implying a higher electron column density in the hot channels. AIA and STEREO EUVI observations indicate that the prominence and two hot channels originate from the same source region, forming a unified system with flux ropes surrounding the prominence. These events provide key insight into the connection between hot channels and prominence-associated three-part CMEs.

USO50YR-ST-04-0039

CME speed detection at $20R_\odot$ using machine learning techniques

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Coronal Mass Ejections (CMEs) are major drivers of space weather, and accurate prediction of their propagation speed is essential for improving space weather forecasting. In this study, we apply machine learning techniques to predict CME speeds at a heliocentric distance of 20 $R_\odot$ using data from the Coordinated Data Analysis Workshop (CDAW) catalog. CME events from Solar Cycles 23 and 24 are analyzed across different phases of solar activity. Multivariate Linear Regression, Random Forest, and XGBoost models are trained using CME linear speed, acceleration, angular width, and kinetic energy as input features.
Our results show that Random Forest and XGBoost significantly outperform linear regression, achieving high accuracy with R^2 values of 0.97 and relative errors of $\sim$ 6%. Feature importance analysis identifies CME linear speed and acceleration as the dominant predictors, consistent with drag-based CME propagation. Application of the trained models to Solar Cycle 25 events shows very good agreement with observed CME speeds, demonstrating the robustness and generalizability of machine learning approaches for CME prediction.

USO50YR-ST-04-0040

Study of solar prominence eruption using multiwavelength observations

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Solar prominence are found to exhibit noticeable temperature variations. Observations on the formation and evolution of an off-limb prominence eruption on December 30, 2023, through coaligned observations from the Atmospheric Imaging Assembly (AIA/SDO) and Solar Ultraviolet Imaging Telescope (SUIT/Aditya-L1) offer valuable insights. The gradual growth and motion of the prominence observed in NB04 (Mg II h, 280.3 nm) is one of the earliest observations using SUIT and the first prominence observed using the same. A distinct rising phase and gradual evolution of the prominence in a two-hour duration was observed. Some part of the rising plasma is ejected as a CME, and the rest of the material is being relocated. The brightening at footpoints and formation of cusp-like structures were observed in the high-temperature SDO EUV channels. Motion of the footpoint, followed by the appearance of footpoint brightenings, can be clearly observed in AIA171, 193, 211 and 304 Angstrom channels. However, the formation of cusps was observed in AIA 94 well before the prominence started erupting. We employed differential emission measures (DEM) on the AIA observations to study the thermal evolution of plasma material at various locations during different stages of this prominence eruption. The same event was observed in SWAP174(PROBA2) with a larger field of view as well. This study can be expanded through coupled observation of an associated solar flare (C-class) recorded in STIX/SolO and coronal mass ejection (CME) observed in Lasco/SOHO. This multiwavelength study is expected to provide details on the underlying mechanisms on the formation and evolution of prominences.

Topic – 5

Diagnostic Techniques - Spectral Inversion Codes & Radiative MHD Simulations

USO50YR-ST-05-0001

Spectropolarimetric inversions for the lower solar atmosphere: state-of-the-art and challenges

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During the last decade, we have witnessed a wealth of diffraction-limited spectropolarimetric datasets delivered by various meter-class telescopes, as well as the advent and first science results from the 4-m DKIST telescope. At the same time, the first successful implementations of integral field unit (IFU) instruments are transforming the way we observe the Sun at high spatial and temporal resolution. These datasets require new diagnostic techniques, not only in terms of raw computational power and efficiency, but also in the way we design inversion techniques. In this talk, we will review the current state of the art in inversion techniques for the photosphere and chromosphere and discuss various avenues for moving forward. We will argue that the number of photons per resolution element can only decrease, and that this fact necessitates focusing on inversions that are inherently spatially coupled and make use of multi-line observations. We will discuss spatio-temporal regularization, physics-based regularization, challenges brought by 3D radiative transfer effects, and, finally, machine learning–based approaches.

