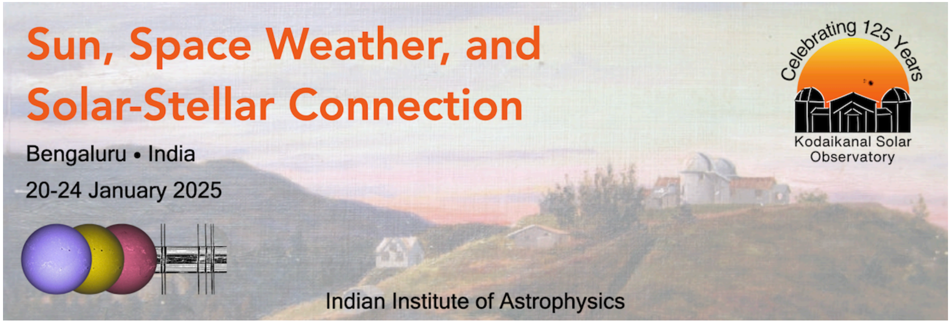
# Sun, Space Weather, and Solar-Stellar Connection

Monday, January 20, 2025 - Friday, January 24, 2025




# Book of Abstracts

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**Long Term Synoptic Observations / 63**

## Unveiling the Significance of Ca II K Observations for Long-Term Solar Irradiance Reconstructions

**Author:** Theodosios Chatzistergos[1]

**Co-authors:** Natalie Krivova [1]; Ilaria Ermolli [2]; Sami K. Solanki [1]

[1] *Max Planck institute for solar system research*

[2] *INAF OAR*

Direct measurements of solar irradiance started in 1978, which is a rather short period for climate studies. Irradiance variations on timescales of days and longer are attributed to the evolution of the solar surface magnetic field, which allows irradiance reconstructions for periods that appropriate data describing solar surface magnetism exist. In particular, such models require information on both sunspots and faculae. Although sunspot observations readily exist back to early 1600s, facular data are significantly more scarce. The longest available record of facular data is Ca II K observations, dating back to 1892, with one of the most prominent such Ca II K archives being from Kodaikanal observatory. Unfortunately, the use of Ca II K data for irradiance studies has been hampered by significant challenges with analysing the Ca II K images, including the non-linear response of photographic plates and the presence of large-scale artifacts in the images. Our analysis of Ca II K data has allowed us to overcome many of these obstacles. We also reassessed the link between Ca II K brightness and magnetic field strength, enabling the conversion of Ca II K observations into detailed maps of the solar surface magnetic field. Here we will present our latest advancements in utilizing Ca II K data to reconstruct past solar irradiance variations.

**Contribution Type**:

**Theme**:

Solar Magnetism over Long-Time Scales

**Long Term Synoptic Observations / 126**

## Revisiting Sunspot Groups Tilt Angle Study from Kodaikanal Data

**Author:** Manjunath Hegde[1]

**Co-author:** Ravindra B [1]

[1] *Indian Institute of Astrophysics*

The solar cycle is driven by the emergence and evolution of active regions on the Sun's surface, which play a critical role in the Sun's magnetic dynamics. One of the fundamental properties of these regions is the tilt angle, which describes the inclination of a sunspot group's axis relative to the solar equator. Tilt angles are essential for understanding the solar dynamo, as they contribute to the generation and evolution of large-scale solar magnetic fields.
Using daily sunspot group data from the Kodaikanal Solar Observatory for the period 1954-2017, we have studied the statistical properties of sunspot tilt angles. Key findings such as the distribution of sunspot groups tilt angles in both solar hemispheres, their variation with latitude etc. will be presented providing a comprehensive view of how tilt angles evolve over multiple solar cycles.

**Contribution Type**:

**Theme**:

Solar Magnetism over Long-Time Scales

**Long Term Synoptic Observations / 33**

## Characteristics of Supergranulation Network from Kodaikanal Archival Data

**Author:** Raju K P[1]

[1] *Indian Institute of Astrophysics*

The large-scale convection in the sun, supergranulation, is manifested as a network structure on the solar surface. The network cells have an average lifetime of 24 hours, a size of about 30 Mm, and a lane width of about 6 Mm. We have obtained the lane widths and intensities of the network as functions of latitude and time from the Ca II K spectroheliograms of the 100-year Kodaikanal archival data. We studied the spatial and temporal variations of these parameters which give important information on the flux transport on the solar surface. Also, the lane widths and intensities are found to be dependent on the sunspot cycle. The correlation between lane widths and sunspot number is used as a prediction tool for the latter. The results have implications for solar dynamo models and space weather predictions.

**Contribution Type**:

**Theme**:

Solar Magnetism over Long-Time Scales

**Long Term Synoptic Observations / 173**

## Exploring Solar Magnetism Over Long Time Scales with Regular Full-Disc Observations

**Author:** Ilaria Ermolli[1]

[1] *INAF Osservatorio Astronomico di Roma*

Time series of regular full-disc solar observations acquired in white light and at the Ca II K and Halpha lines provide direct information on magnetic regions on the Sun with an almost complete daily coverage over the last century. This makes them extremely important for studies of the solar magnetism over long time scales. Here, we first provide an overview of the most prominent archives of synoptic full-disc solar observations and of their exploitation in time, followed by a summary of the main results on solar magnetism derived with such data.

**Contribution Type**:

**Theme**:

Solar Magnetism over Long-Time Scales

**Solar Interior Dynamics / 202**

## Helioseismology with Inertial Modes

TBA

**Contribution Type**:

**Theme**:

**Solar Interior Dynamics / 115**

## A Unified Family of Mixed Inertial Modes in the Sun

**Author:** Rekha Jain[1]

[1] *University of Sheffield*

In this talk, I will present an analytical model that unifies many of the solar inertial waves as a single family of mixed inertial modes. Here, mixed modes refer to the prograde- and retrograde-propagating members of this family. Thermal Rossby waves exist as prograde-propagating waves, while the high-frequency retrograde (HFR) wave is possibly a member of the retrograde branch. The higher overtones may correspond to many of the inertial modes that have been recently identified by numerical eigenmode solvers. I will also discuss some properties of the mixed modes in the context of this model.

**Contribution Type**:

**Theme**:

Solar Magnetism over Long-Time Scales

**Solar Interior Dynamics / 170**

## Inertial Waves in the Solar Convection Zone

**Author:** Catherine Blume[1]

**Co-authors:** Bradley Hindman [1]; Loren Matilsky [2]; Rekha Jain [3]

[1] *University of Colorado Boulder*

[2] *University of California-Santa Cruz*

[3] *University of Sheffield*

The past several years have seen a dizzying array of both modeled and observed inertial oscillations in the solar convection zone. While classical Rossby waves are relatively well understood, the recently observed high-frequency retrograde vorticity (HFR) modes lack a convincing theoretical explanation. There have also been several different types of retrograde inertial waves that have been modeled but not observed. Here, we present a 3D numerical simulation in spherical geometry that models the Sun's convection zone and upper radiative interior. This model features many of these inertial oscillations and will provide a good overview of the current landscape. We additionally demonstrate that every inertial oscillation present in the model that is not a classical Rossby wave is part of the same family of mixed modes, greatly simplifying the theoretical picture.

**Contribution Type**:

**Theme**:

Solar Magnetism over Long-Time Scales

**Solar Interior Dynamics / 171**

## Reconciling Helioseismic Measurements of Solar Deep Meridional Flow from SDO/HMI and GONG Observations

**Author:** Ruizhu Chen[1]

**Co-authors:** Junwei Zhao [1]; Paul Rajaguru [2]; Shukirjon Kholikov [3]

[1] *Stanford University*

[2] *Indian Institute of Astrophysics, Bangalore, India*

[3] *National Solar Observatory*

The Sun's meridional circulation is crucial to understanding its dynamo and interior dynamics. However, helioseismic determination of deep solar meridional flows is complicated by multiple systematic effects, leading to inconsistent results in previous studies. To find the cause of the discrepancies, we collect measurement codes from multiple previous studies and analyze over 13 years of HMI and GONG data. We conduct a comprehensive comparison across different methods, data sources, and data preparation procedures, and analyze the multiple systematic effects in measurements by HMI and GONG. A systematic GONG-HMI offset in the North-South direction is confirmed. No discrepancies are found among independent measurements by multiple authors. After correcting for known systematic effects, the meridional-flow signals are consistent between GONG and HMI.

**Contribution Type**:

**Theme**:

Solar Magnetism over Long-Time Scales

**Dynamo Models and Observations / 116**

## Nonlinearities, Stochasticity, and Long-Term Modulations in Solar and Stellar Dynamos

**Author:** Paul Charbonneau[1]

[1] *Université de Montréal, Canada*

The basic concepts underlying our current understanding of solar and stellar magnetic activity cycles as being due to an internal dynamo process were laid out in more or less their current form some 70 years ago. Yet, at this writing, there exist no concensus "dynamo model of the solar cycle"; be it at the level of the relative importance of various potential inductive processes, of the nonlinear backreaction on inductive flows regulating the amplitude of magnetic cycles, or on the mechanism(s) driving long-term cyclic variability, including both quasi-periodic amplitude modulationand aperiodically recurring "Grand Minima" in activity. In this talk I will discuss results from non-kinematic mean-field-like dynamo simulations exploring the interaction between different nonlinear magnetic backreaction mechanisms acting concurrently, in the presence or absence of stochastic forcing. My presentation will be in the form of "vignettes" illustrating a number of interesting and often counter-intuitive effects of jointly acting nonlinearities, including (1) cycle amplitude regulation and modulation, (2) chaos and its suppression, and (3) stochastic amplification of deterministic long-term modulations.

**Contribution Type**:

**Theme**:

Solar Magnetism over Long-Time Scales

**Dynamo Models and Observations / 181**

## Deep Cyclic Activity and Radial Flux Transport in the Sun by Assimilating Observed Magnetogram in a 3D Dynamo Model

**Author:** Soumyadeep Chatterjee[1]

**Co-author:** Gopal Hazra [1]

[1] *IIT Kanpur*

The solar magnetic cycle is crucial for understanding solar activity and space weather. Two key models for studying it are the Surface Flux Transport (SFT) model and the 3D Babcock-Leighton dynamo model, respectively. The SFT model examines large-scale magnetic field evolution on the Sun's surface to predict solar cycles. In contrast, the 3D Babcock-Leighton model explores internal processes that drive the solar magnetic cycle, detailing how toroidal and poloidal magnetic fields regenerate through differential rotation and sunspot decay. In our research, we are the first to incorporate daily magnetogram data into the 3D Babcock-Leighton model. We use a modified data assimilation technique akin to the Advective Flux Transport model. This approach allows us to generate cyclic variations in the toroidal field and investigate the role of internal dynamics in the solar magnetic cycle and polar fields. Additionally, by integrating insights from the SFT model, we also constrain the radial turbulent transport parameters. Our findings will be presented in detail.

**Contribution Type**:

**Theme**:

Solar Magnetism over Long-Time Scales

**Dynamo Models and Observations / 69**

## Surmounting the Solar Grand Minima: A Quantification of the Polar Flux Threshold

**Author:** Chitradeep Saha[1]

**Co-authors:** Dibyendu Nandy [2]; Sanghita Chandra [3]

[1] *CESSI, IISER Kolkata*

[2] *CESSI and Department of Physical Sciences, IISER Kolkata*

[3] *Max Planck Institute for Solar System Research, Gottingen, Germany*

The 11-year sunspot cycles undergo amplitude modulation over longer timescales. As a part of this long-term modulation in solar activity, the decennial rhythm occasionally breaks, and sunspots disappear from the solar surface for multiple decades, leading to a period of magnetic quiescence on the Sun –known as the solar grand minimum. Observation of solar magnetic activity proxies suggest that the solar polar fields reach a minimum during such episodes, with a temporary halt in the polar field reversal. Eventually, with the accumulation of sufficient polar fluxes, the polarity reversal resumes, revitalizing regular sunspot cycles. Using multi-millennial dynamo simulations, we quantify the threshold of polar flux necessary to restart the polarity reversal and surmount the grand minimum phase. We also find that the duration of a grand minimum is independent of the onset rate and does not affect the recovery rate. These results may help forecast the Sun's recovery once it enters a grand minimum.

**Contribution Type**:

**Theme**:

Solar Magnetism over Long-Time Scales

**Dynamo Models and Observations / 162**

## Observational Constraints for Dynamo Modeling & Active Region Flux Emergence Patterns

**Author:** Aimee Norton[1]

[1] *Stanford University*

I describe some of the defining observations of the solar cycle that provide insights into the dynamo process, including the basics such as Hale and Joy's law, the spatio-temporal emergence of active regions that creates the butterfly diagram, and large-scale flows including zonal, meridional, etc. I also discuss new research on activity nests and active region flux emergence patterns. Locations where active regions repeatedly emerge are known as nests, of interest because they commonly host flares and CMEs but also because they inform us about the origins of sunspots. Why do ARs cluster spatially to form nests and is the bursty activity observed in quasi-biennial oscillations and Rieger periodicities related to nesting? The physical mechanism that causes nests is unknown but could be due to instabilities acting on the interior magnetic field or flow fields such as giant convection or inertial modes. We report on activity nests observed during Solar Cycle 24 as studied using HMI/SDO magnetic synoptic maps. Using a traditional definition of nests and searching the data with a narrow range of allowed rotation rates similar to the Carrington rate, we find that one-quarter of ARs and one-third of AR magnetic flux participate in nesting behavior. Using wavelet and Fourier analysis, we find hemispheric asymmetry in nesting behavior. We discuss these issues as well as report on the average characteristics such as lifetimes, rotation rates and amount of magnetic flux contained in the observed nests.

**Contribution Type**:

**Theme**:

Solar Magnetism over Long-Time Scales

**Dynamo Models and Observations / 41**

## Statistical Properties of Solar Active Region Potential Magnetic Fields

**Author:** Stephane Regnier[1]

[1] *Northumbria University*

In the solar atmosphere, active regions are dominated by the magnetic field, its complex topology and evolution. To understand the divers nature of active regions, we study a large sample of 3D magnetic field configurations to derive general properties relating magnetic flux, magnetic energy and magnetic field scale-height. We compute the magnetic fields under the potential field assumption for about 900 snapshots of active regions observed by SDO/HMI (CEA SHARP series) during solar cycle 24. We found that the magnetic energy follows a power law of the total unsigned photospheric flux with an index of about 1.5. We show the relationship (or lack of) between the activity solar cycle and the magnetic energy. We also provide a statistical distribution of the decay index during the solar cycle: the magnetic field strength is decaying differently (e-folding) depending on the properties of photospheric magnetic field (i.e., imbalance of flux, center of mass, characteristic size) and the stage of evolution. We discuss the implications for modelling active region magnetic fields and the requirements for advanced models.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Solar Cycle Variations in the Interior / 199**

## Solar Cycle Variations in the Solar Interior

**Author:** H. M. Antia[1]

[1] *CEBS, Mumbai 400098*

Using the helioseismic data for the last nearly 30 years from GONG, MDI and HMI instruments it is possible to study the solar cycle variations in structure and dynamics. Variations in frequencies are found to be correlated to solar activity and the inversion of these frequency differences, shows that the variation is confined to near surface region and is generally attributed to variation in the solar magnetic field. The solar rotation shows a distinct pattern of variation with solar cycle and this is referred to as the zonal flows. These results will be discussed.

**Contribution Type**:

Invited talk

**Theme**:

**Solar Cycle Variations in the Interior / 129**

## Geostrophic Nature of Flows Around Active Regions and Changes in the Near-surface Shear Layer of the Sun

**Author:** S.P. Rajaguru[1]

**Co-authors:** Anisha Sen [1]; H.M. Antia [2]; Junwei Zhao [3]; Ruizhu Chen [3]; Shukur Kholikov [4]

[1] *Indian Institute of Astrophysics*

[2] *UM-DAE Centre for Excellence in Basic Sciences*

[3] *Stanford University*

[4] *National Solar Observatory, USA*

Using solar-cycle long measurements of meridional and zonal flows in the near-surface shear layer (NSSL) of the Sun, we study temporal variations in them and their connections to active regions. We find that inflows towards active regions are part of a local circulation with an outflow away from active regions at depths around 0.97 $R_\odot$, which is also the location where the deviations in the radial gradient of rotation change sign. These results, together with a reverse pattern observed during solar minimum period, point to the geostrophic nature of large-scale flows across latitudes as primary cause of the observed depth profile of changes in rotation gradient within the NSSL. We also find that the observed changes due to active regions only marginally change the amplitude of zonal flow and hence are not likely its driving force. Close agreements between the depth profiles of changes in rotation gradient and in meridional flows measured from very different global and local helioseismic techniques, respectively, provide an important validation for the measurement procedures, especially for the latter.

**Contribution Type**:

**Theme**:

Solar Magnetism over Long-Time Scales

**Solar Cycle Variations in the Interior / 201**

## Global Nonlinear MHD of Solar Tachocline and Implications for Surface Magnetism

**Author:** Mausumi Dikpati[1]

[1] *NSF-NCAR, High Altitude Observatory*

The tachocline, a thin shear-layer located in a subadiabatic region at/near the base of the solar convection zone, can be modelled using a 3D thin-shell shallow-water type formalism. In such models the Sun's global differential rotation and toroidal magnetic fields undergo nonlinear dynamical interactions by exchange of energies among differential rotation and toroidal magnetic fields, and unstable MHD Rossby waves that are longitude-dependent perturbations of the global system. Major features produced include: (i) clam-shell opening of broad toroidal fields; (ii) tipping or deformation of narrow toroidal bands; (iii) Tachocline Nonlinear Oscillations or "TNOs", most likely responsible for short-term, quasi-annual bursts of solar activity; (iv) 'teleconnections' that cross-equatorially link the two hemispheres, as well as high and low latitudes within a hemisphere; (v) formation of organized, global patterns in the toroidal bands. If active regions observed at the surface are the manifestations of magnetic flux rising from the convection-zone base to the surface, their global-scale, spatio-temporal distribution could be originating from the nonlinear MHD of the tachocline. After describing these results, we will close by discussing our recent efforts to connect the bottom tachocline dynamics with surface magnetograms.

**Contribution Type**:

Invited talk

**Theme**:

**Solar Cycle Variations in the Interior / 20**

## Study of Bipolar Magnetic Regions Using AutoTAB: Support of Thin Flux Tube Model?

**Author:** Anu Sreedevi[1]

**Co-authors:** Bibhuti Kumar Jha [2]; Bidya Binay Karak [1]; Dipankar Banerjee [3]

[1] *Indian Institute of Technology (BHU) Varanasi*

[2] *Southwest Research Institute, Boulder, CO 80302, USA*

[3] *Aryabhatta Research Institue of Observational Sciences, Nainital 263002, Uttarakhand, India*

The solar convection zone is characterized by the birth of the concentrated magnetic field regions known as Bipolar Magnetic Regions (BMRs), which are tilted with respect to the equatorial line. The thin flux tube model, employing the rising of magnetically buoyant flux loops twisted by the Coriolis force, is a popular paradigm to explain the formation of the tilted BMRs. In this study, we assess the validity of the thin flux tube model by analyzing the tracked (Hale and Anti-Hale) BMR data obtained through the Automatic Tracking Algorithm for BMRs (AutoTAB). Our observations reveal that the tracked BMRs exhibit the expected collective behaviors and the polarity separations of BMRs increase over their normalized lifetimes, supporting the assumption of the rising flux tubes from the CZ. Furthermore, we observe an increasing trend of the tilt with the flux of the BMR, suggesting that rising flux tubes associated with lower flux regions are primarily influenced by drag force and Coriolis force, while in higher flux regions, magnetic buoyancy dominates. Additionally, we observe Joy's law dependence for emerging BMRs from their first detection, indicating that at least a portion of the tilt observed in BMRs can be attributed to the Coriolis force. Finally, we observe that the lower flux regions exhibit a higher amount of fluctuations associated with their tracked tilt measurements, suggesting that they are more susceptible to turbulent convection. All these results hint towards the thin flux tube model.

**Contribution Type**:

**Theme**:

Solar Magnetism over Long-Time Scales

**High Resolution Observations of Solar Magnetic Fields / 128**

## A High Resolution View of Solar Magnetic Fields

**Author:** Jaime de la Cruz Rodriguez[1]

[1] *Institute for Solar Physics, Stockholm University*

We cannot directly observe the magnetic field vector on the surface of the Sun, only infer it from observations using a model. Therefore, our ability to obtain an accurate picture of the magnetic topology, strength and connectivity in the outer layers of the Sun, relies on having high signal-to-noise observations and a robust model that can be used to fit the observations. Such requirements are particularly hard to achieve in the chromosphere, where non-LTE conditions must be included in the modelling of spectral lines and where spectral lines are weakly sensitive to the magnetic field. In this review, I will cover a selection of recent developments in the inference techniques, the state-of-the-art in solar observations and new results from the solar community in relation to high resolution solar magnetic fields.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**High Resolution Observations of Solar Magnetic Fields / 114**

## High-resolution Measurements of Coronal Magnetic Field in Solar Flares and Associated Phenomena

**Author:** Gregory Fleishman[1]

[1] *Institute for Solar Physics (KIS)*

This talk reviews recent accomplishments and current status of dynamic high-resolution high-cadence measurements of coronal magnetic field and plasma parameters in solar flares. Such measurements are of exceptional importance, particularly because release of the magnetic energy due to reconnection is believed to drive such transient solar phenomena as solar flares, eruptions, and jets. This energy release should be associated with a decrease of the coronal magnetic energy, which implies a decrease of the magnetic field. Quantitative measurements of the evolving magnetic field strength in the corona are required to find out where exactly and at which rate this decrease takes place. The only available methodology capable of providing such measurements employs microwave imaging spectroscopy of gyrosynchrotron emission from nonthermal electrons. Here, we present and review microwave observations of several solar flares showing spatial and temporal changes in the coronal magnetic field in the flare volume including flaring loops and the cusp region. In large flares the flaring magnetic field shows a prominent decay over a large coronal volume. The typical decay rate of the magnetic field is several Gauss per second, which continues at a given location for one-two minutes. Spatially resolved maps of the nonthermal and thermal electron densities derived from the same microwave spectroscopy data set allow us to detect the very acceleration site and also produce maps of such important physical parameters as Alfven speed and plasma beta in the flare volume. Using stereoscopic observations from different vantage points, these maps are converted to 3D measurements, thus, adding earlier unavailable constraints for 3D models. We discuss implications of these new findings for understanding the solar flare phenomenon including details of the energy release, particle acceleration process, and coronal waves.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**High Resolution Observations of Solar Magnetic Fields / 34**

## Unravelling the Stratification of the Chromospheric Magnetic Field Using the Hα Line

**Author:** Harsh Mathur[1]

**Co-authors:** Jayant Joshi [1]; Nagaraju K [1]; Rahul Yadav [2]

[1] *Indian Institute of Astrophysics*

[2] *Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80303, USA*

The Hα line is widely utilized for studying the solar chromosphere, but there is a scarcity of polarimetric studies aimed at inferring magnetic fields. One of the many reasons could be that there are no polarimetric studies of the Hα line utilizing 3-D radiative transfer, and earlier 1-D radiative transfer studies suggested a significant contribution of the photospheric fields in the Stokes V profiles. In our recently published work, Mathur et al. 2023, using spectropolarimetric data of a pore simultaneously recorded in the Hα and Ca II 8542 Å lines we investigated the potential of Hα Stokes V profiles in determining chromospheric magnetic fields. Our findings suggested that the line core of the Hα line probes the chromospheric magnetic field. However, the previous study was limited to a small pore. In this study, using spectropolarimetric observations of an active region recorded simultaneously in the Hα and Ca II 8662 Å lines, we inferred the stratification of the chromospheric magnetic field. The sunspot exhibits multiple structures, viz., 4 umbras and a lightbridge and a region where Ca II 8662 Å line core is in emission. The Hα line core image also displays brightening in the emission region, a signature of localized heating, with the spectral profiles showing elevated line cores. Consistent with the Mathur et al. 2023, we found that the magnetic field inferred from the Hα line core is consistently smaller than that inferred from inversions of the Ca II 8662 Å line at log $\tau500 = -4.5$, however, in contrast with Mathur et al. 2023, uncorrelated. The field strength and morphology inferred in the heating region from the inversions at log $\tau500 = -4.5$ is comparable to that of at log $\tau500 = -1$. There is also a good agreement with the field strengths at log $\tau500 = -1$ with that inferred from WFA over Hα full spectral range, except in the heating region. In addition, the fields inferred in the heating region from the WFA over Hα line core and full spectral range are similar in strengths and morphology. In addition, we have also performed a theoretical study of synthesizing the polarization profiles of the Hα line in 3D. We show that the line of sight magnetic field retrived is sensitive to log $\tau500 = -5.7$, which is at higher heights compared to the Ca II IR line. Thus, we suggest that the line core of the Hα line always probes the chromospheric magnetic field at higher heights than that probes by the Ca II IR triplet. In case of heating events, the full Hα line becomes sensitive to the chromospheric magnetic field instead of just the line core. Consequently, the Hα line spectropolarimetry is a valuable diagnostic for studying the chromosphere, especially in regions with localized heating, where the Ca II IR triplet lines probe deeper layers of the solar atmosphere.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**High Resolution Observations of Solar Magnetic Fields / 111**

## Solar Magnetic Fields Before and During Eruptions

**Author:** Maria Kazachenko[1]

[1] *University of Colorado Boulder / National Solar Observatory*

Space weather is largely caused by the activity of our Sun. Invisible yet powerful magnetic fields, created within the Sun, determine when and where the next solar eruption will happen. In this talk, I will review how advances in solar observations and data-driven models allowed scientists to understand flare magnetism in a lot more detail than ever before. I will overview highlights of statistical analyses of flare magnetism using SDO/HMI datasets and will show examples of recent data-driven MHD models of eruptive X-class flares.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**High Resolution Observations of Solar Magnetic Fields / 12**

## Unveiling the Dynamics and Genesis of Small-scale Fine Structure Loops in the Lower Solar Atmosphere

**Author:** Annu Bura[1]

**Co-authors:** Tanmoy Samanta ; Alphonse Sterling [2]; Yajie Chen [3]; Jayant Joshi [1]; Vasyl Yurchyshyn [4]; Ronald L. Moore [2]

[1] *Indian Institute of Astrophysics*

[2] *NASA Marshall Space Flight Center, Huntsville, AL 35812, USA*

[3] *Max-Planck Institute for Solar System Research, 37077 Göttingen, Germany*

[4] *Big Bear Solar Observatory, New Jersey Institute of Technology, 40386 North Shore Lane, Big Bear City, CA 92314 9672, USA*

Recent high-resolution solar observations have unveiled the presence of small-scale loop-like structures in the lower solar atmosphere, often referred to as unresolved fine structures, low-lying loops, and miniature hot loops. These structures undergo rapid changes within minutes, and their formation mechanism has remained elusive. In this study, we conducted a comprehensive analysis of two small loops utilizing data from the Interface Region Imaging Spectrograph (IRIS), the Goode Solar Telescope (GST) at Big Bear Solar Observatory, and the Atmospheric Imaging Assembly (AIA) and the Helioseismic Magnetic Imager (HMI) onboard the Solar Dynamics Observatory (SDO), aiming to elucidate the underlying process behind their formation. The GST observations revealed that these loops, with lengths of ~3.5 Mm and heights of ~1 Mm, manifest as bright emission structures in Hα wing images, particularly prominent in the red wing. IRIS observations showcased these loops in 1330 Å slit-jaw images, with TR and chromospheric line spectra exhibiting significant enhancement and broadening above the loops, indicative of plasmoid-mediated reconnection during their formation. Additionally, we observed upward-erupting jets above these loops across various passbands. Furthermore, differential emission measurement analysis reveals an enhanced emission measure at the location of these loops, suggesting the presence of plasma exceeding 1 MK. Based on our observations, we propose that these loops and associated jets align with the minifilament eruption model. Our findings suggest a unified mechanism governing the formation of small-scale loops and jets akin to larger-scale X-ray jets.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**High Resolution Observations of Solar Magnetic Fields / 51**

## Magnetic Field and Plasma Diagnostics Using Infrared Spectral Lines: Forward Modeling

**Author:** Weihang Zhang[1]

[1] *School of Earth and Space Sciences, Peking University, Beijing 100781, People's Republic of China*

Regular measurements of the magnetic field in the solar corona are critically lacking, hindering investigations of key physical processes involved in coronal heating, solar wind generation, and explosive eruptions such as flares. Using a CME model of the Predictive Science Inc., we synthesized observations from the upcoming COronal Solar Magnetism Observatory (COSMO) Large Coronagraph (LC), which provides multiwavelength spectroscopic and polarimetric coronal measurements. We present maps of the magnetic field and plasma parameter distribution predicted based on the Zeeman effect and the known relationship between intensity ratio and plasma density, using the synthesized Stokes parameters of the Fe XIII 10747/10798 Å line pair. We examined the accuracy of magnetic field and density diagnostics during the pre-eruption and eruption stages, respectively, with different sets of instrumental parameters such as exposure time, spatial resolution and spectral resolution. Considering that the ionization and recombination processes do not have ample time to drive the ionic populations to their equilibrium state during CME propagation, especially at the CME front, and that the MHD model assumes the condition of equilibrium ionization (EI), we also performed the non-equilibrium ionization (NEI) calculation to obtain the ionic fractions by solving time-dependent ionization equations. This allows us to achieve a more physically realistic simulation of observation and diagnosis.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Solar Chromospheric Dynamics / 56**

## Solar Chromospheric Dynamics

**Author:** Bart De Pontieu[1]

[1] *Lockheed Martin Solar & Astrophysics Laboratory*

I will review recent progress in observations and numerical simulations of the dynamics of the solar chromosphere. During the last decade, novel high-resolution space-based and ground-based instrumentation has provided new views of the role of shocks, jets, waves, and magnetic reconnection in the dynamics and energetics of the chromosphere and the layers above. These observations have been accompanied by advances in state-of-the-art numerical modeling of the partially ionized chromosphere, including ion-neutral interactions and multi-fluid effects, providing novel insights into the physics that drive the dynamics of the solar chromosphere. I will review how the synergy between observations and modeling is key to make advances in our understanding of this critical layer in the Sun's atmosphere. I will also discuss the impact of chromospheric dynamics on the transition region and beyond.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Solar Chromospheric Dynamics / 154**

## Quiet-Sun Ellerman Bombs and Their Impact on the Upper Solar Atmosphere

**Authors:** Jayant Joshi[1]; Luc H. M. Rouppe van der Voort[2]; Aditi Bhatnagar[2]; Mats Ola Sand[2]

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Recent high-resolution observations have shown that quiet-Sun Ellerman bombs (QSEBs), thought to be driven by magnetic reconnection in the deep solar atmosphere, are more prevalent than previously known, with about 750,000 present across the quiet Sun at any given time. Analyzing H$\beta$ and H$\epsilon$ observations from the Swedish 1-m Solar Telescope, we detected ubiquitous QSEBs characterized by rapid variability and flame-like morphologies. While a subset of these events showed localized heating in the transition region, indicated by UV brightenings in Si IV observations from the Interface Region Imaging Spectrograph, only a small fraction of QSEBs contributed to such heating. Additionally, we found cases where QSEBs were linked to the formation of type II spicules, suggesting that magnetic reconnection could be a driving mechanism for spicules. However, these associations account for only a small portion of the total number of QSEBs and spicules, indicating that QSEBs likely play a limited role in global upper-atmosphere heating and spicule formation.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Solar Chromospheric Dynamics** / **75**

## Simulations of the Solar Spicule Forest - Dependence on Magnetic Field Strength and Coronal Temperature

**Author:** Piyali Chatterjee[1]

**Co-authors:** Kartav Kesri [2]; Robertus Erdelyi [3]; Sahel Dey [4]

[1] *IIA*

[2] *Sorbonne Université, paris*

[3] *University of Sheffield, UK*

[4] *University of Newcastle, Newcastle, Australia*

We perform radiation magneto-hydrodynamic simulations of the solar atmosphere, driven self consistently by sub-surface convection, thereby producing a forest of spicules commensurate with the observed properties (Dey et al, 2022, Nat Phys). By varying the strength of the imposed magnetic field (mimicking the dynamo generated large scale field of the Sun), we show that kinematic properties of the spicules (e.g., height, acceleration) depend on the properties of the magnetic environment. We also present the analysis to understand the physics behind such dependence on the magnetic field (Kesri et al, 2024, ApJ) and coronal temperature.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Solar Chromospheric Dynamics** / **2**

## Vortex Dynamics in Various Solar Magnetic Field Configurations

**Authors:** Arjun Kannan[1]; Nitin Yadav[1]

[1] *Indian Institute for Science Education and Research*

We investigate vortex dynamics in three magnetic regions, viz., Quiet Sun, Weak Plage, and Strong Plage, using realistic three- dimensional simulations from a comprehensive radiation-MHD code, MURaM. We find that the spatial extents and spatial distribution of vortices vary for different setups even though the photospheric turbulence responsible for generating vortices has similar profiles for all three regions. We investigate kinetic and magnetic swirling strength and find them consistent with the Alfvén wave propagation. Using a flux tube expansion model and linear magnetohydrodynamics (MHD) wave theory, we find that the deviation in kinetic swirling strength from the theoretically expected value is the highest for the Strong Plage, least for the Weak Plage, and intermediate for the Quiet Sun at chromospheric heights. It suggests that Weak Plage is the most favoured region for chromospheric swirls, though they are of smaller spatial extents than in Quiet Sun. We also conjecture that vortex interactions within a single flux tube in Strong Plage lead to an energy cascade from larger to smaller vortices that further result in much lower values of kinetic swirling strength than other regions. Fourier spectra of horizontal magnetic fields at 1 Mm height also show the steep cascade from large to smaller scales for Strong Plage. These findings indicate the potential of vortex-induced torsional Alfvén waves to travel higher in the atmosphere without damping for weaker magnetic regions such as the Quiet Sun, whereas vortices would result in dissipation and heating due to the vortex interactions in narrow flux tubes for the strongly magnetized regions such as Strong Plage.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Solar Chromospheric Dynamics / 54**

## Chromospheric and Coronal Heating in Active Regions: A Joint Perspective from Observations and Numerical Simulations

**Author:** Souvik Bose[1]

[1] *Lockheed Martin Solar & Astrophysics Lab/SETI Institute*

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

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Solar Chromospheric Dynamics / 9**

