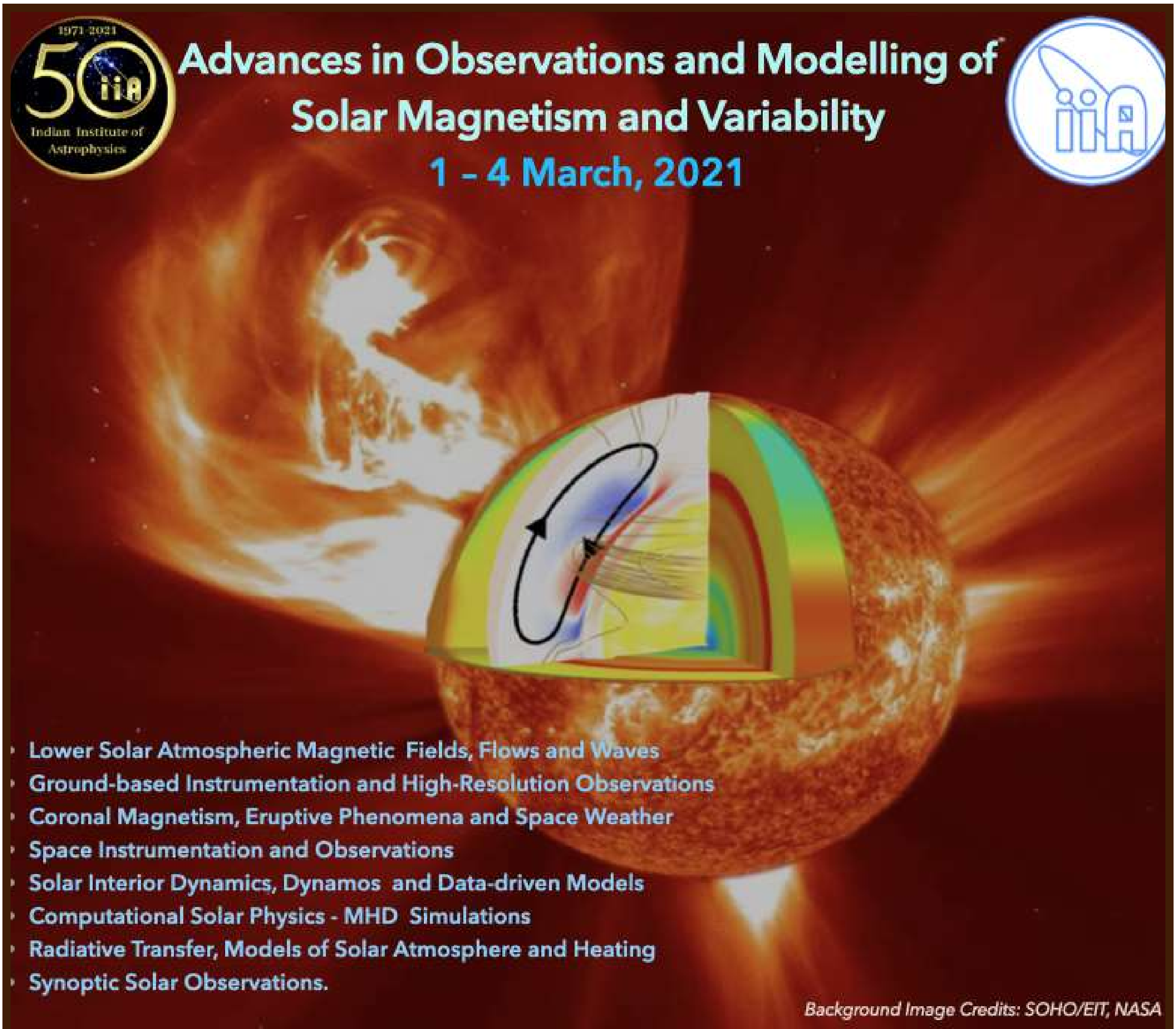

Abstract Book

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Scientific Programme

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Overview of Selected Solar Fine-Scale Structures: Chromospheric Spicules and Coronal Jets

Alphonse Sterling

NASA/MSFC

We present an overview of a sub-category of fine-scale features of the Sun, focusing on small-scale jet-like features. Our focus is on spicules, which are primarily chromospheric features, and on coronal jets. Spicules have been observed for over 100 years, while jets have been investigated in detail only since the 1990s. However, recent observational studies and theoretical considerations have revolutionized our view of both phenomena. Here we discuss both the historical context and newer views of these solar features.

Signatures of 3D magnetic reconnection in circular ribbon flares

Bhuwan Joshi
Udaipur Solar Observatory, PRL

Circular ribbon flares belong to a subclass of flares for which one of the ribbons presents an almost fully closed quasi-circular or quasi-ellipsoidal shape. In the simplest case, the photospheric magnetic field distribution associated with circular-ribbon flares consist of a parasitic polarity embedded in an opposite sign polarity of a larger dipolar active region. In this talk, I will present a few complex cases of circular ribbon flares where the primary event also exhibits the presence of parallel ribbons, remote ribbons, and jet activity. The typical morphological features and other complexities of such events are discussed in view of the topological structure of a 3D null point. These observations also enable us to explore analogies between the circumstances that govern the onset of jets, confined flares or CMEs.

Source Region Dynamics of White-Light Flares

Kyoko Watanabe

National Defense Academy of Japan

In association with strong solar flares, we sometimes observe enhancements of visible continuum radiation, which is known as a "white-light flare (WLF)". As most white-light (WL) events show close correlations in time and location with hard X-rays and/or radio emission, there is some consensus that WL emission originates from accelerated particles, especially non-thermal electrons. However, the generation mechanism of WLF has not yet been elucidated.

In this talk, we report the statistical properties of WLFs, and discuss the possibility that other candidates (accelerated protons etc.) may produce the WLFs. We will then discuss the dynamics of high-energy phenomena in the source regions of solar flares, especially in the low solar atmosphere.

Chromospheric Thermodynamics and Magnetic Fields

Gianna Cauzzi

National Solar Observatory, USA

The role of the chromosphere as an essential "mediator" in the transfer of non-thermal energy from the photosphere to the corona has come to the forefront in recent years. Together with numerical simulations, high resolution observations and novel diagnostics are necessary to advance our understanding of this complex, non-equilibrium part of the solar atmosphere.

Imaging spectrographs based on Fabry-Perot interferometers have helped spurring a "renaissance" for classical chromospheric diagnostics such as Halpha and CaII H&K, highlighting the complex spatio-temporal thermo-dynamics of features such as fibrils and spicules and their relevance to the upper atmosphere. New capabilities in spectropolarimetry, especially in the CaII IR and HeI 1083nm triplets, are now starting to allow inference of the chromospheric magnetic field in a variety of features, including prominences and coronal rain, providing a key piece of the puzzle that has been missing for decades. Novel, complementary diagnostics have also entered the scene recently, such as UV spectral lines from IRIS and CLASP, and the much awaited
millimiter continuum observed at high resolution by ALMA, which can provide a unambiguous measure of the electron temperature and its temporal evolution.

During this talk I will provide an overview of how these new observations and diagnostics are shaping our understanding of the chromosphere.

Generation of solar spicules and subsequent atmospheric heating

Hui Tian, Vasyl Yurchyshyn, Hardi Peter, Wenda Cao, Alphonse Sterling, Robertus Erdelyi, Kwangsu Ahn, Song Feng, Dominik Utz, Dipankar Banerjee, Yajie Chen

Tanmoy Samanta
NASA/Marshall Space Flight Center

Rapidly evolving fine-scale jets known as spicules are the most prominent and dynamical phenomena observed in the solar chromosphere. At any given instant, around a few million of these spicules shoot plasma material out from the Sun's surface. It is highly likely that these spicules play a crucial role in key solar physics mysteries, such as chromospheric and coronal heating and mass supply to the solar wind. Despite intensive delving in the past decades, there is still no clear consensus on how these small-jets of magnetized plasma originate from the solar surface, nor we understand how exactly they transfer energy into and possibly heat the solar atmosphere. The exact source of these small-scale jets is hard to observe due to earlier telescopes' resolution limitations. Therefore, they remain poorly understood. Using unprecedented multi-wavelength and high-sensitive magnetic field observations from the 1.6-m Goode Solar Telescope at the Big Bear Solar Observatory, we strive to reach conclusions on the possible scenario among the many proposed hypotheses of spicule's origin. We found that the dynamical interaction of magnetic fields in the partially ionized lower solar atmosphere is the precursor of these high-speed jets, which subsequently energizes the upper solar atmosphere.