USO50YR-ST-05-0002

Multi-line Spectropolarimetry of Solar Flares: insights from high-resolution observations and simulations

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We present a comprehensive analysis of spectropolarimetric data relevant to flaring chromospheres at high spatial and spectral resolution. Our primary focus is on an observation obtained with the Interferometric BIdimensional Spectrometer (IBIS) during an X-class flare. By performing simultaneous inversions of the photospheric Fe I 6173 Å and chromospheric Ca II 8542 Å lines, we investigate the spatial distribution and vertical stratification of atmospheric parameters throughout the flare evolution. We also include preliminary results from a recent observing campaign conducted at the GREGOR telescope during a C-class flare. Beyond the observational perspective, we compare the measured Stokes profiles with synthetic profiles computed from 3D MHD simulations of flaring events. This comparison represents a key step toward filling the gap between models and observations. Understanding the spectropolarimetric signatures of flares is essential for validating theoretical predictions and for improving the physical reliability of numerical simulations. In addition, the characterization of these profiles provides the basis for future, coupled analysis between advanced MHD models and high-resolution flare observations.

USO50YR-ST-05-0004

Statistical relationship between subsurface convective flows and the magnetic energy build-up in sunspots

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Strong solar flares occur in δ-spots characterized by the opposite-polarity magnetic fluxes in a single penumbra. Sunspot formation via flux emergence from the convection zone to the photosphere can be strongly affected by convective turbulent flows. It has not yet been shown how crucial convective flows are for the formation of δ-spots. To reveal the impact of convective flows in the convection zone on the formation and evolution of sunspot magnetic fields, we simulated the emergence and transport of magnetic flux tubes in the convection zone using radiative magnetohydrodynamics code R2D2. 93 simulations were carried out by allocating the twisted flux tubes to different positions in the convection zone. As a result, both δ-type and β-type magnetic distributions were reproduced only by the differences in the convective flows surrounding the flux tubes. The δ-spots were formed by the collision of positive and negative magnetic fluxes on the photosphere. The unipolar and bipolar rotations of the δ-spots were driven by magnetic twist and writhe, transporting magnetic helicity from the convection zone to the corona. We detected a strong correlation between the distribution of the non-potential magnetic field in the photosphere and the position of the downflow plume in the convection zone. The correlation could be detected 20-30 h before the flux emergence. The results suggest that high free energy regions in the photosphere can be predicted even before the magnetic flux appears in the photosphere by detecting the downflow profile in the convection zone.

USO50YR-ST-05-0005

Influence of numerical domain design in simulations of solar coronal heating with MAGEC code

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Understanding the structure and heating of the solar atmosphere requires numerical models that accurately capture the interplay between physical processes and numerical choices. In this work, we investigate how key modelling parameters—such as domain height, boundary conditions, and grid resolution—affect the thermal structure and energy balance of simulated open-field regions, with particular emphasis on the transition region. Using a series of controlled numerical experiments, we compare how different setups influence the resulting temperature profiles and their stability over time. We also examine how variations in these parameters modify the distribution of heating and cooling contributions throughout the atmosphere. Our results show that choices related to the upper boundary and the vertical extent of the domain can substantially reshape the transition-region structure and the inferred energy budget. These findings highlight the sensitivity of solar-atmosphere simulations to numerical configuration and provide guidance for selecting setups that produce reliable results while keeping computational costs manageable.

USO50YR-ST-05-0007

On the Role of Slow Magnetoacoustic Waves in Driving Solar Spicules: Insights from MHD Simulations and Synthetic Spectral Diagnostics

Apanba Khuman

Indian Institute of Technology Delhi (IITD), India

Acoustic waves naturally excited by the turbulent convection leak to higher solar atmospheric layers along the magnetic fields. These magneto-acoustic waves are known to play an important role in the dynamics of the solar chromosphere. In this work, we analyse the spatio-temporal evolution of these waves by applying a magnetic field-line tracking method on high resolution simulation data representing a solar plage region. The variations of field aligned velocities serve as a proxy of propagation of the slow magneto-acoustic waves in low-beta chromosphere and allow us to examine the steepening of linear slow magneto-acoustic waves into slow shocks at higher layers of the chromosphere. These slow magnetoacoustic shocks have been proposed as a possible mechanism leading to generation of solar spicules observed in the chromosphere.

In order to relate slow wave propagation with observed spicule characteristics and to examine their possible correlation, we explore synthetic spectra of typical chromospheric lines. Comparing these synthetic observations against observational signatures of spicules help us discover their mutual correlation in strongly magnetic solar plage region. By combining field-line tracking, acoustic wave analysis, and synthetic observations, this work offers a framework for linking numerical simulations with observations in the lower chromosphere. This approach highlights the potential role of wave-driven processes in producing spicule-like features in the solar chromosphere.