## Small-Scale Swirls in the Solar Atmosphere

**Author:** Jiajia Liu[1]

[1] *University of Science and Technology of China*

The solar atmosphere is populated by ubiquitous swirling structures, believed to play a crucial role in exciting various magnetohydrodynamic waves, pulses, as well as spicules. However, their small scale and short lifespan have posed significant challenges to automated detection, hindering comprehensive studies of their statistical and collective behavior. This talk summarizes recent advancements in the automated detection of solar atmospheric swirls, highlighting their role in exciting Alfvén pulses channeling energy to the upper solar atmosphere and exploring the spatial and temporal relationship between swirls and photospheric magnetic concentrations. Furthermore, our analysis reveals periodicities in swirl parameters ranging from 3 to 8 minutes, remarkably coinciding with the dominant period of the global p-mode spectrum. This suggests a potential link between global p-modes and the triggering of both photospheric and chromospheric swirls.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Waves in the Solar Atmosphere / 172**

## MHD Waves in the Solar Atmosphere: Recent Advances from High-resolution Observations

**Author:** Shahin Jafarzadeh[1]

[1] *Queen's University Belfast, UK/Max Planck Institute for Solar System Research, Germany*

A new era of high-resolution solar observations, driven by advancements in ground-based, balloon-borne, and space-based facilities (e.g., SST, DKIST, ALMA, SUNRISE, and Solar Orbiter, among others), has revolutionised our understanding of magnetohydrodynamic (MHD) waves in the solar atmosphere in recent years. These cutting-edge facilities provide unprecedented high-resolution observations, enabling the study of MHD wave phenomena in intricate detail, and revealing their diverse manifestations and crucial role in energy transport and heating. This review talk will explore the latest observational findings, highlighting the diverse nature of MHD waves. A key challenge in this field is disentangling the various MHD wave modes superimposed on each other within the same magnetic structures, a complex task due to their overlapping signatures in observational data. This talk will emphasise how the combination of advanced instrumentation, multi-wavelength observations, and sophisticated analysis techniques is crucial for the correct identification and interpretation of these different wave modes. We will discuss the implications of these observations for our understanding of chromospheric and coronal heating, providing new insights into the overall dynamics of the solar atmosphere.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Waves in the Solar Atmosphere / 152**

## Investigation of Umbral Wave Dynamics in the Chromospheric Resonator through Multi-Height Observations

**Author:** Kartika Sangal[1]

**Co-authors:** Abhishek Srivastava [1]; Ding Yuan [2]

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[2] *HIT, Shenzhen, China*

The Sun's dynamic atmosphere is rich in magnetohydrodynamic (MHD) waves, particularly in regions of intense magnetic activity like sunspots, where these waves are most pronounced and powerful. These waves in sunspots may play a crucial role in providing energy for plasma heating and contribute to the early stages of solar wind formation, and they can also serve as valuable diagnostic tools for studying sunspots. We investigate wave propagation patterns in the chromosphere of a large sunspot using high-resolution, multi-wavelength optical data from the Goode Solar Telescope (GST) at Big Bear Solar Observatory. Our analysis focuses on intensity oscillations at various points in the Hα line profile, as well as the Doppler velocity of the Hα line. By applying wavelet analysis, we identify the periodicity of these oscillations. Statistical analysis reveals a prevalent 3-minute oscillation across all Hα line measurements. To show the phase relationships between different Ha channels, we conduct phase difference analysis, estimating the phase difference between intensity in different bandpasses (such as Hα line core, Hα±0.2Å, Hα±0.4Å, Hα±0.6Å, Hα±0.8Å, and Hα±1Å) and Doppler velocity of Hα line. We found that the umbra waves exhibit a pattern of slow wave in forms of upward propagating wave, standing wave and a mixture of both. The observed phase relationships suggest that these umbral waves are confined within a non-ideal acoustic resonator.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Waves in the Solar Atmosphere / 22**

## Shock Wave Propagation in the Solar Atmosphere

**Author:** Ravi Chaurasiya[1]

**Co-author:** Raja Bayanna Ankala [2]

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[2] *Udaipur Solar Observatory/Physical Research Laboratory*

The chromosphere exhibits various acoustic waves that are generated in the photosphere or deeper layers due to convective motions. As these waves encounter the steep density gradient between the photosphere and the chromosphere, they transform into shock waves, often characterized by a sawtooth pattern in λ-time plots of chromospheric spectral lines, such as Hα and Ca II. In this study, we investigate the formation and propagation of these shock waves in the chromosphere, examining their implications in the higher solar atmosphere using observations from the Multi Application Solar Telescope (MAST), the Swedish 1-meter Solar Telescope (SST), the Interface Region Imaging Spectrograph (IRIS), and the Solar Dynamics Observatory (SDO). Our results show that these shock waves are predominantly observed in or near magnetic flux concentration regions and can propagate atleast up to the transition region. In this talk, I will discuss the identification of these shock waves, their propagation characteristics, and their potential implications in coronal dynamics.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Waves in the Solar Atmosphere / 65**

## Exploring Wave Coupling and Energy Dissipation in the Solar Atmosphere

**Author:** Elena Khomenko[1]

[1] *Instituto de Astrofisica de Canarias*

The solar atmosphere is now understood as a fully interconnected system, where dynamic events in one layer may be the cause or effect of those occurring in the layers above. Photospheric flows, through interactions with magnetic structures, facilitate energy transfer to the chromosphere and beyond, often in the form of waves. These processes depend on frequency, with evidence suggesting that the high-frequency part of the spectrum plays a key role in energizing the solar atmosphere. However, probing high frequencies presents challenges for both instrumentation and modeling. On the modeling side, new physical aspects, such as the interaction between neutrals and plasma, are being incorporated. In this talk, I will review recent advances in theoretical studies of high-frequency waves, shocks, and vorticity propagation through the solar atmosphere, with a focus on multi-fluid modeling of these dynamic phenomena.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Waves in the Solar Atmosphere / 167**

## The Properties of Propagating Compressive Waves in a Multithermal Coronal Loop

**Author:** Krishna Prasad Sayamanthula[1]

[1] *Aryabhatta Research Institute of Observational Sciences (ARIES)*

Observations often suggest that the solar coronal loops are multi-stranded and multi-thermal at the current instrument resolution. The goal of this work is to study the effect of this multi-strandedness on the propagation and damping of compressive slow magnetoacoustic waves. We employ an ideal 3D MHD numerical model to achieve this objective. The simulation results are forward modelled to generate synthetic images, which reveal that the observed propagation speeds are dependent on the temperature response of the filter used. Furthermore, we find that the slow waves are damped despite the absence of any dissipation mechanism in our model. This is because of the phase differences in their propagation across different strands. We call this the Multithermal Apparent Damping (MAD). Our results indicate that MAD is as effective as thermal conduction, especially, for the short period waves.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Instruments/Facilities and Science: New and Upcoming / 135**

## Scientific Achievements Based on Data from Solar Orbiter/EUI

**Author:** Hardi Peter[1]

[1] *Max Planck Institute for Solar System Research (MPS), Göttingen and Institut for Solar Physics (KIS), Freiburg, Germany*

The Extreme UV Imager (EUI) on-board Solar Orbiter consists of three telescopes, two high-resolution imagers providing information on the corona and the chromosphere, and an EUV full-disk imager that does not only allow to observe the whole solar disk but provides us with unprecedented information of the corona far above the limb in a coronagraphic mode. Hence, the scientific results through EUI range from new insights into the smallest coronal structures ever resolved in the EUV to the large-scale evolution, e.g. of CMEs, at much larger distances above the limb than what was possible before. In this short overview I will concentrate on dynamic features in the quiet Sun, coronal holes and active regions and how these might be understood with the help of (coronal) models. The comparison of models and observations gives new insight into the mass and energy supply at the base of the solar wind through small-scale jets or of the heating of small-scale brightening through magnetic reconnection processes, to name just two examples. However, there are also coronal features or properties that elude an explanation by current models. Many modern 3D models of coronal features are driven by the near-surface magneto-convection, which allows us to address the question how (small-scale) magnetic patches evolve and through this energize the upper atmosphere of the Sun. Together with observations of the photospheric magnetic field, on Solar Orbiter with the PHI instrument, this can put new constraints on our understanding of the structure, heating and dynamics of the Solar atmosphere.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Instruments/Facilities and Science: New and Upcoming / 211**

## Aditya-L1: An Observatory Class Mission for Solar and Heliospheric Observations

**Author:** Sankarasubramanian Kasiviswanathan[1]

[1] *U R Rao Satellite Centre, Indian Space Research Organization*

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 Lagrangian (L1) point. Aditya-L1 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 observe the photosphere, chromosphere, and coronal regions of the solar atmosphere. The in-situ payloads cover the electrons, protons, heavier ions along with vector magnetic field at L1. Aditya-L1 have certain unique capabilities which allow them to carryout observations which are complementary to the other space observatories. In this presentation, Aditya-L1 capabilities will be brought out.

**Contribution Type**:

Invited talk

**Theme**:

Connecting Solar Corona to Heliosphere

**Instruments/Facilities and Science: New and Upcoming / 146**

## The Fabry-Pérot Imaging Spectropolarimeters for the European Solar Telescope

**Author:** Luis Bellot Rubio[1]

**Co-authors:** Francisco Javier Bailén [2]; Javier Sánchez Barranquero [2]; Jose Carlos del Toro Iniesta [2]; Luca Giovannelli [3]; Francesco Berrilli [3]; Matteo Munari [4]; Ilaria Ermolli [5]; Göran Scharmer [6]; Mihalis Mathioudakis [7]

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The European Solar Telescope (EST) will be equipped with a comprehensive suite of state-of-the-art intruments designed to observe the solar atmosphere at high spatial and temporal resolution and high polarimetric sensitivity. Among them are three Tunable-Imaging Spectropolarimeters/Fixed-Band Imagers (TIS/FBIs) that will provide diffraction-limited measurements of photospheric and chromospheric magnetic fields over large fields of view. Each of these instruments consists of a narrow-band imaging spectropolarimeter and a broad-band imager. The spectropolarimeter is based on a dual Fabry-Pérot etalon system and a polarimeter incorporating two nematic liquid crystal variable retarders. The imager consists of two large-format, fast cameras to allow reconstruction of the narrow-band images by means of multi-frame blind deconvolution and phase diversity. The three TIS/FBIs will be operated in parallel for high cadence monitoring of the lower solar atmosphere in three or more spectral lines simultaneously, greatly improving the capabilities of existing filtergraphs that measure individual lines sequentially. In addition, the TIS/FBI instruments will provide unprecedented polarimetric sensitivity due to their optimized design and the large photon collecting area of the 4.2 m diameter primary mirror of EST. In this talk we will present the science goals of the EST TIS/FBI instruments. We will also review the current status of the TIS/FBIs, focusing on the main design drivers and the technological solutions adopted in this development phase. The TIS/FBIs are expected to go through a conceptual design review in 2025, together with the other instruments of the EST Instrument Suite.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Jets and Magnetic Reconnection / 113**

## Spicules and Jets in the solar Chromosphere: A Perspective of Recent Advances

**Author:** Tiago Pereira[1]

[1] *University of Oslo*

Jets permeate the upper solar atmosphere, from the powerful and extended coronal jets to the smaller but more abundant spicules. They appear as a natural bridge to transport mass and energy from the surface to the upper atmosphere, and possibly also drive the solar wind. I will review the progress made over the last few years, in particular about the elusive spicules. The age old question of their driver being magnetic reconnection or waves is very much still alive, and simulations of ever increasing realism provide important clues about different drivers. The coronal connection of spicules is now placed on much stronger footing thanks to detailed multi-instrument observations. Finally, thanks to modern techniques for big data we can now analyse complex spectral and imaging data and detect events on a vast scale, providing unique statistics that give us more insight into the atmospheric impact of these enigmatic phenomena.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Jets and Magnetic Reconnection / 42**

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

**Author:** Navdeep Panesar[1]

**Co-authors:** Alphonse Sterling [2]; Ronald L. Moore [3]; Sanjiv Tiwari [1]; Viggo Hansteen [1]; David Berghmans [4]; Mark Cheung [5]; Daniel Müller [6]; Frederic Auchere [7]; Andrei Zhukov [4]

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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 ~1018 Mx hr−1 (ii) majority of campfires are preceded by a cool-plasma structure, analogous to minifilaments in coronal jets. Our observations suggest that (a) the presence of magnetic flux ropes may be ubiquitous in the solar atmosphere and not limited to coronal jets and larger-scale eruptions that make CMEs, and (b) magnetic flux cancelation, most likely accompanied with magnetic reconnection in the lower solar atmosphere, is the fundamental process for the formation and

triggering of most solar campfires and coronal jets. Finally, we compare fine-scale jets with those found in a Bifrost MHD simulation.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Jets and Magnetic Reconnection / 168**

## Transition Region Brightening in a Moss Region and their Relation with Lower Atmospheric Dynamics

**Authors:** Tanmoy Samanta[1]; Bhinva Ram[2]; Yajie Chen[None]; Alphonse Sterling[None]; Jayant Joshi[1]; Vasyl Yurchyshyn[None]; Lakshmi Pradeep Chitta[None]; Vaibhav Pant[3]

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Small-scale Brightenings (SBs) are commonly observed in the transition region that separates the solar chromosphere from the corona. These brightenings, omnipresent in active region patches known as "moss"regions, could potentially contribute to the heating of active region plasma. In this study, we investigate the properties of SB events in a moss region and their associated chromospheric dynamics, which could provide insights into the underlying generation mechanisms of the SBs. We analyzed the data sets obtained by coordinated observations using the Interface Region Imaging Spectrograph and the Goode Solar Telescope at Big Bear Solar Observatory. We studied 131 SB events in our region of interest and found that 100 showed spatial and temporal matches with the dynamics observed in the chromospheric Hα images. Among these SBs, 98 of them were associated with spicules that are observed in Hα images. Furthermore, detailed analysis revealed that one intense SB event corresponded to an Ellerman Bomb (EB), while another SB event consisted of several recurring brightenings caused by a stream of falling plasma. We observed that Hα far wings often showed flashes of strong brightening caused by the falling plasma, creating an Hα spectral profile similar to an EB. However, 31 of the 131 investigated SB events showed no noticeable spatial and temporal matches with any apparent features in Hα images. Our analysis indicated that the predominant TR SB events in moss regions are associated with chromospheric phenomena primarily caused by spicules. Most of these spicules display properties akin to dynamic fibrils.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Jets and Magnetic Reconnection / 64**

## Small-scale Magnetic Flux Emergence Preceding a Chain of Energetic Solar Atmospheric Events

**Author:** Daniel Nóbrega-Siverio[1]

**Co-authors:** Iballa Cabello [2]; Souvik Bose [3]; Luc Rouppe van der Voort [4]; Reetika Joshi [5]; Clara Froment [6]; Vasco Henriques [5]

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Advancements in instrumentation have revealed a multitude of small-scale extreme-ultraviolet (EUV) events in the solar atmosphere and considerable effort is currently undergoing to unravel them. Our aim is to employ high-resolution and high-sensitivity magnetograms to gain a detailed understanding of the magnetic origin of such phenomena. We used coordinated observations from the Swedish 1-m Solar Telescope (SST), the Interface Region Imaging Spectrograph (IRIS), and the Solar Dynamics Observatory (SDO) to analyze an ephemeral magnetic flux emergence episode and the following chain of small-scale energetic events. These unique observations clearly link these phenomena together. The high-resolution (0.057"/pixel) magnetograms obtained with SST/CRISP allowed us to reliably measure the magnetic field at the photosphere and to detect the emerging dipole that caused the subsequent eruptive atmospheric events. Notably, this small-scale emergence episode remains indiscernible in the lower resolution SDO/HMI magnetograms (0.5"/pixel). We report the appearance of a dark bubble in Ca II K 3933 Å related to the emerging dipole, a sign of the canonical expanding magnetic dome predicted in flux emergence simulations. Evidence of reconnection is also found, first through an Ellerman bomb and later by the launch of a surge next to a UV burst. The UV burst exhibits a weak EUV counterpart in the coronal SDO/AIA channels. By calculating the differential emission measure (DEM), its plasma is shown to reach a temperature beyond 1 MK and to have densities between the upper chromosphere and transition region. Our study showcases the importance of high-resolution magnetograms in revealing the mechanisms that trigger phenomena such as EBs, UV bursts, and surges. This could hold implications for small-scale events similar to those recently reported in the EUV using Solar Orbiter. The finding of temperatures beyond 1 MK in the UV burst plasma strongly suggests that we are examining analogous features. Therefore, we recommend caution when drawing conclusions from full-disk magnetograms that lack the necessary resolution to reveal their true magnetic origin.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Jets and Magnetic Reconnection / 70**

## Campfires and Nanoflares: Signatures of Finest-scale Magnetic Reconnection in Quiet-Sun Corona Observed by Extreme Ultraviolet Imager aboard Solar Orbiter

**Author:** Nancy Narang[1]

**Co-authors:** Cis Verbeeck [1]; Marilena Mierla [1]; David Berghmans [1]

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The extreme-ultraviolet (EUV) brightenings identified by Solar Orbiter (SolO), commonly known as campfires, are the smallest detected, to date, transient brightenings or bursts observed in the non-active regions of the lower solar corona. Campfires have been proposed to be the finest-scale members of the nanoflare family. Our understanding about the role of campfires in coronal heating stands elusive due to the absence of extensive statistical studies. We perform statistical analysis of the

campfires by using the highest possible resolution observations obtained by the Extreme Ultraviolet Imager (EUI) onboard SolO. We use observations in the 17.4 nm passband of the High Resolution EUV Imager (HRIEUV) of EUI obtained during the closest perihelia of SolO in the years of 2022 and 2023. SolO being at a distance 0.29 AU from the Sun, these observations have exceptionally high pixel resolution of 105 km with a fast cadence of 3 seconds. We report the detection of the smallest campfires ever in the quiet-Sun. The detected campfires have sizes of 0.01 $Mm^2$ to 10 $Mm^2$. Their lifetimes vary between 3 s and 1000 s. Their distribution of size and lifetime show the power-law behaviour. We find a positive correlation between size, lifetime, and intensity of the campfires. We estimate that about 4000 campfires appear per second on the whole Sun. Considering the HRIEUV bandpass that is most sensitive to the 1 MK plasma, the increasingly high number of campfires at smaller spatial and temporal scales over the quiet-Sun regions supports the nanoflare model of solar coronal heating.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Jets and Magnetic Reconnection** / **48**

## Localized Heating and Dynamics in Coronal and Chromospheric Plasmas due to a Symbiosis of WAves and Reconnection (SWAR)

**Author:** Abhishekh Kumar Srivastava[1]

**Co-authors:** Eric R. Priest [2]; David I. Pontin [3]; Sripan Mondal [4]; Sudheer K. Mishra [5]; Ryun Kwon [6]; Akash Bairagi [4]; Ding Yuan [7]; K. Murawski [8]; Ayumi Asai [5]

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Dissipation of electric current due to magnetic reconnection provides a viable physical mechanism for the heating and dynamics of solar plasma. However, magnetohydrodynamic (MHD) waves may also contribute to its dynamics and heating. External wave-like perturbations may drive reconnection in the solar chromosphere and corona, but coalescing plasmoids in a reconnecting current sheet can also generate waves. We present and review our recent observations and numerical models which show how wave-like perturbations can help forming a localized current sheets in the solar atmosphere and thereby heat it. We also demonstrate how the energetics and dynamics of the large-scale corona can be influences by waves emitted from reconnecting current sheets. Furthermore, we discuss the broad implications of such a Symbiosis of WAves and Reconnection (SWAR) for chromospheric and coronal dynamics at disparate scales.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Flares and CMEs / 16**

## Origin and Energization of Solar Eruption Events

**Author:** Xin Cheng[1]

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Coronal mass ejections (CMEs) and flares are the most energetic explosive phenomena occurring in the solar atmosphere and subsequently propagating into the interplanetary space, probably affecting the safety of human high-tech activities in the outer space. To understand and predict the transient events, we need to elucidate some fundamental but still puzzled questions, one of which concerns their origin and energization. My talk, on the one hand, will address the new discovery of pre-eruptive configurations causing solar eruptions and deliver a new understanding of how the pre-eruptive configurations evolve from the slow-rise precursor to the violent eruption. The second part of my talk will focus on observations and simulations of magnetic reconnection within the current sheet between the erupting CME and flare loops with a preference on its turbulent nature, aiming to understand the basic energy release pattern of flare reconnection and disclose the physical origins of various flare fine structures.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Flares and CMEs / 131**

## Low Coronal Disturbances and Coronal Mass Ejections

**Authors:** Nariaki Nitta[1]; Meng Jin[1]; Marc DeRosa[1]

[1] *Lockheed Martin Advanced Technology Center*

Coronal mass ejections (CMEs) can create the most hazardous space weather effects. Therefore it is extremely important to advance our understanding of how they start in the corona, which would be useful for scientifically and accurately predicting them. This may be partially achieved by studying the signatures that CMEs may leave in the low corona as identified in Extreme Ultraviolet (EUV) images before they emerge in coronagraph images. Among them, the coronal dimming may be the most reliable indicator, which is often accompanied by a large-scale coronal propagating front (or an EUV wave as more commonly referred to). We present an ensemble study of EUV waves based on images from the Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics Observatory (there are many hundreds of events since 2010) and from the Extreme-Ultraviolet Imager (EUVI) on board the Solar-Terrestrial Relation Observatory (STEREO). The focus of this study is on the relation of EUV waves with CMEs, which are characterized in coronagraph data from SOHO and STEREO. We discuss the relative magnitude of EUV waves, dimmings and CMEs, which may vary in different phases of solar cycles. The involvement of EUV waves in CMEs may depend on the height at which the CME starts to accelerate and on the large-scale magnetic field surrounding the eruption.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Flares and CMEs / 27**

## Solar Jets: Insights from High-Resolution Observations and Numerical Simulations

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Solar jets are highly collimated plasma flows accelerated along magnetic field lines due to magnetic reconnection, often originating from anemone-shaped arcades. These impulsive jets, particularly broader ones, frequently exhibit untwisting motions. In this study, we analyze a solar jet associated with a circular flare ribbon using high-resolution data from the Swedish 1-meter Solar Telescope (SST), in coordination with IRIS and SDO. We compared the observed jet features with a 3D numerical simulation of reconnection-driven jets performed with the ARMS code. Three significant observational signatures were identified: (1) the formation of a hook along the circular ribbon, (2) the jet's widening through displacement of its kinked edge toward the reconnection site, and (3) the fallback of some jet plasma toward an offset footpoint. These features, which align with the 3D asymmetric reconnection geometry of swirled-anemone loops, suggest that such characteristics are common in impulsive solar jets. The generic nature of the simulation supports the hypothesis that these features are typical in similar jet events.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Flares and CMEs / 132**

## Onset, Eruption, and Thermal Properties of Coronal Jets via MHD Simulation

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Jets are one of the eruptions which impact the solar atmosphere significantly along with other transients like solar flares and coronal mass ejections (CMEs). Magnetic reconnection is believed to be one of the reasons behind these transients. The onset and factors contributing to the morphology and thermal structures are still complex to comprehend. In order to understand them, we have studied a blowout jet using observations from AIA/SDO and employing the non-force-free-field (NFFF) extrapolation model. We then simulate the magnetic field evolution via EULAG-MHD model. We have compared the simulated dynamics to the observed features as well as the emission profile obtained from the differential emission measurement (DEM) analysis. We have utilized the HMI/SDO magnetogram as an input to the NFFF model. The simulation is initialized with the non-zero Lorentz force inherent to the extrapolated magnetic field with a line-tied bottom boundary condition. Interesting are the initial magnetic configurations, where we find a bald patch and a flux rope near the jetting region. The reconnections near the bald patch may trigger the onset of the jet. The untwisting of the flux rope channels the plasma material to escape. Further to supplement the study of the onset process and thermal changes, we have analyzed different parts of the jet in detail, where we find profiles of simulated current density, and energy densities (magnetic+kinetic), in congruent with the measured emissions. We have shown the role of Lorentz force in driving the jet and compared its effect over the plasma flow during the whole simulation period. In future, to understand the role of boundary in initiating such transients and the simultaneous thermal properties, we plan to carry out a complete magnetohydrodynamics study with a data-driven boundary approach aided with spectroscopic data with high-spatial and temporal cadence from instruments like IRIS, and SP/Hinode, SST.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Flares and CMEs / 66**

## Small and Large Scale Episodic Events in Smaller and Larger Scale Numerical Simulations Spanning the Convection Zone to the Corona

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Field stored just below or rising to the photosphere will break through the surface and enter the upper atmosphere once the gradient of the sub-photospheric field strength becomes sufficiently large. Driven by convective motions and the expansion of field in the chromosphere's low-β plasma, opposite polarity flux bundles will reconnect. Some of this emerging flux is likely due to a local dynamo, but also the emergence of larger scale magnetic structures from deeper layers is important, even in the quiet Sun. A significant proportion of this field likely reaches the chromosphere and leaves imprints on chromospheric and coronal dynamics and energetics. Using a number of numerical models, (24x24x17) and (72x72x60) Mm, the high resolution spectra and slit jaw images from IRIS, imaging data from SDO/AIA and Solar Orbiter's EUI/HRI, as well as ground based Ca II 854.2 and Ca II spectrograms, are synthesised and compared to observed data. We also synthesise observations from the upcoming MUSE and EUVST observatories in the context of episodic heating. The magnetic structure and dynamics of small scale events such as jets and dots, more energetic Ellerman bombs and a small C-class flare are discussed and analysed.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Shocks and Particle Acceleration and Transport in IP Medium / 77**

## Energetic Particle Acceleration and Transport: Interplanetary Coronal Mass Ejections and Shocks

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Solar Energetic Particles (SEPs) from suprathermal (few keV) up to relativistic (~few GeV) energies are accelerated at the Sun in association with solar flares and coronal mass ejection (CME)-driven shocks. In this review, we present important recent results of the study of Interplanetary CMEs and shocks in relation to energetic particle acceleration and transport, taking advantage of multi-point, multi-instrument observations available by a fleet of spacecraft in the heliosphere. The Solar Orbiter (SolO) and Parker Solar Probe (PSP) pioneering missions have been providing unprecedented measurements of energetic particles in the near-Sun environment. In particular, we present the properties of an Interplanetary CME-driven shock and its evolution with heliocentric distance, observed on September 5, 2022 by PSP at an unprecedentedly low heliocentric distance of 0.07 au, then reaching SolO which was radially well-aligned at 0.7 au. An overview of the characteristics of the energetic particle population at each spacecraft is also discussed in relation to magnetic and plasma structures and expectations from acceleration processes. Furthermore, we present the detailed analysis of the widespread SEP event on January 20, 2022, during which the measurements of the EPD experiment onboard SolO made the unusual observation that particles first arrived from the anti-Sun direction. i.e. streaming towards the Sun. The STEREO-A and MAVEN spacecraft also observed the event suggesting that particles spread over at least 160° in the heliosphere. The aim of the study is to show how SEPs are accelerated and transported to SolO and near-Earth spacecraft as well as the examination of the influence of a magnetic cloud present in the heliosphere at the time of the event onset on the propagation of the energetic particles. An overview of interesting observations made by multiple spacecraft in the heliosphere (e.g. PSP, BepiColombo, SolO, STEREO-A) during the widespread SEP event on February 15-16, 2022, one of the most intense SEP events observed so far in solar cycle 25 is also presented. Results from analyses of the corresponding Energetic Storm Particle (ESP) event (~0.05 –2 MeV ions) as observed by the PSP ISʘIS/EPI-Lo instrument on February 16, 2022 at 0.35 au from the Sun is also summarized and other unique observations of multi-spacecraft events.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Shocks and Particle Acceleration and Transport in IP Medium / 81**

## Connecting Energetic Electrons at the Sun and in the Heliosphere through X-ray and Radio Diagnostics

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One of the main objective of the Solar Orbiter mission is concerned with the production of energetic particles in the heliosphere, in particular with understanding how particles are released from their acceleration sources and distributed in space and time in the heliosphere. For energetic electrons, part of this question can be addressed by combining X-ray and radio observations. Indeed, while downward moving electrons produce X-rays in the chromosphere, upward moving electrons may generate coherent radio emissions when propagating through the corona, such as radio type III bursts. The launch of the Solar Orbiter in early 2020 marked a significant milestone, as it is equipped with the capability to simultaneously capture both types of emission. In this contribution, we shall present the first tresults derived from the comparison of X-ray flares observed by STIX in the 4-150 keV range on Solar Orbiter with radio type III bursts detected by RPW below 10 MHz on Solar Orbiter. The study focuses on 15 Interplanetary Type III radio bursts (IT3s) associated with HXR emission peaks, observed during the second commissioning phase of the STIX from November 17 to 21, 2020. Changes in the X-ray source morphology are found coinciding with the occurrence of IT3 emissions, and combined observations with the EUI instrument suggest a delayed access to existent open magnetic field lines within the active region. In the second part of the presentation we will investigate the link between the speed of the electron beams traveling outward (deduced from radio) and the energy density of the electrons traveling downward (deduced from X-rays). Indeed, assuming both electron populations share properties from a common acceleration region, some correlations should be found between these two quantities. Higher velocities in type III bursts are thus expected to be associated with a harder electron spectrum and larger beam density, as inferred from X-ray observations, indicating a larger amount of high-energy electrons interacting with Langmuir Waves. We shall present results derived from the comparison of more than 20 flares observed by STIX and associated in time with radio type III bursts detected by RPW below 10 MHz.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Shocks and Particle Acceleration and Transport in IP Medium / 68**

## Suprathermal Ion Observations Associated with the Heliospheric Current Sheet Crossings by Parker Solar Probe

**Author:** Mihir Desai[1]

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We report observations of <500 keV/nucleon suprathermal (ST) H, He, O, and Fe ions in association with several crossings of the heliospheric current sheet that occurred near perhelia during PSP encounters 7-18. In particular, we compare and contrast the ST ion time-intensity profiles, velocity dispersion, pitch-angle distributions, spectral forms, and maximum energies during the three HCS crossings. We find that these unique ST observations are remarkably different in each case, with those during E07 posing the most serious challenges for existing models of ST ion production in the inner heliosphere. In contrast, the ISOIS observations during the remaining HCS crossings appear to be consistent with a scenario in which ST ions escape out of the reconnection exhausts into the separatrix layers after getting accelerated up to ~50-100 keV/nucleon by HCS-associated magnetic reconnection-driven processes. We discuss these new observations in terms of local versus remote acceleration sources as well as in terms of expectations of existing ST ion production and propagation, including reconnection-driven and diffusive acceleration in the inner heliosphere.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Shocks and Particle Acceleration and Transport in IP Medium / 120**

## Time Evolution of Thermal and Non-Thermal Energies in Solar Flares

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We analyze two solar flares—an X-class flare from October 28th, 2021, and an M-class flare from November 29th, 2020—to investigate the dynamic changes in thermal energy during their evolution. Our study uses data from several sources, including the Atmospheric Imaging Assembly (AIA) on the Solar Dynamics Observatory (SDO), the X-ray Telescope (XRT) on Hinode, and the Spectrometer/Telescope for Imaging X-rays (STIX). By utilizing these datasets, we estimate the total thermal energy for both flares by calculating the Differential Emission Measure (DEM) to track changes in thermal energy over time. For the X-class flare, we further incorporate spectra from STIX on the Solar Orbiter to estimate the non-thermal energy component. Additionally, we examine how evolving volume estimates of the flare structure affect our thermal energy calculations, highlighting the value of high-resolution imaging from multiple wavelengths and perspectives. We propose a method to accurately determine the Line of Sight (LOS) throughout the Field of View (FOV) by using near-simultaneous observations from different vantage points, leading to a more precise volume estimate of the flare arcade. For the M-class event, we also analyze the thermal structure of the fan compared to the overall thermal evolution of the flare, finding that the thermal energy decay in the fan is slower than in the flare loops, which suggests a unique heating mechanism within the fan structure.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Instruments/Facilities and Science: New and Upcoming / 121**

## National Large Solar Telescope (NLST) of India

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National Large Solar Telescope, a state-of-the-art 2-meter telescope, is designed to revolutionize solar atmospheric research. Its primary goal is to conduct high-resolution observations, both spatially and spectrally, of the Sun's outer layers. To ensure optimal performance, a rigorous site characterization program was initiated in 2007. This led to the selection of two prime locations in the Himalayas, situated above 4,000 meters. These sites offer exceptionally low water vapor content and are shielded from monsoon disruptions, providing ideal conditions for solar observations. The NLST's innovative optical design employs an on-axis Gregorian configuration with a minimal number of optical elements. This reduces the number of reflections, enhancing throughput and minimizing polarization effects. Furthermore, the telescope incorporates high-order adaptive optics to achieve near-diffraction-limited imaging, compensating for atmospheric turbulence. To mitigate atmospheric and thermal disturbances, the NLST will operate with a fully open dome, maximizing its capabilities. The telescope will be mounted on a 20-meter tall tower, providing additional stability and isolation from ground-based disturbances. The NLST's post-focus instrumentation suite includes a range of advanced devices, such as broad-band and tunable Fabry-Perot narrow-band imagers, and a high-resolution spectropolarimeter. Led by the Indian Institute of Astrophysics and supported by domestic and international collaborators, the National Large Solar Telescope (NLST) project will significantly advance our understanding of the Sun. Strategically located in Asia, the NLST will complement existing solar observatories in the United States and Europe, providing valuable new insights into our nearest star.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Instruments/Facilities and Science: New and Upcoming / 71**

## Performance of the Upgraded GRIS@GREGOR Spectrograph

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**Co-authors:** Antonio Matta-Gómez [1]; Claudia Ruiz de Galarreta [1]; Francisco González Pérez [1]; Jonai Bienes [1]; Jorge Quintero Nehrkorn [1]; Juan Carlos Trelles Arjona [1]; Manuel Collados [1]; Mary Barreto Cabrera [1]; Patricia Gómez González [1]; Silvia Regalado Olivares [1]