Torsional Motion and Short-Period Oscillations in a Quiescent Prominence

Jain Jacob P. T. & R.A. Maurya

National Institute of Technology, Calicut

Solar prominences are consist of cool and dense plasma surrounded by hot atmosphere. The high-resolution observations provided by the Atmospheric Imaging Assembly (AIA) onboard Solar Dynamical Observatory (SDO) and Interface Region Imaging Spectroscopy (IRIS) is used to study the dynamical properties of a large scale prominence. One of the prominence legs, exhibit tortional motion, is investigated using time-slices of intensity images across the prominence legs and Local Correlation Tracking (LCT) of SDO/AIA observations. It undergoes clockwise rotation followed by an anti-clockwise movement indicating torsional motion. We found large scale rotation confirmed by the blue and redshift in the Doppler velocities in the prominence's upper part. The power spectrum using IRIS slit-jaw imaging observations of Mg II k 2796Å and Si IV 1394Å are constructed to study the oscillatons within the prominence structure. An oscillatory motion of 7-11 minutes is detected from the wavelet analysis also, which may be associated with Alfven waves propagating along magnetic flux tubes.

Instabilities in the Solar Chromosphere

Abhishek Kumar Srivastava
Indian Institute of Technology (BHU)

The significance of the chromosphere in the localised dynamical plasma processes, as well as mass & energy transport within the solar atmosphere is now widely recognised. In the present talk, we discuss the physics of magnetic and fluid instabilities in the frame-work of various chromospheric magneto-plasma systems and plasma ejecta. We highlight a number of key observational aspects that have helped our understanding of the role of these instabilities on a variety of dynamical processes and heating of the localised solar chromosphere. The potential implications, future trends and outstanding questions related to the chromospheric instabilities are also elucidated.

Global p-modes in the solar chromosphere at high resolution

Shahin Jafarzadeh

Rosseland Centre for Solar Physics, University of Oslo

The solar chromosphere is historically known to be dominated by ~ 3-min oscillations of acoustic/magneto-acoustic waves. However, recent studies of the p-modes in the upper chromosphere have also revealed significant power suppression at the 3-min characteristic periodicity. Here, we present a thorough study of such global oscillations from observations with the Atacama Large Millimeter/submillimeter Array (ALMA) and Swedish 1-m Solar Telescope (SST), as well as from numerical simulations with Bifrost. We find that the presence or absence of the dominant periodicities depends on the solar regions captured by the observations, linked to their underlying magnetic topology.

Photospheric Magnetic Fields: Challenges Ahead

Luis Bellot Rubio
Instituto de Astrofisica de Andalucia (IAA-CSIC, Spain)

Understanding the dynamics and energetics of the solar atmosphere requires a good understanding of photospheric magnetic fields, particularly on small spatial scales. Through processes of emergence, interaction, and decay, photospheric magnetic fields give rise to a multitude of phenomena that couple the entire solar atmosphere. Characterizing their properties, origin and evolution will be one of the main challenges of solar physics in the next decade. To reach such an ambitious goal, we need high polarimetric sensitivity, high temporal resolution, long time sequences, and multi-wavelength observations at a resolution of 20 km or better. In this talk I will discuss recent advances in the characterization of photospheric magnetic fields, focusing on the quiet Sun and sunspots. These results offer a glimpse of the whole new revolution that will soon be made possible by facilities such as the Daniel K. Inouye Solar Telescope and, in the longer term, the Indian National Large Solar Telescope and the European Solar Telescope. A brief update on the status of the European Solar Telescope will be given, as an example of a facility designed to excel in high-precision, high-cadence, multi-wavelength polarimetry from the outset.

Role of surface magnetic field evolution in impulsive coronal heating

Lakshmi Pradeep Chitta

Max Planck Institute for Solar System Research, Germany

The outer atmosphere of the Sun, the corona is comprised of tenuous, highly ionized plasma that is governed by magnetic fields and is heated to more than a million degrees Kelvin. Such hot coronal plasma is thought to be powered by numerous impulsive heating events called nanoflares. What drives these impulsive nanoflares? and what role does magnetic field play in coronal heating? We address these long-standing questions through multi-wavelength observations of the Sun that span from the photosphere through the corona. In this talk, we will present new results that reveal an intricate link between the impulsive coronal heating and the evolution of magnetic fields at the solar surface. In particular, we will discuss the role of magnetic reconnection, a process through which magnetic energy is liberated, in the heating of the solar coronal.

Waves in the Lower Solar Atmosphere

David B. Jess

Queens University Belfast, UK

Within the last decade, solar physics has moved into a golden era of discovery. A diverse assortment of ground- and space-based facilities has helped make rapid progress in the detection, identification, characterisation and understanding of dynamic motions spanning the photosphere through to the chromosphere. Combined modelling efforts have resulted in a number of outstanding science questions that can only be addressed with more advanced, larger aperture telescopes. Here I will outline some of the recent landmark discoveries that have developed into overarching science questions in solar physics, before highlighting how upcoming facilities, including the Indian NLST, will shine light on these challenging problems.

Observations on the spatial variations of the Sr i 4607 Å scattering polarization signals with ZIMPOL

Sajal Kumar Dhara

Istituto Ricerche Solari Locarno (IRSOL)

The Sr i 4607 Å spectral line shows one of the strongest scattering polarization signals in the visible solar spectrum. The amplitude of this polarization signal is expected to vary at granular spatial scales, due to the combined action of the Hanle effect and the local anisotropy of the radiation field. At present, few detections of such spatial variations have been reported due to the difficulty of these measurements, which require combining high spatial, spectral, and temporal resolution with increased polarimetric sensitivity. Using the Zurich IMaging POLarimeter (ZIMPOL) system mounted at the GREGOR telescope and spectrograph in Tenerife, Spain, we carried out spectro-polarimetric measurements in the Sr i line at different limb distances, from μ = 0.2 to μ = 0.8, on the solar disk. Spatial variations of the scattering polarization signal in the Sr i 4607 Å line, with a spatial resolution of about 0.66

Observations with Multi-Application Solar Telescope (MAST)

Shibu Mathew

Udaipur Solar observatory (USO), Physical Research Laboratory

MAST is a 50 cm off-axis telescope used for solar photospheric and chromospheric observations. The telescope is equipped with a narrow-band spectral imager along with adaptive optics. In this talk I will be presenting the capabilities of the imager, and some of the recent observations and the data eduction techniques. Polarimteric observations are also tried out with this telescope, the status of which also will be presented.

National Large Solar Telescope (NLST)

Ravindra B and NLST team

Indian Institute of Astrophysics, Bangalore

The National Large Solar Telescope is a 2-m class optical telescope to carry out observations of fine structures of the magnetic features in the solar atmosphere at high spatial and temporal resolution. Extensive site characterization is carried out between 2007-2010 at three sites in the Himalayas. An incursion site near the Pangong Tso Lake in the Changtang cold desert is identified as an excellent site to install the NLST. The proposed telescope will have an innovative optical design with a few reflecting surfaces to maximize the optical throughput. The NLST will be an on-axis Gregorian telescope with a polarimeter located close to the secondary focus will provide a better handle on instrumental polarization. The higher-order adaptive optics in the telescope light path will give the diffraction-limited performance. The telescope will be kept at the height of 20 m above the ground to avoid the ground level seeing effect. An open dome or the ventilated dome is planned to prevent the thermal fluctuations in and around the telescope. For the first light operation, the broadband imager, Fabry-Perot based narrow band imager, and a high spectral resolution polarimeter are planned. This will be extended to infrared wavelength regions in the second stage. The solar community in India is eagerly looking forward to the approval of this project.

The 1.5 m GREGOR Solar Telescope

Thomas Berkefeld

Leibniz Institute for Solar Physics, Freiburg, DE

We give an overview of the 1.5m GREGOR solar telescope including current results and we present future developments. GREGOR is an open-dome Gregory-type telescope run by German Insitutes on the Island of Tenerife, Spain. It features state-of the art postfocus instrumentation including a solar adaptive optics system which provides - in conjunction with postprocessing - diffraction-limited observing from 390nm to 1600nm. Current developments will expand the two-dimensional spectro-polarimeter (Fabry-Perot) setup, add more (simultaneous) wavelength measurements to the spectrograph and complement the adaptive optics with night-time and solar off-limb (prominence) locking.

DKIST Instrumentation and Adaptive Optics

Freidrich Woeger

National Solar Observatory, USA

The NSF's Daniel K. Inouye Solar Telescope (DKIST) is the world's largest observatory for the sun. Its four meter aperture and state-of-the-art wavefront correction system and instrumentation will facilitate new insights into the complexities of the solar atmosphere. In this contribution, we will lay out the details and status of the integrated high order adaptive optics system and the diverse first light instruments that are being commissioned: The Visible Spectro-Polarimeter (ViSP), the Visible Broadband Imager (VBI), the Visible Tunable Filter (VTF), the Diffraction-Limited Spectro-Polarimeter (DL-NIRSP) and the Cryogenic Spectro-Polarimeter (Cryo-NIRSP). We will present first data demonstrating the telescope's instrument systems performance.