USO50YR-ST-05-0009

Dynamic evolution of the solar chromosphere using non-LTE nonequilibrium radiative transfer

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To understand the structuring and dynamics of the upper photosphere and chromosphere of the Sun, it is essential to improve and extend existing numerical radiation–magnetohydrodynamical (MHD) simulations. In the solar chromosphere, the assumption of local thermodynamic equilibrium (LTE) for the radiation field is well known to be invalid. A full non-LTE treatment of the radiation field, together with time-dependent nonequilibrium population evolution, is therefore required in a dynamically evolving chromosphere.
The radiation field couples to the hydrodynamic equations through radiative flux divergence and gas pressure, making a self-consistent treatment essential. In the equation of state, the kinetic temperature is determined by treating molecular hydrogen formation and dissociation in nonequilibrium, while the remaining elements contributing to the gas are treated using collisional rates only.
Based on these considerations, we have developed a non-LTE, nonequilibrium radiative transfer module for the well-known radiation–MHD code MURaM. In this framework, the nonequilibrium rate equations, non-LTE radiative transfer, and hydrodynamic equations are solved self-consistently and iteratively. The module is implemented for one-, two-, and three-dimensional geometries, and is currently tested in one dimension.
In this talk, I will present the first results of the dynamic evolution of the solar atmosphere obtained from these radiative (M)HD simulations.

Topic – 6

Existing, Upcoming Ground- & Space-based Facilities

USO50YR-ST-06-0001

Instrumentation for the Next-Generation Solar Monitoring

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Synoptic solar observations have become indispensable for the solar physics as well as the space weather programs. By definition, they need to be renewed with new technologies, especially as the operating facilities approach their end-of-life. Solar Physics Research Integrated Network Group (SPRING) and next-generation Global Oscillations Network Group (ngGONG) are initiatives that are preparing the future ground-based solar monitoring network.

At the site of TLS Tautenburg, Germany, we have built a pathfinder platform to develop state-of-the-art instrumentation for SPRING. Our present focus is a key instrument that can record Dopplergrams and magnetograms at several heights of the solar atmosphere. In this presentation, I will outline our objectives towards the solar synoptic observations, and the ongoing technology developments led by our Optical Technologies and Photonics Group.

USO50YR-ST-06-0003

Scientific Results from Adtiya-L1 and Further Prospects

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U R Rao Satellite Centre, Bengaluru, India

Aditya-L1, is an observatory class mission to study the solar dynamics and its influence in the inner heliosphere especially at the first Sun-Earth Lagrange (L1) point. It is conceived with four remote sensing and three in-situ payloads. The remote sensing payloads carry out observations of the source regions of the dynamical events while the in-situ payloads observe the events at L1. Remote sensing payloads are configured to observe the photosphere, chromosphere, and coronal regions of the solar atmosphere. The in-situ payloads cover the electrons, protons, heavier ions along with in-situ magnetic field at L1.
Aditya-L1 is in science phase operation from July 2024 onwards and have observed many of the solar events in the solar cycle 25 including some of the major geo-effective storms. Many of the results from the observations are already published in peer reviewed international journals and many are under review. In this talk, I will consolidate the major science results from Aditya-L1 as on today an also the strength of multi-wavelength capability giving a glimpse of its potential for the audience.
Aditya-L1 is also conceived with certain unique capabilities which allow them to carryout observations which are complementary to the other space observatories – past, present as well as near future. In this presentation, I will also touch upon the potential science cases where Aditya-L1 capabilities will complement other ground- as well as space-based missions, either in operation or in near future.

USO50YR-ST-06-0004

Observing the Sun with ALMA

Stephen White
Air Force Research Laboratory, New Mexico, USA

Observations of the Sun at millimeter wavelengths provide a very different and complementary view of the solar atmosphere compared to optical and IR wavelengths. Millimeter wavelengths penetrate down to different layers of the chromosphere depending on wavelength, and do not suffer from the issue of non-equilibrium formation that complicates the interpretation of chromospheric line observations: mm data are in the Rayleigh-Jeans limit, and being optically thick they provide a direct and straightforward measure of the temperature in the layer observed. Millimeter observations have been revolutionized by the construction of the Atacama Large Millimeter-submillimeter Array (ALMA) in Chile by an international consortium, and with suitable observing modifications we are able to observe the Sun with high cadence at subarcsecond resolution with ALMA. This talk will review high-resolution observations with ALMA and discuss related developments.