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Since its installation in 2012, the Gregor Infrared Spectrograph (GRIS) has been operating with a single detector that could be tuned to any wavelength in the bands 1.0-1.3 microns or 1.5-1.8 microns in spectroscopic or spectropolarimetric mode, or in the band 2.0-2.3 microns in spectroscopic mode. Few years ago, a removable integral field unit (IFU) was added to the system to make the long-slit and IFU modes available to the observers. More recently, two additional spectroscopic channels have been added to make feasible simultaneous spectroscopic observations in three spectral intervals. The second channel has already been implemented, tested and commissioned during 2024, with simultaneous observations obtained in two wavelengths (mainly centered in Ca II 854 nm and He 1083 nm, but not exclusively). In this talk, the performance of the dual channel configuration will be described, presenting actual data obtained during the commissioning phase.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Instruments/Facilities and Science: New and Upcoming / 43**

## Solar Orbiter/EUI Observations and a Bifrost MHD Simulaton of Fine-scale Dot-like Heating Events in Emerging Flux Regions

**Author:** Sanjiv Tiwari[1]

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Solar coronal EUV/X-ray bright points (CBPs) are believed to be major contributors to quiet solar coronal heating. Solar Orbiter's EUI/\hri\ observations of an emerging flux region (a typical CBP) in 174 \AA, emitted by the coronal plasma at $\sim$1 MK, reveals the presence of numerous tiny bright dots. These dots are roundish with a diameter of $675\pm300$ km, a lifetime of $50\pm35$ seconds, and an intensity enhancement of 30\% $\pm$10\% from their immediate surroundings. About half of the dots remain isolated during their evolution and move randomly and slowly ($<$10 \kms). The other half show extensions, appearing as a small loop or surge/jet, with intensity propagations below 30\,\kms. Many of the bigger and brighter \hri\ dots are discernible in SDO/AIA 171 \AA\ channel, have significant EM in the temperature range of 1–2 MK, and are often located at polarity inversion lines observed in HMI LOS magnetograms. The Bifrost MHD simulations of an emerging flux region do show dots in synthetic \fe\ images, although dots in simulations are not as pervasive as in observations. The dots in simulations show distinct Doppler signatures – blueshifts and redshifts coexist, or a redshift of the order of 10 \kms\ is followed by a blueshift of similar or higher magnitude. The synthetic images of \oxy\ and \siiv\ lines, which form in the transition region, also show the dots that are observed in \fe\ images, often expanded in size, or extended as a loop, and always with stronger Doppler velocities (up to 100 \kms) than that in \fe\ lines. Our results, together with the field geometry of dots in the simulations, suggest that most dots in emerging flux regions form in the lower solar atmosphere (at $\approx$1 Mm) by magnetic reconnection between emerging and pre-existing/emerged magnetic field. The dots are smaller in \fe\ images (than in \oxy, and \siiv\ lines) most likely because only the hottest counterpart of the magnetic reconnection events is visible in the hotter emission. Some of these dot-like heating events might be manifestations of magneto-acoustic shocks (driven from the lower atmosphere) through the line formation region of \fe\ emission. Because these fine-scale heating events carry magnetic energy of the order of $10^{26}$ erg, they contribute significantly to a CBP's heating, and mark where exactly the heating happens within CBPs.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Instruments/Facilities and Science: New and Upcoming / 184**

## The Gauribidanur Radio Observatory: Current Status and Future Plans

**Authors:** Gireesh G. V. S,[1]; Indrajit Barve[1]; Kathiravan Chidambaram[1]; Ramesh R[1]

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The Gauribidanur Radio Observatory (GRO) is one of a few solar radio observatories functioning for the past few decades. It has four major facilities, viz., the Gauribidanur RAdioheliograPH (GRAPH), the Gauribidanur LOw-frequency Solar Spectrograph (GLOSS), the Gauribidanur Radio Interferometric Polarimeter (GRIP), and the Gauribidanur RAdio Spectro-polarimeter (GRASP). The GRAPH simultaneously images the Sun at two spot frequencies, viz., 53 and 80 MHz, during its local meridian transit; the spatial resolution at 80 MHz is $4' \times 7'$(RA×Dec.), and the image-dynamic range is ≈22 dB. The GLOSS observes the Sun as a point source and produces the solar radio dynamic spectrum in 50-500 MHz over 2:30-10:30 UT. The frequency resolution and the dynamic range of a dynamic spectrum are ≈500 kHz and 40 dB, respectively. The GRIP observes the polarized radio emission from the Sun in 30-130 MHz over 2:30-10:30 UT. The dynamic range of the total and circularly polarized flux profiles is ≈30 dB and has a spectral resolution of about 1.5 MHz. The GRASP observes the Sun as a point source and produces the dynamic spectra of the total and circularly polarized flux in the 15-35 MHz during 2:30-10:30 UT. The spectra have a dynamic range of ≈30 dB and a spectral resolution of 2 kHz. Apart from the solar facilities, we have recently established a new small array to observe the non-solar radio transients, the Pulsars, FRBs, etc. The talk will briefly cover the observing facilities, highlight the results, the ongoing facility upgrade, and the plans for the future.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Instruments/Facilities and Science: New and Upcoming / 93**

## Investigations on Suprathermal Ions Observed by ASPEX/STEPS on board Aditya-L1 During its Earth-Bound Orbits

**Author:** Bijoy Dalal[1]

**Co-authors:** Dibyendu Chakrabarty [1]; Santosh V. Vadawale [1]; Shiv Kumar Goyal [1]; Jacob Sebastian [1]; Neeraj Kumar Tiwari [1]; Arpit R. Patel [1]; M. Shanmugam [1]; Piyush Sharma [1]; Aveek Sarkar [1]; Aaditya Sarda [1]; Tinkal Ladiya [1]; Abhishek J. Sharma [1]; Nishant Singh [1]; Sushil Kumar [1]; Deepak Kumar Painkra [1]; Prashant Kumar [1]; Manan S. Shah [1]; Pranav R. Adhyaru [1]; Hiteshkumar L. Adalja [1]; Swaroop B. Banerjee [1]; K. P. Subramanian [1]; Bhas Bapat [2]; Madhavji B. Dadhania [1]; Abhishek Kumar [1]; P. Janardhan [1]; Anil Bharadwaj [1]

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Suprathermal particles (with energies in the range from 10s of keV to 1-2 MeV) are thought to be the seed populations for solar energetic particles accelerated by shocks associated with interplanetary coronal mass ejections (ICMEs). Origins, energizations, and modulations of suprathermal particles in the interplanetary (IP) medium have been widely debated in the contemporary space era, thanks to numerous particle detectors on board various spacecraft. Recently launched India's Aditya-L1 includes the SupraThermal Energetic Particle Spectrometer (STEPS), a subsystem of the Aditya Solar wind Particle EXperiment (ASPEX) suite, which can measure suprathermal and high energetic ions from multiple directions. After the launch on 02 September 2023, the Aditya-L1 spacecraft completed several highly elliptical earth-bound orbits before it started cruising towards the halo orbit around the L1 point on 19 September 2023. Two detector units, Parker Spiral (PS) and North Pointed (NP), were the first to start measurements from 10 September 2023 onwards whenever the altitude of the spacecraft crossed ~ 52000 km. During 10 –18 September 2023, STEPS units sampled suprathermal ions from the Earth's magnetosphere, magnetosheath, and IP medium. Coincidentally, three ICMEs hit the Earth during the above interval. The results from this interesting observation will be discussed in this presentation.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**The Sun as a Prototype of Stellar Variability / 11**

## The Sun as a Proxy for Stellar Variability

**Author:** Nina-Elisabeth Nemec[1]

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Simultaneous monitoring of stellar brightness and chromospheric activity shows that the brightness variations of stars with near-solar level of chromospheric activity appear to be faculae dominated over their activity cycle, whereas they are spot dominated at higher chromospheric activity. Additionally, the unprecedented precision of broadband stellar photometry achieved with the planet-hunting missions CoRoT and *Kepler* initiated a new era in examining the magnetically-driven brightness variations of stars. Such brightness variations, on both the rotational timescale, but also on the timescales of decades, are well studied and understood for the Sun. The plethora of data available now allows to accurately compare solar and stellar brightness variations. An intriguing question is whether the observed trends in the stellar photometric variability can be explained by utilising the solar paradigm, in particular the physical concepts of brightness variations learnt from the Sun. In this talk, I will present recent efforts of modelling stellar variability by following the path of extending the solar paradigm (e.g. the physical mechanisms causing solar variability) to stars with higher activity and rotation rates.

**Contribution Type**:

**Theme**:

Solar - Stellar Connections

**The Sun as a Prototype of Stellar Variability / 136**

## The Role of Meridional Flow in the Generation of Solar/Stellar Magnetic Fields and Cycles

**Authors:** Bidya Binay Karak[1]; Vindya Vashishth[2]

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Meridional flow is crucial in generating the solar poloidal magnetic field by facilitating the poleward transport of the field from the decayed Bipolar Magnetic Regions (BMRs). As the meridional circulation changes with the stellar rotation rate, the properties of stellar magnetic cycles are expected to be influenced by this flow. In this study, we explore the role of meridional flow in generating magnetic fields in Sun and sun-like stars using STABLE [Surface flux Transport And Babcock–LEighton] dynamo model. We find that a moderate meridional flow increases the polar field by efficiently driving the trailing polarity flux toward the pole. In contrast, a strong flow tends to transport both polarities of BMRs poleward, potentially reducing the polar field. Our findings agree with what one can expect from the surface flux transport model. Similarly, the toroidal field initially increases with moderate

flow speeds and then decreases after a certain value. This trend is due to the competitive effects of shearing and diffusion. Furthermore, our study highlights the impact of meridional flow on the cycle strength and duration in stellar cycles. By including the meridional flow from a mean-field hydrodynamics model in STABLE, we show that the magnetic field strength initially increases with the stellar rotation rate and then declines in rapidly rotating stars, explaining the observed variation of the stellar magnetic field with rotation rate.

**Contribution Type**:

**Theme**:

Solar - Stellar Connections

**The Sun as a Prototype of Stellar Variability / 137**

## Dynamics of Photospheric Magnetic Flux Distribution and Variations in Solar RVs: A Study Using HARPS-N Solar and SDO Observations

**Authors:** Anisha Sen[1]; S.P.K. Rajaguru[1]

[1] *Indian Institute of Astrophysics*

The distribution and evolution of photospheric magnetic fields in sunspots, plages, and network, and variations in their relative flux content, play key roles in radial velocity (RV) fluctuations observed in Sun-as-a-star spectra. Differentiating and disentangling such magnetic contributions to RVs help in building models to account for stellar activity signals in high-precision RV exoplanet searches. In this work, we employ high resolution images of the solar magnetic field and continuum intensities from SDO/HMI to understand the activity contributions to RVs from HARPS-N solar observations. Using well-observed physical relationships between strengths and fluxes of photospheric magnetic fields, we show that the strong fields (spots, plages, and network) and the weak inter-network fields leave distinguishing features in their contributions to the RV variability. We also find that the fill factors and average unsigned magnetic fluxes of different features correlate differently with the RVs and hence warrant care in employing either of them as a proxy for RV variations. In addition, we examine disk-averaged UV intensities at 1600 and 1700 Å wavelength bands imaged by SDO/AIA and their performances as proxies for variations in different magnetic features. We find that the UV intensities provide a better measure of contributions of plage fields to RVs than the Ca II H-K emission indices, especially during high activity levels when the latter tend to saturate.

**Contribution Type**:

**Theme**:

Solar - Stellar Connections

**The Sun as a Prototype of Stellar Variability / 8**

## In Situ Observation of Mass Ejections Caused by Magnetic Reconnections in the Ionosphere of Mars

**Author:** Yudong Ye[1]

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Explosive mass ejections triggered by magnetic activities are common on our Sun and other stars in the Universe. However, there is a lack of evidence for such explosive phenomena in magnetized or partially magnetized planets with atmospheres. Here we present direct evidence for explosive mass ejections from the Martian ionosphere, resulting from magnetic reconnections between strong crustal field regions with open magnetic fields. A plasma density cavity with signatures of magnetic reconnection that is directly evident for an eruptive mass ejection caught in the act indicates that a considerable amount of ionospheric mass has been rapidly ejected into space. Although Martian mass loss associated with magnetic reconnection has been reported previously, our results demonstrate that explosive mass ejections can occur even on partially magnetized planets without global magnetic fields. In this scenario, we suggest that strong localized magnetic fields extending above the exobase are needed. In situ observations reveal explosive mass ejections due to magnetic reconnection in the ionosphere of Mars, with a density cavity as direct evidence. Reconnection between strong open crustal fields can rapidly eject a large amount of mass from Mars.

**Contribution Type**:

**Theme**:

Solar - Stellar Connections

**The Sun as a Prototype of Stellar Variability / 200**

## The Sun as a Prototype of Stellar Variability

**Author:** Sami Solanki[1]

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The Sun is variable on timescales ranging from minutes to millenia. Its variability has been shown to be dominantly caused dominantly by the solar magnetic field, with contributions by granular convection and oscillations. Until a decade ago, the known variable stars were distinctly different from the Sun. Their variability was caused by large-scale pulsations, binarity, or, for the most highly active cool stars, by magnetic features. Only stars showing large amplitude brightness fluctuations were detected as variable. Moderately active Sun-like stars were considered to be constant as their variability was hidden in the noise of most stellar observations. Only thanks to the advent of space missions doing highly sensitive photometry (mainly aimed at detecting exoplanets via planetary transits) have other sun-like stars been found to be variable in ways similar to the Sun. Whereas the causes of solar variability have been identified and are reasonably well understood, for stars, we are still at the start of the journey leading to a good understanding. Here the Sun serves as a prototype and guide, helping to interpret and understand the observed variability of cool stars. Stellar observations in turn also give new insights into the possible behavior of the Sun, particularly on timescales that are longer than those for which we have good solar data.

**Contribution Type**:

Invited talk

**Theme**:

Solar - Stellar Connections

**Asteroseismology / 204**

## Solar-like Stars: Seismology and Stellar Magnetic Activity

Helio- and astero-seismology allow us to extract information on the structure and dynamics of the Sun and stars from the surface to the deeper layers.
Magnetic activity affects the properties of the acoustic modes: at maximum magnetic activity the frequencies of the modes increase while the amplitudes of the modes decrease. This was first observed for the Sun and was applied to many more solar-like stars observed by space missions such as CoRoT and Kepler. By combining these observables with the internal structure from asteroseismic models, we can obtain a broader picture of how magnetic activity operates in stars. Thanks to the larger sample stars observed by space missions, we can study how magnetic activity evolves with different stellar parameters and with time. This also means that p-mode amplitudes are suppressed for very active stars preventing us from detecting them. For those more active stars, surface magnetism can be measured with photometric data, increasing the sample to several tens of thousands of stars. With this enlarged sample we can study the evolution of magnetic activity with age and Rossby number.

**Asteroseismology / 139**

## Latitudinal Differential Rotation in Red Giants

**Authors:** Meenakshi Gaira[1]; Shravan Hanasoge[1]

[1] *Tata Institute of Fundamental Research*

Asteroseismology is the study of oscillations in stars, which helps in understanding their interior structure and dynamics. In the last two decades, NASA's Kepler and TESS space missions have revolutionized the field of asteroseismology by providing vast datasets of photometric time series for hundreds of thousands of stars. In this talk, I will be discussing the application of asteroseismology in studying the differential rotation in stars. The envelope of a star doesn't rotate with a constant rate along the latitude. For eg., the differential rotation between the equator and poles of the Sun is 30% of the average rotation rate. Measurements of differential rotation in stars could provide insights into the mechanisms of angular momentum transport and magnetic activity in stars. Theoretical simulations have predicted the possibility of anti-solar rotation (i.e. the poles rotating faster than the equator) in stars with slower rotation rates. However, so far, there have been only a couple of reliable observations of anti-solar rotation. I will present our results of detecting significant differential rotation in several red giants, with nearly half of them showing anti-solar rotation, and the others showing solar-like rotation. We use a machine learning algorithm to infer the key seismic parameters of a star, and then we use these inferences to set the prior probability distributions for MCMC (Markov chain Monte Carlo), a standard method for fitting the oscillation spectra of stars.

**Contribution Type**:

**Theme**:

Solar - Stellar Connections

**Asteroseismology / 118**

## Anomalous Rotators and New Evolutionary Pathways in Red Giants

**Author:** Shravan Hanasoge[1]

[1] *Tata Institute of Fundamental Research*

Stellar pulsations offer valuable insights into the internal structure and rotation profiles of stars. The availability of high-quality observations from numerous space-based instruments makes it possible to pursue ensemble analyses on an unprecedented scale. To this end, we have used machine learning to accelerate these studies by several orders in magnitude. I will describe how deep learning models applied to Kepler observations have revealed new physical insights into angular momentum transport, magnetism and structure evolution in the red-giant phase.

**Contribution Type**:

**Theme**:

Solar - Stellar Connections

**Solar/Stellar Dynamo and Activity / 112**

## Progress in Modelling Solar and Stellar Activity Cycles

**Author:** Alfio Maurizio Bonanno[1]

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Understanding the solar activity cycle within the broader framework of stellar magnetic field dynamics is pivotal for comprehending the solar and stellar dynamos. A significant challenge in this pursuit lies in the presence of multiple branches in the relationship between stellar rotation and activity cycle period among main sequence stars. In this presentation, I will elucidate recent advancements addressing this challenge, drawing connections with mean-field dynamo theory and Direct Numerical Simulations (DNS). Additionally, I will explore the implications of these findings for the modelling of solar and stellar cycles.

**Contribution Type**:

**Theme**:

Solar - Stellar Connections

**Solar/Stellar Dynamo and Activity / 36**

## Dynamo Modelling for Cycle Variability and Occurrence of Grand Minima in Sun-Like Stars at Different Rotation Rates

**Author:** Bidya Binay Karak[1]

**Co-author:** Vindya Vashishth [1]

[1] *IIT (BHU) Varanasi*

Like the solar cycle, stellar activity cycles are also irregular. Observations reveal that rapidly rotating (young) Sun-like stars exhibit a high level of activity with no Maunder-like grand minima and rarely display smooth regular activity cycles. On the other hand, slowly rotating old stars like the Sun have low activity levels and smooth cycles with occasional grand minima. We, for the first time, model these observational trends using flux transport dynamo models. We build kinematic dynamo models of one solar mass star with different rotation rates. Differential rotation and meridional circulation are specified by computing them using equivalent mean-field hydrodynamic models of these stars. We include stochastic fluctuations in the Babcock-Leighton source of the poloidal field to capture the inherent fluctuations in the stellar convection. Based on extensive simulations, we find that rapidly rotating stars produce highly irregular cycles with strong magnetic fields and rarely produce Maunder-like grand minima, whereas the slowly-rotating stars (with a rotation period of 10 days and longer) produce smooth cycles of weaker strength, long-term modulation in the amplitude, and occasional extended grand minima. The average duration and the frequency of grand minima increase with decreasing rotation rate. These results can be understood as the tendency of less supercritical dynamo in slower rotating stars to be more prone to produce extended grand minima. We further conclude that even in rapidly rotating stars for which the star spots appear at high latitudes, the Babcock-Leighton dynamo operates.

**Contribution Type**:

**Theme**:

Solar - Stellar Connections

**Solar/Stellar Dynamo and Activity / 25**

## 3D Radiative MHD Models of Cool Main-Sequence Starspots

**Author:** Tanayveer Singh Bhatia[1]

**Co-authors:** Robert Cameron [1]; Sami Solanki [1]; Mayukh Panja [1]

[1] *Max Planck Institute for Solar System Research*

Stellar variability presents a significant lower limit to detecting and characterizing exoplanets accurately. Contemporary methods of studying the impact of stellar magnetic fields (in the form of starspots and stellar faculae) involve using simple 1D model atmospheres with a specified effective temperature. We present realistic 3D MHD models of starspots with significant penumbral extent. We model a K2V and an M0V starspot, along with a reference G2V starspot. The models show considerable complexity in thermodynamic structure, velocities and field distribution. Various properties like contrast between spot and quiet star region, as well as horizontal velocities at the surface, scale with stellar type. These models represent a first step towards modelling this aspect of stellar variability more accurately.

**Contribution Type**:

**Theme**:

Solar - Stellar Connections

**Solar/Stellar Dynamo and Activity / 84**

## Star-Planet Interactions: From Solar System Planets to Exoplanets

**Author:** Dibyendu Nandi[1]

[1] *IISER Kolkata*

Magnetized plasma winds and storms from host stars such as the Sun shape (exo)planetary magnetospheres and influence atmospheric mass loss. In the solar system, solar magnetic transients also force planetary environments creating adverse space weather. Magnetohydrodynamic modelling of star-planet interactions provide a physics-based window to explore these phenomena that have profound implications for protection of space-based technologies and (exo)planetary habitability. In this talk, I shall discuss the fascinating science underlying star-planet interactions –focussing on our research on the interplay of magnetized stellar winds and (exo)planets with and without magnetospheres.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Stellar Activity as a Limiting Factor for Characterising Exoplanets / 18**

## Stellar Activity as a Limiting Factor for the Discovery and Characterisation of Exoplanets

**Author:** Ignasi Ribas[1]

[1] *Institut d'Estudis Espacials de Catalunya (IEEC) & Institut de Ciències de l'Espai (ICE, CSIC)*

Extreme-precision radial velocity (RV) instruments (e.g., ESPRESSO), offering 10 cm $s^{-1}$ stability, and space telescopes (e.g., JWST), attaining relative flux uncertainties of 10 ppm, are becoming a reality. Such precision is, in principle, sufficient to enable the discovery and characterisation of small rocky planets, including true Earth analogues. However, the intrinsic variability of stellar hosts can overwhelm the instrument error and become the dominant source of uncertainty. An ambitious, comprehensive effort to model and correct for stellar activity effects must therefore be undertaken if we wish to explore the realm of exo-Earths. In this talk, I will review the current understanding of the impact of stellar activity on planet detection and characterisation, as well as some of the most promising efforts to decontaminate RV and transmission spectroscopy data. I will specifically discuss our approach, which is based on the unique combination of a physical model and contemporaneous multi-technique monitoring. The SPOTLESS project will implement this methodology by building a realistic stellar activity simulator and developing correction strategies using, for example, machine learning algorithms and direct inversion. With ongoing efforts, we should be able to attain new, challenging exoplanet RV discoveries and unbiased transmission spectra.

**Contribution Type**:

**Theme**:

Solar - Stellar Connections

**Stellar Activity as a Limiting Factor for Characterising Exoplanets / 94**

## Magnetospheric Dynamics and Atmospheric Mass Loss Driven by Solar-Stellar Winds and Storms

**Author:** Sakshi Gupta[1]

**Co-authors:** Dibyendu Nandi [1]; Souvik Roy [1]

[1] *Indian Institute of Science Education and Research Kolkata*

Coronal Mass Ejections (CMEs) are massive eruptions of supersonic magnetized plasma from stellar atmospheres. They create adverse space weather conditions around (exo)planets and can significantly perturb their environment. We investigate how varying ICME characteristics —such as speed, orientation, and magnetic field strength —affect the global dynamics, atmospheric mass loss rates and magnetotail current density during reconnection events in (exo)planetary magnetospheres. We find a highly correlated polarity reversal of the induced magnetosphere with stellar wind magnetic field orientations for unmagnetised planets, and as the planetary magnetospheric field strength increases, the polarity reversal in the vicinity of the planet becomes less pronounced. Detailed analysis of the magnetotail current density during polarity reversals for unmagnetized planets aligns closely with observations of the Venusian-induced magnetosphere. We discuss the implications of our findings for solar forcing of planetary atmospheres that are relevant for upcoming space missions.

**Contribution Type**:

**Theme**:

Solar - Stellar Connections

**Stellar Activity as a Limiting Factor for Characterising Exoplanets / 178**

## Magnetic Interaction of Stellar Coronal Mass Ejections with Close-In Exoplanets

**Author:** Gopal Hazra[1]

[1] *IIT Kanpur*

Coronal Mass Ejections (CMEs) erupting from the host star are expected to have enormous effects on the atmospheric erosion processes of the orbiting planets. For planets with a magnetosphere, the embedded magnetic field in the CMEs is thought to be the most important parameter to affect planetary mass loss. In this work, we investigate the effect of different magnetic field structures of stellar CMEs on the atmosphere of a hot Jupiter with a dipolar magnetosphere. We use a time-dependent 3D radiative magnetohydrodynamics (MHD) atmospheric escape model that self-consistently models the outflow from hot Jupiters magnetosphere and its interaction with stellar CMEs. For our study, we consider three configurations of magnetic field embedded in stellar CMEs –(a) northward Bz component, (b) southward Bz component, and (c) radial component. We find that both the CMEs with northward Bz component and southward Bz component increase the mass-loss rate when CME enters the stellar side but the mass-loss rate becomes higher for the CME with northward Bz component when it arrives at the opposite side. The largest magnetopause is found for the CME with a southward Bz component when the dipole and the CME magnetic fields have the same direction. We also find that during the passage of a CME, the planetary magnetosphere goes through three distinct changes - (1) compressed magnetosphere, (2) enlarged magnetosphere, and (3) relaxed magnetosphere for all three considered CME configurations. We compute synthetic Ly-⍰ transits at different times during the passage of the CMEs. The synthetic Ly-⍰ transit absorption generally increases when the CME is in interaction with the planet for all three magnetic configurations. The maximum Ly-⍰ absorption is found for the radial CME case when the magnetosphere is the most compressed.

**Contribution Type**:

**Theme**:

Solar - Stellar Connections

**Solar Active Regions and Eruptions / 151**

## Eruptive and Non-Eruptive Solar Active Regions: What Sets them Apart?

**Author:** Manolis Georgoulis[1]

[1] *Johns Hopkins Applied Physics Laboratory*

An overview of works on potential distinct behaviors between flaring / eruptive and flare-quiet / non-eruptive solar active regions will be attempted. Focus will be assigned to the most distinctive physical quantities that characterize active regions, namely magnetic energy and helicity budgets, as well as associated non-neutralized electric currents. Emphasis will also be on the single most significant topological feature of eruptivity, namely, the magnetic polarity inversion line (PIL) and adjacent subregions in active regions, along with their size and intensity characterizations. How all these diagnostics, inferred as low in the solar atmosphere as vector magnetic field measurements exist, transpire to the overlying coronal volume will also be discussed. This is an action often overlooked, despite being necessary to enforce consistency between different physical layers, from where active-region observations and physically meaningful moments are available to where eruptions actually occur. A key question is how one might tell of imminent flaring activity or eruptivity in active regions, at physically meaningful timescales of hours or days before these instability manifestations. This question has physical and operational aspects, the latter in terms of space weather forecasting efforts, but we will be focusing on physics. Space missions along and beyond the Sun-Earth line, such as SOHO, SDO, STEREO and, to an increasing extent, Solar Orbiter and Parker Solar Probe, have also made important or even decisive contributions to our present understanding of solar active regions. We will sample key observations from these missions that have shaped this understanding and have enabled us to pursue further progress.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Solar Active Regions and Eruptions / 14**

## Coronal Structure and Rotation Enforced by Nested Active Region Emergence: Near-Continuous Monitoring of an Active Nest with Solar Orbiter

**Author:** Adam Finley[1]

**Co-authors:** Antoine Strugarek ; Sacha Brun

[1] *CEA Paris-Saclay*

The formation of active nests/longitudes on the Sun may relate to instabilities at the base of the convective zone or the way in which magnetic flux emerges through the solar surface. Persistent hot spots of activity are frequently observed on other Sun-like stars, hinting that their formation may be universal for stars with dynamo-driven magnetic fields. Nested active region emergences contribute significantly to solar activity and modify the structure of the Sun's coronal magnetic field. As a large fraction, up to 50%, of active regions form in this way, a better understanding of their formation and evolution is needed to improve space weather forecasts as well as model the magnetic connectivity of spacecraft in the heliosphere. The strong magnetic fields that develop in active nests couple the surface rotation rate to the coronal plasma, leading to enhanced rotational flows in the solar wind. ESA's Solar Orbiter now acts as a far-side monitor of solar activity for several months each year. This facilitates near-continuous observations of long-lived active regions that span multiple solar rotations. We use these observations to build a complete record of activity for an active nest identified

in 2022 (during the rising phase of activity for cycle 25). We constrain the influence this active nest had on the coronal magnetic field and solar wind outflow using measurements from NASA's Parker Solar Probe in the inner heliosphere.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Solar Active Regions and Eruptions / 28**

## Global Coronal Magnetic Field Modelling to Study Solar Eruptive Events

**Author:** Prantika Bhowmik[1]

[1] *Department of Physics, Indian Institute of Science Bangalore*

Coronal mass ejections (CMEs) are the most energetic events originating from the Sun, causing significant and sudden disruption to the magnetic and particulate environment of the heliosphere. Thus, in the current era of space-based technologies, an early warning that a CME has left the Sun is crucial. Our magnetofrictional simulations that capture the global corona's continuous and dynamic evolution over many months demonstrate that the non-potential evolution of the corona leads to the accumulation of magnetic free energy and helicity, which is periodically shed in eruptive events. We find that these events fall into two distinct classes: One set of events is caused by eruption and ejection of low-lying coronal flux ropes, and they could explain the origin of filament-erupting CMEs. The other set of events is not driven by the destabilisation of low-lying structures but rather by the eruption of overlying sheared arcades. These are associated with streamer blowouts or stealth CMEs, which are sources of problematic geomagnetic storms. Further investigation into the second class of events predicts the occurrence of repeated eruptions without clear low-coronal signatures from such arcades, provided that the high, overlying magnetic field lines are sufficiently sheared by differential rotation. Thus, our study suggests that magnetofrictional models can, in principle, provide early indication - pre-onset of CMEs, irrespective of whether they originate from the eruption of a low-coronal flux rope.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Solar Active Regions and Eruptions / 13**

## What Could Bridge the Gap Between Medium and Shorter-Term Solar Flare Prediction Methods?

**Author:** Marianna Korsos[1]

[1] *University of Sheffield*

The integration of medium-term and short-term solar flare predictions is a crucial component of space weather forecasting, given their potential impacts on Earth's technological infrastructure and astronaut safety. This presentation examines the importance of combining medium-term and short-term solar flare prediction methods to improve the reliability and precision of forecasts. Medium-term predictions provide a broad understanding of solar activity, facilitating better preparedness for heightened periods of solar activity. In contrast, short-term predictions are based on recent solar observations and the rapidly evolving phenomena on the solar surface, offering warnings within hours or a daily timeframe. By merging medium-term and short-term insights, a more robust and effective solar flare prediction framework can be established. This comprehensive approach enhances the accuracy of specific flare event predictions and significantly advances our grasp of solar dynamics.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Solar Active Regions and Eruptions / 123**

## Reconstruction of Interplanetary Magnetic Field: A Novel Approach to Constrain the Solar Source Surface and Its Response to Solar Activity

**Author:** Shaonwita Pal[1]

**Co-author:** Dibyendu Nandy [1]

[1] *IISER Kolkata*

The Interplanetary Magnetic Field (IMF) plays a crucial role in shaping space weather and its impact on Earth's magnetosphere. However, the availability of direct IMF measurements is limited to recent decades, leaving a gap in our understanding of the Sun's magnetic behavior over longer timescales. To address this, we present a detailed reconstruction of the IMF over the past century by integrating a data-driven photospheric flux transport model, coronal magnetic field extrapolations, and historical geomagnetic data. We introduce a novel technique for optimizing polar flux to match observations to address the persistent challenge of solar open flux, which is critical for accurate IMF reconstruction. We also explore long-term variations in solar open flux across different phases of solar activity, offering improved physical constraints on the solar source surface height and its response to solar activity levels. This work enhances our ability to reconstruct and predict solar open flux and solar wind dynamics.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Solar Active Regions and Eruptions / 159**

## Multiwavelength Study of Pre-flare Signatures Using Aditya-L1

**Author:** Adithya HN[1]

**Co-authors:** Sreejith Padinhatteeri [2]; Durgesh Tripathi [3]; Srikar Paavan Tadepalli ; Abhilash Rajendra Sarawade ; Sankarasubramanian Kasiviswanathan [4]; Ramaprakash A. N. [5]

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Solar Flares release large amounts of energy in the form of radiations in multiple wavelengths. Predicting solar flares starting time and their class is a difficult task. When and at what solar atmospheric layer the flare trigger happens, whether in the corona, transition region or in the chromosphere, is still a puzzle. One way forward is to study the pre-flare signatures in multi-wavelengths originating from different layers of the solar atmosphere. In this study, we use simultaneous observations from Solar Ultraviolet Imaging Telescope (SUIT), High Energy L1 Orbiting X-ray Spectrometer (HEL1OS) and SOlar Low Energy Spectrometer (SoLEXS) that observe the sun in the near ultraviolet (NUV) Soft X-ray and Hard X-ray to study the signatures during multiple pre-flare conditions. We also use HMI onboard SDO to study the magnetic parameters. Preliminary results suggest enhancements in NUV, especially in calcium and magnesium emissions, which are connected with the flux emergence during preflare conditions.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Extreme Events / 185**

## Connecting Sun to Heliosphere over Time and Space: Extreme Events

**Author:** Nat Gopalswamy[1]

[1] *NASA Goddard Space Flight Center*

An extreme event can be defined as an event that falls on the tail of a distribution and characterized by its uniqueness either in its occurrence itself or in its consequences. In the case of the Sun, one talks about coronal mass ejections (CMEs) and flares of extreme energy. Taking one level deeper, one can think of the extremeness of the solar source of these events: active regions and their magnetic content/complexity. Ultimately, the energy that powers CMEs and flares are stored in active regions, so regions of extraordinary size and magnetic field strength have the potential to produce extreme events. The mass and magnetic field of CMEs and solar flare photons propagate into the heliosphere that can cause widespread impact on planets and human-made technological systems. Obvious examples of extreme consequences are super-intense geomagnetic storms caused by CME impact on Earth's magnetosphere and high energy/intensity solar energetic particle (SEP) events caused by CME-driven shocks in the corona and interplanetary medium. Geomagnetic storms and SEP events result in a number of effects in various layers of planetary environment, especially in geospacer. Cumulative distribution of all available observations of event sizes can be used to identify the tail of the distribution and estimate the extremeness on various timescales (e.g., one-in-100-year events). I discuss cumulative distribution of CME kinetic energy, flare size, SEP fluence, and strength of geomagnetic storms and how historical space weather events fall on the tail of these distributions. If the mechanism that produces an extreme event is no different from the regular events, the extreme event if often referred to as a "black swan"event. On the other hand, if an extreme event deviates significantly from the tail, a different mechanism may be coming into play, making it a "dragon king"event. This talk summarizes some of these aspects of extreme events in the Sun-Earth system.