Coronal Magnetic Field Measurements and Models

Sarah Gibson

NCAR/HAO, USA

The coronal magnetic field is fundamental to our understanding of solar and heliospheric structure and dynamics, but remains a difficult quantity to observe spectropolarimetrically. In the infrared (IR), proof-of-concept measurements of circular polarization have diagnosed line-of-sight magnetic field strength, and multiple years of synoptic linear-polarization observations have demonstrated capability for diagnosing topology of coronal structures. From these it is clear that the advent of larger-aperture telescopes, including the Daniel K. Inouye Solar Telescope (DKIST) and the Coronal Solar Magnetism Observatory (COSMO), will open a new window on our understanding of coronal magnetic fields. The upcoming VELC instrument on board the Aditya satellite will also obtain linear polarization measurements in the IR from space for the first time. An intriguing possibility would be to complement these existing and planned ground- and space-based IR measurements with space-based spectropolarimetric measurements in the ultraviolet (UV). Here the magnetic Hanle effect is unsaturated, resulting in different sensitivities to magnetic field direction and strength than in the infrared. By combining forward models of IR and UV spectropolarimetry with a variety of idealized coronal physical state models, including magnetic flux ropes, pseudostreamers, and streamer-solar wind interfaces, we consider the relative sensitivities of these diagnostics to coronal magnetic structure and strength, and, in particular, non-potentiality.

Forward modelling of magnetohydrodynamic waves in the solar atmosphere

Vaibhav Pant

Aryabhatta Research Institute of Observational Sciences, Nainital

Several spectroscopic and imaging observations have established the ubiquity of Alfvénic waves in the solar atmosphere. In the past, several studies have suggested that the Alfvenic waves carry energy enough to heat the solar corona. However, an apparent discrepancy was noted in the measured Alfvénic wave energy flux in the solar atmosphere. Some studies have suggested that this discrepancy could be due to the unresolved wave amplitudes along the line-of-sight (LOS) in the solar atmosphere. In this work, I will present the 3D MHD simulations of propagating Alfvénic waves in a gravitationally stratified plasma with properties similar to the open and closed magnetic field regions in the Sun. I will discuss the variation of the Doppler velocities and non-thermal line widths derived from the forward modelling of the Alfvénic waves. I will present the amount of underestimation of true energy in the MHD simulations due to LOS superposition. The LOS superposition of waves makes the emission line profiles asymmetric which can be detected with the future space or ground-based instruments. Finally, I will discuss the relevance of these studies in the context of upcoming solar observatories, especially ADITYA-L1.

Coronal spectroscopy and spectropolarimetry

Haosheng Lin

IfA,Hawaii

First radio evidence for ubiquitous magnetic reconnections and impulsive heating in the quiet solar corona

Divya Oberoi

National Centre for Radio Astrophysics, Tata Institute of Fundamental Research, Pune

How the solar corona maintains its million K temperature sitting atop a much cooler photosphere has been a longstanding puzzle. The “nanoflare” hypothesis proposes that individually small contributions from numerous and ubiquitous flares of energies $\sim 10^{24}$ ergs collectively provide the energy to maintain the million K corona. Given their very small spatial, temporal and energy scales, direct detection of nanoflares has been challenging with the current instrumentation at EUV and X-rays. These nanoflares are also expected to produce nonthermal electrons, which are expected to emit in the radio band. These nonthermal emissions are also expected to be much brighter than their thermal counterparts and might be detectable with current radio instruments. We describe the results from our effort to use the data from the Murchison Widefield Array (MWA) to search for impulsive radio emissions in the quiet solar corona. By pushing the detection threshold of nonthermal emission by about two orders of magnitude lower than previous studies, we have uncovered ubiquitous impulsive nonthermal emissions from the quiet sun. We refer to them as Weak Impulsive Narrowband Quiet Sun Emissions (WINQSEs). Using independent observations spanning very different solar conditions we show that WINQSEs are present throughout the quiet corona at all times. Their occurrence rate lies in the range of many hundreds to a $\sim$thousand per minute, implying that on average ~10 or so WINQSEs are present in every 0.5 s MWA image. Preliminary estimates suggest that WINQSEs have a bandwidth of $\sim$2 MHz. Buoyed by their possible connection to the hypothesised “nanoflares”, we are pursuing several projects to characterise and understand them. These include developing machine learning algorithms to identify WINQSEs in radio images and characterise their morphologies; exploring the ability of the present generation EUV and X-ray instruments to estimate the energy corresponding to the brightest of WINQSEs; and attempting very high time resolution imaging to explore their temporal structure. Here we present the results from our past and ongoing investigations of WINQSEs and argue that these might be a key step towards detecting nanoflares and the resolution of the coronal heating problem.

Prevalent transverse waves in the corona and their potential for mapping the coronal magnetic field

Hui Tian, Zihao Yang, Christian Bethge, Steven Tomczyk, Richard Morton, Giulio Del Zanna, Scott W. McIntosh, Bidya Binay Karak, Sarah Gibson, Tanmoy Samanta, Jiansen He, Yajie Chen, Linghua Wang

Hui Tian

Peking University, China

Understanding many physical processes in the solar atmosphere requires determination of the magnetic field in each atmospheric layer. However, direct measurements of the magnetic field in the Sun's corona are difficult to obtain. Using observations with the Coronal Multi-channel Polarimeter, we have determined the spatial distribution of the plasma density in the corona, and the phase speed of the prevailing transverse magnetohydrodynamic waves within the plasma. We combine these measurements to map the plane-of-sky component of the global coronal magnetic field. The derived field strengths in the corona from 1.05 to 1.35 solar radii are mostly 1-4 Gauss. These results demonstrate the capability of imaging spectroscopy in coronal magnetic field diagnostics.

Coronal magnetic field extrapolations

Michael Wheatland

University of Sydney, Australia

In this talk I will present a review of methods of coronal magnetic field extrapolation, i.e. calculation of a coronal magnetic field model from observed solar boundary data. I will focus on approaches using the nonlinear force-free model, but consider also more general models. Different methods make different use of available boundary data, and involve different computational methods and assumptions. I will discuss the success of the methods, in terms of their ability to solve the assumed model and their performance in tests, and survey the wide range of applications for the resulting field reconstructions. Finally I will consider some of the outstanding questions in the modelling.

Asymmetry in the Inward-Outward Polarity in the Interplanetary Magnetic Field

A.B.Asgarov, V.N. Obridko

Shamakhy Astrophysical Observatory (SAO) named after N.Tusi

Distribution of the magnetic field of solar wind near the Earth was investigated and compared with one expected from the classical model. It is shown that the presence of two peaks in the distribution of interplanetary magnetic field values, founded by Belov, Obridko and Shelting (2006), is not an artefact of averaging but reflects the real structure of magnetic field inside a sector. Moreover, the magnetic field of the polarity corresponding to the leading sunspot of the Northern Hemisphere is observed more frequently. With solar activity rise the growth of both the module of a magnetic field and the fields of each polarity separately were determined. The distance between peaks increases from 6 nT to 10 nT. In alternate amplification of peaks a quasi-22-year cycle was observed while in the intensity of a field of each polarity there was revealed a 11- year cycle, and in ratio of peaks to frequency of occurrence of zero values – a quasi-2-year (2.6±0.3 year) cycle. Approximately in 25 % of all cases the classical model is violated.

On modeling and simulation of coronal magnetic structures: coronal transients

Ramit Bhattacharyya

Udaipur Solar Observatory, Physical Research Laboratory

The solar coronal transients are manifestations of magnetic reconnection in which the magnetic free energy gets converted into heat and accelerate charge particles along with a rearrangement of magnetic field lines. Exploration of magnetic structures related to these transients is a challenge in solar and space physics that requires a combined approach of multi-wavelength observations and data based numerical simulations. In absence of a reliable measurement of the coronal magnetic field, extrapolations provide a glimpse of the relevant magnetic structures and, can initiate data based MHD simulations to explore the physics of reconnection in a realistic scenario. In this presentation, the focus will be on the extrapolation of coronal magnetic field, its usage in MHD simulations and their overall synergy with multi-wavelength observations.

Sequential Lid Removal in a Triple-decker Chain of CME-producing Solar Eruptions

Navin Chandra Joshi, Alphonse C. Sterling, Ronald L. Moore, Bhuwan Joshi

Navin Chandra Joshi
SRM University, Delhi-NCR

We investigate the onsets of three consecutive coronal mass ejection (CME) eruptions in 12 hr from a large bipolar active region (AR) observed by the Solar Dynamics Observatory (SDO), the Solar Terrestrial Relations Observatory (STEREO), the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI), and the Geostationary Operational Environmental Satellite (GOES). Evidently, the AR initially had a “triple-decker” configuration: three flux ropes in a vertical stack above the polarity inversion line (PIL). Upon being bumped by a confined eruption of the middle flux rope, the top flux rope erupts to make the first CME and its accompanying AR-spanning flare arcade rooted in a far apart pair of flare ribbons. The second CME is made by eruption of the previously arrested middle flux rope, which blows open the flare arcade of the first CME and produces a flare arcade rooted in a pair of flare ribbons closer to the PIL than those of the first CME. The third CME is made by blowout eruption of the bottom flux rope, which blows open the second flare arcade and makes its own flare arcade and pair of flare ribbons. Flux cancellation observed at the PIL likely triggers the initial confined eruption of the middle flux rope. That confined eruption evidently triggers the first CME eruption. The lid-removal mechanism instigated by the first CME eruption plausibly triggers the second CME eruption. Further lid removal by the second CME eruption plausibly triggers the final CME eruption.