USO50YR-ST-06-0006

METEOROLOGICAL CHARACTERIZATION AND LONG-TERM WIND PATTERNS AT THE NLST SITE IN MERAK, LEH-LADAKH

Belur Ravindra, Deepangkar Sarkar, Shantikumar Singh Ningombam, Stanzin Tundup, Namgyal Dorje, Angchuk Dorje, Manjunath Hegde and Dipankar Banerjee

Indian Institute of Astrophysics, India

This study evaluates the meteorological characteristics of the proposed National Large Solar Telescope (NLST) site at Merak, near Pangong Tso, Leh-Ladakh, utilizing a continuous dataset from a Campbell Scientific weather station installed in 2008. By analyzing over a decade of wind speed and direction data, supplemented by comprehensive temperature and humidity measurements spanning 2010 to 2024, we provide a robust 14-year climatological profile of the region. Surface observations reveal a consistent dominance of north-westerly winds, particularly during morning hours, with typical speeds remaining below 5 m/s. While seasonal variations influence local conditions, the long-term meteorological trends remain remarkably stable. These findings, characterized by low surface wind speeds and predictable atmospheric patterns, reinforce the site's potential for high-resolution solar observations and long-term solar astronomical research.

USO50YR-ST-06-0007

The European Solar Telescope

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European Solar Telescope Foundation / Instituto de Astrofísica de Canarias, Spain

The European Solar Telescope (EST) is advancing towards its construction phase as the most powerful solar telescope in Europe, designed to observe the Sun at unprecedented spatial and temporal resolution. Featuring a 4.2-meter aperture and an innovative polarization-free optical train, EST integrates a suite of advanced subsystems including an adaptive secondary mirror (ASM), an evacuated Pier Optical Path (POP), and a Coudé light distribution system optimized for high-precision polarimetry and diffraction-limited imaging across a 380–2300 nm spectral range, with multiple instruments operating simultaneously. The project's baseline includes a design for integrated Multi-Conjugate AO (MCAO), ensuring stable, high-quality correction over a wide field of view. Significant progress has been made in the design but also on the administrative and political fronts to prepare for construction. This presentation is an update of the current status of the project and future steps.

USO50YR-ST-06-0008

Next generation GONG: future facilities for research and operational space weather forecast

Alexei Pevtsov

National Solar Observatory, USA

The US National Science Foundation recently funded the design of the next generation Ground-based Solar Observing Network (ngGONG). The global network of 6 robotic stations will provide continuous observations of the magnetic field, Doppler velocities, narrowband images, and sun-as-a-star measurements for solar synoptic research and operational space weather forecasting. To understand the solar cycle and dynamo, ngGONG will have an operational lifetime of two complete magnetic cycles (about 50 years). ngGONG will expand the boundaries in investigating subsurface flows in the solar convection zone to larger depths and higher latitudes than is currently done. It will provide full vector magnetic fields at several heights in the solar atmosphere, thus improving our understanding of the upward flow of magnetic energy and helicity. This presentation will provide an update on status of ngGONG.

USO50YR-ST-06-0009

Bi-spectrum phase-only reconstruction of adaptive optics corrected images of the MAST

R. Sridharan

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Speckle imaging is a valuable post-processing technique that mitigates the effects of the earth's atmospheric turbulence on the images obtained from ground-based telescopes. In solar speckle imaging, a burst of short exposure images obtained under quasi-monochromatic conditions are processed in the Fourier domain. The Fourier amplitudes are recovered using a model-dependent speckle transfer function while the Fourier phases are recovered from ensemble averaged bi-spectrum that are immune to the atmospheric turbulence. In this work, we apply the bi-spectrum phase recovery process, using the speckle masking code developed by us, to the images that have already been subjected to real-time low-order adaptive optics correction at the Multi-Application Solar Telescope (MAST). Our aim is to see if the image quality improves further with the post processing. Any increase in the image quality with phase-only reconstruction is likely to ascertain, not only the level of residual phase errors but also the level of corrections needed with a high-order adaptive optics correction. Also, we compare the phase-only reconstructions of images with and without adaptive optics correction. Our goal is to evaluate the efficacy of combining both real-time AO and post-processing techniques for ground-based solar observations.