**Contribution Type**:

Poster

**Theme**:

Connecting Solar Corona to Heliosphere

**Extreme Events / 165**

## A Study Of The May 10-11 Superstorm : Solar Sources And Technological Impacts

**Author:** Yoshita Baruah[1]

**Co-authors:** Suvadip Sinha [1]; Souvik Roy [2]; Utkarsh Sharma [1]; Dibyendu Nandi [2]

[1] *Center of Excellence in Space Sciences India, Indian Institute of Science Education and Research Kolkata*

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Earth directed coronal mass ejections (CMEs), particularly those with high speeds and southward-pointing magnetic fields, are the main drivers of geomagnetic storms. While the solar wind constantly deposits particles and energy into Earth's magnetosphere, this process is enhanced during geomagnetic storms. One of the most striking effects of these storms is the appearance of auroras. However, the energy transferred from the solar wind also causes increased Joule heating, which leads to the thermosphere expanding upward. This expansion raises the thermospheric density at satellite altitudes, increasing drag and affecting their orbital lifetimes. Extreme geomagnetic storms can also severely disrupt GPS-dependent technology by altering radio signal paths through the atmosphere. The geomagnetic storm of May 10-11, 2024, produced vivid auroras seen as far south as 34° N in Ladakh and 18° N in Puerto Rico, highlighting the storm's intensity. Multiple reports of GPS-reliant farm equipment failures in the U.S. and satellite de-orbiting from various regions surfaced as the storm intensified. In fact, geomagnetic indices indicate that this storm was the most powerful in the past 20 years. In our study, we investigate the solar sources of the geomagnetic storm and identify their near Earth counterparts from an extremely complex in-situ solar wind profile at L1. We apply magnetohydrodynamic and empirical simulations to assess the impact of the CMEs on Earth's magnetosphere and satellite orbital lifetimes. Additionally, our work examines this storm in a historical context to compare its strength to previous extreme storms and likelihood of occurrence.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Extreme Events / 163**

## Constraining CME Magnetic Flux in EUHFORIA Using Helicity Content: Case Study of the 10 March 2022 CME Observed by Solar Orbiter

**Author:** Shifana Koya[1]

**Co-authors:** Alexander Nindos [1]; Alexey Isavin [2]; Anwesha Maharana [2]; Kris Murawski [3]; Manolis Georgoulis [4]; Ranadeep Sarkar [5]; Spiros Patsourakos [1]

[1] *University of Ioaninna Greece*

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[3] *UMCS, Poland*

[4] *John Hopkins Applied Physics Laboratory*

[5] *University of Helsinki*

Constraining the magnetic field strength of coronal mass ejections (CMEs) from observations is one of the key challenges in predicting their space weather impact on Earth. In this work, we present a new method for constraining the magnetic flux of a spheromak CME model in the frame of the EUropean Heliospheric FORecasting Information Asset (EUHFORIA). In this approach, we use the estimated magnetic helicity content of the CME to determine its axial field strength (B0), which we equate to the magnetic field strength (Bspheromak) at the spheromak's magnetic axis. The amount of helicity transported to the CME has been estimated by taking the net helicity difference between the pre- and post-eruptive phase of the source active region (AR). This estimated helicity budget of the associated CME is further used to constrain a Lundquist flux-rope model with geometrical parameters obtained through a graduated cylindrical shell (GCS) model to determine B0 at the GCS-fitted height. From this, Bspheromak and radius derived from the geometrical parameters of the CME, we estimate the CME's toroidal magnetic flux, which is then used as input for the EUHFORIA simulation. We validate our approach by applying the method to the CME that erupted on 10 March 2022 from NOAA AR 12962, observed by Solar Orbiter at 7.8 degrees east of the Sun-Earth line at a distance of 0.43 AU, complemented by WIND measurements at L1 (0.99 AU). The CME's helicity was estimated to be $(-7.1 \pm 1.2) x 10^{41} Mx^2$. The CME's axial magnetic field at GCS fitted height of 7.6 Rs was B0=2067 ± 405 nT, with a power-law variation with distance extending to L1 and characterised by an index of −1.23 ± 0.18. Extrapolating this magnetic field to the inner boundary of EUHFORIA (21.5 Rs), we obtained Bspheromak=1058 ± 288 nT, from which we estimate the spheromak's toroidal flux as (10.32 ± 6.4) × $10^{12}$ Wb. By modelling this CME from 21.5 Rs to Earth, we assess how well in situ magnetic field measurements align with the model's predictions at 0.43 AU and 0.99 AU. We report a reasonable agreement which demonstrates our method's efficiency and value.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Extreme Events / 100**

## Interplanetary Shocks at 1 AU: Automated Detection and Characterization Over Solar Cycles (1996–2023)

**Author:** Wageesh Mishra[1]

**Co-author:** Anjali Agarwal [1]

[1] *IIA, Bengaluru*

This study aims to understand the behavior and characteristics of interplanetary MHD shocks observed at 1 AU using in situ measurements spanning 1996 to 2023. We developed an automated algorithm for shock detection and analyzed the distribution and properties of various shock types, including fast forward, fast reverse, slow forward, and slow reverse shocks. Key shock parameters such as shock speed, Mach number, shock normal direction, and compression ratio were calculated, with their annual variations examined across two solar cycles. The origins of these shocks are also investigated, differentiating between those driven by coronal mass ejections (CMEs) and corotating interaction regions (CIRs). Additionally, we explored the impact of these shocks on Earth by correlating them with storm sudden commencement (SSC) events. This work offers new insights into shock physics, space weather, and their broader implications.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Representative Results from New Heliospheric Missions / 108**

## Recent Results on Solar Wind and Suprathermal Ions in the Interplanetary Medium and the Relevance of Aditya Solar Wind Particle Experiment (ASPEX) On-Board Aditya-L1

**Author:** Dibyendu Chakrabarty[1]

[1] *Physical Research Laboratory*

The alpha (doubly ionized Helium or He2+) to proton (Singly Ionized Hydrogen or H+) ratios (AHe = Na/Np*100) in the solar wind showed distinctive changes in the solar cycle 24 compared to the previous three solar cycles. Further, this ratio is often found to get enhanced in the interplanetary coronal mass ejections (ICME) and gets changed across the stream interface structures of the stream interaction region (SIR). On some occasions, AHe goes to very low values (compared to what is expected in the solar wind in general) as well. Some of the insights obtained from the recent results will be presented related to the above themes. Also, changes in the suprathermal ions in the quiet interplanetary medium during the last two solar cycles will be presented and contrasted with the corresponding variations in the stream interaction regions. Recent results obtained by analysing the upstream (of the terrestrial bow shock) events will also be discussed. It will be argued that directional, alpha-proton separated measurements of the ions in the interplanetary medium in both low and high energies by the Aditya Solar wind Particle Experiment on-board Aditya-L1 holds great potential to address some of the unresolved problems related to solar and heliospheric processes.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Representative Results from New Heliospheric Missions / 205**

## Multi-Spacecraft Exploration of the Formation Stages of a Coronal Mass Ejection During a Composite Flare: Heating, Particle Acceleration, and Hot-Channel Eruption

**Author:** Bhuwan Joshi[1]

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In this paper, we present a multi-spacecraft view of the activation of a large magnetic flux rope (MFR) which accompanies a composite flare that evolved into a halo CME. The composite flare consists of an impulsive event during which GOES flux peaked up to C6.3 level and a subsequent long-duration M1.0 event. The term 'composite' refers the collective roles of two distinct events of large-scale reconnection in triggering the activation and eruption of an MFR. The eruption occurred in solar active

region NOAA 12975 and observed from a suite of instruments including two solar X-ray telescopes: Solar X-ray Monitor (XSM) on board Chandrayaan-2 (Ch-2) and the Spectrometer Telescope for Imaging X-rays (STIX) on board Solar Orbiter (SO). During our observing period, the SO-Sun-Earth angle was 85.2 degree, making it possible to address the relationship between emission from different segments of the flare loops, viz. coronal loop-tops and foot-points sources. A comparison between the imaging observations from Atmospheric Imaging Assembly (AIA) on board Solar Dynamics Observatory (SDO) in extreme ultraviolet (EUV) channels and X-ray time profiles at multiple energy bands clearly reveal the physical connection between the two events as the rising EUV hot channel (i.e. MFR in low corona) attains eruptive motions around the transition period between the two flaring episodes. Our observations indicate that the MFR initially ascended with a projected speed of ≈80 km s-1 while the corresponding halo-CME expanded with a speed of ≈900 km s-1 within ≈3−11 R⊠. The analysis of high-resolution X-ray spectra at 1-15 keV energies from XSM/Ch-2 reveal that the highest plasma temperature was attained at the peak C6.3 flare which did not show significant increase during the subsequent M1 event; on the other hand, the emission measure (EM) almost doubled during the peak of M-class event in comparison to that at the peak of the preceding event. The observations provide new insights on the role of precursor emission toward the destabilization of MFR. A distinct C6.3 event happening as a precursor to M1.0 flare clearly points toward a feedback relationship between large-scale, two-phase magnetic reconnection and corresponding step-wise evolution of the MFR.

**Contribution Type**:

**Theme**:

**Representative Results from New Heliospheric Missions / 107**

## Investigating the Possible Origin of Magnetic Switchbacks in the Low Solar Atmosphere

**Author:** Clara Froment[1]

[1] *CNRS/LPC2E-Orléans*

The recent in situ observations in the young solar wind made by Parker Solar Probe PSP, revealed a small-scale structuring of the magnetic field that consists of sudden magnetic deflections. These "switchbacks" are particularly pronounced in the radial component of the field, and have a duration of a few seconds to a few hours. These structures are not new but PSP observations uncovered that they are ubiquitous in the young solar wind. There is currently no unique generation model explaining all the switchback's observed properties. However, there is a growing consensus that dynamical processes, such as a variety of jetting activity in the solar atmosphere can be the seed of deflections becoming switchbacks in the expanding solar wind. I will present two recent works, one observational and one numerical, in which we aim to test this hypothesis. These two approaches are complementary as from the observations (in situ and remote-sensing ones) alone we are missing informations on the propagation of the structures. I will conclude on the current state of knowledge and on what one should focus on in future studies.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Representative Results from New Heliospheric Missions / 90**

## The Coherent Morphology and Evolution of Solar Coronal Loops

**Author:** Bhinva Ram[1]

**Co-authors:** Lakshmi Pradeep Chitta [1]; Sudip Mandal [1]; Hardi Peter [1]

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Coronal loops, the arching structures filled with magnetically confined million Kelvin hot plasma, are the prominent features of the solar atmosphere. These loops are best observed in the extreme ultraviolet (EUV) and X-ray wavelengths. Coronal loop emission generally traces the magnetic field lines in the upper solar atmosphere. Thus probing their spatial morphology and evolution will help us better understand the dynamics of the magnetic field and the nature of plasma heating processes operating in the corona. The spatial morphology of coronal loops is still not fully understood. Some studies have indicated that coronal loops might be apparent optical illusions, similar to veils, caused by folds in the two-dimensional current sheets. Stereoscopic observations of coronal loops will be crucial to decipher their morphology. To this end, we used high-resolution imaging data from the Extreme Ultraviolet Imager (EUI) on the Solar Orbiter spacecraft and the Atmospheric Imaging Assembly on the Solar Dynamics Observatory to stereoscopically analyze a set of coronal loops in an active region. Our findings show that the loops have nearly circular cross-sectional widths and consistent intensity variations along their lengths over timescales of 30 minutes. We suggest that the morphology of coronal loops is consistent with three-dimensional flux tube-like structures and not emissions from randomly aligned two-dimensional current sheets along the line of sight as proposed in the 'coronal veil' hypothesis.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Representative Results from New Heliospheric Missions / 183**

## Polarization Characteristics of Active Solar Radio Emissions: Studies with SKAO Precursors and Pathfinders

**Author:** Soham Dey[1]

**Co-authors:** Divya Oberoi [1]; Devojyoti Kansabanik [2]; Puja Majee [1]; Pietro Zucca [3]; Surajit Mondal [4]; Mattia Mancini [3]

[1] *National Centre for Radio Astrophysics*

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[3] *ASTRON*

[4] *NJIT*

Solar radio bursts are among the most extensively studied radio phenomena originating in the solar corona and serving as valuable probes of the coronal medium. Their polarization properties are particularly sensitive indicators of coronal magnetic fields, which have historically been difficult to measure. Despite these advantages, instrumental and algorithmic limitations have restricted the use of imaging techniques for solar and coronal studies at low radio frequencies. Most existing research is based on analyzing dynamic spectra, which do not provide imaging information. This is now set to change due to two primary reasons. The first is the availability of the next-generation telescopes, such as the Murchison Widefield Array (MWA), LOw Frequency ARray (LOFAR), and the upgraded Giant Metrewave Radio Telescope (uGMRT), all precursors or pathfinders for the Square

Kilometre Observatory (SKAO) expected to become available by the end of this decade. The second is the advances in calibration and imaging algorithms, which have enabled the generation of high fidelity, full polarimetric spectroscopic snapshot images of the Sun from the data obtained using these instruments. These images facilitate the study of active emissions varying on small spectral and temporal scales. We have conducted full polarization imaging studies of multiple active solar radio emissions using MWA, LOFAR, and uGMRT. Our findings reveal that these emissions are predominantly circularly polarized, with polarization fractions exhibiting significant variation, and almost always remaining significantly lower than theoretical expectations. Notably, the location of the polarized sources appears to be shifted by several arcseconds to few arcminutes relative to total intensity sources with the polarized source being more compact, hinting that a substantial amount of polarization might have been lost due to scattering.
We will summarize our results and discuss their potential implications.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Radio Input to Heliospheric Studies and Space Weather / 110**

## Solar and Heliospheric Science from the New Generation Radio Telescopes: Status and Opportunities

**Author:** Divya Oberoi[1]

[1] *National Centre for Radio Astrophysics, Tata Institute of Fundamental Research*

In principle, the usefulness of radio observations for solar and heliospheric science (heliophysics) is well recognized. In practice, instrumental and algorithmic limitations have kept this promise from being realized. This is now set to change. Several new-generation radio interferometers have recently become available, and more are expected in the near future. These are the many precursors and pathfinders of the Square Kilometre Array Observatory (SKAO) and the SKAO itself (expected first-light 2029). The vastly improved observational abilities of these instruments are very well aligned with the needs of heliophysics. Between the various instruments and available techniques, they can be used to study regions from the base of the corona to beyond an AU and address a large variety of science targets. Considerable work has already been devoted towards enabling heliophysics with these instruments, which are optimized to look at faint radio sources orders of magnitude weaker than the Sun. This talk will showcase some example science areas where considerable progress has been made, share the status and near-term plans for radio heliophysics observations with the new-generation instruments and the science opportunities they present.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Radio Input to Heliospheric Studies and Space Weather / 156**

## Bringing Together World's Best Radio Telescopes for Remote Sensing of Heliospheric Magnetic Field

**Author:** Devojyoti Kansabanik[1]

**Co-authors:** Angelos Vourlidas [2]; John Morgan [3]

[1] *University Corporation for Atmospheric Research*

[2] *Johns Hopkins University Applied Physics Laboratory*

[3] *CSIRO, Australia*

Magnetic field measurements in the outer corona and inner heliosphere using remote sensing observations are crucial for improving space-weather prediction. However, routine observations using white-light heliospheric imagers cannot provide these measurements. At radio wavelengths, changes in the polarization angle of background linearly polarized astronomical sources can estimate line-of-sight (LoS) integrated magnetic fields when a plasma blob intercepts that LoS. To date, this technique has been limited at coronal heights <15 R_sun using high-frequency telescopes with lower sensitivity to magnetic field strength and narrow fields of view (FoV), such as the JVLA. Over the past two decades, new-generation ground-based radio telescopes like MWA, LOFAR, ASKAP, and MeerKAT have become operational. These telescopes offer wide FoVs and lower observing frequencies, which can overcome previous limitations. Despite their capabilities, these instruments face challenges in calibration and trigger time-of-opportunity observations for space-weather events. This talk presents our recent efforts to address these challenges by utilizing these leading radio telescopes and preparing for upcoming new-generation radio telescopes (like ngVLA, SKAO) for heliospheric magnetic field measurements using radio polarimetry, a technique we call "Heliopolarimetry." By leveraging these advancements, along with other white-light missions (like PUNCH), we aim to enhance space-weather research and prediction capabilities.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Radio Input to Heliospheric Studies and Space Weather / 207**

## Radio Eyes for the Sun, Heliosphere and Ionosphere: Status and Plans for the LOFAR2.0 Era.

**Author:** Pietro Zucca[1]

[1] *ASTRON*

The Low-Frequency Array (LOFAR) has established itself as a formidable instrument in the field of solar physics and space weather, providing a unique vantage point for observing the Sun, heliosphere, and ionosphere. As we transition into the LOFAR2.0 era, this abstract outlines the current status and future plans for leveraging LOFAR's capabilities, and the LOFAR IDOLS (Incremental Development of LOFAR Space-weather) project. LOFAR's current work in solar physics involves high-resolution imaging and dynamic spectral analysis, enabling detailed observations of solar radio bursts and other coronal heliosphere and ionosphere phenomena. These observations are critical for understanding the mechanisms behind solar activity and improving our predictive models of space weather events. The LOFAR IDOLS station, a dedicated space-weather science facility, has been instrumental in advancing this work. It currently provides continuous monitoring of the ionosphere and Sun, tracking disturbances that can affect space wetaher on Earth, but also the astronomical observations of LOFAR itself. The LOFAR2.0 upgrade promises to enhance these capabilities significantly. Plans include improving the sensitivity and spatial resolution of the array, and the simoultaneus observations in LBA and HBA, which will allow for even more precise and broad imaging and tracking of solar phenomena. This will enable researchers to dissect the fine structures within the solar corona and track the development of space weather events with greater accuracy. Furthermore, the LOFAR IDOLS project is set to continue observation during the period of transition to LOFAR2.0 enabling us to test the monitorning capabilities. In conclusion, the LOFAR2.0 era opens a new opportunity for solar and space weather research. With the ongoing work and future plans for the LOFAR IDOLS station and LOFAR2.0 observations, we are preparing to gain deeper insights into the Sun's influence

on our space environment and to develop more robust forecasting capabilities for space weather phenomena.

**Contribution Type**:

**Theme**:

**Radio Input to Heliospheric Studies and Space Weather / 109**

## The First Detailed Polarimetric Study of a Type-II Solar Radio Burst with the MWA

**Author:** Puja Majee[1]

**Co-authors:** Divya Oberoi [1]; Devojyoti Kansabanik [2]

[1] *National Centre for Radio Astrophysics, Tata Institute of Fundamental Research*

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Type-II solar radio bursts are plasma emissions generated by magnetohydrodynamic shocks that are mostly associated with energetic solar eruptions such as CMEs and flares. Several studies have concluded that metric type-IIs are initiated by coronal mass ejections (CMEs). These CMEs are expected to drive shocks and are responsible for giving rise to solar energetic particles (SEPs), the biggest concern of space weather. The evolution and geo-effectiveness of these eruptions are governed by their entrained magnetic fields and interactions with the ambient magnetized plasma medium. Hence, understanding the entrained magnetic fields and the ambient medium is crucial. Polarimetric properties of metric type-IIs are promising diagnostics to understand the strength and topology of the CME-shock entrained magnetic fields and ambient plasma medium at the low-coronal heights where only a handful of direct probes are available. The majority of previous studies are based on dynamic spectra that do not provide spatially resolved information. Polarized emissions can be both positive and negative; hence, spatially integrated information may lead to incorrect measurements of polarization properties. For robust estimations of these spatio-temporally variable emissions, high-fidelity spectro-polarimetric images are essential. Instruments like the Murchison Widefield Array (MWA) and its dedicated robust solar calibration and imaging pipeline have made such studies possible. We have used this pipeline to carry out a detailed polarimetric study of a type-II solar radio burst observed with the MWA. Here we summarize the new findings from this work and discuss the potential of high-fidelity spectro-polarimetric imaging studies for understanding the shock-entrained magnetic fields and the plasma medium at the lower corona.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Radio Input to Heliospheric Studies and Space Weather / 37**

## Type II Radio Burst Without Coronal Mass Ejection

**Author:** Natchimuthukonar Gopalswamy[1]

**Co-author:** Anshu Kumari [2]

[1] *NASA Goddard Space Flight Center*

[2] *Physical Research Laboratory (PRL)*

Type II solar radio bursts are commonly associated with shocks generated by coronal mass ejections (CMEs), where plasma waves are excited by magnetohydrodynamic (MHD) processes and converted into radio waves at the local plasma frequency or its harmonics. However, there are instances where type II bursts occur in the absence of white-light CMEs. We analyse one such metric type II radio burst observed on November 2, 2023, characterised by split band features. Notably, no CME was detected with space-based coronagraphs during this event. However, a M1.6 class flare was observed just before the type II burst and an EUV disturbance was observed expanding into surrounding regions. Further analysis will be performed to determine the cause of the EUV disturbance as due to a failed eruption. This talk will discuss preliminary findings on the generation of the shock and shed light on the occurrence of type II bursts in the absence of white-light CMEs.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**47**

## Analysis of the sunspot drawings from the Royal Observatory of Belgium

**Author:** Sabrina Bechet[1]

[1] *Royal Observation of Belgium*

Sunspot drawings are a unique source of data to retrieve long-term information on the evolution of the solar cycle. The sunspot drawings taken at the Royal Observatory of Belgium (ROB) with the USET observing station cover more than 80 years, and they continue to be made nowadays with the same refractor. Recently, the collection has been fully digitized and analysed.

In this talk, we present the analysis of the USET sunspot drawings with our in-house software DigiSun, and the physical parameters extracted from them. This includes sunspot count, sunspot area, and measure of spatial and morphological information. We also show some preliminary results obtained from those parameters.

**Contribution Type**:

**Theme**:

Solar Magnetism over Long-Time Scales

**Poster Session-II / Coffee Break / 1**

## Quasi-Periodic Oscillations in Si IV Doppler Velocity During an M-6.5 Class Solar Flare

**Authors:** Jayant Joshi[1]; Ayush Kumar Pal[1]; Tanmoy Samanta[1]

[1] *Indian Institute of Astrophysics*

Quasi-periodic oscillations (QPOs) observed in the solar chromosphere and transition region during flares offer valuable insights into the atmospheric response to sudden energy releases and the evolution of the magnetic field. We analyzed an M-6.5 class flare observed by the Interface Region Imaging Spectrograph (IRIS), emphasizing QPOs in the Doppler velocity measured in the Si IV line at the flare ribbons. Our findings reveal variations in the periods of oscillatory signals during different phases of the flare. Specifically, during the flare's impulsive phase, Doppler velocity oscillations with a periodicity of approximately 5 minutes were observed. Pre-flare oscillations exhibited maximum power at around 3 minutes. However, during the gradual decay phase of the flare, longer-period oscillations (~8-12 minutes) were detected in and around the flare ribbons. We interpret the shift to a 5-minute periodicity during the impulsive phase as indicative of a change in the formation height of the Si IV line, corresponding to a deeper atmospheric layer responding to the local acoustic cut-off frequency. Additionally, the extended-period oscillations observed during the decay phase may be attributed to a reorientation of the magnetic field, which could become more inclined post-flare.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Poster Session-II / Coffee Break / 133**

## Modulation in Cosmic Rays During a Period of Anomalously Low Solar Activity

**Author:** Bhupendra Kumar Tiwari[1]

[1] *A.P.S.University Rewa M.P.*

A study of the long-term modulation of galactic cosmic rays in positive and negative phases of the 22-year solar magnetic cycle, including a period of anomalously low solar activity between 2008 and 2020 is performed. Solar magnetic field lines reconnect with galactic ones in the negative phases. In the positive phases, there is a magnetic barrier between these fields that must be considered when describing the modulation of galactic cosmic rays.

**Contribution Type**:

Poster

**Theme**:

Connecting Solar Corona to Heliosphere

**Poster Session-I / Coffee Break / 160**

## Coronal Seismology using Fundamental and Overtones in Transverse Oscillations of Coronal Loops

**Authors:** RamAjor Maurya[1]; Safna Banu K[1]

[1] *National Institute of Technology, Calicut*

The solar corona is a dynamic environment that contains various magnetic structures, such as coronal loops, coronal holes, polar plumes, etc. These structures are perturbed by energetic activities such as solar flares, coronal mass ejections, and magnetohydrodynamic waves, leading to oscillations that serve as indirect tools for investigating the properties of the coronal atmosphere. In this study, we identify the fundamental mode and overtones in the transverse oscillations of two coronal loops associated with an active region. We analyze intensity observations from the Atmospheric Imaging Assembly (AIA) onboard the Solar Dynamics Observatory (SDO). Our investigation reveals fundamental oscillation periods of approximately 17.0 minutes for the first loop and 15.2 minutes for the second loop. The first coronal loop exhibits oscillations in both the first and second overtones, with periods of about 6.9 minutes and 4.3 minutes, respectively. In contrast, the second loop was detected only in the first overtone, which has a period of approximately 7.7 minutes. The period ratios of the fundamental to first overtones for these loops are 1.24 and 0.99, respectively, while the ratio of the fundamental to the second overtone for the first loop is 1.33. These deviations from unity in period ratios provide critical insights into estimating the density scale height and loop expansion factor. Our results indicate a density scale height of 11 Mm for the second loop and a loop expansion factor of 1.5 for the first loop. This suggests that the properties of coronal loops significantly influence the loop expansion factor, more so than the longitudinal density stratification typically associated with sigmoidal active regions. Additionally, by correlating the lengths of the coronal loops with their oscillation periods, we estimated the average magnetic field strength within these loops to be in the range of 20-30 G. We also present statistical studies that evaluate the consistency of magnetic field measurements using coronal seismology and extrapolation techniques.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Poster Session-I / Coffee Break / 98**

## A Deep-Learning Based Algorithm to Extract Filaments from Kodaikanal Solar Observatory Suncharts

**Author:** Srinjana Routh[1]

**Co-authors:** Subhamoy Chatterjee [2]; Dipankar Banerjee [3]

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The long-term evolution of solar filaments, prominently observed in Hα, is closely related to the large-scale solar cycle, with their parameters tracing the solar surface magnetic fields and have been long thought to contribute to the polar fields of the next cycle. The Kodaikanal Solar Observatory (KoSO) hosts one of the longest reserves of archival data with the information of these features in the unique form of hand-drawn suncharts, where features like filaments, plages and sunspots are marked in different colours. In this study, we created a Convolutional Neural Network (CNN) based model for the extraction of these features from the entire period from 1954-1976 and present the preliminary results of the training. A comparison will be made with other extracted statistics and relevant solar cycle properties will be studied from the new filament time series.

**Contribution Type**:

**Theme**:

Solar Magnetism over Long-Time Scales

**Poster Session-II / Coffee Break / 19**

## Coronal Mass Ejections: Propagation Time Delay due to Magnetospheric Interactions

**Author:** Ajith Shanbhag[None]

For my MSc thesis, I focused on investigating the timescales of interactions between Earth's magnetosphere and solar transients, with an emphasis on **Coronal mass ejections (CMEs)** as they traveled through space and passed Earth. CMEs, which are massive expulsions of plasma and magnetic fields from the Sun, can have significant effects on Earth's magnetic environment. My goal was to better understand the timing of these interactions, which is crucial for predicting space weather events and assessing their potential impacts on satellite operations, communication systems, and power grids. In the course of my research, I analyzed data from a network of spacecraft positioned at various Lagrange points, including L1 (the point between the Earth and the Sun), as well as satellites operating within Earth's magnetosphere. These Lagrange points provided stable observation platforms for capturing solar and geomagnetic activity. By incorporating data from multiple sources, I was able to create a more complete picture of how CMEs propagated through space and interacted with Earth's magnetic field. A key part of my thesis involved monitoring the magnetic field components and calculating the total magnetic field strength. This method helped standardize the magnetic field measurements across different instruments, allowing for reliable comparisons. The approach minimized inconsistencies that could arise due to varying spacecraft positions and angles. To determine the true propagation times of CMEs, I cross-referenced the arrival times recorded by instruments at Lagrange points with those observed by satellites within Earth's magnetosphere. This enabled me to accurately measure the timing of CME interactions with Earth's magnetic field, shedding light on how long it took for solar disturbances to travel from Lagrange points to Earth. The timing data I gathered offered valuable insights into the dynamics of CME propagation. By focusing on the timescales of these interactions, my thesis contributed to a deeper understanding of the relationship between solar phenomena and Earth's magnetosphere. The results from my research helped refine space weather prediction models, providing more accurate tools for forecasting geomagnetic storms and mitigating the risks posed by solar activity to critical infrastructure. My findings are especially important for improving the resilience of technological systems, such as satellites and power grids, against the effects of space weather. This project has inspired me to continue working in this field. I plan to further investigate the mechanisms behind CME propagation and their interaction with Earth's magnetosphere, with the goal of enhancing space weather forecasting models and developing strategies to better protect technological infrastructure from solar disturbances.

**Contribution Type**:

Poster

**Theme**:

Energetic Phenomena

**Poster Session-II / Coffee Break / 6**

## Limit of Alfvènic Heating in ICME Magnetic Clouds: An Observational Perspective

**Author:** Kishor Kumbhar[1]

**Co-authors:** Anil Raghav [1]; Kalpesh Ghag [1]; Omkar Dhamane [1]; Takeru K. Suzuki [2]; Utkarsh Sharma [1]

[1] *Department of Physics, University of Mumbai*

[2] *School of Arts & Sciences, The University of Tokyo*

We investigate the temperature distribution for Alfvénic and non-Alfvénic regions in Interplanetary Coronal Mass Ejections (ICMEs). Our analysis reveals that approximately 63% of the ICME magnetic cloud regions are non-Alfvénic, while 37% exhibit Alfvénic characteristics, predominantly outward fluctuations. We observe significant temperature enhancements in Alfvénic regions, with the most notable heating occurring around 20 eV, whereas heating extends up to 40 eV. These findings align with theoretical models and simulations of Alfvén wave dissipation mechanisms. Our observations also show distinct parallel and perpendicular heating behavior, with outward Alfvénic regions exhibiting higher parallel heating and both inward and outward regions showing perpendicular heating. This study highlights the crucial role of Alfvénic fluctuations in ICME plasma heating and may offer potential constraints on their contribution to other space plasma environments.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Poster Session-I / Coffee Break / 119**

## Temperature and Velocity Structure of an Active Region in MAST Observations

**Author:** Raja Bayanna Ankala[1]

**Co-authors:** Rohan Eugene Louis [2]; Christian Beck [3]; Shibu K Mathew [2]; Ravi Chaurasiya [2]

[1] *Physical Research Laboratory, Udaipur Solar Observatory*

[2] *PRL, Udaipur Solar Observatory*

[3] *National Solar Observatory*

We analyse chromospheric observations of NOAA AR 12765, which were acquired using a narrow-band imaging spectrometer installed with the 50-cm MAST at the Udaipur Solar Observatory. The active region included a large plage region in the vicinity of a sunspot, and we employed the NICOLE inversion code to determine 2D maps of temperature and velocity as a function of height. Photospheric vector magnetograms from SDO/HMI were used to ascertain the underlying magnetic field configuration. We will present preliminary results from our study in this talk.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Poster Session-II / Coffee Break / 38**

## Generation and Annihilation of 3D Nulls in a Magnetic Field Initially Devoid of Any Nulls

**Author:** Yogesh Kumar Maurya[1]

**Co-authors:** Ramit Bhattacharyya [1]; David Pontin [2]; Sanjay Saini [3]

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[2] *University of New Castle*

[3] *Patna University*

Three-dimensional (3D) magnetic nulls are abundant in the solar atmosphere, as have been firmly established through contemporary observations [1]. They are established to be important magnetic structures in solar atmosphere, for example, jets [2] and circular ribbon flares [3,4,5]. The flare emissions at the footpoints of the fan field lines constitute a closed circular flare ribbon. Recent simulations and extrapolations support this [6], the mechanisms behind 3D null generation remain an open question. Recent magnetohydrodynamics (MHD) simulations propose that magnetic reconnection is responsible for both generating and annihilating 3D nulls, where the initial magnetic fields already support preexisting nulls [7,8], raising the question whether magnetic reconnection can create nulls in the field initially devoid of them. For the purpose, the initially chaotic magnetic field devoid any nulls have been utilized for MHD simulations. The generation, annihilation, and dynamics of nulls are explored by a complementary usage of updated trilinear null detection technique and tracing of magnetic field line dynamics. It is found that the nulls can spontaneously generate/annihilate in pairs and the reconnection its being underlying cause. The simulation results also demonstrate a direct correlation between the chaoticity levels and the number of null generations, with higher chaoticity leading to earlier null creations and increased null count.