Mass loss rate from the Sun over solar cycles 23 and 24

Wageesh Mishra, Nandita Srivastava, Yuming Wang, Jie Zhang, and Zavkiddin Mirtoshev

Wageesh Mishra

Indian Institute of Astrophysics, Bangalore

Similar to other stars, our Sun also sheds mass and magnetic flux via ubiquitous steady wind and episodic coronal mass ejections (CMEs). To investigate the mass loss rate of the Sun over different solar cycles, we exploited the remote sensing observations of CMEs near the Sun and in situ observations of the solar wind at 1 AU. We estimate the contribution of solar CMEs to the solar wind and its variation over different phases of the solar cycles. Further, we investigate that how the mass-loss rate from the Sun is related to its magnetic variability represented in terms of sunspots number and background solar X-ray flux. Our study shows that mass loss from Sun via solar wind is almost independent of cyclic variation in sunspots number and background solar X-ray flux for solar cycles 23 and 24. However, the mass-loss rate via CMEs is found to depend on solar magnetic variability, and the dependence could be expressed in terms of a simple expression. These results have significant implications for the study of solar-type stars.

Aditya-L1 Mission

Nigar Shaji

Indian Space Research Organization (ISRO)

Visible Emission Line Coronagraph on AdityaL1 – India's First Space Solar Mission

B.R.Prasad

Indian Institute of Astrophysics, Bangalore

AdityaL1 is India's first space solar mission with a suite of seven payloads to study the solar dynamics. Visible Emission Line Coronagraph (VELC) on Aditya(L1) is an internally occulted solar coronagraph with simultaneous imaging, spectroscopy and spectro-polarimetry channels close to the solar limb. The primary science goals of this mission are (1) Diagnostics of the coronal and coronal loops plasma (Temperature, Velocity, & Density), (2) Heating of the corona, (3) Development, dynamics & origin of CME's, (4) Studies on the drivers for space weather and (5) Measurement of coronal magnetic fields in the corona (not planned by any mission so far). VELC is designed to image solar corona and multi-slit spectroscopic channels at three emission lines namely 530.3nm, 789.2nm and 1074.7nm. It has dual-beam spectro-polarimetry at 1074.7nm for magnetic field measurements. The stringent demands on design, realization of subsystems, integration and finally the calibration challenges will be discussed in this talk.

The Solar Ultraviolet Imaging Telescope on board Aditya-L1

Durgesh Tripathi, A N Ramaprakash, P. Sreejith and SUIT Team

Durgesh Tripathi

IUCAA, Pune

The Solar Ultraviolet Imaging Telescope (SUIT) onboard the Aditya-L1 mission will observe the Sun in the wavelength range 200-400 nm using 11 science filters centered at different wavelengths. It will provide full disk and partial disk images with a pixel size of 0.7 arcsec and variable time resolution that will depend on the size of the region of interest and the number of filters being used. The observations from SUIT will help us understand the coupling and dynamics of the lower solar atmosphere. Moreover, it will help us measure and monitor the spatially resolved solar spectral irradiance in near ultraviolet, which is central to the dynamics of oxygen and ozone in the Earth's stratosphere. This talk will summarise the primary science goals of SUIT and salient technical features.

Science with Solar Low Energy X-ray Spectrometer

K. Sankarasubramanian, Monoj Bug, Abhilash Sarwade, Smrati Verma, Kumar, Ramadevi, Ankur Kushwaha

Sankarasubramanian Kasiviswanathan

URSC, ISRO

Solar Low-energy X-ray spectrometer (SoLEXS) observes the sun-as-a-star and provide low energy X-ray spectra during solar flare events. The primary science objectives of this instrument: (i) Thermal energy content of solar flares and the break energy variation for different classes of solar flares, (ii) Coronal abundance variations (FIP variation) during flare events and the physical mechanism behind the same, (iii) Along with other instrument on-board study the Flare-CME associations as well as understand the mechanism behind the Flare driven prominence eruption. This talk will briefly describe the above science objectives along with the instrument specification to achieve the same.

HEL1OS

Anuj Nandi

Indian Space Research Organization (ISRO)

Aditya Solar wind Particle EXperiment (ASPEX) on Aditya-L1 Mission

Dibyendu Chakrabarty

Physical Research Laboratory (PRL), Ahmedabad

Many aspects of the origin, acceleration and anisotropy of solar wind particles are poorly understood till date. These particles can arrive at the first Lagrangian point (L1) of the Sun-Earth system from a number of directions. Further, thermal anisotropy of the solar wind particles along and across the Parker spiral direction is also known. Therefore, in order to understand the solar and interplanetary processes based on solar wind measurements, it is essential to have multi-directional measurements of both low and high energetic particles. In addition, it is also important to measure He^{2+} (second most abundant ions) and H^{+} (most abundant ions) ions separately as their differential behavior may throw light on the physical processes associated with the origin, acceleration and anisotropy of solar wind. Keeping these aspects in mind, Aditya Solar wind & Particle EXperiment (ASPEX) experiment on Aditya-L1 mission has been designed. ASPEX will make in-situ, multi-directional measurements of the slow & fast solar wind, supra-thermal and energetic particles in the energy range of 100 eV to 5MeV /n using its two sub-systems - Solar Wind & Ion Spectrometer (SWIS) and the Supra Thermal & Energetic Particle Spectrometer (STEPS).

Scientific objectives of Plasma Analyser Package for Aditya (PAPA) payload onboard Aditya-L1 Mission

R Satheesh Thampi and PAPA Team
SPL/VSSC/ISRO

Solar wind is a magnetized plasma consisting of charged particles with embedded magnetic field, flowing out of the Sun in all directions at very high speeds. Plasma Analyser Package for Aditya (PAPA) is an in-situ observing payload onboard Aditya-L1 Mission, meant for exploring the solar wind composition and its energy distribution by measuring electrons and ions from the first Lagrangian point (L1). PAPA has two sensors: Solar Wind Electron Energy Probe (SWEEP) and Solar Wind Ion Composition AnalyseR (SWICAR), which would measure, respectively, the solar wind electron and ion fluxes and composition as a function of direction and energy. SWICAR also provides: (1) the elemental composition of solar wind low energy ions, and (2) the differential energy spectra, abundances of dominant ion species in the mass range 1-60 amu with energies between 0.01 and 25 keV/q. From the differential energy spectra, the macroscopic properties such as the bulk velocity, density and kinetic temperature of the dominant solar wind ion species can be derived routinely, and which can be used to identify sources of low energy ion populations as well as the nature and dynamics of solar wind plasma. In this talk, the scientific objectives of the PAPA payload will be presented and discussed in detail.

Fluxgate Magnetometer (MAG) onboard Aditya-L1 Solar Mission

Vipin K Yadav and MAG Team

SPL/VSSC/ISRO

Magnetic field measurements are regularly carried out in space to sample the local plasma and magnetic environment around a planetary body or a specific location in space. The fluxgate magnetometers (FGMs) are an integral part of most of the spacecraft as they are highly sensitive instruments which measure the feeble magnetic fields in outer space and the interplanetary magnetic field (IMF) emanating from the Sun such as WIND in 1994 and ACE in 1997 to the first Lagrangian (L1) point from NASA. The Aditya-L1 fluxgate magnetometer (MAG) is a 3-axis magnetic sensor mounted on a 6 m boom away from the spacecraft. Two sets of such triaxial sensors are planned to be mounted, one set at the boom tip and the other set midway on boom ~ 3 m from the spacecraft so as to eliminate the magnetic contamination from spacecraft itself. The scientific objectives of this magnetic field experiment are to measure the magnitude and nature of local IMF at L1 point and to study the effect of extreme solar events such as coronal mass ejection (CME), solar magnetic storm, etc. on space weather near the Earth and solar plasma waves. In this talk, the scientific objectives of the MAG onboard Aditya-L1 solar mission shall be presented.