USO50YR-ST-06-0011

Highlights and First Results from the Sunrise III 2024 Campaign

Andreas Korpi-Lagg
Max Planck Institute for Solar System Research, Germany

The Sunrise III 2024 flight was highly successful. The balloon-borne solar observatory captured spectropolarimetric data of a diverse range of solar targets during its 6.5-day-long excursion to the stratosphere. Under seeing-free conditions, the three science instruments SUSI (Sunrise UV Spectropolarimeter and Imager) in the near-UV,TuMag (Tunable Magnetograph) in the visible, and SCIP (Sunrise Chromospheric Imager and Polarimeter) in the near-IR, obtained synchronized data at the diffraction limit of the 1-meter main telescope. This presentation shows an overview of the flight and the obtained data sets. In addition, first scientific results obtained by the various instruments are highlighted, demonstrating the quality of the data sets and the high potential for detailed studies on fundamental processes in the solar photosphere and chromosphere.

USO50YR-ST-06-0012

IFU spectropolarimetry at the SST: adventures in 5D

Michiel Jan Van Noort
Max Planck Institute for Solar System Research, Germany

Since the installation of the first prototype of a microlensed hyperspectral imager (MiHI), a specific type of integral field instrument, at the SST in 2016, an ongoing series of upgrades, aimed at improving and extending its capabilities, has taken place. Many of the lessons learned from the experience gained with this prototype have influenced the design and construction of the Helium spectropolarimeter (HeSP). In this talk the operating principles of a MiHI, the technical challenges, and the specific peculiarities of the data reduction will be presented. The most important properties of the data that can be obtained with such an instrument, such as resolution, cadence, and signal to noise, will be discussed using recent results.

USO50YR-ST-06-0013

Magnetographs for Synoptic Solar Science from Ground and Space

Sanjay Gosain
National Solar Observatory, USA

Synoptic full-disk magnetograms are essential for mapping the long-term modulation of the magnetic activity, in order to better understand the solar dynamo mechanism. Such measurements typically require continuity and high sensitivity at a decent spatial resolution. At National Solar Observatory there is a strong heritage of such measurements made by a generation of instruments over past many decades such as KPVT, GONG, SOLIS/VSM. In this talk I will present two example instruments: (i) SOLIS/VSM - a ground-based 50 cm aperture telescope which makes high-sensitivity vector field measurements in photosphere and chromosphere, and (ii) CDM - a compact Doppler magnetograph derived from GONG, designed for space-based observations. Finally, I will briefly talk about the next generation of magnetographs being considered for the proposed ground-based NG-GONG network.

USO50YR-ST-06-0014

Data Product Generation for the Solar Ultraviolet Imaging Telescope (SUIT) Instrument on Aditya-L1

Janmejoy Sarkar

Max Planck Institute for Solar System Research, Germany and IUCAA, Pune

The Solar Ultraviolet Imaging Telescope (SUIT) onboard the Aditya-L1 mission records full-disk solar images across eleven bandpasses within the 200–400 nm wavelength range. Operating from a halo orbit around the Sun–Earth Lagrange-1 point, SUIT takes continuous observations of the solar photosphere and chromosphere.Image data received from SUIT undergoes a series of calibrations, including dark and bias subtraction, flat-field correction, removal of stray light, and application of a coordinate system, to generate science-ready Level-1 data. The Level-1 data is further processed to generate Level-2 data products. This stage focuses on morphological corrections such as spot and contamination removal, spiked pixel removal, and image deconvolution for sharpening of morphological features. Additionally, a modular toolkit for Level-2 processing will be made publicly available, enabling users to apply selected corrections tailored to their research needs. In this presentation, we describe the calibration pipeline developed for SUIT, with an emphasis on the Level-2 data products. We also discuss the performance of these corrections and provide quantitative estimates of the residual uncertainties in the final data.