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**Contribution Type**:

**Theme**:

Energetic Phenomena

**Poster Session-I / Coffee Break / 72**

## Evershed Effect: Unraveling Ion-Neutral Decoupling

**Author:** Iván Bonilla Mariana[1]

**Co-authors:** Carlos Quintero Noda [2]; Elena Khomenko [2]; Manuel Collados [2]; Natalya Shchukina [3]

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Theory suggests that an ion-neutral velocity drift may exist in the solar atmosphere if the collisional momentum exchange between both species is not large enough. This work aims to offer a fresh perspective on this issue by investigating the drift velocity within the Evershed flow. In a previous analysis (Khomenko et al. 2015), the authors derived the Evershed velocities associated to Fe I and Fe II species in a sunspot using the lambda-meter method, estimating the formation heights of the observed spectral lines using semi-empirical models. The results showed that the flow measured using the Fe I lines was a few hundred ms-1 faster than that derived from the Fe II lines at all photospheric heights and radial distances to the sunspot centre. In this work, we have applied the SIR (Stokes Inversion based on Response functions) technique to different spectral regions, carefully selecting pairs of spectral lines from Fe I and Fe II. In addition to various atmospheric parameters, we consistently and separately obtained the ion and neutral velocity stratifications as a function of optical depth at all individual penumbral points around a sunspot. This contribution describes the

main results obtained with this analysis. The influence of NLTE effects in the velocity and height determinations is also under study.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism in High-Resolution

**Poster Session-I / Coffee Break / 46**

## Latitudinal Variations and Periodicities in the Penumbra-Umbra Ratio Observed at Kodaikanal Observatory

**Author:** Partha Chowdhury[1]

**Co-authors:** Ravindra Belur [2]; Manjunath Hegde [2]

[1] *Calcutta University, India*

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Sunspots, dark features on the Sun's surface, consist of a central, darker umbra and a surrounding, less dark, filamentary region called the penumbra. Their penumbra to umbra area size ratio is crucial for understanding sunspot radiation and its contribution to total solar irradiance. This study explores this penumbra-to-umbra area ratio (q) for sunspots across solar cycles 21 to 24 (1976-2017) using data from the Kodaikanal Solar Observatory. We analyzed variations in q across different latitude belts and opposite hemispheres. The results show that 'q'exhibits a distinct pattern across latitudes. The temporal evolution of q shows a small asymmetry between hemispheres and most prominent at the start of a new cycles. Analysis revealed periodicities ranging from 2 months to 11 years, including Rieger-type (130-190 days) and quasi-biennial oscillations (QBOs, 1.4-2.5 years). Overall, this study highlights the complex interplay of latitude, hemisphere, and solar cycle phase in determining the penumbra-to-umbra area ratio of sunspots.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism in High-Resolution

**Poster Session-I / Coffee Break / 143**

## The Firefly (4π) Constellation: Going Above and Beyond in the Heliosphere Exploration

**Author:** Nour E. Rawafi[1]

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Heliospheric exploration has soared to unprecedented heights in recent decades thanks to innovative spaceborne missions, ground-based observatories, and advancements in computing, models, and theory. However, the progress of inner-heliospheric research is hindered by observing limitations, preventing resolving long-standing problems such as understanding the solar dynamo, solar cycle, solar wind acceleration, and the impact of active region magnetic fields on space weather and Earth. These limitations stem from observing a dynamic 3D star from a single vantage point in the ecliptic. Holistic observations, encompassing the Sun and the inner heliosphere with full 4π-steradian coverage, will open new research avenues and bridge knowledge gaps in heliophysics and astrophysics. The Firefly Constellation mission concept aims to enable simultaneous observations of the Sun and inner heliosphere from multiple viewpoints, revolutionizing our understanding of the Sun's interior, solar atmosphere, and the inner heliosphere. The mission includes spacecraft strategically positioned in the ecliptic plane and at high solar latitudes, all equipped with a comprehensive payload including remote sensing and in situ instruments. We provide an overview of the Firefly mission, which is under consideration by the 2024-2033 Decadal Survey for Solar and Space Physics (Heliophysics), and its success could pave the way for groundbreaking discoveries, building upon the achievements of previous NASA missions.

**Contribution Type**:

**Theme**:

Solar Magnetism over Long-Time Scales

**Poster Session-I / Coffee Break / 122**

## Exploring Reliability and Physical Link between Polar Field Rise Rate and the Waldmeier Effect for Solar Cycle Prediction: Cycle 25 is likely to be Stronger than Cycle 24

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**Co-authors:** Akash Biswas [2]; Bidya Binay Karak [2]

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The solar activity is directly related to its variable magnetic field, which is generated in the Sun's convection zone. Solar activity increases and decreases with the solar cycle strength, popularly measured by the sunspot number (SSN). This activity creates space weather and impacts the interplanetary and Earth's atmosphere. The sunspot number (solar cycle) prediction provides a cutting-edge advantage in comprehending space weather and understanding the dynamo process physically. However, predicting the solar cycle is challenging but several physics-based methods are used to forecast the cycle strength. We have shown an aspect of the Waldmeier effect to predict the solar cycle strength and its physical connection with the polar field rise rate, which makes the solar cycle prediction possible much earlier. Additionally we have explored the reliability of the polar field rise rate as a precursor for solar cycle prediction using dynamo and SFT models. Using the polar field rise rate after the polar field reversal, we can predict the upcoming cycle strength to be about 7 to 8 years before the solar cycle maximum. Our prediction of cycle 25 based on the polar field rise rate is 137 +/- 23, which shows that cycle 25 will be slightly stronger than cycle 24.

**Contribution Type**:

**Theme**:

Solar Magnetism over Long-Time Scales

**Poster Session-II / Coffee Break / 53**

## Rotational Characteristics of the Sun Using SDO/AIA Images at Wavelength 1600 Å

**Author:** Ved Prakash Gupta[1]

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Temporal and spatial variations in solar rotation with accurate determination and its correlation with solar activities are interesting topic in solar physics since earlier. Solar rotation can be measured by tracking the tracers across the solar disk, or via spectroscopy, or via flux modulation method using radio waves, X-rays, and UV rays that emitted out in the space. Solar Dynamics Observatory, a space mission of NASA to study the magnetic behavior in the Sun. Onboard instrument SDO/AIA continuously observing the Sun and data can be used to estimate the rotation of solar atmosphere, which in turn provides information about change in solar magnetic field as variation in solar cycle. In present work possible variation in latitudinal solar rotation is estimated by using flux modulation method. The SFD images at 1600 Å and at a cadence of one image per day, obtained from SDO/AIA have been used for each year of the whole mission period (2011-2023). In flux modulation method, the variation in flux emitted over the latitudinal bin (formed on equally separated latitude region of SFD images that extended from 80oN to 80oS) on solar disc generates annual time series at each latitude. Statistical tool LSP has been used to estimate periodic oscillations present in the time series. Solar Full Disk image at 1600 Å shows a highly complex and magnetically structured region lies between chromosphere and upper most layer of solar atmosphere called corona, in this region phenomenon of rapid rising of temperature from relatively cool photosphere to much hotter corona takes place and this region is also responsible for generating solar wind in which charged particle is streamed outward from Sun to the solar system.

**Contribution Type**:

Poster

**Theme**:

Solar - Stellar Connections

**Poster Session-I / Coffee Break / 191**

## Numerical Modelling of MHD Wave Propagation in Twisted Magnetic Flux Tubes

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Various configurations of the magnetic field in the solar atmosphere effectively link plasma processes between the photosphere, chromosphere, and solar corona. In a majority of cases, these magnetic configurations are twisted. Therefore, studying excitation and propagation of magnetohydrodynamic waves in the magnetic flux tubes when twist is present is a key to understanding energy transport and dissipation processes. Due to the complexity of analytical study, it is natural to model

the wave excitation and propagation numerically. In this work, we implemented the different configurations of twisted 3D magnetic fields with varying magnetic pressure (plasma-beta changing in the range of 0.2-20). The magnetohydrostatic equilibrium within a non-stratified atmosphere was obtained analytically under solar atmospheric conditions based on the results reported by Sen and Mangalam (2018, 2019). The proposed magnetic configurations are consistent with the magnetic field within solar magnetic bright points regarding field strength and radial distribution. Related solutions are found by taking the complex conjugate of the flux function and by using current-free boundary conditions. Our analysis shows that these quasi-stable solutions and their extensions are suitable candidates for localised twisted configurations that may exist singly or in a network on the photosphere. The stability of magnetic configurations was analysed using a newly developed MPI-based numerical code. We investigated the propagation characteristics and contribution to the energy budget of MHD waves excited by realistic vortical drivers applied at footpoints of the constructed twisted magnetic flux tubes.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism in High-Resolution

**Poster Session-I / Coffee Break / 138**

## Solar High Resolution Imaging with the 76 cm Telescope of the Vainu Bappu Observatory

**Author:** Sridharan Rengaswamy[1]

**Co-authors:** Ramachandran Annamalaisamy [1]; Sagayanathan K ; Saraswathi Kalyani Subramanian [1]

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Ground-based telescopes have an inherent inability to attain diffraction-limited imaging due to the presence of the earth's atmospheric turbulence. Speckle imaging technique helps to achieve diffraction-limited imaging by post-processing a series of short exposure imaging. In this poster, we report ongoing work of obtaining high-resolution (sub-arc seconds) images of solar surface features with the 76 cm telescope of the Vainu Bappu Observatory. The entrance aperture of the telescope is masked with an annular mask to prevent heating due to the sunlight. The image formed by the telescope is suitably re-imaged with a combination of collimating and imaging lenses and a spectral filter to have suitable image plane sampling to enable diffraction-limited imaging. Speckle imaging is used to achieve high-contrast images with resolution down to the diffraction limit of the telescope. Preliminary results are presented.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism in High-Resolution

**Poster Session-II / Coffee Break / 49**

## Exploring Propagation of Small-Scale Flare Heat Flux in the Lower and Upper Atmosphere of Solar Active Region

**Author:** Girjesh Gupta[1]

**Co-author:** Ananya Rawat [2]

[1] *Physical Research Laboratory*

[2] *Udaipur Solar Observatory, Physical Research Laboratory*

During the solar flares, whole solar atmosphere gets heated; however, the energy deposition process in the lower solar atmosphere is still unclear. In this paper, we present spectroscopic and imaging observations of a small-scale transient of life-time $\approx$2-min and subsequent formation of a hot transient loop of life-time $\approx$4-min in a solar active region. The event is classified as an A-class flare by GOES. We utilize multi-wavelength observations recorded by the Interface Region Imaging Spectrograph (IRIS) Slit-Jaw Imager (SJI) and Solar Dynamic Observatory (SDO). Differential emission measure (DEM) analysis shows that the transient attained a more than 10 MK temperature. The observed transient shows hot plasma moving upward, forming a small-scale transient loop with a similar temperature. Using the IRIS density-sensitive O IV line pair, we obtained the average electron number density of $10^{11.25}$ cm$^{-3}$ at the foot-point of the transient. IRIS transition region lines such as O IV and Si IV show a redshift of 10-15 km s$^{-1}$, whereas neutral lines such as C I and S I show a redshift of about 5 km s$^{-1}$. These Doppler shifts suggest a down-flowing plasma in the lower atmosphere, which decelerates in the deeper layers of the lower atmosphere. HMI magnetogram shows that the transient occurred beneath the mixed polarity region and provides evidence of flux emergence of both polarity fields which powers the transient. The observed transient shows enhancement in intensities in all the passbands of the AIA, IRIS, and HMI continuum which are sensitive to different temperatures and follow very clean temperature-dependent time delays in both the lower and upper atmosphere. Enhancement recorded in HMI photospheric visible continuum emission is very much unexpected for such a small energetic A-class flare; such enhancements are generally reported only for giant flares. These enhancements in intensities in the lower atmosphere result from efficient heating either due to the electron beams, or back-warming effects, or damping of downward propagating Alfv\'en waves.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Poster Session-I / Coffee Break / 155**

# On the Latitudinal Variation of Sun's Radius

**Author:** K M Hiremath[1]

[1] *Indian Institute of Astrophysics*

Kodaikanal solar observatory white light image data is used to explore the possible variation of sun's radius with respect to latitude. For the year 1904, very good calibrated digitized and limb darkening removed image is used. After unambiguously detected solar edge, circle is fitted, mean radius and central coordinates are estimated. By knowing these important parameters, heliographic coordinates are fixed for the pixels of the detected edge and, radii at different position angles are computed. Preliminary results show that, for different position angles, from 0-360 degrees, there is indeed a variation of radius with respect to latitude with a mean variation of ~ 0.2 arc secs is estimated. Assuming spherical symmetry, perturbed radius is fitted with Legendre polynomial and it is found that combined modes of dipole, quadruple and octupole terms fit very well with the perturbed sun's radius.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism over Long-Time Scales

**Poster Session-II / Coffee Break / 158**

## Denoising Helioseismic Far-Side Images

**Author:** Aarushi Rawat[1]

**Co-authors:** Dan Yang [1]; Laurent Gizon

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Helioseismology can detect active regions on the Sun's far side days before they rotate onto the Earth's side, using solar acoustic oscillations. These far-side maps provide an important input for space weather models. Recent advances in theoretical and computational helioseismology have improved far-side imaging, which enables high-confidence detection and daily tracking of medium-size active regions. However, these images still suffer from substantial noise due to the stochastic nature of the oscillations. Our study aims to denoise these images by implementing spatial and temporal filters in spectral space to mitigate this noise.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Poster Session-II / Coffee Break / 76**

## Properties of Super Active Region 13664 in Context of the Extreme Geomagnetic Storm of 10-11 May 2024

**Author:** Priyansh Jaswal[1]

**Co-authors:** Dibyendu Nandy [1]; Suvadip Sinha [1]

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Temporary perturbations in the Earth's magnetosphere and upper atmosphere driven by coronal mass ejections (CME) are called geomagnetic storms. It is important to understand the solar sources of geomagnetic storms in order to constrain physical drivers of space weather. A severe geomagnetic storm was observed during 10-11 May 2024. It was the strongest storm on record in the last two decades since 2003. It is believed to have occurred due to multiple Earth-directed intense CMEs which eventually hit the Earth during the aforementioned period. Most of these CMEs were associated with active region (AR) 13664. In our study, we investigate AR 13664 and compare it to other active regions in the historical context to ascertain the rarity of occurrence of such a complex active region and identify the properties that made it super active. We find that AR 13664 was significantly larger in size when compared to other sunspot groups archived by Royal Greenwich Observatory and National Oceanic and Atmospheric Administration (RGO/NOAA). Apart from its size, AR 13664 manifested high magnitudes of flare relevant physical properties simultaneously which led to intense flaring activity over its lifespan. In total, AR 13664 spawned 23 X-class flares over the period 30 April-11 June 2024 during which it completed roughly one and half solar rotation. Our investigations support the idea that energization of complex and large sized AR flux systems can induce

intense flaring activity. We establish AR 13664 to be a super active region (SAR). Our study is important for identifying Super Active Regions given their potential to generate adverse space weather events.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Poster Session-II / Coffee Break / 141**

## Interpretable ML Based Forecasting of CMEs Associated with Flares

**Authors:** Hemapriya Raju[1]; Saurabh Das[1]

[1] *Indian Institute of Technology Indore*

Coronal mass ejections (CMEs) that cause geomagnetic disturbances on the Earth can be found in conjunction with flares, filament eruptions, or independently. Though flares and CMEs are understood as triggered by the common physical process of magnetic reconnection, the degree of association is challenging to predict. From the vector magnetic field data captured by the Helioseismic and Magnetic Imager (HMI) onboard the Solar Dynamics Observatory (SDO), active regions are identified and tracked in what is known as Space Weather HMI Active Region Patches (SHARPs). Eighteen magnetic field features are derived from the SHARP data and fed as input for the machine-learning models to classify whether a flare will be accompanied by a CME (positive class) or not (negative class). Since the frequency of flare accompanied by CME occurrence is less than flare alone events, to address the class imbalance, we have explored the approaches such as undersampling the majority class, oversampling the minority class, and synthetic minority oversampling technique (SMOTE) on the training data. We compare the performance of eight machine-learning models, among which the Support Vector Machine (SVM) and Linear Discriminant Analysis (LDA) model perform best with True Skill Score (TSS) around $0.78 \pm 0.09$ and $0.8 \pm 0.05$, respectively. To improve the predictions, we attempt to incorporate the temporal information as an additional input parameter, resulting in LDA achieving an improved TSS of $0.92 \pm 0.04$. We utilize the wrapper technique and permutation-based model interpretation methods to study the significant SHARP parameters responsible for the predictions made by SVM and LDA models. This study will help develop a real-time prediction of CME events and better understand the underlying physical processes behind the occurrence.

**Contribution Type**:

Poster

**Theme**:

Connecting Solar Corona to Heliosphere

**Poster Session-II / Coffee Break / 87**

## Investigation of Source Regions of Geo-Effective Coronal Mass Ejections (CMEs)

**Author:** Saurabh Tripathi[1]

**Co-authors:** Jayant Joshi [1]; Tanmoy Samanta [1]

[1] *Indian Institute of Astrophysics, Bengaluru*

This study investigates the origins, characteristics, and impacts of Geo-effective Coronal Mass Ejections (CMEs) on Earth's space environment during Solar Cycle 24 th (2009-2019),with a focus on their contribution to space weather phenomena. Specifically, we examine Interplanetary Coronal Mass Ejections (ICMEs) detected at the first Lagrangian point (L1),using their key features such as enhanced magnetic field strength, magnetic field rotation, and reduced proton temperatures,Plasma-β ratio particularly within Magnetic Clouds (MCs). Our work emphasizes CMEs that triggered significant Geomagnetic disturbances, identifying their heliospheric distribution and Solar source regions. Using data from LASCO,SDO, ACE,GOES, and catalogs such as Cane and Richardson's ICME list, CDAW, ARIES, and the HESSI Flare Catalog, we trace the Solar origins of these ICMEs through the Graduated Cylindrical Shell (GCS) model and Jhelioviewer software. This research also investigates the characteristics of Solar flares associated with Geo-effective CMEs, offering insights into the link between solar activity and space weather. By analyzing the variation in Geo-magnetic storms over the Solar cycle, our findings enhance the understanding of Solar-terrestrial interactions and improve predictive capabilities for space weather events.

**Keywords:**
Sun: Coronal Mass Ejection; Sun: Solar Flares; Geomagnetic Storms; Model: GCS model

**Contribution Type**:

Poster

**Theme**:

Connecting Solar Corona to Heliosphere

**Poster Session-I / Coffee Break / 62**

## On the Origin of Near Surface Rotational Shear Layer : Evidence of Mass Accretion During Early History of Solar System Formation

**Author:** K M Hiremath[1]

[1] *Indian Institute of Astrophysics*

Helioseismic inferences show that sun's rotational gradient increases and is positive from base of convection zone to 0.935 radius of the sun. Whereas near surface (from 0.935 to 1.0 sun's radius) rotational gradient is decreasing and is negative. First question arises why present day sun adopted two regions of positive and negative rotational gradients. Hence, any theoretical work should not only explain correctly rotational isocontours but also whether both the positive and negative rotational gradients are dynamically stable or not. Present study examines stability of both the regions of positive and negative rotational gradients. It is found from the MHD stability criterion that positive rotational gradient satisfies such a stability criterion, whereas negative rotational gradient and hence near surface rotational shear does not satisfies unless there is a large-scale toroidal magnetic field structure. Hence, it is concluded that if one accepts negative rotational gradient and toroidal magnetic field structure to coexist near surface, inevitable explanation is probably co-moving planetary mass accretion would have occurred on the sun's surface during early history of solar system formation during when large-scale poloidal magnetic field structure of primordial origin might have wound up as a toroidal magnetic field structure that might have survived upto present epoch near the surface. Evidence of mass accretion and implication especially for solution of "Faint Young Sun Paradox" are presented. Second question to be answered is why near surface (0.935 radius to 1.0 radius) rotational isocontours are different compared to rotational isocontours in the positive rotational gradient. Although questionable, most of models invoke observed Reynolds stresses and temperature difference between equator and both the poles for maintenance of differential rotation and reproduce isorotational contours. In order to reproduce near surface isorotational contours,

with appropriate boundary conditions at the surface and at 0.935 radius of the sun, Chandrasekhar's MHD equations are analytically solved and isorotational contours are reproduced.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism over Long-Time Scales

**Poster Session-II / Coffee Break / 148**

## Investigating the Solar Wind Source Regions through Middle Corona Observations

**Author:** Arpit Shrivastav[1]

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Large-scale coronal structures, such as helmet streamers (HS) and pseudo-streamers (PS), have been studied extensively as potential source regions for solar wind generation. Historically, white-light observations of the outer corona have provided insights into these features. Yet, the dynamics of HS and PS are more clearly observed in the middle corona, where the Sun's magnetic field transitions from closed to open configurations. Despite their significance, the processes driving the dynamic behavior of streamers and pseudo-streamers and their contribution to the slow solar wind remain insufficiently understood, primarily due to the limited availability of high-resolution observations in the middle corona. We address these limitations by utilizing two complementary vantage points: the Full Sun Imager (FSI) onboard Solar Orbiter and the Atmospheric Imaging Assembly (AIA) onboard the Solar Dynamics Observatory (SDO). These instruments allow us to observe the dynamics in the inner and middle corona with the opportunity to connect them. Our analysis focuses on the dynamics around a pseudo-streamer footpoint, where we detect the presence of propagating disturbances (PDs). Our findings highlight the importance of middle corona observations in understanding the physical mechanisms behind the origin of solar wind. These results could contribute to refining models of slow solar wind formation.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Poster Session-II / Coffee Break / 117**

## Connection Between Coronal Abundances and Underlying Lower Atmospheric Properties in Solar Active Regions

**Author:** Paola Testa[1]

**Co-authors:** Andy To [2]; Bart De Pontieu [3]; David Brooks ; Juan Martinez-Sykora [4]

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The solar corona and solar wind are often observed to have elemental abundances different from the solar photosphere, and the observed fractionation appear to depend on the element's first ionization potential, and it is thought to be linked to the processes leading to the solar atmospheric heating. We have used coordinated coronal (Hinode/EIS) and chromospheric and transition region (IRIS) observations to investigate the presence of a footprint of the fractionation process in the lower atmosphere. We discuss intriguing correlations between observed coronal abundances and the properties (turbulence, non-thermal width) of the lower atmosphere, and the potential implications for models of chemical fractionation.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Poster Session-I / Coffee Break / 212**

## Effects of High-Frequency Viscous MHD Waves in Magnetic Flux Tube on Coronal Magneto- Seismology and Coronal Heating

**Authors:** Ankit Kumar[1]; Vinay S. Pandey[1]

[1] *National Institute of Technology Delhi*

Coronal seismology, an essential tool for diagnosing the physical conditions of the solar corona has gained significant attention due to its ability to probe the solar magnetic field and plasma properties through the study of magnetohydrodynamic (MHD) waves in coronal loops. The oscillating signature of these loops, the key features of the solar corona have been extensively observed through both ground-based instruments like CoMP (Coronal Multi-channel Polarimeter) and space-based missions such as TRACE, SDO, Solar Orbiter, and Parker Solar Probe. These high-resolution observations have revealed a variety of oscillatory phenomena within the loops, providing the foundation for modelling them using one dimensional cylindrical geometry. This geometric approach has proven to be particularly effective in the study of magnetohydrodynamic (MHD) waves in structured magnetic environments. Over the past two to three decades, considerable theoretical efforts have been focused on analyzing both trapped and leaky mode waves in ideal plasmas. However, studies of MHD waves in non-ideal plasmas—incorporating dissipative mechanisms like viscosity and resistivity—remain limited, particularly concerning trapped modes. While leaky modes in non-ideal plasmas is still under investigation. This study addresses this gap by investigating both trapped and leaky mode waves in non-ideal plasmas, using transport coefficients as a primary damping mechanism. We developed a generalized dispersion relation for these modes within a cylindrical geometry by modifying the boundary conditions to accommodate them together. This theoretical framework enables the calculation of critical diagnostic parameters, including period, damping time, magnetic field strength, density contrast, and Q-factor, which are essential for coronal seismology. The above said formulation would be tested to the observational finding of the latest solar missions e.g., Hinode, SDO, Solar Orbiter, and Parker Solar Probe. This work would enhance the utility of magneto-seismology in diagnosing solar atmospheric conditions, particularly by offering new insights in the role of viscosity and other non-ideal effects in wave damping and coronal heating processes.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism in High-Resolution

**Stellar Activity as a Limiting Factor for Characterising Exoplanets / 97**

## Star Planet Interaction from Solar System to Exoplanets

**Author:** Arghyadeep Paul[1]

**Co-author:** Antoine Strugarek [1]

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The interaction between stellar winds and planetary magnetospheres has been a focus of research for decades. Within the heliospheric context, star-planet interactions similar to that between the Sun and the Earth reshapes the planet's local magnetic environment leading to the formation of magnetospheres. In the context of exoplanetary systems, star-planet interactions vary depending on the planet's orbital location. For close-in orbits located in the sub-Alfvénic stellar wind, the Poynting flux generated by star-planet interactions can propagate toward the star, giving rise to chromospheric hotspots. Our current work characterises and quantifies the efficiency of this energy transfer between the planet and the star, revealing that a significant portion of the energy is reflected by the stellar transition region back toward the planet. The firm detection and characterisation of such magnetic interactions from observations of chromospheric hotspots would lead to constraints on the amplitude of the magnetic field of exoplanets, to which we are blind so far. Future research, utilising the previously developed magnetosphere-ionosphere model, will explore how the presence or absence of a planetary ionosphere influences the Poynting flux generated by the planet.

**Contribution Type**:

**Theme**:

Solar - Stellar Connections

**Poster Session-I / Coffee Break / 29**

## Evaluating the Importance of High Resolution Active Region Data in the Large-scale Coronal Magnetic Field Evolution

**Author:** Prantika Bhowmik[1]

[1] *Department of Physics, Indian Institute of Science Bangalore*

Active regions are one of the primary sources of solar eruptive events like flares and coronal mass ejections, causing adverse space weather conditions. Complex magnetic field distributions of observed active regions are often quantified using diverse tools and techniques, which are later used for measuring the chance of their eruptivity. Similar tools are also utilised to validate magnetic field data generated from magnetohydrodynamic simulations of active region emergence and justify their similarities with observation. In both cases, the resolution of the active region plays a crucial role. However, there is a need for more generalised ways to evaluate how the active region magnetic field is distributed across different length scales. We have developed a method characterising the active regions based on Zernike polynomial analysis, the Cartesian counterpart of spherical polar decomposition, which is applicable to most Cartesian solar active regions models and CEA magnetogram data. This framework for Zernike mode comparison provides a precise and straightforward method for quantitatively comparing magnetic fields whilst accounting for their complex spatial variations. Such a tool based on polynomial decomposition is also useful for identifying the relevant length

scales of active-region-associated magnetic fields reaching the upper heights of the solar corona, thus guiding us in understanding the importance of high-resolution active region data.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Poster Session-II / Coffee Break / 31**

## Investigation of Plasma Relaxation in Solar Flares Using Data-Constrained MHD Simulations

**Author:** Satyam Agarwal[1]

**Co-authors:** Ramit Bhattcharyya [1]; Shangbin Yang [2]; Thomas Wiegelmann [3]

[1] *Physical Research Laboratory*

[2] *Key Laboratory of Solar Activity, National Astronomical Observatories*

[3] *Max-Planck-Institut für Sonnensystemforschung*

Solar flares are transient events occurring over a time scale of minutes to hours, characterized by a sudden release of magnetic energy in the form of heat and kinetic energy of the plasma. These events are believed to be the manifestations of the magnetic reconnection process. We have explored the effects of 3D reconnection in solar flares, focusing on (a) magnetofluid dynamics from the perspective of plasma relaxation theory (b) reconfiguration of magnetic geometries such as null points, QSL, and HFT (c) spatiotemporal evolution of magnetic energy, current density, and related quantities namely twist and magnetic field gradient. A novel research problem exploring effects of two competing extrapolation techniques on the study of flare dynamics in data-constrained simulations is formulated. The novelty is in recognizing that reconnection is dissipative, which suggests its implications to be nearly independent of the used extrapolation model. The numerical model EULAG-MHD is used for the simulations, initiated using three different initial conditions constructed using non-linear force-free and non force-free field extrapolations. Both models produced similar null point and HFT geometries. The dissipated free magnetic energy and changes in field line connectivity because of reconnection were also similar in all simulations. Further, a null point topology generated spontaneously and disappeared in each case near HFT. During its existence, its fan plane exhibited slipping reconnection, which is found to be indicative of having plausible contribution in the investigated flare. The key conclusions are (a) both extrapolation models are suitable for initiating data-constrained MHD simulations and (b) short lived magnetic structures may also be relevant in the overall energetics of flare dynamics. The release of magnetic energy in transients leads to the expectation that magnetic field should relax to a lower energy state. Therefore, it is natural to consider the feasibility of known relaxed states in the post-transient state of magnetofluid. Notably, the Taylor's state is of immediate interest because it minimizes magnetic energy and hence relates directly to the transients. In this regard, earlier studies focused on analytical magnetic fields or observations, but to account for the complexity of active-region magnetic fields, simulated dynamics of an actual flare is investigated. Taylor's theory assumes conducting walls but since the solar corona is an open system, three integration volumes of different sizes are envisaged to navigate through this challenge. The study revealed an important result: to realize magnetic energy decay and hence relaxation, the size of the chosen relaxation volume needs to be large enough such that energy transfer due to Poynting flux is small. In absence of physical resistivity, Poynting flux is estimated using ideal MHD and the problem of validating it in various regions of the computational box is tackled by calculating the deviation of the induction equation from its ideal form. The analysis of angular alignment between current density and magnetic field showed evolution toward force-free state but relaxation is not enough to achieve the Taylor's state. The key conclusion from this study is that flare energetics may have a bearing on the extent of relaxation. To explore further, three energetically different flares are analyzed and it is found that from the viewpoint of energy decay, relaxation extent is in concurrence with the general relation between the energy classes of chosen flares. However, an interpretation of change in angular alignment in the context of relaxation extent is found to be non-trivial. An

interesting finding of the work is a parameter based on reconnection morphologies that may predict the strength of solar flares and hence might prove useful in space-weather applications.

**Contribution Type**:

Poster

**Theme**:

Energetic Phenomena

**30**

## Solar Wind-Magnetosphere Coupling Efficiency and Its Dependence on Solar Activity During Geomagnetic Storms of 23-24 Solar Cycles

**Authors:** Manju G[1]; Sini R[2]; Vm Ashna[2]

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Space weather forecasts are of utmost importance in safeguarding navigation, communication, and electric power system operations, satellites from orbital drag, and the astronauts in the International Space Station from hazardous space radiation during extreme space weather conditions. The finest space weather prediction requires a clear understanding of solar wind-magnetosphere coupling. The in-situ measurements of the solar wind properties give unique information about the Sun and its activity on smaller to longer timescales. The present work investigates the influence of solar activity on the coupling of solar wind and Earth's magnetosphere during 23–24 solar cycles. The geomagnetic storms with Symmetric H-component (SYMH) $\leq -85$ nT during the 23–24 solar cycles are considered. We present the results of statistical analysis and relationships between the various solar wind parameters such as the total strength of interplanetary magnetic field (B) and its three-axis components (Bx, By, and Bz), solar wind proton density (Nsw), solar wind speed (Vsw), SYMH indices, the amplitude, duration, and profile of the geomagnetic storms. The integrated electric field and integrated SYMH index during storms show the highest correlation of 0.92, implying that integrated SYMH is a better proxy of the injected solar wind energy in the magnetosphere in the form of the ring current. Moreover, we do see the difference in the solar wind-magnetosphere coupling efficiency during the phases of 23–24 solar cycles which is intriguing.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism over Long-Time Scales

**Poster Session-II / Coffee Break / 157**

## Forecasting Space Weather Using a CNN-LSTM Model: A Multi-spacecraft Approach with Aditya-L1.

**Authors:** Dibyendu Chakrabarty[1]; Prashant Kumar[1]; Abhishek Kumar[1]; Jacob Sebastian[1]; Yogesh Sharma[2]; Aakash Gupta[1]; Shivam Parashar[1]

[1] *Physical Research Laboratory, Department of Space, Ahmedabad*

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The dynamic connection between the solar corona and the heliosphere is critical for understanding and forecasting space weather. Active regions and solar eruptions, including extreme events, significantly influence the heliospheric environment, with profound implications for Earth's magnetosphere. Leveraging data from new space missions like ASPEX-SWIS from Aditya-L1, Parker Solar Probe (PSP), Solar Orbiter, and WIND, we aim to enhance space weather forecasting capabilities through a data-driven approach.

A machine learning model based on a hybrid CNN-LSTM architecture has been developed to forecast space weather conditions by predicting the Dst index using bulk parameters at L1 and IMF Bz. This work presents a comprehensive approach by integrating Aditya-L1, WIND, and Solar Orbiter observations with ground-based data. The model processes L1-point measurements to classify and quantify Earth's response to solar disturbances. Initial results suggest that by incorporating Aditya-L1's observations of the solar wind, magnetic fields, and energetic particles, the accuracy of predicting geomagnetic storms has improved, offering critical insights into their potential impact on Earth's technological systems.

Our results demonstrate the strength of data fusion from multiple space missions, providing a more comprehensive understanding of solar-heliospheric coupling. This approach opens new avenues for advancing heliospheric and space weather studies, with significant implications for extreme solar events and their terrestrial consequences. These findings and their broader impact will be discussed.