Flares, CMEs and Space Weather

Nat Gopalswamy
NASA Goddard Space Flight Center, USA

Coronal mass ejections (CMEs) and flares from the Sun are important sources of space weather. Solar flares cause sudden change in the ionization level in the ionosphere. CMEs accelerate particles to high energies observed as solar energetic particle (SEP) events and cause geomagnetic storms owing to the southward field in the CME and/or in the shock sheath. While flares and CMEs have different space weather consequences, their origin at the Sun are closely related through the magnetic reconnection process in the source active region. In fact, the flare reconnection flux has turned out to be an important quantity that has important implications for characterizing the magnetic properties of CMEs (e.g., the flux rope structure). In this talk, I highlight some recent developments in our understanding of solar eruptions.

Radio observations of CMEs.

Kathiravan, C.

Indian Institute of Astrophysics, Bangalore

The radio signatures of the coronal mass ejections and their associated phenomena shall be presented.

A Review of Solar Flare Prediction Using a Modern Scientific Workflow

Monica Bobra

Stanford University, USA

In this talk, I will give an overview of flare prediction using machine learning techniques. I will also talk about open problems and future directions for the field.

Association of type IV radio bursts with CMEs in solar cycle 24

Anshu Kumari, Diana Morosan and Emilia Kilpua

Anshu Kumari

University of Helsinki, Finland

Solar activities, in particular coronal mass ejections (CMEs), are often accompanied by bursts of radiation at metre wavelengths, some of which are long duration and broadband in nature, such as type IV radio bursts. However, the association of type IV bursts with coronal mass ejections is still not well understood. We perform the first statistical study of type IV solar radio bursts in the solar cycle 24. Our study includes a total of 446 type IV radio bursts that occurred during this cycle. Our results show that a clear majority, ∼81% of type IV bursts, were accompanied by CMEs, based on a temporal association with white-light CME observations. However, we found that only ∼2.2% of the CMEs are accompanied by type IV radio bursts. We categorised the type IV bursts as moving or stationary based on their spectral characteristics and found that only ∼18% of the total type IV bursts in this study were moving type IV bursts. Our study suggests that type IV bursts can occur with both 'Fast' (≥500km/s) and 'Slow' (<500km/s), and also both 'Wide' (≥60◦) and 'Narrow' (<60◦) CMEs. However, the moving type IV bursts in our study were mostly associated with 'Fast' and 'Wide' CMEs (∼52%), similar to type II radio bursts. Contrary to type II bursts, stationary type IV bursts have a more uniform association with all CME types

Comparison of physical properties of the solar atmosphere and synthetic SDO/HMI line-of-sight observables from 3D Radiative MHD simulations

Viacheslav M Sadykov, Irina N Kitiashvili, Alexander G Kosovichev, Alan A Wray

Viacheslav Sadykov
Georgia State University, USA

In this study, we compare the SDO/HMI line-of-sight observables (magnetic field, velocity, continuum intensity, and line depth) with the related physical properties for several dynamo simulation runs performed using the "StellarBox" 3D Radiative MHD code. The modeling of the Fe I 6173 Å Stokes profiles is performed using the SPINOR radiative transfer code in the LTE approximation. The reproduced SDO/HMI line-of-sight pipeline is applied to the modeled spectra, and the observables are synthesized with high (numerical) and SDO/HMI (instrumental) resolutions. Correlations between the observables and the physical properties at various heights in the atmosphere are studied for a set of view angles (0, 30, 45, 60, 70, and 80 degrees away from the solar disk center). It was found that the SDO/HMI magnetic field and velocity measurements are unambiguously correlated with physical parameters at certain heights of the solar atmosphere. These heights increase from about 100 km above the photosphere for the disk center case to 300-600 km above the photosphere for the 80 degree case. The heights are found to be slightly lower in regions where higher magnetic fields are found. The total photospheric magnetic flux derived from SDO/HMI observables underestimates the high-resolution magnetic flux by a factor of 3 on average. Integrated SDO/HMI continuum intensity observables underestimate the actual integrated continuum intensity by about 5%. The results of our study allow us to better understand and interpret the line-of-sight observations of quiet Sun regions from the SDO/HMI mission.

From Flux Emergence to Sunspot Structure – A Modeling Perspective

Matthias Rempel

High Altitude Observatory / NCAR, USA

Our understanding of flux emergence has undergone in the past few decades a substantial paradigm change. While models more than 2 decades ago treated flux emergence as an active process in which super-equipartition flux tubes rise towards the surface owing to their magnetic buoyancy, more recent models rely mostly on a passive transport by means of the ambient convection. This change was due to both modeling advances and new observational constraints. Rising flux-tube models that incorporate the advective transport from ambient convection were able to explain active region properties with flux tubes of weaker field strength. Global dynamo simulations demonstrate that flux bundles with a strength of a few 10kG can be formed within the turbulent convection zone and rise towards the surface mostly due to convective transport. Helioseismic flow measurements in the 24 hours prior to the onset of active region formation were not able to discern the flow fields that were predicted by active flux emergence models, such as retrograde flows and persistent upflows in the flux emergence region. Instead, flux-emergence appears mostly as a "stealth" process in the last 20Mm beneath the photosphere, implying that flux is primarily transported by the present convective flows with only minor modification. This is in part due to a significant weakening of the magnetic field strength as consequence of horizontal expansion in the highly stratified convection zone, leading to flux bundles of just a few 100G reaching the photosphere. While the subsequent reamplification to spots of several kG in the photosphere has been found as a robust feature in most radiation MHD simulations, there remains some debate about the detailed physical processes involved. Another critical detail that still evades the grasp of current radiation MHD simulations is the formation of a penumbra as part of the spot formation process. While sunspot fine-structure has been modeled in great detail, the presence of a penumbra remains heavily dependent on details of the numerical setup. While fine-structure models about a decade ago produced penumbra through an artificially enhanced horizontal field component at the top boundary, recent research focuses more on the critical role of the sunspot sub-surface structure. In this talk I review about 3 decades of model development while strongly focusing on recent results and critical observations that have guided the way.

3D simulations of convection and why

Regner Trampedach

Space Science Inst., Boulder, USA

Convection affects stars by determining the interior structure, by mixing the chemical elements and transporting angular momentum, as well as setting the photospheric stage for photons to start their long trip to our telescopes. But convection is inherently a 3D and time dependent phenomenon making it a lot harder to model and harder to apply to our interpretation of observations than most other phenomena. I will provide an overview of the different kinds of convection simulations that are available, and how they have been applied to a wide range of issues in astrophysics.

Self-consistent formation of sunspot-like magnetic flux concentrations

Petri Kaepylae, Maarit Kaepylae
Nishant K. Singh
IUCAA, Pune

An important goal of solar physics is to understand the mechanism of sunspot formation on the photosphere. In our recent high resolution simulations of turbulent magneto-convection, we find that the sunspot-like magnetic flux concentrations form on the surface in a self-consistent manner. I will highlight some details of these simulations and will share some new insights on the possible mechanism involved in formation of such concentrations in simulations.

Slow Magneto-acoustic Wave Propagation in Three-Dimensional Simulations of a Unipolar Solar Plage

Nitin Yadav, R H Cameron, and S K Solanki

Nitin Yadav

KU Leuven, Belgium

We investigate the properties of slow magneto-acoustic waves that are naturally excited due to turbulent convection and investigate their role in the energy balance of a plage region using three dimensional (3D) radiation-MHD simulations. To study slow magneto-acoustic waves traveling along the magnetic field lines, we track 25 magnetic field lines both in space and time inside a strong magnetic element. We calculate velocity component parallel to the background field and compute the temporal power spectra at various heights above the mean solar surface. Additionally, horizontally averaged (over the whole domain) power spectra for both longitudinal (parallel to the background magnetic field) and vertical (i.e. the component perpendicular to the surface) components of velocity are calculated using time-series at fixed locations. We also degrade our simulation data to compare our results with observations. The power spectra of longitudinal component of velocity, averaged over 25 field lines in the core of a kG magnetic flux concentration, reveal that the dominant period of oscillations shifts from ∼ 6.5 minutes in the photosphere to ∼ 4 minutes in the chromosphere. This behaviour is consistent with earlier studies restricted to vertically propagating waves. At the same time, the velocity power spectra, averaged horizontally over the whole domain, show that low frequency waves (∼ 6.5 minute period) may reach well into the chromosphere possibly along the inclined magnetic field lines at the edges of selected magnetic patch. In addition, the power spectra at high frequencies follow a power law with an exponent close to -5/3, suggestive of turbulent excitation. The horizontally averaged power spectra of vertical component of velocity at various effective resolutions show that the observed acoustic wave energy fluxes are underestimated, by a factor of three even if determined from observations carried out at a high spatial resolution of 100 km. Since the waves propagate along the non-vertical field lines, measuring the velocity component along the line-of-sight, rather than along the field contributes significantly to this underestimate. Moreover, this underestimation of energy flux indirectly indicates the importance of high-frequency waves that are shown to have a smaller spatial coherence and are thus more strongly influenced by spatial averaging effect compared to low-frequency waves. Our results show that, in contrast to claims made in the literature, longitudinal waves within magnetic elements carry sufficient energy to heat the chromosphere, although only just.