USO50YR-ST-06-0017

Solar Orbiter: High resolution observations from unique viewpoints

Hanna Strecker
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The ESA/NASA Solar Orbiter mission was launched in February 2020 and carries four in-situ and six remote-sensing instruments. For most of the mission, in-situ measurements and full-disk remote-sensing observations at moderate spatial resolution are performed. Since the beginning of the Nominal Mission Phase the spacecraft has completed eight perihelion passes, during which it has approached the Sun each time to distances as small as 0.29 au. These closest-approach are typically used for high resolution observations. The High Resolution Telescope (HRT) of the Polarimetric and Helioseismic Imager (SO/PHI) provides vector magentograms and Doppler velocities at a spatial resolution down to $\sim$200 km on the solar surface at perihelion. This allows the study of small-scale dynamics and magentic field evolution in the solar photosphere. Cospatial observations from the High Resolution Imager (HRI) of the Extreme Ultraviolet Imager (EUI) show the rapid evolution in the corona, capturing small-scale features, like campfires, jets, and small-scale heating events, at thesame spatial resolution and a cadence of seconds. Solar Orbiter's unique orbit allows observations from well outside the Sun–Earth line. In combination with near-Earth observatories, this enables multi-perspective and stereoscopic studies as well as extended tracking of solar regions beyond what is possible from a single viewpoint. The Venus gravity-assist manoeuvre in February 2025 has further provided a new perspective, increasing the spacecraft's heliographic latitude to about 17° out of the ecliptic. Future gravity assists will raise the maximum heliographic latitude reached even further, up to 33°. The combination of high-resolution imaging and spectropolarimetric measurements from these unique viewing geometries open new opportunities for studying the structure and evolution of magnetic fields at the solar poles.

USO50YR-ST-06-0018

IBIS2.0 at THEMIS: upgraded imaging spectropolarimetry and science prospects

Paolo Romano

INAF - Catania Astrophysical Observatory, Italy

IBIS2.0 is the new generation of the Interferometric BIdimensional Spectrometer, developed to deliver stable, high-cadence imaging spectroscopy and spectropolarimetry in visible photospheric and chromospheric lines. The instrument will be installed at THEMIS, where hardware and software integration is currently underway. We present the upgrade concept and current status, highlighting the main technical innovations and observing capabilities (fast spectral scans, multi-line operation, improved polarimetric reliability), together with the calibration and data-reduction approach being prepared for routine THEMIS operations. We also place IBIS2.0 in the context of the scientific legacy of IBIS at the Dunn Solar Telescope, which demonstrated the instrument's potential for multi-height investigations of solar magnetic structures and their dynamics. We discuss how the enhanced stability, cadence, and polarimetric performance of IBIS2.0 at THEMIS will enable more systematic and statistically robust studies, especially in coordinated campaigns, providing stronger constraints for models of solar magneto-convection and activity.

USO50YR-ST-06-0020

Preliminary design of higher order AO system for MAST

Shruti Sinha
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Light coming from the celestial objects has to pass through the Earth's atmosphere before it reaches to our optical systems. Earth's atmosphere is a turbulent medium because of differential heating. This causes the phase fluctuations. As a result, the light which we receive on our ground-based optical systems has a distorted wavefront instead of a plane one. The images get blurred and the high frequency components that represent fine spatial features get washed out. Thus, astronomers concerned with high resolution imaging are greatly troubled by the blurring caused by the atmospheric turbulence. The effect is known as "seeing" and thus the systems, especially those with the large apertures, are called seeing-limited instead of diffraction limited. One of the methods that can be applied to get rid of this, is an adaptive optics (AO) system, which compensates for the atmospheric turbulence in real time. An AO system mainly comprises of a wavefront sensor (WFS) and a wavefront corrector (a deformable mirror (DM) in most cases) which are used to perform real-time corrections of the incoming wavefront. The choice of number of corrective elements and therefore the number of sensing elements depend upon the turbulent "nature" of the atmosphere at the observation site. The atmospheric turbulence can be quantified by estimating Fried's parameter or Fried's coherence length, r_0 and coherence time, τ, that tells us about how fast the turbulence changes and thus how fast the corrections must be done for applying faithful real-time compensations to the incoming wavefronts. The current AO system deployed in MAST (50 cm solar telescope, USO, Udaipur) has a 37-electrode membrane-based DM and a Shack-Hartmann WFS (SHWFS) with an array of 37 lenslets. With this, we are able to improve the contrast of the observations at spatial frequencies corresponding to 0.2-0.6 times of the highest spatial frequency for up to 20th Zernike terms. We are aimed to upgrade this to a higher order AO system which can apply corrections for more than fifty Zernike terms, further improving resolution. This work gives details about the Fried parameter estimation for the observation site of MAST using differential image motion (DIM) measurements and, based on this, the preliminary design of the upgraded AO system.