**Contribution Type**:

Poster

**Theme**:

Connecting Solar Corona to Heliosphere

**Poster Session-I / Coffee Break / 35**

# Spectroscopy of Chromospheric Fibrils at High Resolution: DKIST Observations

**Author:** Sanjay Gosain[1]

[1] *National Solar Observatory*

We perform high resolution spectroscopy of chromospheric fibrils near a plage network observed with the DKIST ViSP spectropolarimeter. The physical properties of the fibrils are inferred with the novel inversion approach of machine learning and k-means clustering. We infer the temperature and density structure of the fibrils with optical depth and analyze their variation along the fibrils. Finally, we confront the plasma flows in the fibrils in terms of thermal nonequilibrium and/or siphon flow models.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism in High-Resolution

**Poster Session-I / Coffee Break / 32**

## Athermal Solar Plasma Fluctuations in Helioseismic Perspective

**Author:** Souvik Das[1]

**Co-author:** Pralay Kumar Karmakar [1]

[1] *Tezpur University*

A plethora of waves and oscillations are ubiquitously excitable in the entire solar plasma spatiotemporal regime. A linear perturbation analysis on the kappa($\kappa$)-modified viscoturbulent nonthermal solar plasmas is herein methodically carried out. It yields in a unique linear cubic dispersion relation for the self-gravitationally bounded solar plasma system. The multi-parametric dispersion signatures sensitively depend on the nonthermality spectral index, plasma temperature, fluid dynamic viscosity, thermal conductivity, and geometrical curvature effects. Diverse modal features of the helioseismic *g*-mode and *p*-mode are analytically explored. The *g*-mode dominates only in the deeper constituent concentric layers of the Sun. The *p*-mode propagates throughout the Sun up to its surface. Existence of the solar five-minute oscillation is theoretically confirmed. The plasma nonthermality index, conductivity, and temperature serve as mode accelerating agents; while, the dynamic viscosity plays the role of a decelerating one. The radially outward photospheric *p*-mode energy flux density is estimated as $10^4$ W m$^{-2}$. Leakage of this longitudinal *p*-mode energy flux contributes significantly to the chromospheric transverse spicule formation through mode conversion processes. Numerous solar observational data existing in the literature justifiably corroborate the findings of this proposed analyses.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism over Long-Time Scales

**Poster Session-II / Coffee Break / 102**

## Precise and Accurate Short-Term Forecasting of Solar Energetic Particle Events with Multivariate Time-Series Classifiers

**Author:** Sumanth Rotti[1]

**Co-authors:** Berkay Aydin [1]; Petrus Martens [1]

[1] *Georgia State University*

Solar energetic particle (SEP) events are one of the most crucial aspects of space weather that require continuous monitoring and forecasting using robust methods. We demonstrate a proof of concept of using a data-driven supervised classification framework on a multivariate time-series data set covering solar cycles 22, 23, and 24. We implement ensemble modeling that merges the results from three proton channels (E>10 MeV, 50 MeV, and 100 MeV) and the long-band X-ray flux (1–8 Å) channel from the Geostationary Operational Environmental Satellite missions. Our task is binary classification, such that the aim of the model is to distinguish strong SEP events from nonevents. Here, strong SEP events are those crossing the Space Weather Prediction Center's "S1"threshold of solar radiation storm and proton uxes below that threshold are weak SEP events. In addition, we consider periods of nonoccurrence of SEPs following a flare with magnitudes $\geq$ C6.0 to maintain a natural imbalance of sample distribution. In our data set, there are 244 strong SEP events comprising the positive class. There are 189 weak events and 2460“SEP-quiet”periods for the negative class. We experiment with summary statistic, one-nearest neighbor, and supervised time-series forest (STSF) classifiers and compare their performance to validate our methods for prediction windows from 5 minutes up to 60 minutes. We find the STSF model to perform better under all circumstances. For an optimal classification threshold of ≈0.3 and a 60 minutes prediction window, we obtain a true skill statistic TSS= 0.850, Heidke skill score HSS= 0.878, and Gilbert skill score GSS= 0.783.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Instruments/Facilities and Science: New and Upcoming / 142**

## Parker Solar Probe: From Exploration to Paradigm Shifting Discoveries

**Author:** Nour E. Rawafi[1]

[1] *Johns Hopkins Applied Physics Laboratory*

Parker Solar Probe has been trailblazing around the Sun for nearly half a solar cycle, delivering groundbreaking insights into its immediate atmosphere. To date, Parker has completed 21 of its scheduled 24 orbits during the prime science phase of the mission. The diverse and unparalleled quality data it gathers has captivated both the international space science community and the public. With its closest approach to the Sun scheduled for 24 December 2024, excitement and anticipation are at an all-time high. The mission has already resulted in paradigm-shifting discoveries and shows no signs of slowing down, making it arguably the most successful heliophysics mission to date. The future looks bright as the spacecraft and its payload continue to perform exceptionally well, which is very promising for the continuation of the mission beyond its prime science phase. I will provide an overview of the outstanding achievements of the mission and the outlook as we enter the declining phase of solar cycle 25 and beyond.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Poster Session-II / Coffee Break / 182**

## An Automated Real-Time Trigger for Solar Radio Burst Detection for the Murchison Widefield Array using Yamagawa Spectrograph

**Author:** Deepan Patra[1]

**Co-authors:** Devojyoti Kansabanik [2]; Yuki Kubo [3]; Divya Oberoi [4]; Andrew Williams [5]; Naoto Nishizuka [3]

[1] *National Centre for Radio Astrophysics*

[2] *University Corporation for Atmospheric Research*

[3] *National Institute of Information and Communications Technology, Japan*

[4] *National Centre for Radio Astrophysics, Tata Institute of Fundamental Research*

[5] *International Centre for Radio Astronomy Research, Curtin University, Bentley, WA, Australia*

Solar radio bursts are often byproducts of phenomena like coronal mass ejections (CMEs) and/or solar flares. They are capable of producing very high brightness temperatures and hence lead to a large increase in the observed intensity. Depending upon the details of the physical processes and emission mechanisms involved, their dynamic spectra can show markedly different spectro-temporal structures, based on which they are classified into several types. Detecting and studying solar bursts is extremely important for understanding coronal emission mechanisms as well as for improving space-weather predictions. However, most studies of solar radio bursts have been performed using dynamic spectra which do not provide any spatial or morphological information. In recent times, the capabilities of the cutting edge radio interferometers, like the Murchison Widefield Array (MWA), a precursor for the Square Kilometre Array Observatory (SKAO), accompanied by the developments in interferometric calibration and imaging, provide a good match to the needs of solar radio observations. However the observing time of these versatile instruments is rather oversubscribed and only a limited amount is available for solar observations. In addition, the infrequent and unpredictable nature of radio bursts makes it very inefficient to observe them using observations based on an observing schedule decided well ahead of time. These 'blind'observations tend to be a bit like fishing expeditions – one never knows what one will come back with. A robust and reliable automated near-real-time observing trigger can improve this situation dramatically. By enabling one to use precious observing time only when some solar activity is known to have just taken place, such a system can vastly increase the efficiency of limited available observing time to capture instances of solar activity. With observatories like the SKAO on the horizon, the need for such a system is even more imperative. We demonstrate a solar burst triggering pipeline which takes near-real time data from the Yamagawa spectrograph, analyzes it to detect presence of solar activity and generates a trigger, when required, to schedule solar observations at the MWA. These triggers have been tested and tuned using the archival Yamagawa data and end-to-end tests of triggered observations have successfully been carried out at the MWA. Recently this real-time triggering has been operationalized at the MWA, a very timely development in view of the approaching solar maxima.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Poster Session-II / Coffee Break / 192**

## Studying Electrostatic Solitary Wave Phenomena Due to Solar Wind-Magnetosphere Interaction at Mars's Reconnection Region

**Author:** Nivedita Chakraborty[1]

**Co-authors:** Selvaraj Devanandhan [1]; Satyavir Singh [1]; Gurbax Lakhina [1]

[1] *Indian Institute of Geomagnetism*

Solar wind interaction with the planetary magnetic field (or a conducting ionosphere), results in the formation of a magnetosphere which may be intrinsic or induced, depending upon whether the planet has its own magnetic field or not. Plasma waves are the means through which different subsystems of the magnetosphere like the magnetopause, ionopause, plasmasphere, etc. interact with each other, thus controlling the dynamics of the magnetosphere. Though the planet Mars lacks a global intrinsic magnetic field, but due to the presence of its crustal magnetic anomalies and its direct interaction with the solar wind, a mini-magnetosphere is formed. The MAVEN (Mars Atmosphere and Volatile EvolutioN) data has shown magnetic-reconnection events at mini-magnetopause. Due

to the intermixing of different plasma populations coming from the solar wind and the planetary ionosphere results in the rich wave phenomena in this region. Ion-acoustic solitary waves have been observed by MAVEN Langmuir Probes and Waves (LPW) medium frequency burst capture data. These waves are isolated sinusoids having bipolar structures in the electric field. In our study, we have examined the wave activity in the magnetic reconnection region by setting up a theoretical model consisting of solar wind protons and Martian ions (O+ and O2+) with superthermal electrons in order to explain the generation of ion-acoustic solitary waves observed by MAVEN.

**Contribution Type**:

Poster

**Theme**:

Energetic Phenomena

**67**

## Gravity Waves in the Lower Solar Atmosphere

**Author:** Hirdesh Kumar[1]

**Co-authors:** Brajesh Kumar [1]; S.P. Rajaguru [2]

[1] *Udaipur Solar Observatory, Physical Research Laboratory, Udaipur*

[2] *Indian Institute of Astrophysics*

Gravity waves are generated by turbulent subsurface convection overshooting or penetrating locally into a stably stratified medium. While propagating energy upwards, their characteristic negative phase shift over height is a well-recognized observational signature. Since their first detailed observational detection and estimates of energy content, a number of studies have explored their propagation characteristics and interaction with magnetic fields and other wave modes in the solar atmosphere. We have investigated atmospheric gravity wave dispersion diagrams utilizing intensity observations that cover photospheric to chromospheric heights over different magnetic configurations of quiet-Sun (magnetic network regions), a plage, and a sunspot as well as velocity observations within the photospheric layer over a quiet and a sunspot region. In order to investigate the propagation characteristics, we construct two–height intensity-intensity and velocity-velocity cross-spectra and study phase and coherence signals in the wavenumber-frequency dispersion diagrams and their association with background magnetic fields. We find signatures of association between magnetic fields and much reduced coherence and phase shifts over height from intensity-intensity and velocity-velocity phase and coherence diagrams, both indicating suppression/scattering of gravity waves by the magnetic fields. Our results are consistent with the earlier numerical simulations, which indicate that gravity waves are suppressed or scattered and reflected back into the lower solar atmosphere in the presence of magnetic fields.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism in High-Resolution

**Poster Session-II / Coffee Break / 196**

## Pushing the Boundaries of Planet Detection in the RV Method

**Authors:** Anoop Gavankar[1]; Tanish Mittal[2]

**Co-authors:** Joe Ninan [1]; Shravan M Hanasoge [3]

[1] *Tata Institute of Fundamental Research, Mumbai*

[2] *Birla Institute of Technology, Pilani*

[3] *Tata Institute of Fundamental Research and Centre for Space Science*

Radial velocity measuring instruments are nearing the precision needed for detecting Earth-like exoplanets, yet a new challenge emerges the star's own fluctuations. Disentangling the signatures of spurious radial velocity changes because of photospheric fluid flows is a complicated, multidimensional problem. Traditional methods, though partly successful, haven't fully tapped into the spectrum's hidden information. Identifying hidden patterns and exploiting higher-order correlations is where machine learning algorithms shine. We used the NEID solar data observations spanning the period 2020 to 2022 for training the network and for the injection recovery tests. During this period, the stellar jitter had an r.m.s. of 1.77 m/s. We show our ML algorithm can recover planetary signal periods and semi-amplitudes between 65-95 cm/s in semi-amplitude, with high accuracy(>76%), for temporally shuffled solar spectra. Even with real solar noise and aperiodic observations, our ML algorithm adeptly handles signals as low as 65 cm/s. We also present a method to use ML to decorrelate solar rotation from the Keplerian signal Period prediction algorithm, while preserving the temporal order of solar data, demonstrating AI's potential in EPRV research.

**Contribution Type**:

Poster

**Theme**:

Solar - Stellar Connections

**Poster Session-II / Coffee Break / 74**

## Thermal Evolution of Earth-Directed CMEs Driving the Extreme Geomagnetic Storm on May 10, 2024

**Author:** Soumyaranjan Khuntia[1]

**Co-authors:** Wageesh Mishra [1]; Anjali Agarwal [1]

[1] *Indian Institute of Astrophysics*

In May 2024, a series of solar eruptions occurred, triggered by a complex active region ($\beta\ \gamma\delta$ ), leading to the extreme geomagnetic storm on May 10, 2024, the strongest storm in the last two decades. We investigate the kinematic and thermal evolution of coronal mass ejections (CMEs) responsible for this extreme event using multi-point coronagraphic data and near-Earth in-situ measurements, focusing on potential CME-CME interactions and their influence on observed in-situ data. We identified six CMEs directed towards Earth using SOHO/LASCO and STEREO-A/COR2 coronagraphs and applied the GCS model to estimate their 3D kinematics. To study the thermal evolution of the CMEs, we used the flux rope internal state (FRIS) model, which links their expansion to thermal properties. Further, we analyzed data from the Wind spacecraft to understand the heating and cooling within the ejected plasma near Earth. Our results show that the CMEs exhibited varying thermal behavior as they expanded, with many reaching an isothermal state at larger distances from the Sun. We also found that slower CME expansion tends to cause heat release in the plasma. Interestingly, electrons exhibit distinct thermal behaviors pre and post-ICME (heating) compared to those within the ICME (heat release). In contrast, ions within the CME show a two-phase temperature pattern. Overall, the interactions between CMEs strongly influence their kinematic and thermodynamic evolution and the resulting space weather effects.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Poster Session-I / Coffee Break / 82**

## Solar Chromospheric Differential Rotation Using Ca-K Features Derived from Kodaikanal Data

**Author:** Hema Kharayat[1]

**Co-authors:** Jagdev Singh [2]; Muthu Priyal [2]; B. Ravindra [2]

[1] *M. L. K. P. G. College, Balrampur, U.P., India*

[2] *Indian Institute of Astrophysics, Bangalore*

Solar differential rotation plays an important role in the generation of Sun's magnetic fields and its activities. For the present work, the digitized data of four chromospheric features viz plage area, enhanced network (EN), active network (AN), and quiet network (QN) obtained from Kodaikanal Observatory for the period 1907-1996 are used to investigate the differential rotation at different latitude belt from 0 to 80 degrees with a step size of 10° in both hemispheres. We find that plages and all types of networks exhibit the differential rotation of the chromosphere. Furthermore, the rotation rate shows a decreasing pattern as one move from the equator to the higher polar latitudes for all the features used in the study. At the equator, the rotation rate (rotation period) is obtained to be ~13.98° $day^{-1}$ (25.74 days), ~13.91° $day^{-1}$ (25.88 days), ~13.99° $day^{-1}$ (25.74 days), and ~14.11° $day^{-1}$ (25.51 days) for plage, EN, AN, and QN areas, respectively. By analyzing how the area of chromospheric features varies over time, we can effectively map the Sun's rotation rate at all latitudes, including the polar regions. Interestingly, both plages and small-scale networks exhibit a similar differential rotation rate. This suggests these features likely rooted at the same layer below the visible surface of the Sun. Therefore, the long-term Ca-K data is very useful for studying the solar rotation rate at all latitudes including the polar regions.

**Contribution Type**:

**Theme**:

Solar Magnetism over Long-Time Scales

**Poster Session-II / Coffee Break / 85**

## Radio Occultation Observations to Probe the Solar Corona and Solar Wind

**Author:** Sasikumar Raja Kantepalli[1]

**Co-authors:** Prasad Subramanian [2]; Ramesh R [1]

[1] *Indian Institute of Astrophysics*

[2] *IISER Pune*

When distant radio point sources are observed through the foreground solar corona or solar wind, they experience angular or scatter broadening, and lead to change in peak flux density, anisotropy, and orientation of the major axis of the source. Such modulations are useful for probing solar wind parameters such as the amplitude of turbulence, density modulation index, proton heating rates, and dissipation scales. By utilizing the Crab Nebula occultation observations carried out with the Gauribidanur Radio Heliograph, along with data available in the literature, we probed the solar wind density turbulence and how these parameters vary with heliocentric distance and the solar cycle. Such studies are essential for addressing long-standing issues such as solar wind heating and solar wind acceleration. Furthermore, based on these results, I will emphasize the importance of short baseline solar-dedicated radio telescopes at low frequencies.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Poster Session-II / Coffee Break / 144**

## An Effective Approach for Identifying Magnetic Field Switchbacks in the Solar Wind

**Author:** Dipali Vadher[1]

**Co-authors:** Ankush Bhaskar [2]; Kamlesh Pathak [1]; Smitha Thampi [2]

[1] *Sardar Vallabhbhai National Institute of Technology*

[2] *Space Physics Laboratory, VSSC*

Magnetic field switchbacks, crucial for understanding solar wind dynamics, are typically identified through magnetic field reversals (Dudok de Wit et al., 2020). This methodology is susceptible to mistakes stemming from data contamination caused by phenomena such as coronal mass ejections (CMEs), flux ropes, magnetic clouds (MICCS), heliospheric current sheets (HCS), partial heliospheric plasma sheets, and strahl dropout. To improve identification accuracy, we provide an advanced method that employs stringent criteria by utilizing several solar wind parameters, including density, temperature, plasma beta, deflection angle, and solar wind velocity. This multi-parameter approach significantly enhances the accuracy of switchback identification by removing data contamination and reducing false positives. Our methodology provides a more reliable analysis of magnetic field Switchbacks in the solar wind.

**Contribution Type**:

Poster

**Theme**:

Connecting Solar Corona to Heliosphere

**Poster Session-II / Coffee Break / 189**

## Machine Scientist for Understanding and Mitigating Stellar Activity in Exoplanet Detection

**Authors:** Lev Tal-Or[1]; Mangesh Daspute[1]

[1] *Ari'el University*

Stellar activity produces noise in radial velocity data, which hinders Earth-mass exoplanet detection. Radial velocity jitter is a complex nonlinear combination of effects of stellar spots, faculae, p-mode oscillation, and granulation which also works on different timescales. We use a data-driven approach to determine the effect of stellar activity on radial velocity. We used the normalised flux of multiple absorption lines from HARPS-N solar spectra as input and radial velocity in a heliocentric rest frame as output for the machine learning model. To model stellar activity, we used a Bayesian Machine Scientist. By predicting and subtracting the effect of stellar activity on radial velocity we were able to reduce the standard deviation in the noise in the data to 1.2 m/s and 1.6 m/s of effect was modeled out.

**Contribution Type**:

Poster

**Theme**:

Solar - Stellar Connections

**Poster Session-I / Coffee Break / 45**

## Temporal Evolutions of Fractional Ca-K Plage Area Measured at Kodaikanal Observatory

**Author:** Partha Chowdhury[1]

**Co-authors:** Jagdev Singh [2]; Muthu Priyal [2]; Ravindra Belur [2]

[1] *Calcutta University, India*

[2] *Indian Institute of Astrophysics,*

The "Equal-Contrast technique" (ECT) methodology is developed to generate uniform long time series of Ca-K images obtained during the 20th century from the Kodaikanal Observatory (KO), India for studying the long- and short-term variations in the solar chromosphere. We investigate temporal and periodic variations of the fractional Ca-K plage area time series of the full solar disk for cycle 14 -22. We have studied the correlation between the fractional plage area and sunspot number for each cycle under study. We have found the prominent presence of different intermediate term periodicities in the plage area data along with the ~ 11 year solar cycle period. Possible interpretations of our findings are discussed with the help of existing theoretical models and observations.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism over Long-Time Scales

**Poster Session-I / Coffee Break / 91**

## Results and Methods of the Test and Calibration of SUIT on board Aditya-L1

**Author:** Janmejoy Sarkar[1]

**Co-authors:** A.N. Ramaprakash [2]; Durgesh Tripathi [2]; Sreejith Padinhatteeri [3]; Rushikesh Deogaonkar [2]; Nived V.N. [2]; Rahul Gopalakrishnan [2]; Soumya Roy [2]; SUIT Team

[1] *IUCAA, Pune and Tezpur University*

[2] *IUCAA, Pune*

[3] *MCNS, MAHE*

The Solar Ultraviolet Imaging Telescope (SUIT) onboard Aditya-L1 performs spatially resolved full-disk imaging of the Sun across the 200–400 nm wavelength range with eleven bandpasses. SUIT provides a comprehensive view of different layers of the solar atmosphere, enabling the study of dynamic solar phenomena such as flares and jets, magnetic structures like plages, active regions, and network regions, and irradiance studies in NUV bands absorbed by $O_2$ and $O_3$ in Earth's upper atmosphere- necessary for studying Sun-Earth climatic relationships. Given the volume and complexity of SUIT's observations, precise calibration is essential to derive scientifically accurate data. Reliable calibration profiles and an accurate account of payload optical characteristics, such as plate scale, modulation transfer function (MTF), field of view, and total photometric error, are critical for the reliability of data calibration in the image processing pipeline. This work presents the calibration test methodology and the results, helping us quantify the payload's optical properties and perform reliable calibration of SUIT data.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Poster Session-I / Coffee Break / 86**

## Segmentation of Full-Disk H-alpha Images to Understand the Lower Solar Chromospheric Variability

**Authors:** B Prabhu Ramkumar[1]; R Kariyappa[2]; H N Adithya[3]; B Ravindra[2]; Yoichiro Hanaoka[4]; Kazuki Nishida[4]

[1] *Indian Institute of Astrophysics, Kodaikanal , India*

[2] *Indian Institute of Astrophysics, Bangalore, India*

[3] *Manipal Centre for Natural Science, Manipal Academy of Higher Education, Manipal, 576104, India*

[4] *National Astronomical Observatory of Japan, Mitaka, Japan*

The CaII H and K resonance lines are widely used to study the solar chromospheric structures and their variability. These lines are very sensitive to the variations in temperature and the magnetic field strength, therefore they are excellent indicators of the chromospheric structural changes related to solar magnetic activity. The studies on the lower chromospheric variability using H-alpha images have not been done. It is important to study the lower chromospheric variability by segmenting the different chromospheric features from the spatially resolved full-disk H-alpha images. We have developed an algorithm in python to analyze the full disk H-alpha images observed from Kodaikanal Solar Observatory (KSO) and National Astronomical Observatory of Japan (NAOJ) for the period: 2014 to 2024. We have segmented the spatially resolved H-alpha images and extracted the different features such as bright faculae, dark filaments and background regions to understand the lower chromospheric variability. The intensity and area of the segmented features are determined. The contributions of the segmented H-alpha features to total lower chromospheric variations are estimated. The preliminary results of the intensity and area variations of all features and their contributions to total lower chromospheric variability will be discussed in this paper. The results obtained from both KSO & NAOJ images will be inter-compared.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism over Long-Time Scales

**Poster Session-I / Coffee Break / 149**

## Solar Coronal Magnetic Field Strength Estimation from the Observations at Low Radio Frequencies (35-85MHz) Using Augmented Gauribidanur RadioheliograPH (GRAPH)

**Author:** Sayuf Shaik[1]

**Co-authors:** Kathiravan Chidambaram ; Ramesh R [1]; Gireesh GVS ; Indrajit Barve [1]

[1] *Indian Institute of Astrophysics*

The coronal magnetic field (B) is predominant in forming structures such as streamers, holes, etc., and in determining their spatio-temporal evolution. Its routine estimation will most likely provide clues/answers to several unsolved problems in solar physics and, therefore, gain significance among solar physicists. Extrapolating the Photospheric magnetic field strength using the Potential Field Source Surface (PFSS) model is one of the current approaches to determining B since direct measurements are currently unavailable. High-resolution circular polarization observations in the 1-20 GHz frequency range help estimate B above active regions (r ⊠ 1.05 Ro; where 'r'is heliocentric distance and Ro = Photospheric radius), whereas spectro-polarimetric observations using coronal emission lines help occasionally in the height range of 1.05 ⊠ r ⊠ 1.2 Ro. Estimating it above 1.2 Ro is difficult because the strength is feeble (~ Gauss). Researchers use Faraday rotation measurements to determine B, especially in the 3 Ro ⊠ r ⊠ 15 Ro height range. In the intermediate range (1.2 ⊠ r ⊠ 3.0 Ro), spectro-polarimetric observations of fortuitous radio bursts at meter wavelength and above are used. These radio bursts are occasional and are enhanced by associated solar activity. Given the above, the estimate of B in the quiet coronal regions in a routine manner is scarce. In the recent past, theoreticians indicated the possibility of estimating B from the observed quiet coronal thermal radio emission. The foundation for this came from the magneto-ionic theory, which conveys that B makes the plasma medium anisotropic and thereby splits the original randomly polarized thermal radio emission from the corona into two orthogonal circularly polarized components (viz., the ordinary and extraordinary waves). While propagating, the magnetized plasma absorbs these two components differently due to the difference in absorption coefficients and propagation directions. So, the resultant emission has the sense of circular polarization of the dominant component and an appreciable magnitude at the meter wavelength range and above. Due to the above, we started commissioning a dedicated radio facility to routinely measure B in the quiet corona, particularly in the 1.1 - 2.0 Ro heliocentric distance range, to address the various pertinent scientific problems. For that, the existing Gauribidanur RAdioheliograPH (GRAPH) of the Gauribidanur radio observatory is being augmented to image the circularly polarized (CP) radio emission, in addition to total intensity in the 30 - 130 MHz frequency range. The necessary analog and digital receivers are being built and characterized. The computer algorithms based on the ray-tracing technique using Haselgrove equations are also being developed to reproduce the observed total and CP intensity images.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism in High-Resolution

**Poster Session-II / Coffee Break / 209**

## Magnetic Reconnection: An Alternative Explanation of Radio Emission in Galaxy Clusters

**Author:** Subham Ghosh[1]

[1] *International Centre for Theoretical Sciences*

We observe non-thermal radio emission with spectral indices ranging from 1 to 3, extending over megaparsec scales almost in the centre of the galaxy clusters containing largely collisionless plasma. To explain this, the electrons must be energized. While turbulence or shocks generated by merger events can accelerate electrons, their efficiency is relatively low. We explore an alternative mechanism: particle acceleration via magnetic reconnection in the turbulent intracluster medium (ICM). Reconnection sites naturally arise from the fluctuation dynamo, which generates strong magnetic fields reversing on short length scales. Using particle-in-cell (PIC) simulations for non-relativistic plasma (typical ICM temperatures of ~10^8 K), we investigate how magnetic energy is converted to electron kinetic energy, which eventually gets converted to radio through the synchrotron cooling of electrons. Driven by the tearing instability, magnetic reconnection begins by giving rise to magnetic islands and x-points, where the inductive electric field gets generated and accelerates the particles. Soon after the saturation of the tearing instability, the plasmoid instability takes over and enhances the reconnecting electric field. Thus, magnetic energy gets converted to electrons kinetic energy. Our results show that initial non-relativistic and thermal electrons become relativistic and non-thermal through reconnection. The resulting energy spectra match with that inferred from the observed radio spectra in galaxy clusters. Moreover, the estimated maximum electron energy (Lorentz factor ~10^5) agrees with observations, and the synchrotron luminosity (~10^41 ergs/s) is consistent with the observed values. This supports reconnection as an efficient particle acceleration mechanism in the ICM.

**Contribution Type**:

Poster

**Theme**:

Solar - Stellar Connections

**Poster Session-I / Coffee Break / 150**

## Long-Term Correlation Studies of the Ca-K and H-alpha Spectroheliograms from the Kodaikanal Archival Data

**Author:** Apoorva Srinivasa[1]

**Co-authors:** Raju K.P. [2]; Narayanankutty Karuppath [1]

[1] *Amrita Vishwa Vidyapeetham*

[2] *Indian Institute of Astrophysics*

We studied the sun's chromosphere through Ca-K and H-alpha full-disk spectroheliograms from Kodaikanal archival data. Our study looks at the long-term correlation analysis of features such as plages, filaments, and active regions across these two chromospheric lines. By developing robust methodologies for feature extraction, we have tried to understand the long-term behavior of the chromosphere and its relationship to solar activity. We report some preliminary results in this presentation. This work is significant for solar physics, as it will deepen our understanding of the solar magnetic evolution and its influence on the sun's outer layers.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism over Long-Time Scales

**Poster Session-II / Coffee Break / 99**

## ADCMI - Study of Stellar Variability and Their Comparisons with Sun like Stars.

**Author:** Janvi Agarwal[1]

**Co-authors:** Jitendra Joshi [2]; Raka Dabahde [3]

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Astronomers have uncovered a captivating facet among the myriad celestial bodies, known as Variable Stars. These mysterious entities undergo changes in their radiance over time, offering astronomers a unique opportunity to study the complexities of stars. Since 1911, the **American Association of Variable Star Observers (AAVSO)** has been diligently monitoring these stars. Variable star astronomy is a vital field of study as it provides valuable information about stellar properties and their evolution. In the course of this project, the main focus is centred on the study of **AD CMI**, a **Cepheid variable** star. Cepheids are a type of variable star that pulsates radially, varying in both diameter and temperature. This study aims to provide an overview of stars, with a particular emphasis on variable stars, using AD CMI as an illustrative subject. The brightness of AD CMI varies within a magnitude range of 9.596 to 9.284 over its variable period. Within a three-hour period, it is observed that the magnitude of AD CMI decreases, remains constant for a few minutes, and then increases once again. The process of the complete project included several night sky observations and post-processing of these images. It also involved performing photometric methods and data analysis at the end of it. Furthermore, this study results in the creation of a light curve representing the variability of AD CMI. This curve is generated by plotting brightness against time using the Python programming language. After performing a sine curve fitting, this plot facilitates the extraction of crucial attributes such as amplitude, frequency, and phase of AD CMI's variable behaviour. These discoveries offer valuable insights into the complex nature of Stars and Sun like stars. The finding into the project can be further used to study Stellar variability of other stars and compare it with the Sun. Not only this but also can be used as initial level studies to differentiate between regular stars and Sun like stars. In summary, the continuation of this study with more complex celestial objects may open new doors to gain a more detailed understanding of the Sun and the Stellar variability.

**Contribution Type**:

Poster

**Theme**:

Solar - Stellar Connections

**Poster Session-II / Coffee Break / 210**

## Characterization of Magnetic Activity on the Sun Using Disc-integrated Spectra

**Author:** Parvathy Menon[1]

**Co-authors:** Anagha K. B. [1]; S.P. Rajaguru [1]; Thirupathi sivarani [1]

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Stellar surface inhomogeneities presented by convection, magnetic spots, bright plages, and faculae are recognized as important in the accurate retrieval of exoplanet properties as they can be a source of noise and confusion in stellar radial-velocity (RV) measurements. The identification and characterization of exoplanets around Sun-like stars are impacted by changes in intensity and other spectral signatures due to such spatial inhomogeneities over time scales spanning a few minutes to years. High-energy events like solar flares and coronal mass ejections (CMEs) also leave characteristic signatures in the activity indices derivable from various spectral lines. In this work, we investigate activity-related features seen in the disk-integrated spectra of the Sun using time series of Sun-as-as-star spectral observations by HARPS-N and NEID instruments. We also look for signatures of high-energy solar events and solar cycle variation in the spectral indices, which in turn help us understand such variations in sun-like exoplanet host stars. Further, we carry out an analysis examining correlations between spot, faculae, and plage fill factors and the stellar activity indices.

**Contribution Type**:

**Theme**:

Solar - Stellar Connections

**Poster Session-II / Coffee Break / 103**

## Evolution of CME Radial Size and Expansion Speed: 3D Kinematics and Non-Conventional Approach to In Situ Observations

**Author:** Anjali Agarwal[1]

**Co-author:** Wageesh Mishra [1]

[1] *Indian Institute of Astrophysics*

Coronal Mass Ejections (CMEs) are expulsions of magnetized plasma bubbles from the Sun episodically, and they are the potential candidates for severe space weather impacts on the Earth. However, the impact duration of CMEs on Earth is governed by their radial sizes and speeds upon arrival. In our work, we estimate a CME's radial size and instantaneous expansion speed at different instances during its passage over a single point in situ spacecraft by introducing a non-conventional approach. Using the 3D kinematics of CME substructures, leading edge (LE), center, and trailing edge (TE), we estimate the continuous evolution of a CME's radial size and expansion speed from the Sun to 1 AU. The 3D kinematics of CME substructures are estimated using 3D reconstruction methods, GCS and SSSE, applied on multipoint coronagraphs and heliospheric imagers combined with the drag-based model. For our study, we selected a 2010 April 3 CME, a favorable candidate, to provide a better comparison between remote and in situ observations. We show that our non-conventional approach can better estimate the radial size and expansion speed at different instances than the conventional approach on remote and single-point in situ observations. We also examine the role of the aspect ratio on the continuous evolution of CME's radial size and expansion speed from the Sun to 1 AU. We demonstrate that the value of the aspect ratio is different in the corona and interplanetary medium. Our study highlights the discrepancies in the estimates of arrival time, radial size, and expansion speed of remote and in situ observations, even in the case of a favorable CME. Moreover, multipoint in situ spacecraft and our non-conventional approach can improve our understanding of the CME and its substructure's evolution in the solar wind.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Poster Session-II / Coffee Break / 106**

## Modeling the Dynamics of Sun's Atmosphere to Study Its Energy Balance and Heating in Coronal Region.

**Author:** Devesh Sharma[1]

**Co-author:** Bhargav Vaidya [1]

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**Heating** in the solar atmosphere has been a long standing problem in solar physics. Despite advancements in both observational and theoretical frameworks, the precise mechanisms that heat the corona are not yet well understood. Phenomena like **magnetic reconnection** and **wave heating** have been suggested as the cause, but the extent to which each process contributes to the overall energy balance is still unclear. This study aims to develop a simple numerical model of the Sun's atmosphere, encompassing the upper convection layer up till the corona, using **magnetohydrodynamic (MHD) code PLUTO** and to study the energy balance of the solar atmosphere. Accurate chromosphere representation requires **non-local thermodynamic equilibrium (NLTE)** approach for radiative transfer which gives a good approximation for radiative cooling while ambipolar diffusion and hall effect are crucial for heating in the atmosphere. Lines from neutral hydrogen, calcium ions (Ca II), and magnesium ions (Mg II) are prominent in the chromosphere for radiative cooling which is calculated using the recipe formulated by Carlsson and Leenaarts (2012). By including the NLTE radiative transfer approximation in the MHD model we seek to explore the energetic events such as **magnetic reconnection, chromospheric jets and magneto-acoustic waves** and their corresponding EUV emissions to probe the heating mechanisms.