Beyond MHD simulations of solar atmospheric dynamics

Elena Khomenko
Instituto de Astrofisica de Canarias (IAC), Spain

The MHD approximation is a classical approximation that is successfully used to treat the dynamical processes in the solar atmosphere. Nevertheless, in weakly ionized and weakly collisional astrophysical plasmas, different species composing the plasma are not coupled and move under the action of different forces. This creates net collisional interactions between the species of different kind, providing additional dissipative and dispersive non-ideal plasma mechanisms. In the recent years, it has been realized that energy propagation and release through the solar atmosphere are affected by the presence of a large fraction of neutral atoms, and their presence may be of importance to solve the problem of chromospheric heating, dynamics and fine structure. Since then, non-ideal MHD and multi-fluid simulations that include neutrals, have become an active topic of research. In this talk I will describe recent advances in the modeling of partially ionized plasma processes in the Sun beyond MHD.

MHD Simulation of a repeatedly flaring delta sunspot

Piyali Chatterjee

Indian Institute of Astrophysics, Bangalore

Active regions (AR) appearing on the surface of the Sun are classified into alpha, beta, gamma, and delta by the rules of the Mount Wilson Observatory, California on the basis of their topological complexity. Amongst these, the delta-sunspots are known to be super-active and produce the most X-ray flares. Here, we present results from a simulation of the Sun by mimicking the upper layers and the corona, but starting at a more primitive stage than any earlier treatment. We find that this initial state consisting of only a thin sub-photospheric magnetic sheet breaks into multiple flux-tubes which evolve into a colliding-merging system of spots of opposite polarity upon surface emergence, similar to those often seen on the Sun. The simulation goes on to produce many exotic delta-sunspot associated phenomena: repeated flaring in the range of typical solar flare energy release and ejective helical flux ropes with embedded cool-dense plasma filaments resembling solar coronal mass ejections.

Large-amplitude prominence oscillations following the impact by a coronal jet

Manuel Luna, Fernando Moreno-Insertis

Manuel Luna

Universitat de les Illes Balears

Observational evidence shows that coronal jets can hit prominences and set them in motion. The impact leads to large-amplitude oscillations (LAOs) of the prominence. We attempt to understand this process via 2.5D MHD numerical experiments. In our model, the jets are generated in a sheared magnetic arcade above a parasitic bipolar region located in one of the footpoints of the filament channel (FC) supporting the prominence. The shear is imposed with velocities not far above observed photospheric values; it leads to a multiple reconnection process, as in previous jet models. Both a fast Alfvénic perturbation and a slower supersonic front preceding a plasma jet are issued from the reconnection site; in the later phase, a more violent (eruptive) jet is produced. The perturbation and jets run along the FC; they are partially reflected at the prominence and partially transmitted through it. There results a pattern of counter-streaming flows along the FC and oscillations of the prominence. The oscillations are LAOs (with amplitude above 10 km/s in parts of the prominence both in the longitudinal and transverse directions. In some field lines, the impact is so strong that the prominence mass is brought out of the dip and down to the chromosphere along the FC. Two cases are studied with different heights of the arcade above the parasitic bipolar region, leading to different heights for the region of the prominence perturbed by the jets. The obtained oscillation amplitudes and periods are in general agreement with the observations.

MHD Simulations of Small-scale Magnetism and Vortical Flows

Oskar Steiner

Leibniz-Institut fuer Sonnenphysik, Freiburg, Germany

Small-scale vortical flows in the solar atmosphere have attracted increasing attention over the past decade. What kind of vortical motions are these, how to formally describe them, what is their physical nature, how do they propagate, what is their energetics? These are questions that became addressed with the help of numerical simulations. This talk concentrates on two types of vortical flows: the so called "magnetic tornadoes" and vortex tubes at the edges of granules. The latter are thought to have relevance for the small-scale dynamo in the surface layers of the convection zone.

Vainu Bappu Memorial Lecture

Dynamics of convection in the Sun

K.R. Sreenivasan,
New York University, USA

There is considerable literature on convection under controlled conditions, in both the laboratory and simulations. Very little of it pertains directly to the Sun but some of it allows us to ask pointed questions which bring us a bit closer to the real thing. My talk will be about this approach in a broad setting.

Meridional flow in the deep convection zone

Laurent Gizon

Max Planck Institute for Solar System Research

We report on work published in the 26 June 2020 issue of Science magazine. We analysed GONG, MDI and HMI helioseismic data to infer the (mass-conserving) meridional flow in the solar convection zone. The GONG and MDI solutions averaged over 1996-2019 are consistent with a single-cell solution in each hemisphere. Implications for the solar dynamo are discussed using a simplified flux-transport model. We find that the observed return flow at the base of the convection zone may explain the drift of latitudes at which sunspots emerge during the solar cycle.

Equatorially confined turbulence in the Sun

Shravan Hanasoge

Tata Institute of Fundamental Research, Mumbai

Convection in the Sun's outer envelope generates turbulence and drives differential rotation, meridional circulation, and the global magnetic cycle. We develop a greater understanding of these processes by contrasting observations with simulations of global convection. These comparisons also enhance our comprehension of the physics of distant Sun-like stars. Through helioseismic analyses of space-based observations, I will describe inferences of toroidal flow power as a function of wave number, frequency, and depth in the solar interior. The inferred flows grow with spatial wave number and temporal frequency and are confined to low latitudes, supporting the argument that rotation induces systematic differences between the poles and equator. In contrast, the simulations used here show the opposite trends—power diminishing with increasing wave number and frequency while flow amplitudes become weakest at low latitudes. I will describe how these differences highlight gaps in our understanding of solar convection and point to challenges ahead.

Seismic Mapping of the Sun's Farside

Kiran Jain

National Solar Observatory, USA

Seismic maps of the non-visible side (farside) of the Sun are of great importance for monitoring large active regions before they rotate into our view from the east limb. Early detection of these regions on farside is important for space weather forecasting as well as for planning large observing campaigns. In this talk, I will discuss the basic principles of the farside imaging technique along with the latest developments and improvements. I will also discuss how seismic mapping was recently used, for the first time, to successfully predict the largest active region of the current solar cycle five days in advance.

Helioseismic observations of torsional oscillations and constraints on solar-cycle theories

Alexander G. Kosovichev

New Jersey Institute of Technology, USA

Helioseismological observations of the internal dynamics of the Sun during the last two solar activity cycles make it possible to trace the development of solar dynamo processes throughout the depth of the convective zone and to link them with models of solar cycles. Observational data obtained from the GONG (1995-2020), SoHO (1996-2010) and SDO (2010-2020) represent measurements of the internal differential rotation, meridional circulation, and thermodynamic parameters. The structure and dynamics of zonal plasma flows (torsional oscillations) reveal the processes of generation and transport of magnetic fields inside the Sun. The observed structure of zonal flows and their latitudinal and radial migration in deep layers of the convective zone correspond to dynamo waves predicted by dynamo theories and numerical MHD simulations. The data reveal that the subsurface rotational shear layer (leptocline) plays a key role in the formation of the magnetic butterfly diagram. The helioseismic observations strongly support Parker's theory of solar cycles.

Solar and Stellar dynamos: Concensus and divergences

Paul Charbonneau

University of Montreal, CA

The past two decades have witnessed remarkable progress in the dynamo-based modelling and prediction of the solar magnetic activity cycle. However, and somewhat surprisingly, these advances have not yet led to a concensus view on the mode of operation of the solar dynamo, and even less so of stellar dynamos. In this talk I will briefly review some of these advances, including global magnetohydrodynamical numerical simulations as well as semi-empirical models based on reduced or mean-field magnetohydrodynamics. I will then survey the resulting diverging views on solar and stellar dynamos, and highlight potential paths to convergence for some of the more outstanding divergences.

Global Solar Activity Forecast Using Synoptic Magnetograms

Irina Kitiashvili

NASA Ames Research Center, USA

The problem of predicting the solar 11-year activity cycles remains unsolved for many reasons, such as the complexity of physical processes in the solar interior, the lack of knowledge about past and current global solar dynamics, and limitations of available observations. The sunspot number, which has the longest observational time series, is traditionally considered as the principal measure of a solar cycle's strength. Synoptic observations of magnetic fields on the solar surface provide a more physics-based dataset for the solar cycle prediction problem. In this presentation, I discuss a data assimilation approach to predict global solar activity using synoptic magnetograms and a non-linear dynamo model. I present validation of the approach and prediction results for Solar Cycle 25 and examine criteria for model predictive capabilities in situations with limited available observational data.