USO50YR-ST-06-0021

Early-Stage of the development of a Multi-Channel Digital Backend for ARUN-SSW

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Indian Institute of Technology, Indore, India

The Sun is an active and constantly evolving star, and its eruptive events, such as solar flares and coronal mass ejections (CMEs) and has a major role in shaping space weather and influencing modern technological systems. These eruptions arise from magnetic reconnection and the acceleration of energetic particles, which produce strong radio emission, particularly in the microwave band. However, there is a noticeable lack of microwave solar observations in the Asian sector, especially during 02:00–08:00 UT, when no dedicated imaging facilities are available.

This work presents the early steps toward developing an indigenous digital backend for the Advanced Radio Telescope Udaipur Network for Solar and Space Weather Research (ARUN-SSW) at USO. The system is intended to enable routine observations of the lower corona and upper chromosphere and to strengthen our capabilities in signal processing, data acquisition, and scientific analysis. The proposed digital backend is designed for solar observations between 1–4 GHz, helping fill a critical regional and global gap in microwave monitoring. The initial design uses a ZCU216 RFSoC board, providing 16-channel data acquisition and processing through the CASPER toolflow. As a first stage, a four-element interferometer is being assembled and tested to verify amplitude and phase closure, a key requirement for reliable interferometric imaging. This work also examines gate and flip-flop utilisation on the ZCU216 to guide future deployment of DSP modules for preprocessing and identifying high-power radio signatures associated with flares and CMEs.

USO50YR-ST-06-0022

Solar Adaptive Optics system at Udaipur Solar Observatory

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It is well known that atmospheric turbulence limits the resolution of ground-based telescopes. An adaptive optics (AO) system compensates for this turbulence in real-time, enabling high-resolution observations. Since 2015, a multi-application solar telescope (MAST) with a 50 cm aperture has been in operation in Udaipur. To enhance the imaging quality of MAST, a low-order AO system has been developed. This system features a Shack-Hartmann wavefront sensor with 37 lenslet array along with a high-speed camera, and a 37-channel deformable mirror for wavefront sensing and correction, respectively. The improvement in wavefront quality ranges from 2 to 8, depending on the seeing conditions. Work is currently underway to develop a higher-order AO system aimed at improving correction to the diffraction limit of the 50 cm telescope. In this talk, we present details of the existing low-order AO system, along with the calibration of a monomorph deformable mirror for the higher-order AO system.

USO50YR-ST-06-0023

EUV polarimeter optics based on metal coatings

Savitha M S

Indian Institute of Astrophysics, India

Direct measurement of the solar coronal magnetic field is key to understand heating and other process in the solar corona. The Hanle effect in EUV spectral lines is one of the promising diagnostic techniques for probing the vector magnetic field in the solar corona. This technique requires precise polarization measurements of Hanle-sensitive lines, yet no spectropolarimeter currently exists for such observations in the EUV range.

Reflective polarizers, particularly single-layer or multilayer-coated mirrors operated near Brewster's angle, offer a promising approach for an EUV polarimeter. However, most materials exhibit a wavelength-dependent Brewster angle, restricting operation to a narrow spectral range. To overcome this limitation, we employ metal coatings, which maintain a nearly constant Brewster angle across a broad wavelength range. The metallic-coated mirrors can be effectively incorporated into the polarimeter, by optimizing the telescope optics with dielectric coatings which are transparent to visible and IR light and effectively reflects the EUV light into the polarimeter.