**Contribution Type**:

Poster

**Theme**:

Energetic Phenomena

**Poster Session-I / Coffee Break / 4**

## Periodicities in Solar Microwave Emissions during Solar Cycles 20-24

**Author:** Mahender Aroori[1]

**Co-authors:** Sasikumar Raja Kantepalli [2]; Vemareddy Panditi [2]

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[2] *Indian Institute of Astrophysics*

We have performed time-series analysis of sunspot number (SSN) and solar radio flux at five different frequencies (1000 MHz, 2000 MHz, 3750 MHz, 9400 MHz, and 17000 MHz) observed during solar cycles 20-24 (i.e., from 1964-10 to 2019-11; ≈ 55 years). We measured the Pearson correlation coefficient between SSN and solar flux density measured at the aforementioned frequencies and found a maximum correlation ≈ r = 0.93 at 2000 MHz. However, r value decreases either side of 2000 MHz and minimum was observed at 17000 MHz. Further, from this time-series data, the LS periodogram is derived for combined as well as individual cycle data. Based on LSP analysis, we found rotational periods (26-29 days) in all data sets except at 17000 MHz. We also detected Rieger type periods in all frequencies in the range of 155-190 days except at 1000 MHz. In addition to the rotational and Ri´ger type periods, we found other short-term periods (37-100 days), intermediate periods (200-300 days), annual periods (≈ 365), quasi-biennial periods (475-730 days), and other long-term periods (>

730) as categorized in (Aroori et al., 2021). For the individual cycles, the Lomb-Scargle (LS) spectrum presents variation of the significant periods in Rieger, annual and quasi-biennial range from cycle to cycle. This variation may be related to the variation of the solar activity from cycle to cycle and from large to small scale. The combined LS spectrum of all the cycles exhibits significant periods in all period bands and they are largely consistent with each observations as well as sunspot number.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism over Long-Time Scales

**Poster Session-I / Coffee Break / 105**

## The Relation between Solar Spicules and Magneto-Hydrodynamic Shocks

**Authors:** Sankalp Srivastava[1]; Sahel Dey[2]; Piyali Chatterjee[1]

[1] *Indian Institute of Astrophysics*

[2] *School of Information and Physical Sciences, University of Newcastle, Australia*

Spicules are thin, elongated jet-like features ubiquitously seen shooting upwards in observations of the solar atmosphere, appearing to protrude into the corona before (mostly) falling back to the solar surface. These features exhibit highly complex dynamics during their short lifetimes of 5-10 minutes and seem to be a necessary connecting link between the cooler, denser solar chromosphere and the extremely hot, tenuous corona. In this work, we explore the spatial and temporal relation between solar spicules and magneto-hydrodynamic (MHD) shocks using data from a 2D radiative MHD (rMHD) simulation of the solar atmosphere driven by realistic solar convection that was earlier reported by Dey et al. 2022. This model was able to self-consistently excite a forest of spicules with heights in the range of 6–25 Mm and speeds in the range 30–80 km/s, in agreement with observations. In this work, we demonstrate that slow MHD shocks, which propagate along magnetic field lines, are regions of strong positive vertical acceleration of the plasma that forms the tip of the spicule material during its rise phase. We further show that the strength of these shocks may play a vital role in determining the heights of the spicules, supporting the idea that shocks act as drivers of spicules. In addition, we report some results on the presence of structures similar to propagating coronal disturbances (PCDs) in the simulation, linked with the spicules.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism in High-Resolution

**Poster Session-II / Coffee Break / 10**

## Dimming Inferred Estimation of CME Direction - DIRECD

**Author:** Shantanu Jain[1]

**Co-authors:** Tatiana Podladchikova [1]; Galina Chikunova [2]; Karin Dissauer [3]; Astrid Veronig [4]

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[4] *University of Graz*

Coronal mass ejections (CMEs) are intense solar phenomena where plasma and magnetic fields are ejected from the Sun, playing a significant role in influencing Space Weather. However, traditional coronagraphs struggle to accurately capture the early stages of Earth-directed CMEs due to projection-related distortions. Coronal dimmings, which manifest as localized reductions in extreme-ultraviolet (EUV) and soft X-ray emissions, are key indicators of CMEs in the low corona. These dimmings result from the loss and expansion of mass during a CME eruption. This study presents a novel approach called DIRECD (Dimming InfeRred Estimate of CME Direction), designed to estimate the initial propagation direction of CMEs based on the expansion of these dimmings. The method utilizes 3D CME simulations combined with a geometric cone model, considering parameters such as width, height, source location, and deviation from the radial path. By identifying the primary direction of dimming expansion, the method solves an inverse problem to reconstruct a series of CME cones at various heights, widths, and deviations. The 3D direction of the CME is then determined by matching the CME projections on the solar sphere with the dimming geometry. This approach has been validated through case studies of events on October 1, 2011, September 6, 2011, and May 2024, demonstrating that the initial propagation directions of CMEs closely align with those derived from 3D tie-pointing of the CME bubble observed in the EUV (lower corona) and the GCS 3D modeling of the white-light CME (higher corona). Moreover, these results are consistent with multi-viewpoint coronagraph observations from SOHO and STEREO, underscoring the potential of coronal dimming data for early CME direction estimation.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Poster Session-II / Coffee Break / 79**

## Numerical Modeling of Multiple Magnetic Reconnection in Chromospheric Current Sheet

**Author:** Akash Bairagi[1]

**Co-authors:** Abhishekh Kumar Srivastava [1]; David I. Pontin [2]; Eric R. Priest [3]; Sripan Mondal [1]

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The solar chromosphere possesses complex magnetic structuring and plasma dynamics at diverse spatio-temporal scales. Using MPI-AMRVAC, we have modeled the chromospheric magnetic reconnection process by externally perturbing a localized horizontal current sheet (CS) in the presence of radiative cooling and thermal conduction. Due to the an applied pressure gradient across the CS, the magnetic fields are trying to primarily reconnects at the centre of the CS, generating bidirectional plasma outflows. A central steady plasmoid is formed in the CS. After a certain time, two X-points are formed within the CS, on either side of the central plasmoid. at both the sides of the central region of the CS. This causes multiple reconnections at those X-points. In this entire process reconnection takes place in those locations during which, the magnetic energy is converted into joule heating, kinetic energy and internal energy. The outflow speed is about 20 km/s that is equivalent to the speed of observed typical cool chromospheric jets. The average temperature of the cool chromospheric plasma is elevated up to upper chromospheric temperature at around 21104 K. We further include ambipolar diffusion and ionisation fraction in our simulation. In the case of weakly ionised

plasma and in the presence of ambipolar diffusion, the temperature remains almost constant in the later phase of magnetic reconnection.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Poster Session-II / Coffee Break / 15**

## Improving Solar Wind Forecasting Models Over the Phase of Solar Cycle: Source Surface Height Optimization and Magnetogram Impact

**Author:** Sandeep Kumar[1]

**Co-authors:** Dana Camelia Talpeanu [2]; Elke D'Huys [2]; Marie Dominique [2]; Marilena Mierla [2]; Nandita Srivastava [3]

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The operational solar wind prediction models used by the community are based on the Potential Field Source Surface (PFSS) model for the magnetic field using synoptic magnetograms. Previous studies comparing observed and modeled open magnetic flux at L1 based on PFSS extrapolations have suggested the need to optimize the source surface (SS) height with the phase of the solar cycle. The current study investigates the effects and necessity of optimizing the source surface height in popular solar wind forecasting model, i.e., Wang Sheeley and Arge (WSA) model, along with the heliospheric extrapolation model, i.e., Heliospheric Upwind eXtrapolation (HUX). Conventionally, the Carrington rotation (CR) maps obtained from the GONG network have been used in the framework. We performed a long-term study from Jan 2010 to June 2023 spanning SC24 and SC25 to optimize SS height in the WSA model. Our study confirms the need for optimization with the solar cycle phase. We also performed a detailed study on 16 CRs that considers the effect of using different types of magnetograms obtained from the GONG network on the performance of the framework, i.e., Pearson's coefficient of the modeled and observed solar wind velocity profile at L1. Our findings based on 16 representative CRs at different phases of SC24 and SC25 confirm the need for optimization with the solar cycle phase and agree with the long-term study. A higher source surface height, i.e., 3.0 $R_\odot$ near the solar minimum, resulted in up to 30% increase in the average performance of the framework. Notably, the results also highlight the importance of using zero-point corrected maps, which improves the PFSS performance in solar wind prediction models.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Poster Session-I / Coffee Break / 23**

## Analyses of Features of Magnetic Cycles at Different Amounts of Dynamo Supercriticality: Solar Dynamo is About Two Times Critical

**Authors:** Sanket Wavhal[1]; Pawan Kumar[1]; Bidya Binay Karak[1]; Dipanwita Mishra[1]

[1] *Indian Institute of Technology (BHU) Varanasi*

The growth of a large-scale magnetic field in the Sun and stars is usually possible when the dynamo number $(D)$ is above a critical value $D_c$. As the star ages, its rotation rate and thus $D$ decrease. Hence, the question is how far the solar dynamo is from the critical dynamo transition. To answer this question, we have performed a set of simulations using Babcock–Leighton type dynamo models at different values of dynamo supercriticality and analyzed various features of the magnetic cycle. By (i) comparing the recovery rates of the dynamo from the Maunder minimum and statistics (numbers and durations) of the grand minima and maxima with that of observations and (ii) modeling the amplitudes of the last five solar cycles using the observed polar field, we show that the solar dynamo is only about two times critical and thus not highly supercritical. The observed correlation between the polar field proxy and the following cycle amplitudes and the Gnevyshev-Ohl rule are also compatible with this conclusion.

**Contribution Type**:

**Theme**:

Solar Magnetism over Long-Time Scales

**Poster Session-I / Coffee Break / 104**

## Translation of Ca II K Images to Construct Century-Old Magnetograms using Deep Learning

**Authors:** Dattaraj B Dhuri[1]; Maya Prabhakar[2]; Shravan M Hanasoge[3]; Neelanchal Joshi[4]

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[2] *Tata Institute of Fundamental Research*

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[4] *Max Planck Institute for Solar System Research*

Extending the record of solar activity is very important to improving our understanding of the origins and evolution of solar magnetism. To this end, we attempt to generate solar magnetograms using the valuable century-long Ca II K image database from the Kodaikanal Solar Observatory (KSO). We set up an image-to-image translation model using conditional Generative Adversarial Network (cGAN) to exploit the relationship between the chromospheric emission and the magnetic field strength to convert the KSO Ca II K images to the corresponding magnetograms observed from Michelson and Doppler Imager (MDI) onboard Solar and Heliospheric Observatory (SOHO) between 1996 - 2007. These reconstructions are found to have an accurate correspondence with the unsigned magnetograms from MDI/SOHO based on a pixel-to-pixel as well as total unsigned magnetic flux comparison. By nominally assigning polarities following Hale's law, we generate magnetograms between the past solar cycles over the period 1974 - 1993, and validate them by comparing them with the magnetograms from Kitt Peak Solar Observatory. Using the validated model, we assemble a database of the generated magnetograms between 1908 - 2008. We provide an assessment of the generated magnetograms by inspecting a derived sunspot number time series and the reconstructed butterfly diagram. We believe this century-long database can provide new insights into the long-term variability of the solar activity cycle.

**Contribution Type**:

**Theme**:

Solar Magnetism over Long-Time Scales

**Poster Session-II / Coffee Break / 161**

## Source Region of Intense Solar Radio Burst During an Eruptive Flare: Correlating Flare-CME Signatures from Udaipur-CALLISTO Dynamic Spectrum and AIA/SDO Observations

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**Co-authors:** Bhuwan Joshi [1]; Kushagra Upadhyay [1]

[1] *Udaipur Solar Observatory, Physical Research Laboratory*

Exploration of solar radio dynamic spectrum provides us with an opportunity to probe the multi-scale energetic phenomena during coronal transients including large-scale eruptions. To monitor solar radio bursts at metric wavelengths, the Udaipur Solar Observatory, Physical Research Laboratory (USO-PRL) operates a low-cost solar radio observation facility based on CALLISTO spectrometers. In this work, we present a comprehensive study focusing on the origin of solar radio bursts observed on 10 May 2024 around 06:27-07:50 UT. These radio bursts were associated with an eruptive X4.0 class flare originating from the active region NOAA 13664. The examination of the GOES soft X-ray light curves and Atmospheric Imaging Assembly (AIA) extreme ultraviolet imaging reveal typical characteristics of eruptive flares, such as parallel flare ribbons and post-flare loop systems. HMI line-of-sight magnetograms display a complex morphology with a significantly long polarity inversion line (PIL). The eruption of the magnetic flux rope, lying above the PIL, produced simultaneous type III and type II radio bursts. These observations suggest that the event involved the ejection of relativistic electrons and energetic particles from the Sun, along with the outward propagation of a coronal shock associated with a coronal mass ejection (CME). We also explore the existing ideas in both ideal- and resistive-MHD eruption models to understand the CME initiation process in the source region.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Poster Session-I / Coffee Break / 147**

## A Statistical Study of Ephemeral Regions through HMI Magnetograms

**Authors:** Anu Sreedevi[1]; Bibhuti Kumar Jha[2]; Bidya Binay Karak[1]; Robert Cameron[3]

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Solar activity is readily observed through the emergence of magnetic structures of varying sizes on the solar surface. While larger magnetic regions have been extensively studied and are well understood, Ephemeral Regions (ERs) represent small-scale, short-lived magnetic features that frequently emerge on the photosphere throughout all phases of the solar cycle. The magnetic flux of ERs ranges from $3 \times 10^{18}$ Mx to $9 \times 10^{20}$ Mx (Harvey, 1993), and due to their relatively low contrast, they are not typically visible in white-light images. ERs are thought to play a critical role in terms of the flux budget of Sun and heating the solar corona. Detecting and analyzing ERs is essential for understanding their origin (either through small-scale or large-scale dynamos) and dynamics of solar magnetism at finer scales. In this study, we use line-of-sight magnetogram data from HMI to systematically identify and track ERs with a modified version of the AutoTAB algorithm (Sreedevi et al., 2023, ApJS, 268, 58). Our analysis covers an entire solar cycle, allowing us to explore the emergence, evolution, and decay of ERs across different solar activity phases. We investigate the spatial and temporal characteristics of ERs, their tilt distribution, adherence to Joy's law, and their role in small-scale dynamo processes. In this poster, we present the initial results of this study.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism over Long-Time Scales

**Poster Session-I / Coffee Break / 50**

## Propagation and Damping of 3-min Slow Waves from Photosphere to Corona along the Umbral Fan Loops

**Author:** Ananya Rawat[1]

**Co-author:** Girjesh Gupta [2]

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[2] *Physical Research Laboratory*

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 atmosphere is still unclear. Here, we present study of these waves along a clean fan loop system using the multi-wavelength imaging and spectroscopic observations from IRIS and SDO. We traced 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 transition region and chromosphere. These modulation periods are in the range of 20–35 min at all the heights. Tracing of these loops also provide first observational evidence of cross-sectional area expansion of loops with height from the photosphere to corona. We estimated the energy flux of propagating 3-min SMAWs from the photosphere to corona along the fan loops and obtained damping length to be 208$\pm$7 km. We further investigated the role of area expansion of these loops on the damping of these SMAWs. We deduced the decay of total wave energy content within the loop cross-sectional area with height and estimated the damping length in this case to be 303$\pm$10 km. Henceforth, we present the actual damping of SMAWs after incorporating the geometric effect of area expansion of the loops. Finding reveals the role of area expansion of loops with height in the apparent and actual damping of waves from the photosphere to corona. Result also provides clear evidence of magnetic coupling of the solar umbral atmosphere through the propagation of 3-min waves along the fan loops at different atmospheric heights.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Poster Session-II / Coffee Break / 164**

## Observations of the Homologous Flares by AR 13386 on the 5th and 6th of August 2023.

**Author:** Deepak Kathait[1]

**Co-authors:** A.N. Ramaprakash [1]; Durgesh Tripathi [1]; Nandita Srivastava [2]; Soumya Roy [1]; Sreejith Padinhatteeri [3]; Vishal Upendran [4]

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Flares are the most energetic events on the sun, powered by magnetic reconnection. Here, we study the three homologous flares produced by AR 13386 on the 5th and 6th of August 2023, using imaging and spectroscopy from different instruments and vantage points to study the thermodynamic and elemental abundance evolution. We calculate DEMs from AIA/SDO observations to establish the temporal evolution of the flare thermodynamics, which is then supplemented by the temperatures calculated using GOES and XSM/Chandrayaan-2 data. Temperature profiles from all three calculations match and follow a similar trend. We use XSM data to capture changes in the elemental abundance. Reliable abundance calculations cannot be done for the first flare as the spectrum has contributions from other flaring regions. From the STIX/Solar Orbiter, only the loops of the flare arcade are visible, and the footpoints are occulted, while FERMI observes both footpoints and loops. We compare this data and probe the interaction between loops and footpoints of the flare. The second flare shows an anomalous increase in the elemental abundances during the impulsive phase before dropping to the photospheric values and then returning to coronal values in the decay phase. The third flare does not show an anomalous increase in elemental abundance.

**Contribution Type**:

Poster

**Theme**:

Energetic Phenomena

**Poster Session-I / Coffee Break / 166**

## Do BMRs Emerge with Tilts Consistent with Joy's law?

**Author:** Rambahadur Gupta[1]

**Co-authors:** Anu Sreedevi [1]; Bidya Binay Karak [1]; Bibhuti Kumar Jha [2]

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The Bipolar Magnetic Regions (BMRs) are intense magnetic regions on the Sun's surface, separated by a neutral line. These regions are thought to emerge in the form of magnetic bundles (flux tubes) due to magnetic buoyancy, rising through the convection zone (CZ) in an east-west orientation with a tilt relative to the equator. It has been observed that statistically, BMRs emerging at higher latitudes exhibit larger tilts, Joy's law. According to the thin flux tube model, the tilt is produced by the Coriolis force acting on the diverging flows from the apex of the rising flux tube during its rise in the convection zone. Hence, BMRs are expected to emerge on the photosphere with a tilt. However, this idea has not been supported by any solid observations. In this analysis, using AutoTAB (Sreedevi et al., 2023, ApJS, 268, 58), we identify and track newly emergent BMRs on the solar surface from the time they first appear, using line-of-sight magnetogram observations from MDI and HMI over the past two solar cycles. We particularly examine the tilts during their emergent phase. Our initial analyses show that a large fraction of BMRs show a tilt consistent with Joy's law.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Poster Session-I / Coffee Break / 44**

## Multi-Height Study of the Chromospheric Inverse Evershed Flow and its Association with Photospheric Flows

**Author:** Sandeep K Dubey[1]

**Co-authors:** Christian Beck [2]; Debi Prasad Choudhary [3]; Shibu Mathew [4]

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We analyzed the inverse Evershed flow (IEF) around a sunspot (NOAA 13131) using line scan observations in the Fe I 6173 A and Ca II 8542 A lines. The line scan observations were acquired using a narrow band imager of the Multi-Aplication Solar Telescope (MAST), Udaipur, and were complimented with the data products of HMI onboard SDO. The line-of-sight velocities for different layers of the photosphere and chromosphere were obtained from bi-sector levels in both spectral lines. Additionally, the Ca II 8542 A spectra were inverted using the NICOLE inversion code to retrieve the temperature and velocity stratification over different layers of the photosphere and the chromosphere. The IEF was observed to evolve dynamically in time and with height in the solar atmosphere. The strength of the flow decreased with decreasing height, almost vanishing in the upper photosphere and lower chromosphere. The overall appearance of the flow along the IEF channels seemed consistent with a siphon flow model. We also investigated the association of the IEF with the photospheric Evershed flow (EF), but no obvious connection was found in our analysis. We find that the IEF and EF are aligned along magnetic field lines, which are independent of each other. We also analyzed the effect of the IEF on moving magnetic features, but no obvious association was found in our analysis.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Poster Session-II / Coffee Break / 169**

## Analysing Turbulence in Coronal Mass Ejections Using Empirical Mode Decomposition

**Author:** Akanksha Dagore[1]

**Co-authors:** Giuseppe Prete [2]; Vincenzo Carbone [2]

[1] *University of Trento, Italy and University of Calabria, Italy*

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Coronal mass ejections (CMEs), originating from the sun's corona, are large-scale eruptions of plasma and magnetic flux that propagate into interplanetary space, and are capable of significantly influencing the dynamic environment of the inner solar system. Previous studies have established that CMEs exhibit turbulent behavior, characterized by energy cascades from larger to smaller scales through the formation of eddies. This study investigates the turbulence properties at different stages of a CME evolution. We divide the CME event into three intervals, characterised by the arrival of the CME shock and the magnetic cloud region. The magnetic field signal was decomposed using the method of empirical mode decomposition (EMD) into intrinsic mode functions (IMFs), which capture inherent oscillatory modes within the data. For each magnetic field component (Bx, By, Bz), we generated Fourier power spectra and Hilbert-Huang spectra, representing the power distribution across frequencies within the three intervals. These spectra can provide insights into the turbulent nature of the magnetic field during the different stages of CME evolution.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Poster Session-II / Coffee Break / 194**

## Association Between the Chirality of a Filament and the Helicity of the Supporting Active Regions

**Authors:** Jain Jacob P. T.[1]; Ram Ajor Maurya[1]

[1] *National Institute of Technology, Calicut*

We investigate the handedness in the solar magnetic structures like chromospheric filaments and photospheric active regions using observations obtained from GONG, KSO, and SDO/HMI. At its initial stage near the east limb, we identified a right-bearing sense for the filament barbs and negative helicity in the supporting active region (AR). Subsequently, we observed an emergence of positive helicity in this AR and a change in the bearing sense of the associated filament. Following this emergence, the filament adhered to the hemispheric helicity rule, maintaining the helicity of the underlying AR throughout its disc passage and following to the conservation of helicity. Our conclusion is that the AR in the photosphere and the filament in the chromosphere are interconnected, exhibiting similar patterns of helicity for the long duration of their lifespans.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism over Long-Time Scales

**Poster Session-I / Coffee Break / 180**

## Using Mars Rover's Onboard Imaging Equipment to Observe Solar Far-side Active Regions to Enhance Earth-based Solar Observations.

**Author:** Kere Ravi Arjun[1]

**Co-authors:** Rituparna B Curt [2]; Shea A Hess Webber [3]

[1] *Indian Institute of Science Education and Research, Mohali*

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[3] *Physical Science Research Scientist, Hansen Experimental Physics Laboratory (HEPL), Stanford University*

The Perseverance Rover has been on the Martian surface since February 2021. The rover has Mastcam-Z navigation stereo cameras (Kinch et al., 2020) that can capture direct images of the Sun's surface. During periods of Mars's orbit, the rover has a unique view-point of the Sun's far-side (not visible from Earth at any given time). Solar scientists can use the rover's conveniently positioned cameras to monitor sunspots that we cannot otherwise observe. By collecting these data, we can verify helioseismic detections of the Sun's largest far-side active regions. In this project, solar far-side acoustic images obtained using time-distance helioseismology (Zhao et al., 2019) and SDO/HMI Dopplergrams (Scherrer et al., 2011) are compared with white-light observations from the Perseverance Mastcam-Z cameras. By taking advantage of Mars' orbital positioning, our goal is to refine the acoustic "true/false positive"detections in the helioseismic maps. Ultimately, this can help improve the assimilated boundary conditions of coronal and solar wind models, which in turn can aid in more accurate space weather forecasting.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism over Long-Time Scales

**Poster Session-II / Coffee Break / 130**

## Improved Detection of Superflares on Solar-Type Stars

**Author:** Rohan Kumar[1]

**Co-authors:** Dibyendu Nandi [1]; Ryan Cloutier [2]

[1] *IISER Kolkata*

[2] *McMaster University*

Stellar flares are energetic eruptions and a critical indicator of magnetic activity on stars. Superflares, defined as flares with energies exceeding $10^{32}$ ergs, if they occurred on our Sun, could trigger severe space weather and result in widespread disruption of space-based technologies. While there is debate over whether such events have occurred in the Earth's past, understanding their frequency on solar-type stars is crucial for predicting the likelihood and recurrence of such an event on the Sun. An automated and unbiased flare detection method is essential for enabling these studies. We have developed a Python-based stellar flare detection pipeline, which we have tested on optical light curve data from NASA's Transiting Exoplanet Survey Satellite (TESS). The flare detection process is entirely data-driven, identifying significant contiguous outliers for classification and energy calculations. We are applying this pipeline to study the flare frequency distribution of solar-type stars, which will provide insights into the occurrence of superflares. This research will deepen our understanding of superflares on solar-type stars and has the potential to shed light on the evolution of stellar magnetic activity, as flares serve as probes of stellar magnetism and dynamo action.

**Contribution Type**:

Poster

**Theme**:

Solar - Stellar Connections

**21**

## Evidence of a Non-Orthogonal X-Line in Guide-Field Magnetic Reconnection

**Author:** Neha Pathak[1]

**Co-authors:** A. Chasapis ; N. Ahmadi ; R.E. Ergun [1]; S. J. Schwartz ; T. Vo ; Y. Qi

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We will present compelling evidence suggesting the X-line of guide-field magnetic reconnection is not necessarily orthogonal to the plane in which magnetic reconnection occurs. The plane of magnetic reconnection is often referred to as the L-N plane, where L is the direction of the reversing and reconnecting magnetic field and N is normal to the current sheet. The X-line is often assumed to be orthogonal to the L-N plane (defined as the M direction) in the majority of theoretical studies and numerical simulations. The four-satellite Magnetospheric Multiscale (MMS) mission, however, observes a moderate guide-field magnetic reconnection event in Earth's magnetotail in which the X-line is significantly and credibly oblique to the L-N plane. This finding is somewhat opportune as two of the MMS satellites in the same N location report nearly identical observations in the electron diffusion region (EDR) even though they have substantial separation in L. A minimum directional derivative analysis, which suggests that the X-line is nearly 60o from M, adds support that the X-line is oblique. Furthermore, the measured ion velocity is inconsistent with the apparent motion of the MMS spacecraft in the L direction through the EDR, which can be resolved if one assumes a strong shear of the L-N plane and motion in the M direction. A non-orthogonal X-line, if somewhat common, would call for revisiting theory and simulations of guide-field magnetic reconnection and a reexamination of how the reconnection electric field may supported in the EDR.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Poster Session-I / Coffee Break / 186**

## Pi2 Pulsation Observed in the Magnetosphere and on the Ground.

**Author:** Omar Elsebaei[1]

[1] *Navigation Science and Space Technology Beni Suef University*

Pi2 pulsations are impulsive oscillations associated with magnetospheric substorm onsets. In this study, we investigate a geomagnetic Pi2 pulsation using the electric field data from the Van Allen Probe satellites (NASA'mission) in the magnetosphere, and on the ground. The Pi2 oscillations in the compressional components are investigated. We noticed a high degree of similarity between the Pi2 event in magnetosphere and on the ground.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism over Long-Time Scales

**Poster Session-II / Coffee Break / 145**

## Interpretable Deep Learning for Solar Flare Predictions

**Authors:** A.N. Ramaprakash[1]; Durgesh Tripathi[1]; Linn Abraham[1]; Nandita Srivastava[2]; Ninan Sajeeth Philip[3]; Sreejith Padinhatteeri[4]; Vishal Upendran[5]

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In recent years, the development of machine learning (ML) models for solar flare prediction has primarily relied on magnetogram data. Traditionally, shallow and interpretable ML models have been used, employing various features derived from these magnetograms. These models often show comparable performance after optimization, likely due to the reliance on similar features from photospheric magnetograms. However, advances in using original magnetogram data or coronal imaging for flare prediction have been limited by the complexity of the data and the lack of suitable computational methods. Deep learning (DL) models present a new opportunity to utilize multi-wavelength data for predicting solar flares. In this study, we aim to understand the intensity measurements on the Sun that lead to flare events. We develop a DL model trained to classify data cubes from the AIA Active Region into flaring and non-flaring classes. We interpret the model's decisions by applying Grad-CAM, Shapley values, and Integrated Gradients to identify the most critical features for this classification. By opening the "black box" of DL models, we gain insights into the physical processes that trigger solar flares, enhancing our understanding and prediction capabilities. We also compare the results of the model interpretation technique on two different models, a relatively simple CNN architecture and a state-of-the-art attention based model.

**Contribution Type**:

Poster

**Theme**:

Energetic Phenomena

**Poster Session-II / Coffee Break / 190**

## Energetic and Kinematic Properties of Recurrent Solar Active Region Jets: Multi-Wavelength Analysis with AIA and IRIS Observations

**Author:** Prakhar Singh[1]

**Co-authors:** Arpit Kumar Shrivastav [1]; Vaibhav Pant [1]

[1] *Aryabhatta Research Institute of Observational Sciences (ARIES)*

Solar jets are described as collimated, beam-like structures that eject plasma along straight or slightly oblique magnetic field lines. They can be observed from the lower solar atmosphere up to the corona, spanning a wide range of temperatures. In this study, we present an analysis of recurrent solar jets observed on 6 March 2022 near the active region NOAA 12960, using data from the Atmospheric Imaging Assembly (AIA) onboard the Solar Dynamics Observatory (SDO) and the Interface Region Imaging Spectrograph (IRIS). The jets were observed in various passbands of AIA and multiple spectral channels of IRIS, enabling a comprehensive examination of their dynamics and energetics. We calculated the kinematic properties of four distinct jets, including length, width, duration, and velocity, and estimated mean temperature, as well as electron density, using the differential emission measure (DEM) technique. Using the intensity ratio of the O IV 1399.77/1401.16 Å lines, we further estimated electron densities and energy fluxes within the jets. To investigate the magnetic origins of these jets, we incorporated magnetogram data from the Helioseismic and Magnetic Imager (HMI) onboard SDO. This magnetic field analysis revealed that flux emergence and cancellation events near NOAA 12960 likely contributed to magnetic reconnection, driving the observed jet eruptions. A crude estimate of the energy flux components —kinetic flux, potential flux, enthalpy flux, radiative flux and magnetic flux are calculated —indicating that kinetic and enthalpy fluxes were the largest contributors to the total energy budget of these jets, highlighting their dominant role in jet dynamics.

**Contribution Type**:

Poster

**Theme**:

Energetic Phenomena

**Instruments/Facilities and Science: New and Upcoming / 203**

## TBD

**Contribution Type**:

**Theme**:

**Poster Session-I / Coffee Break / 55**

## On the Million-Degree Signature of Spicules

**Author:** Souvik Bose[1]

[1] *Lockheed Martin Solar & Astrophysics Lab/SETI Institute*

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

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism in High-Resolution

**Poster Session-II / Coffee Break / 193**

## Reformation of a Quiescent Filament and Persistence of its Magnetic and Thermal Properties

**Authors:** Jain Jacob P. T.[1]; Ram Ajor Maurya[1]

[1] *National Institute of Technology, Calicut*

We investigate the reformation of a quiescent filament and its structural and physical properties over two Carrington rotations. Utilizing intensity and magnetic field observations from various ground-based and space-based observatories, we continuously tracked the filament's evolution throughout the observation period. Our analysis reveals that the filament reformed in the same region twice after undergoing every eruption. We assessed its magnetic and thermal properties, including its helicity and the orientation of its barbs. Specifically, we found that the filament exhibited dextral chirality, characterized by right-bearing barbs. Further, our analysis supports the flux rope model for the filament's magnetic structure, while the observed horn-like structures associated with the filament's cavity suggest the presence of a twisted flux rope morphology. Additionally, we estimated the temperature of the filament to be $\log_{10} T = 4.8$ for both instances we observed. The results indicate that the filament has a photospheric origin and reformed from the same underlying filament channel that persisted after a partial eruption.