Solar Cycle Predictions

Dibyendu Nandi

Center of Excellence in Space Sciences India, IISER Kolkata

The Sun's magnetic cycle impacts space environmental conditions. While energetic, short term events such as magnetic storms create space weather, slower long-term variation in solar magnetic output influences planetary atmospheres and climate. A prior understanding of solar activity is therefore deemed crucial in the realm of space weather and climate sciences. However, forecasting solar-stellar magnetic activity has remained an outstanding challenge. We shall critically review the state of understanding of solar cycle predictability and highlight recent progress following the early controversies related to solar cycle 24 predictions. We shall also critically assess solar cycle 24-25 predictions and demonstrate that convergence has been achieved in physics-based predictions for solar cycle 25, indicating a weak to moderate-weak sunspot cycle 25. Based on advances in our understanding we shall also provide answers to several outstanding questions related to solar cycle predictions.

Nonlinearities for the saturation of the magnetic field in the Sun

Bidya Binay Karak

Indian Institute of Technology (BHU), Varanasi

The magnetic field of the Sun increases and decreases in time with a polarity reversal every 11 years. The most interesting aspect here is that the amplitude of the field does not grow all the time, although there is a considerable variation in time. We try to explain this problem under the Babcock-Leighton dynamo framework which appears to be the most successful model for the solar cycle at present. However, most of these models are kinematic, and the saturation of the magnetic field is not well-constrained. We demonstrate a recently proposed mechanism for this under the Babcock–Leighton dynamo framework. This mechanism is based on the observational fact that the stronger solar cycles produce bipolar magnetic regions (BMRs) at higher latitudes and thus have higher mean latitudes than the weaker ones. We capture this effect in our three-dimensional Babcock–Leighton solar dynamo model and show that when the toroidal magnetic field tries to grow, it produces BMRs at higher latitudes. The BMRs at higher latitudes generate a less poloidal field, which consequently limits the overall growth of the magnetic field in our model. Thus, our study suggests that the latitudinal variation of BMRs is a potential mechanism for limiting the magnetic field growth in the Sun.

Closing the solar cycle: emerging active regions

Hannah Schunker

The University of Newcastle, Australia

The emergence of magnetic field from the interior of the Sun generates a poloidal magnetic field from rising toroidal magnetic field. How sunspots and active regions emerge is a crucial, but poorly understood aspect of the solar dynamo. Only since the advent of the SDO/HMI monitoring campaign has it been possible to capture the emergence process of hundreds of active regions in observations of the magnetic field, Doppler velocity and intensity continuum. By measuring the average motion of the polarities, surface velocities and pattern of convection, it is clear that convection plays an important role in the emergence of magnetic field on the Sun.

Synoptic Solar Physics: Results from Long Term Data-sets

Alexei Pevtsov

National Solar Observatory, USA

The research community is pushing hard to explore the Sun with the highest-possible spatial resolution and the fastest time cadence. We justify this by the need to better understand the physics of solar activity and to develop a reliable space weather forecast. However, our understanding of solar activity will be incomplete and even distorted, if we do not know how present activity compares with the past, and what changes may had been occurring in properties of solar phenomena. This talk will outline the importance of long-term datasets and review the results of modern synoptic studies. We will also present the current efforts aimed at addressing the continuity of long-term observations of the Sun.

Kodaikanal Synoptic Programs – Historic and Modern

Jagdev Singh

Indian Institute of Astrophysics, Bengaluru

The synoptic observations of the sun at Kodaikanal observatory were started in the year 1904 by taking the broad-band images of the sun on daily basis and are being taken with the same 15-cm telescope. Afterwards spectro-heliograms in Ca-K and H-alpha were taken on daily basis since 1905 and 1912, respectively. The images of off-limb prominences were also obtained in Ca-K or H-alpha lines and continued till 2007. As the photographic films became unavailable, Ca-K line filter-grams were obtained beginning in 1998 and H-alpha filter-grams in 2014 using newly developed Twin-telescope and H-alpha telescopes. The monitoring of Ca-K line profiles of Sun as a star began in 1969 and as a function of latitude in 1986 at Solar Tower Telescope. A new methodology of Equal Contrast Technique (ECT) has been developed to analyse the Ca-K line historic photographic images. This procedure enables to correlate the sunspot and Ca-K line data on day-to-day basis, for the first time. This methodology will also help to combine the Ca-K data from different instruments at different observatories to generate a long time series with minimum gaps.

Multiple reversals of the Sun's polar-fields and their physical causes

A.V Mordvinov, B.B. Karak, D. Banerjee, S. Chatterjee, E.M.Golubeva, A.I. Khlystova

Alexander Mordvinov

ISTP SB RAS, Russia

Long-term uniform observations for the past 100 years as recorded at the Kodaikanal Solar Observatory (KoSO) provide a wealth of information on solar activity. We develop a method for the reconstruction of the solar magnetic flux using the synoptic observations of the Sun’s emission in the Ca II K and Hα lines from KoSO. The reconstruction is based on the facts that the Ca II K intensity correlates well with the unsigned flux, while the sign of the flux is derived from the corresponding Hα map which provides the information of the dominant polarities. Time-latitude analysis of the reconstructed magnetic flux depicts an overall view of magnetic field evolution: emergent magnetic flux, its further transformations with the formation of unipolar magnetic regions and remnant flux surges in Cycles 15-19. We identify the critical surges of following polarities which result in the regular reversals of the Sun's polar-fields. The poleward transport of predominantly following polarities contributed much of the polar flux and led to polar field reversals. Multiple reversals of the Sun’s polar-fields were identified in Cycles 16 and 19. The decay of non-Joy and anti-Hale active regions results in remnant flux surges that disturb the usual order in magnetic flux transport and sometimes lead to multiple changes of the dominant magnetic polarities at the Sun’s poles. We found also the remnant flux transport between adjacent 11-year cycles. These surges indicate a physical connection of subsequent solar cycles. We further analyze evolution of the Sun’s polar-fields in cycles 21-24. The time-latitudinal analysis of high-resolution synoptic maps makes it possible to identify surges of leading and following polarities in relation to their sources. All these analyses improve our understanding of cyclic patterns that demonstrate global reorganization of the magnetic flux and the polar field buildup.

New results from Kodaikanal long-term datasets

Dipankar Banerjee and the Digitization team

Dipankar Banerjee

Aryabhatta Institute of Observational Sciences, Nainital

Solar observations at Kodaikanal observatory over the last 100+ years provide one of the longest continuous series of solar data. Apart from that, simultaneous observations in different wavelengths make this data a unique one and suitable for multi-wavelength studies. The historical data which were on photographic plates has been digitized. The preservation and distribution of such data sources through the datacenter hosted at IIA, Bangalore to the global scientific community have initiated a new platform for innovative and best practices for dissemination of this historical and heritage resources. In my presentation I will demonstrate how this data archive is producing new science results.

Long-term variations of solar activity

Ilya Usoskin

University of Oulu, Finland

Solar activity is dominated by the 11-yr Schwabe cycle but it varies also on long-term scales. Direct solar observations are available for the last 400 years but their quality before 1900 is poor. Indirect proxy data based on cosmogenic isotopes let us study solar variability on a time scales of ten-thousand years. A brief overview of the current state of the art in the field of solar variability on different times scales is presented. It is discussed that solar activity is a non-periodic and non-stationary process.

Signature of Quenching from Observation of Tilted Bipolar Magnetic Regions on the Sun

Bibhuti Kumar Jha, Bidya Binay Karak, Sudip Mandal and Dipankar Banerjee

Bibhuti Kumar Jha

Aryabhatta Research Institute of Observational Sciences, Nainital

In the Babcock–Leighton process the tilt of bipolar magnetic region (BMR) play a key role for the generation of the poloidal magnetic field in Sun. In the thin flux tube model of the BMR formation, the tilt is believed to be caused by the Coriolis force acting on the rising flux tube of the strong toroidal field from the base of the convection zone (BCZ). Here in this work we analyze the magnetic field dependence of BMR tilts using the magnetograms of MDI (1996–2011) and HMI (2010–2018). We observe that the distribution of the maximum magnetic field (Bmax) of BMRs is bimodal. Its first peak at the low field corresponds to BMRs which do not have sunspots as counterparts in the white light images, whereas the second peak corresponds to BMRs which have sunspots as counterparts. We find that the slope of Joy's law (γ_0) initially increases slowly with the increase of Bmax. However, when Bmax $\ge$ 2 kG, γ_0 decreases. Scatter of BMR tilt around Joy's law systematically decreases with the increase of Bmax. In the white-light digitized data from Kodaiknala Solar Observatory (1923-2011), where we have used sunspot area as a proxy of magnetic field and we find a similar behaviour. This further verify our findings from magnetogram data. The decrease of observed γ_0 with Bmax provides a hint to a nonlinear tilt quenching in the Babcock–Leighton process. We finally discuss how our results may be used to make a connection with the thin flux tube model.