This study focuses on identifying suitable coating materials for a three-mirror EUV polarimeter operating in the 500–1000 Å range. Zemax simulations identified platinum and iridium as the most promising candidates due to their superior reflectivity and polarization efficiency. To validate these results, platinum coated samples were prepared via DC sputtering at the Centre for Nano Science and Engineering (CeNSE), Indian Institute of Science. These mirrors were then characterized using soft x-ray reflectivity beamline (BL-4) at the INDUS-1 synchrotron radiation source at the Raja Ramanna Centre for Advanced Technology (RRCAT). The EUV reflectance measurements, in 12-25 eV (1000–500 Å) photon energy region, were performed by setting the beamline reflectometer in s- and p- polarization geometry. Reflectivity vs incidence angle measurements were used to determine the Brewster angle. The energy scans were used to assess the polarization efficiency. The experimentally obtained Rs/Rp ratios demonstrate strong polarization performance and show good agreement with simulations, confirming the suitability of platinum coatings for EUV polarimeter mirrors.

USO50YR-ST-06-0024

SOLAR-C for high resolution EUV spectroscopy

Toshifumi Shimizu
Japan Aerospace Exploration Agency (JAXA), Japan

This presentation will provide the overall status of the JAXA SOLAR-C mission and its onboard mission performance, which will realize high resolution EUV spectroscopy. The talk will also discuss potential collaboration with science community in India.

USO50YR-ST-06-0025

Early Development of the Multi-Feed Antenna and RF Front-End for ARUN-SSW

Samruddhi Rohokale
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Solar radio emission in the centimeter-decimeter bands carries crucial information about magnetic restructuring, plasma heating, and energetic particle acceleration in the chromosphere and low corona. To enable high-cadence monitoring of these processes, the ARUN-SSW initiative includes the development of an indigenous wideband antenna and RF front-end optimized for solar observations in the 1–18 GHz range. The front-end is intended to provide stable, low-noise analogue reception for both disk and limb imaging, addressing the scarcity of microwave solar facilities in the Asian sector. The initial design focuses on an 11-feed antenna array mounted at the focal plane of the ARUN-SSW dish, enabling multi-directional sampling and improved instantaneous coverage needed for rapid solar snapshot imaging. Each feed element is supported by a dedicated RF chain incorporating band-selection filters and low-noise amplification suitable for integration with high-speed digital backends. Electromagnetic simulations are guiding the optimization of return loss, S-parameters, mutual coupling, and beam shape across the wide operating band. Prototype feed elements are currently being fabricated and evaluated to assess VSWR, inter-element isolation, and noise performance under strong solar signals.
These early front-end developments provide the essential analog foundation for ARUN-SSW, ensuring that the system can reliably capture wideband solar radio signatures and support the next stages of digital signal processing and imaging.

USO50YR-ST-04-0015

ARUN-SSW: An Upcoming Solar Radio Imaging Facility

Anshu Kumari
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Solar eruptive phenomena such as flares and coronal mass ejections (CMEs) are among the primary sources of space weather disturbances. The coronal/chromospheric magnetic field strongly governs their initiation and evolution, yet direct measurements of this field remain one of the significant challenges in observational solar physics. While photospheric magnetograms and numerical extrapolation methods have provided valuable insights into lower-atmosphere activity, they offer limited information on coronal magnetic structures and particle acceleration sites.

Radio observations, particularly in the GHz range, offer a powerful diagnostic window into the solar atmosphere, especially for probing the upper chromosphere and low corona. Instruments like the now-defunct Nobeyama Radioheliograph (NoRH) demonstrated the utility of microwave imaging in constraining coronal magnetic fields and non-thermal electron distributions. Despite this, no operational imaging radioheliograph in the GHz range covers the Asian longitudinal sector, resulting in a significant temporal and spatial observational gap.

The Advanced Radio Telescope Udaipur Network for Solar and Space Weather Research (ARUN-SSW) aims to fill this gap. The facility is being developed at the Udaipur Solar Observatory (USO), Physical Research Laboratory, focusing on high-cadence (few ms), multi-frequency imaging in the 1–18 GHz range. It is designed to simultaneously observe the solar disc and the off-limb corona without occultation. It offers a complementary perspective to the existing Multi-Application Solar Telescope (MAST) at USO, which targets the lower and middle chromosphere. The initial phase will focus on front-end design: antenna and feed development and characterisation, as well as digital Fx correlator development on an FPGA board (ZCU216). Phase II will comply with the antenna deployment and initial on-field characterisation. ARUN-SSW is expected to enhance observational coverage in the Asian timezone significantly and contribute to ongoing global efforts in solar and space weather research.