**Contribution Type**:

Poster

**Theme**:

Energetic Phenomena

**Poster Session-II / Coffee Break / 153**

## Unveiling the Dynamics of Polar Coronal Hole Jets: A Multi-Wavelength Study

**Author:** Rohan Bose[1]

**Co-authors:** Arpit Kumar Shrivastav [1]; Vaibhav Pant [1]

[1] *ARIES*

Solar jets are transient events, ubiquitous across the solar atmosphere. They are thought to play a crucial role in coronal heating and in the transfer of mass and energy through different atmospheric layers, including into the solar wind. Small-scale jets are generally classified into two types: (i) Standard jets, characterized by inverted Y-shaped structures, and (ii) Blow-out jets, which have broader spires and are often linked to mini-filament eruptions. In this work, we analyzed a standard polar coronal hole jet using high-resolution data from the High Resolution Imager (HRI) onboard Solar Orbiter (SoLO). Our observations revealed a filament-like structure interacting with the jet, and we tracked the evolution of both the jet and the filament material. The jet was also visible in the cooler temperature channels of the Atmospheric Imaging Assembly (AIA) and the Interface Region Imaging Spectrograph (IRIS), indicating the presence of both cooler and hotter plasma. The jet's energy is in the nanoflare range, typically associated with jets reaching heights of up to 5 Mm, but in this case, the jet extended up to 30 Mm above the limb.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Poster Session-II / Coffee Break / 3**

## Investigating the Origin of Switchbacks in the Solar Corona - A Statistical Approach

**Author:** Sneha Pandit[1]

**Co-authors:** Clara Froment [2]; Durgesh Tripathi [1]; Vishal Upendran [3]

[1] *IUCAA, Pune*

[2] *CNRS, Orleans*

[3] *LMSAL*

Switchbacks are observed as sudden and large deflections in the magnetic field by the Parker Solar Probe (PSP) ubiquitously in the inner heliosphere. One of the prominent hypotheses for the origin of switchbacks relates to dynamic activities in the solar atmosphere. In this work, we study small scale jets and transient events in the solar corona through Solar Dynamics Observatory (SDO) and perform a statistical comparative analysis with switchback events observed by the PSP. We present preliminary results on statistical association between these events, and perform a quantitative analysis to address the solar connectivity of in-situ structures.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Poster Session-I / Coffee Break / 57**

## Modeling and Observation of Propagating Kink Waves in Coronal Open-field Regions

**Author:** Yuhang Gao[1]

**Co-authors:** Hui Tian [2]; Konstantinos Karampelas [3]; Mingzhe Guo [3]; Tom Van Doorsselaere [3]

[1] *Peking University; KU Leuven*

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In the coronal open-field regions, numerous transverse waves propagate along coronal plumes, typically interpreted as kink or Alfvénic waves. Previous studies have emphasized their potential role in coronal heating, solar wind acceleration, and seismological diagnostics of various physical parameters. However, these propagating kink waves have rarely been investigated with both vertical and horizontal density inhomogeneity using advanced three-dimensional magnetohydrodynamic (MHD) simulations. In this study, we establish a 3D MHD model of a gravitationally stratified open flux tube, incorporating a velocity driver at the lower boundary to excite propagating kink waves. Our findings show that both resonant absorption and density stratification influence wave amplitude. Resonant damping must be carefully considered when diagnosing the relative density profile using velocity amplitude to avoid overestimation. Additionally, unlike standing modes, propagating waves are generally considered Kelvin-Helmholtz stable. However, in the presence of vertical stratification, phase mixing of Alfvénic motions near the tube boundary can still generate small scales, partially dissipating wave energy and leading to a slight temperature increase, particularly at higher altitudes. We also conduct forward modeling to synthesize observational signatures, highlighting the potential of future coronal imaging spectrometers, such as MUSE, to resolve wave-induced signatures. Furthermore, we analyze these waves observationally using Solar Orbiter/EUI data, which provides extreme ultraviolet images with unprecedented spatial and temporal resolution.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Poster Session-I / Coffee Break / 61**

## Identification of the Regime of the Solar Dynamo Operation

**Author:** Dipanwita Misra[1]

[1] *Indian Institute of Technology (BHU), Varanasi*

The theoretical model, excluding meridional flow, magnetic buoyancy, and including the entire α effect from the base of the convection zone to the surface, indicates that multicycle correlations occur near the critical dynamo region, while one-cycle correlations are prevalent in the extremely supercritical dynamo region. These findings align with Kumar et al. (2021), who suggest that solar-cycle memory is influenced by the dynamo regime rather than solely by transport mechanisms, a view that contradicts Yeates et al. (2008). In marginally supercritical regions, minimal non-linearity leads to multi-cycle correlation, whereas in extremely supercritical regimes, heightened non linearity and randomness reduce the correlation. Observational data analysis corroborates these results, showing multi-cycle correlation in both diffusion and advection-dominated data, which diminishes with fewer data points.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism over Long-Time Scales

**Poster Session-II / Coffee Break / 92**

## Investigations on Suprathermal Ions in the Interplanetary Medium Using STEPS/ASPEX Measurements from Aditya L1

**Author:** Aakash Gupta[1]

**Co-authors:** Dibyendu Chakrabarty [1]; Santosh Vadawale [1]; Bijoy Dalal [1]; Shivkumar Goyal [1]; Jacob Sebastian [1]; Neeraj Tiwari [1]; Arpit R. Patel [1]; M Shanmugam [1]; Piyush Sharma [1]; Aveek Sarkar [1]; Aaditya Sarda [1]; Tinkal Ladiya [1]; Abhishek Sharma [1]; Nishant Singh [1]; Sushil Kumar [1]; Deepak Painkra [1]; Prashant Kumar [1]; Manan Shah [1]; Pranav Adhyaru [1]; Hiteshkumar Adalja [1]; Swaroop Banerjee [1]; K.P. Subramanian [1]; Bhas Bapat [2]; M.B. Dadhania [1]; Abhishek Kumar [1]; P. Janardhan [1]; Anil Bhardwaj [1]

[1] *Physical Research Laboratory, Ahmedabad, Gujarat*

[2] *Indian Institute of Science Education and Research (IISER), Pune, Maharashtra*

The whole heliosphere is permeated by the solar wind. An important aspect of the solar wind is the suprathermal ion tail which is manifested in the form of particles in the energy range of a few keV/nucleon to several hundreds of keV/nucleon. In addition to the suprathermal ions, there are energetic ions having energy range exceeding 1 MeV/nucleon which are termed as solar energetic particles (SEPs). Suprathermal particles are ubiquitous in the heliosphere and are continuously observed to arrive at the spacecraft location from multi-directions in the interplanetary medium. Determination of the sources of these particles remains a challenging task till date. The fluxes of these ions get enhanced during the passage of Stream Interaction Regions (SIRs) and Interplanetary Coronal Mass Ejections (ICMEs) events. The exact acceleration mechanism/(s) of suprathermal particles in the interplanetary medium are not well understood till date. In earlier works, "universal"spectral index of -1.5 (in differential directional flux vs. energy approach) of suprathermal particles during quiet (in the absence of transient events) times was proposed. However, a few recent studies have shown that spectral indices of suprathermal particles substantially deviate from the "universal"spectral index even during quiet times. This indicates that there may be several processes involved in the energization and modulation of quiet time suprathermal particles. Multidirectional measurements may be useful to understand these aspects. In this work, multi-directional suprathermal fluxes obtained from Supra-Thermal and Energetic Particle Spectrometer (STEPS) instrument of Aditya Solar Wind Particle Experiment (ASPEX) payload on board Aditya L1 spacecraft during quiet periods are analysed. The analysis reveals significant variations in spectral indices in different directions. These results will be discussed.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Poster Session-I / Coffee Break / 101**

## Automated Detection of Plages in Hand-drawn Suncharts from the Kodaikanal Solar Observatory Using Machine Learning Technique

**Author:** Dibya Kirti Mishra[1]

**Co-authors:** Subhamoy Chatterjee [2]; Bibhuti Kumar Jha [2]; Hemapriya Raju [3]; Dipankar Banerjee [4]; Ravindra B. [5]

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The Kodaikanal Solar Observatory (KoSO), one of the oldest solar observatories, possesses hand-drawn suncharts that depict various solar features such as plages, filaments, sunspots, and prominences, each marked with distinct colors. These suncharts are valuable for addressing the data gap in the Ca II K dataset of KoSO from 1980 to 2007, which resulted from plate damage and changes in observational conditions after 1980, leading to a decline in data quality. However, hand-drawn suncharts, available since 1904, provide detailed representations of solar features on Stonyhurst grids. These charts will help fill gaps in the Ca II K data and contribute to the reconstruction of pseudomagnetograms by integrating information on plages and filaments. Currently, we have 6k x 6k scanned images of these suncharts, and we have applied a CNN-based machine learning model to calculate the center, radius, and P-angle from 1904 to 2007. To train the CNN model for identifying plages on the suncharts, we created a training dataset by detecting plages in Ca II K images. This approach will enhance the automatic identification of solar features and assist in analysing historical solar data.

**Contribution Type**:

**Theme**:

Solar Magnetism over Long-Time Scales

**Poster Session-I / Coffee Break / 60**

## Solar Cycle-to-Cycle Variations in the Coefficients of Joy's Law and Angular Momentum Transport Determined From Sunspot-Group Data: A Comparison

**Author:** J. Javaraiah[1]

[1] *Indian Institute of Astrophysics, Bengaluru*

The tilts of bipolar magnetic regions are believed to be caused by the action of Coriolis force on rising magnetic flux tubes. Here we analysed the combined Greenwich and Debrecen observatories sunspot-group data during the period 1874-2017 and the tilt angles of sunspot groups measured at Mt. Wilson Observatory during the period 1917 1986 and Debrecen Observatory during the period 1994-2013. We find that there exists about 8-solar cycle (Gleissberg cycle) trend in the long-term variation of the slope of Joy's law (increase of tilt angle with latitude). There exists a reasonably significant correlation between the slope/coefficient of Joy's law and the slope (coefficient of the poleward/equatorward angular momentum transport) of the linear relationship between the rotation residuals and meridional motions of sunspot groups in the separate hemispheres during Solar Cycles 16-21. We also find that there exists a good correlation between north-south difference (asymmetry) in the coefficient of Joy's law and that in the coefficient of angular momentum transport. These results suggest that there exists a relationship between the surface/subsurface poleward/equatorward angular momentum transport and the Joy's law. There is a suggestion of the strength of the Joy's law depends on the strength of the poleward angular momentum transport.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism over Long-Time Scales

**Poster Session-I / Coffee Break / 5**

## Solar EUV, UV & X-ray Irradiance Variability and Their Impacts on Earth's Climate and Space Weather

**Author:** Kariyappa Rangaiah[1]

**Co-authors:** Adithya H. N. [2]; Ed DeLuca [3]; J. Zender [4]; J. Zender [4]; Kanya Kusano [5]; Luc Dame [6]; Mark Weber [3]; S. Imada [7]; Satoshi Masuda [5]; Takuma Matsumoto [5]

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It is important to study the variabilities of solar EUV, UV and X-ray irradiance in heliophysics, in Earths climate, and space weather applications. Since the radiative output of the Sun is one of the main driving forces of the terrestrial atmosphere and climate system, the study of solar energy has become of great interest and importance. Although the solar energy flux integrated over the entire spectrum is considered to be one of the major natural forces of the Earths climate system, studying the extreme ultraviolet (EUV), ultraviolet (UV) and X-ray irradiance variability is particularly important in solar and terrestrial physics. The solar EUV, UV and X-ray fluxes play in particular a major role in the heating of the Earths atmosphere and Solar-Terrestrial relationships. Thus it is an important issue to understand their variability and its applications in Earths climate and space weather. In this paper we discuss the variability of the total intensity, temperature and magnetic field of different coronal features such as active regions (ARs), coronal holes (CHs), X-ray bright points (XBPs) and background regions (BGs) for Solar Cycle 24. The contribution of all these features to total energy flux over the full disk will be determined, including the total temperature and magnetic field. The magnetic field is the main source of all the surface features of the Sun. The role of magnetic field on the variability of intensity and temperature of the coronal features and the impacts of EUV/UV/X-ray irradiance variability on Earth's Climate & Space Weather is discussed in great detail in this paper.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism over Long-Time Scales

**24**

## Propagation Characteristics of Acoustic Waves in the Quiet-Sun Lower Solar Atmosphere: MAST Observations

**Author:** Hirdesh Kumar[1]

**Co-authors:** Brajesh Kumar [1]; Shibu Mathew [1]; Ankala Bayanna [1]; S. Paul Rajaguru [2]

[1] *Udaipur Solar Observatory, Physical Research Laboratory, Udaipur*

[2] *Indian Institute of Astrophysics, Bangalore*

Solar atmosphere provides conducive environment for the generation, propagation, and dissipation of various mechanical waves. These waves are considered to play an important role in the heating and dynamics of the solar atmosphere. Acoustic waves are generated by turbulent convection inside the convection zone of the Sun. These waves trapped inside the acoustic cavities are formed due to high temperature inside the Sun and sharp fall in density at the photosphere. The acoustic cutoff frequency of the quiet-Sun photosphere is 5.2 mHz and these waves (<5.2 mHz) are evanescent in the solar atmosphere. In contrast, high frequency (> 5.2 mHz) acoustic waves propagate into the higher solar atmosphere with increasing amplitude. Exploiting the full potential of the Narrow Band Imager (NBI) instrument installed with the Multi-Application Solar Telescope (MAST) operational at Udaipur Solar Observatory (USO), Physical Research Laboratory (PRL), Udaipur, India, we observed a quiet-Sun region located within the disk centre of the Sun for 1h 50m duration. The photospheric Fe I 6173 Å spectral line is scanned at 35 wavelength positions, while chromospheric Ca II 8542 Å line is scanned at 27 wavelength positions. Utilizing the bisector method on the observed spectral line profiles, we obtain seven height line-of-sight velocities within Fe I line and nine height line-of-sight velocities within Ca II line. The fast Fourier transform is used at each pixel over the observed full field of view by the NBI/MAST to obtain phase shift and coherence. The frequency and height-dependent phase shift integrated over the regions having an absolute line-of-sight magnetic field of less than 10 G indicates the nonevanescent nature of low-frequency acoustic waves within the photosphere and photosphere–chromosphere interface regions. We also report that the nonevanescent nature persists beyond the photosphere, encompassing the photospheric–chromospheric height range. Additionally, our observations reveal a downward propagation of high-frequency acoustic waves indicating refraction of these waves from higher layers in the solar atmosphere.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Poster Session-II / Coffee Break / 39**

## Radio Observations and Their Role in Understanding Solar Energetic Particle Events

**Author:** Anshu Kumari[1]

**Co-authors:** Atul Mohan [2]; Diana Morosan [3]; Natchimuthukonar Gopalswamy [4]; Pertti Mäkelä [2]

[1] *Physical Research Laboratory (PRL)*

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[3] *University of Turku*

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We present two case studies on solar energetic particle (SEP) events involving type III storms and type II bursts in metric and decmetric-hectometre (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 Gopalswamy hypothesis, providing insights into particle radiation aspects of space weather forecasting.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Poster Session-I / Coffee Break / 40**

## Estimating Formation Heights of AIA Channels in Sunspot Umbrae Using 3-Min Magneto-acoustic Waves

**Author:** Sanjay Yadav[1]

[1] *UPES, Dehradun*

Multi-wavelength data from the Solar Dynamics Observatory (SDO) provide valuable insights into solar physics. This study estimates the formation heights of chromospheric and low-corona Atmospheric Imaging Assembly (AIA) channels over sunspot umbrae during quiet periods across 20 active regions. By utilizing 3-minute slow magnetoacoustic waves (MAWs) and applying a cross-correlation technique, the most frequent time lags between channel pairs are measured. These time lags, combined with local sound speed, allow estimation of the formation heights. Median formation heights for AIA 1600 Å, 1700 Å, 304 Å, 131 Å, and 171 Å channels range from 356 km to 1470 km, with UV channels showing stable heights, while coronal channels exhibit more variability. This analysis enhances understanding of solar atmospheric structures during quiescent sunspot conditions.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism in High-Resolution

**Poster Session-II / Coffee Break / 58**

## Understanding Hanle Effect in Ca I 4227 Å Line Using Magnetohydrodynamic Simulations of the Solar Atmosphere

**Author:** Devang Agnihotri[1]

**Co-author:** Anusha L. S. [1]

[1] *Indian Institute of Astrophysics*

Scattering polarization in strong resonance lines such as the Ca I 4227 Å, formed in the chromosphere, can probe the chromospheric magnetic fields via the Hanle effect. Predominantly one-dimensional (1D) semi-empirical model atmospheres were used to study the linear polarization in this line. Recently, Harsh et al. (2024) studied the resonance scattering polarization in Ca I 4227 Å using magnetohydrodynamic (MHD) simulations of the solar atmosphere from the Bifrost code, along a slanted ray with heliocentric angle $\mu = 0.3$. In this work, we include the effect of weak magnetic fields (Hanle effect) on the polarization profiles and compare them with the non-magnetic cases.

**Contribution Type**:

Poster

**Theme**:

Solar - Stellar Connections

**Poster Session-II / Coffee Break / 59**

## A Comprehensive Statistical Study of Sub-Alfvénic Intervals Observed at 1 AU

**Author:** Komal Choraghe[1]

**Co-authors:** Soumyaranjan Khuntia [1]; Wageesh Mishra [1]

[1] *IIA*

The solar wind typically maintains a super-Alfvénic character near 1 AU from the Sun. However, in rare cases, the solar wind density drops to the extreme, leading to a transition into a sub-Alfvénic regime. Such solar wind arriving near the Earth prevents the formation of a bow shock and magnetosheath, leading to their direct interaction with the Earth's magnetopause. In this study, we performed a comprehensive statistical analysis of sub-Alfvénic intervals observed between 1995 and 2023 using data from the 3DP and MFI instruments aboard the WIND spacecraft. We identified 11 rare sub-Alfvénic periods embedded within ICME or solar wind, each lasting more than 30 minutes. We focus on understanding the thermodynamic behavior, and turbulence of such sub-Alfvénic regions. We compare these regions' properties with those of neighboring super-Alfvénic regions. Such a study has the potential to identify the differing physical processes in the super- and sub-Alfvénic region of the solar wind.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Poster Session-I / Coffee Break / 127**

## Enhancing the Efficiency of Feature Tracking Algorithms to Analyze High Resolution Solar Observations

**Author:** Jharnesh Verma[1]

**Co-authors:** Anusha L. S. [2]; Kamil Nadaf [3]

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[3] *National Institute of Technology Jamshedpur*

Advancements in ground and space instrumentation have led to high-quality observations of the Sun, both in quiet and actively magnetic regions. Analyzing the formation and destruction of magnetic fields on the Sun is crucial for understanding the physical phenomena that drive magnetic activity. To carry out such analysis, feature-tracking codes are employed. In the era of big data generated by various ground and space-based instruments, improving the efficiency of these feature-tracking codes is essential. The primary objective of this work is to streamline the feature-tracking code used in Anusha et al. (2017) that studied small-scale magnetic features on the Sun. To achieve this, we are developing a parallel C++ version of the code and rigorously testing its accuracy and efficiency against the original IDL implementation.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism in High-Resolution

**95**

## Coronal hole and Quiet Sun comparison through observations and simulations

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We presents a comparison of plasma dynamics in Coronal Holes (CHs) and Quiet Sun (QS) through observations and 2.5D MHD flux emergence simulations. We observe these regions in chromospheric and transition region lines of IRIS as a function of the underlying photospheric magnetic field (|B|). We find excess intensity (blue, redshifts) in QS(CH) with |B|. We observe persistent upflows, downflows, and bidirectional flows, with an acceleration(deceleration) of upflows(downflows) in CH(QS). We simulate flux emergence in 2.5, forming hot, cool jets due to magnetic reconnection, resulting in a confined jet(surge) in QS(CH). Through spectral synthesis, CHs show reduced intensities, excess upflows (downflows), and widths during the jetting (return downflow) period when compared to QS, with velocity, linewidth correlated with B_z at z=0 in CH. During the jetting period in CH, we find upflows in Si IV to be correlated (anti- correlated) with upflows (downflows) in other lines, and downflows in CH in Si IV to be correlated (anti-correlated) with upflows (downflows) in other lines when compared to QS. During downflow, we find no strong correlation between Si IV and other line velocities. The correlation during the jetting period occurs due to coincident, co-spatial origins of the hot and cool jet, while the lack of correlation during the downflow phase suggests a decoupling of hot and cool plasma. These results demonstrate that flux emergence and resultant reconnection with pre-existing flux in the atmosphere support the picture of a unified scenario for the formation of solar wind and coronal heating.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Poster Session-II / Coffee Break / 26**

## Large-Scale Energy Transport in the Solar Corona Due to Fast Magnetosonic Waves Generated by Impulsive Reconnection

**Author:** Sripan Mondal[1]

**Co-authors:** Abhishekh Kumar Srivastava [1]; David I. Pontin [2]; Eric R. Priest [3]; Ryun Y. Kwon [4]; Ding Yuan [5]

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Magnetosonic waves and magnetic reconnection have been studied for a long time as two major processes responsible for coronal heating, solar wind acceleration, and other energetic eruptive processes in the Sun's corona. Here, we study the mutual interactions between these two plasma processes in a physics-based numerical model. In this model, a velocity perturbation representing the effect of a coronal transient fast-mode wave interacts with a coronal null point and forms a current sheet (CS). Due to unbalanced magnetic forces along and across the current sheet, it evolves to give a curved elongated magnetic structure that fragments to form multiple plasmoids. These plasmoids eventually coalesce with each other to enhance the total pressure locally, which generates propagating nearly-circular large-scale wavefronts. An in-phase relation between thermal pressure and magnetic pressure confirms that the propagating wavefronts are fast magnetoacoustic waves. We find that the fast waves carry energy fluxes of $10^5$ erg cm$^{-2}$ s$^{-1}$ which are sufficient to heat coronal holes and the quiet-Sun and to drive the solar wind. We also describe the spatio-temporal correlation of multiple coalescence events in the CS and the resulting wave energy density peaks, thereby establishing a relationship between CS dynamics and the resulting wave motions.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Poster Session-II / Coffee Break / 96**

## MHD Simulation of Flux Rope Eruption Underneath Coronal Streamers

**Authors:** Piyali Chatterjee[1]; Samriddhi Maity[2]

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We develop 3D MHD model in spherical geometry in the Pencil Code framework to understand the dependence of solar wind properties near a coronal streamer by varying the magnetic field and in-situ volumetric heating. The model additionally includes anisotropic heat conduction along field lines, optically thin radiative cooling and a semi-relativistic correction to Lorentz force. Our final aim is to understand the coronal flux rope activation or CME initiation conditions in presence of the ambient magnetic field that has been stretched by the solar wind. This kind of topology is close to H-alpha polar crown filaments observed on the Sun during migration of poloidal flux of the new cycle to the solar poles.

**Contribution Type**:

Poster

**Theme**:

Energetic Phenomena

**Poster Session-II / Coffee Break / 176**

## Revisiting the Relationship Between Prominence Material and CME Core Structures

**Author:** Sunit Sundar Pradhan[1]

**Co-authors:** Jayant Joshi [1]; Tanmoy Samanta [1]

[1] *Indian Institute of Astrophysics, Bengaluru*

A Coronal Mass Ejection (CME) is a large-scale eruption of plasma and magnetic fields from the Sun into interplanetary space. In coronagraph observations, around one-third of CMEs exhibit a characteristic three-part structure consisting of a bright inner core, an outer leading edge, and a darker cavity in the middle. However, observations of the inner corona suggest this three-part structure is more common than previously thought. The traditional view that prominence material forms the bright inner core and that the cavity represents a low-density magnetic flux rope has recently been questioned. Some studies propose that the bright core may instead result from the geometric projection of a twisted flux rope. In contrast, more recent observations from the Solar Orbiter in the He II 304 Å passband of the EUI/Full Sun Imager have detected prominence material as far as six solar radii. To reassess the association between prominence material and the bright inner core of CMEs, we analyzed data from GONG H$\alpha$, MLSO K-Cor (white light), and AIA 304 Å observations, focusing on limb CMEs with visible prominence eruptions in H$\alpha$. Our findings show a strong correlation between H$\alpha$ and white-light observations of the fine structure of CME cores in the inner corona. In many cases, these structures were further traced into the outer corona within the LASCO/C2 field of view. Our initial results suggest the presence of prominence material within the inner core of CMEs.

**Contribution Type**:

**Theme**:

Energetic Phenomena

**Poster Session-II / Coffee Break / 179**

## Extracting the h| E & h| F of the Ionospheric Layers Using the Digitized Kodaikanal Ionograms

**Author:** Pavan Gramapurohit[1]

**Co-authors:** Ramesh K B [1]; Nagaraju K [1]; Ravindra B [1]; Ashrith R [2]; Manjunath Hegde [1]

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Earth's ionosphere owes its existence to the ionization of the neutral constituents by the Solar Extreme Ultraviolet (EUV) and Soft X-ray (SXR). This results in the creation of ionospheric layers like D, E, and F. These layers are distinct only during the daytime ionosphere, and features can be well noticed at the equatorial latitudes. Each layer has its maximum density at a certain altitude, and the density decreases with an increase in height. The peak density and peak height of the E and F layers of the ionosphere can be well understood by probing them at their critical frequencies. These ionospheric features can be well studied using the HF (High Frequency) radar, which is also known as Ionosonde. Ionograms record these high-frequency radio waves reflected back by the ionosphere at different altitudes. The c3 ionosonde at Kodaikanal solar observatory started collecting data of the ionosphere above India (latitude 10° 13' 50" N, longitude 77° 28' 07" E, geomagnetic latitude 0.8° N) from 1950 to 1990, and this location suitable for studying the equatorial-latitude ionospheric phenomenon. The ionosonde operates between the frequency of 1 to 20 MHz, and the ionosphere can be

probed up to an altitude of 1000km. The ionograms were captured using 35mm film on a C-3 analog ionospheric recorder. Now, these ionograms are digitalized (still undergoing) using the CCD camera (4K X 4k) with 32-bit resolution. We have used the image processing technique to identify the critical frequency and the corresponding height of both the h| E and h| F layers. Understanding the peak density and peak height of these layers will provide critical information on how the earth's ionosphere responds to the change in the solar irradiance variation and also to the high energy particle precipitation events.

**Contribution Type**:

**Theme**:

Connecting Solar Corona to Heliosphere

**Poster Session-I / Coffee Break / 134**

## FPGA-based Fast Data Acquisition System for Solar Adaptive Optics

**Authors:** Phanindra DVS[1]; Sridharan Rengaswamy[1]

[1] *Indian Institute of Astrophysics*

The correlation tracking and wave-front sensing cameras in an adaptive optics system correct the wavefront error by locking to a feature in the image acquired by the sensor. The feature is cross-correlated with a reference image to identify the relative shift between consecutive images in the sub-aperture images of a Shack-Hartmann wave-front sensor. The typical frequency of data acquisition is about 1000 frames per second. While the software-based optimized cross-correlations may be sufficient when a small number of sub-apertures are used in a wave-front sensor, hardware-accelerated (FPGA) correlations may be required when a large number of sub-aperture images are involved, for example, in the case of the proposed National Large Solar Telescope (NLST) in India. Here, we suggest developing an FPGA-based readout card to acquire the images using a fast image sensor with a bigger pixel size. Also, we aim to demonstrate readout at 1000 frames per second to correct the effects of atmospheric turbulence. This acquisition system will be integrated with the FPGA-based fast correlation method we developed earlier. In this poster, we will present the design aspects of the FPGA-based data acquisition system with a suitable image sensor.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism in High-Resolution

**Poster Session-I / Coffee Break / 177**

## Nonlinear Time Series Analysis at Different Amounts of Dynamo Supercriticality Suggest Solar Dynamo is Not Highly Supercritical

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The toroidal to poloidal part of the solar dynamo mechanism involves some nonlinearity and stochasticity, which disturb the dynamo loop. Hence, the memory of the polar field decreases in every cycle. On the other hand, the dynamo efficiency and, thus, the supercriticality of the dynamo decreases with the Sun's age. Previous studies indicate that the memory of the polar field decreases as the dynamo supercriticality increases. This work employs prominent time series analysis techniques and computes Higuchi's fractal dimension, Hurst exponent, and Multifractal Detrended Fluctuation Analysis to the amplitude of the solar cycle obtained from dynamo models operating at near-critical and supercritical regimes. We show that the magnetic field in the near-critical regime exhibits strong memory, less stochasticity, intermittency, and breakdown of self-similarity. Conversely, the magnetic field in the supercritical regime has less memory, strong stochasticity, and good amount of self-similarity. Furthermore, applying these analysis techniques to the reconstructed sunspot data of 85 cycles and comparing these results with the model, we conclude that the solar dynamo likely operates near the critical regime rather than the highly supercritical regime.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism over Long-Time Scales

**Poster Session-I / Coffee Break / 175**

## Periodicity in the Ratio of Sunspot Number to the Sunspot-Group Area

**Author:** Manjunath Hegde[1]

**Co-authors:** Javaraiah Javaraiah ; Ravindra B [1]

[1] *Indian Institute of Astrophysics*

The solar dynamo, believed to operate near the base of the convection zone (BCZ), generates the magnetic fields responsible for solar activity and solar cycles. Magnetic structures (flux tubes) formed near BCZ rise through the convection zone, potentially fragmenting/branching into smaller structures. These structures emerge as sunspots or active regions/sunspot groups on the Sun's surface. This process vary with time and latitude, depending on the solar cycle phase and other timescales. In this study, we analyze sunspot data from Kodaikanal Observatory (1904-2017) to examine variations in the ratio of the 13-month smoothed international sunspot number (SN) to the average sunspot group area (A). A large/small SN/A may imply the fragmentation process is less/more. We apply fast Fourier transform (FFT) and Morlet wavelet analysis to study periodicities in the SN/A ratio. We find besides ~11-year periodicity, ~67, 63, 60, 45 year periodicities in SN/A. These results, combined with variations in other solar activity indices, help deepen our understanding of solar variability and the underlying processes driving magnetic field evolution.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism over Long-Time Scales

**Poster Session-II / Coffee Break / 208**

## Impact of Electron Scattering Redistribution on Spectral Line Polarization Formed in Stellar Atmospheres

**Author:** Sampoorna M.[1]

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In a stellar atmosphere, the resonance line polarization arises from scattering of limb-darkened radiation field by atoms. This spectral line polarization is severely affected particularly in the wings, when the line photons suffer scattering on electrons in thermal motion. Electron scattering opacity is known to be significant in higher layers of sun and stars, especially the hotter stars. Scattering of line photons by atoms and electrons are, respectively, described by the atomic and electron scattering redistribution functions, which in general depend on both the frequencies and directions of incident and scattered photons. In this poster/ talk, I will present our recent work (Sampoorna et al. 2022, ApJ and Sampoorna & Supriya 2023, MNRAS) on the impact of electron scattering redistribution on resonance line polarization formed in a spherically symmetric extended and expanding atmosphere. We highlight the importance of including frequency and directional dependence of atomic and electron scattering redistribution on resonance line polarization.

**Contribution Type**:

Poster

**Theme**:

Solar - Stellar Connections

**Poster Session-I / Coffee Break / 195**

## Poynting Flux of MHD Waves in Rotational Plasma Flows

**Author:** Samuel Skirvin[1]

**Co-authors:** Gary Verth [2]; Istvan Ballai [2]; Marcel Goossens [3]; Suzana Silva [1]; Viktor Fedun [4]

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Magnetic flux tubes in the presence of background rotational flows are abundant throughout the solar atmosphere and may act as conduits for MHD waves to transport magnetic energy throughout the solar atmosphere. We investigate the Poynting flux associated with these waves within the presence of background rotational plasma flows. The MHD wave solutions of the equilibrium configuration are obtained using the SESAME code and we derive an expression for the vertical component of the Poynting flux, associated with MHD modes. In addition, we analyse the spatial structure of Poynting flux for different MHD modes under various background flow strengths. We show that the vertical component of the Poynting flux increases in the presence of a background rotational flow compared to a flux tube with no rotational flow. Finally, we present some results of 3D numerical simulations that investigate the energy fluxes associated with MHD waves in the presence of different plasma flow and magnetic twist configurations. These simulations feature a closed magnetic loop system in which a rotational flow is introduced at one footpoint in addition to photospheric perturbations acting as a wave driver. We present the resulting energy fluxes calculated in this setup and compare our findings to the energy fluxes of MHD waves observed in solar spicules or magnetic configurations in the absence of magnetic twist or rotational plasma flows.

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**124**

## Effect of spatial inhomogeneities on the scattering polarization profiles of the solar Ca I 4227 A line

**Author:** Anusha L S[1]

**Co-author:** Harsh Mathur [1]

[1] *Indian Institute of Astrophysics*

Scattering of anisotropic radiation by atoms in the solar atmosphere generates linear polarization in spectral lines such as the Ca I 4227 Å line. Spectro-polarimetric observations of this line, particularly near the solar limb, reveal significant linear polarization. Modeling this line is essential for understanding the sensitivity of scattering polarization to atmospheric parameters and extracting magnetic field information through the Hanle effect. Traditionally, one-dimensional (1D) semi-empirical plane-parallel models have been widely employed for such modeling. In some cases, vertical columns from three-dimensional (3D) magnetohydrodynamic (MHD) simulations of the solar atmosphere have also been utilized to enhance realism. In this study, we investigate the influence of spatial inhomogeneities on the scattering polarization profiles in the Ca I 4227 Å line. To achieve this, we construct inhomogeneous 1D atmospheric models by tracing a large number of rays through a near-limb region of the Bifrost 3D MHD simulation cube (at $\mu = 0.3$), interpolating the 3D atmospheric parameters along these rays. We then perform 1.5D polarized non-local thermodynamic equilibrium (non-LTE) radiative transfer calculations to obtain the emergent Stokes profiles ($I, Q/I$) in these various inhomogeneous atmospheres, focusing on the non-magnetic regime (resonance scattering).

**Contribution Type**:

**Theme**:

Solar Magnetism in High-Resolution

**Poster Session-I / Coffee Break / 197**

## Effect of Dynamo-Generated Large-Scale Magnetic Fields on the f Mode

**Author:** Rajesh Mondal[1]

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In helioseismology, traditional analytical models often neglect the effects of rotation and magnetic fields, limiting their applicability. However, observations frequently reveal instances where these elements are critical. Previous studies have investigated the influence of externally imposed magnetic fields on seismic modes using idealized 2D MHD simulations. Here, we extend this work by performing 3D MHD simulations using the Pencil Code to examine the impact of self-sustained, dynamo-generated magnetic fields on seismic modes, particularly the $f$-mode. Our simulations incorporate naturally excited dynamo action, allowing us to avoid externally imposed uniform or nonuniform magnetic fields. Preliminary results indicate that when the dynamo reaches saturation —transitioning from the kinematic to the saturated phase—the mode mass of the $f$-mode increases, suggesting a strengthening of the $f$-mode. Additionally, we observe other established effects, including frequency shifts and the fanning of the $f$-mode, consistent with prior findings.

**Contribution Type**:

Poster

**Theme**:

Solar Magnetism over Long-Time Scales

**Poster Session-II / Coffee Break / 83**

## Sun-As-A-Star Differential Emission Measure Analysis of Coronal Dimming Associated with CMEs

**Authors:** Dheeraj Vittal Shenoy[1]; Tanmoy Samanta[1]

[1] *Indian Institute of Astrophysics*

Coronal dimmings on the Sun are transient reductions in coronal plasma emissions, often associated with Coronal Mass Ejections (CMEs) triggered by solar flares or filament eruptions. These dimmings typically last between 3 to 12 hours, characterized by a rapid decrease in intensity followed by a gradual recovery. In this study, we conduct a differential emission measure (DEM) analysis using a Sun-as-a-star approach to explore the relationship between dimming depth and emission measures across various temperature bands. We utilize data from the Atmospheric Imaging Assembly (AIA) aboard the Solar Dynamics Observatory (SDO) to perform DEM analysis on six CME-associated events, including four flaring events and two filament eruptions. Our results indicate that while the temperature band for maximum dimming varies across events, significant dimmings are predominantly observed in the 5.85–6.45 log K temperature range. Emission in hotter temperature bands shows little or no dimming. Additionally, we calculate the DEM-weighted temperature of the corona and observe a temperature difference between pre-event conditions and the peak dimming phase. Interestingly, we detect signs of coronal heating in the early stages of the dimming, suggesting complex thermal responses in the corona during CME evolution. These findings provide critical insights into the coronal response to CME events and the associated heating of coronal plasma. Furthermore, they enhance our understanding of the solar-stellar connection and have significant implications for space weather forecasting.

**Contribution Type**:

Poster

**Theme**:

Solar - Stellar Connections

**Poster Session-II / Coffee Break / 88**

## Active Region Magnetic Parameters as Proxies for CME Velocity Prediction

**Author:** Aswin Amirtha Raj S[1]

**Co-author:** Shanmugaraju A [1]

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The space weather inside the heliosphere is dictated by various dynamic processes of the sun; Among these, Coronal Mass Ejections (CMEs) stand out due to their significant impact on space weather. The Geo-effective Interplanetary Coronal Mass Ejections (ICMEs) can trigger severe space weather events, such as geomagnetic storms, which pose substantial risks to modern technological infrastructure, particularly in our developing digital world. Accurate forecasting of CME dynamics, including velocity and impact, is essential for mitigating these risks. Recent breakthroughs in Artificial Intelligence and Machine Learning models have shown promise in improving predictive models for CME. However, the success of these models depends significantly on the proxies used in training them. In this study, we aim to identify the proxies that can enable us to predict the velocity of sunspot-originated CMEs up to 12 hours before their ejection. CME velocity is crucial because it is linked to the geo-effectiveness of CMEs and provides valuable insights for space weather mitigation. Our research investigates the efficacy of magnetic parameters derived from vector magnetograms in predicting CME velocity. Through this study, we identified the best proxies from the derived AR magnetic parameters for velocity prediction and observed notable discrepancies in the correlation of these parameters for slow and fast CMEs. These findings offer new perspectives on the relationship between magnetic parameters and CME dynamics, with implications for improving the accuracy of space weather forecasts.

**Contribution Type**:

Poster

**Theme**:

Energetic Phenomena