Physics of Solar Irradiance Variations

Sami K. Solanki and Natalie Krivova

Max Planck Institute for Solar System Research, Göttingen, Germany

Physics of Solar Irradiance Variations The solar irradiance, i.e. the brightness of the Sun-as-a-star observed at 1AU, has been observed to vary on all accessible timescales, ranging from minutes to decades, with the solar rotation and solar cycle timescales being particularly prominent. Although many physical causes have been proposed to explain these variations, it is now clear that the main cause of irradiance variability at timescales from days to decades is the magnetic features at the solar surface, while at shorter timescales other sources, such as convection are likely to become important as well. This was demonstrated in the last few years using sophisticated modelling including state-of-the-art 3D MHD simulations incorporating as much physics as possible. The understanding gained in this manner has been used to reconstruct solar irradiance variations further back in time, to the Maunder minimum and beyond.

Modelling of the Solar Chromosphere

Mats Carlsson

Rosseland Centre for Solar Physics, University of Oslo, Norway

The chromosphere is arguably the most difficult and least understood domain of solar physics. All at once it represents the transition from optically thick to thin radiation escape, from gas-pressure domination to magnetic-pressure domination, from neutral to ionised state, from MHD to plasma physics, and from near-equilibrium ("LTE") to non-equilibrium conditions.

The heating requirements of the solar chromosphere are not easily determined since the radiative cooling is dominated by optically thick spectral lines that form far from equilibrium. Energy estimates are therefore very model dependent. 1D semi-empirical model atmospheres indicate that to maintain the quiet, average solar chromosphere, the required energy input is in the range 2-12 kW/m2 but these models neglect many important aspects like the dynamics of the chromosphere, non-equilibrium ionization effects and spatial structuring.

In this talk we will review the modelling of the Solar Chromosphere - from 1D semi-empirical models to 3D radiation magnetohydrodynamic models with increasing level of realism in the physical approximations.

Non-equilibrium equation-of-state for the solar atmosphere

Anusha L. S., M. van Noort and R. Cameron

Anusha Lokanathapura S Bhasari

Max Planck Institute for Solar System Research

In the solar chromospheres, radiative energy transport is dominated by only the strongest spectral lines. For these lines, the approximation of local-thermodynamic-equilibrium (LTE) is known to be very inaccurate, and a state of equilibrium cannot be assumed in general. To calculate the radiative energy transport under these conditions, the population evolution equation must be evaluated explicitly, including all time dependent terms. In this talk I present a numerical method that we developed recently to solve the evolution equation for the atomic level populations in a time-implicit way, keeping all time dependent terms to first order. We solve the non-LTE non-equilibrium radiative transfer (RT) problem through a proper time-dependent treatment of the radiation field and non-equilibrium treatment of the atoms and hydrogen molecules. The method is based on an integral equation approach to the RT equation that involves a generalization to the time dimension, of i) the short-characteristic technique for the formal solution of the RT equation and the ii) Multi-level Approximate Lambda Iteration technique to solve the non-linear rate system. We validate our newly developed method with two important benchmark tests: i) we start with LTE populations on a fixed atmospheric structure, allow them to evolve to the equilibrium solution, and verify that this agrees with the kinetic equilibrium solution obtained from the RH code of Uitenbroek (2001), ii) we show that the physical time-scales required to reach equilibrium are similar to those obtained by Carlsson & Stein (2002) who use a different numerical method. We also showed that the solver remains stable and the solution is robust against changes in the time resolution.

Probing the Vector Magnetic Fields from Resonance Line Polarization

M. Sampoorna

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Information about magnetic fields prevailing in the solar atmosphere is encoded in the polarized line spectrum of the Sun. Thus, probing the solar vector magnetic field requires the solution of the polarized line transfer equation in arbitrary magnetic fields that includes the combined influence of Hanle and Zeeman effects. In this talk we present our recent work on polarized line formation in arbitrary magnetic fields. We present the numerically computed emergent Stokes profiles for a range of magnetic fields. We also, discuss the importance of accounting for partial frequency redistribution (PRD) in scattering that is known to be a necessary ingredient to model the strong chromospheric lines.

Coronal spectroscopy and modelling

Peter R. Young

NASA Goddard Space Flight Center, USA

The spectrum of the Sun's corona will be summarized with emphasis on the key features at wavelengths from the infrared to X-rays. The different methods for observing the corona at these wavelengths will be compared and future observatories and mission concepts will be discussed. The CHIANTI database is a critical tool for modeling coronal emission lines and recent developments will be presented. The talk will also describe methods and software developed by the author to make the spectroscopic measurements from the Hinode/EIS experiment more accessible to the wider community.

Poster - Group I

Solar Photospheric and Chromospheric Phenomena (high – resolution observations)

Filigree in the surroundings of polar crown and high-latitude filaments

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Andrea Diercke

Leibniz Institute for Astrophysics Potsdam (AIP)

Bright points are a well-studied phenomenon in the photosphere at low latitudes. However, we study filigree in the vicinity of polar crown and high-latitude filaments and relate their locations to magnetic concentrations at the filaments' footpoints. We used a unique sample of high-resolution polar crown filament observations in Hα broad-band images and H-alpha narrow-band filtergrams obtained with a new fast camera system at the Vacuum Tower Telescope (VTT), Tenerife, Spain. The Chromospheric Telescope (ChroTel) provided full-disk context observations in H-alpha, CaII K, and HeI 10830A. The Helioseismic and Magnetic Imager (HMI) and the Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics Observatory (SDO) provided line-of-sight magnetograms and UV 1700A filtergrams, respectively. We examined size, area, and eccentricity of bright points. The bright points are related to concentrations of magnetic flux, which appear as bright regions in UV filtergrams. Bright points at the footpoints of polar crown filaments are preferentially located at stronger magnetic flux concentrations, which are related to bright regions at the border of supergranules as observed in UV filtergrams. Examining the evolution of bright points on three consecutive days reveals that their amount increases while the filament decays.

Plasma dynamics outlining the characteristics of filament magnetic field

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1. University of Science and Technology of China, Anhui, China

Arun Kumar Awasthi

The magnetic field of solar filament as determined from observations contains huge uncertainties. Instead, dynamical characteristics exhibited by the filament material provide an indirect approach to infer the magnetic field structure since the flows are primarily field-aligned in the low-beta plasma condition. We utilized this characteristic to infer the magnetic field configuration of a filament in one event, and of a prominence bubble in the other, both recorded in the H-alpha line-center as well as in the line-wing wavelengths by the 1-m New Vacuum Solar Telescope (NVST), Yunnan Astronomical Observatory, China. Driven by a surge, filament observed on October 26, 2017, predominately exhibited two kinds of motions, namely, rotation about the spine and longitudinal oscillation along the spine. The composite motions of filament material suggest a double-decker host structure, comprising a flux rope atop a sheared-arcade system. Similarly, dynamical activities of the material inside a prominence bubble were probed in another event, observed on October 20, 2017. Bubbles are cavity-like features located at the base of the prominence and are believed to be the primary location for supplying mass to the prominence. Flow map along with the Doppler map synthesized from the wing observations revealed a circular motion of the material inside the cavity; comprised sequentially of the blue-shifted plasma (towards the observer) to be exhibiting dominant upward motion, while the red-shifted material exhibited a downward motion. This enabled us to infer that the magnetic field structure of the investigated prominence bubble conforms to a kinked flux-rope morphology. Evidently, high spatial-resolution observations of the prominence have a lot of potential in unveiling the complex magnetic field properties of solar eruptive features.

The Magnetic Topology of the Inverse Evershed Flow

Prasad, A., Ranganathan, M., Beck, C., Choudhary, D.P., Hu, Q.

Avijeet Prasad
University of Alabama in Huntsville, USA

The inverse Evershed flow (IEF) is an inflow towards sunspots at chromospheric heights. We combined high-resolution observations from the Dunn Solar Telescope and full-disk vector magnetic field measurements from the Helioseismic and Magnetic Imager (HMI) to determine the driver of the IEF. We derived chromospheric line-of-sight (LOS) velocities from spectra of H-alpha and Ca II IR at 854 nm by a bisector method. The HMI data was used in a non-force-free magnetic field extrapolation to identify closed magnetic field lines (MFLs) near the sunspot. We determined their length and height, located their inner and outer foot points (FPs), and derived the flow velocities along with them. The MFLs related to the IEF reach on average a height of about 3 Mm over a length of 13 Mm. The inner (outer) FPs are located at about 1.2 (1.9) sunspot radii. The average field strength difference dB between inner and outer FPs is about +400 G. The temperature difference dT is anti-correlated with dB with an average value of -100 K. The pressure difference dp is dominated by dB and is primarily positive with a driving force towards the inner FPs of 2 kPa on average and up to 10 kPa at maximum. The velocities predicted from dp reproduce the observed LOS velocities of 2-10 km/s with a square-root dependence. We find that the IEF is driven along MFLs connecting plage and network elements with the outer penumbra by a gas pressure difference that results from a difference in field strength as predicted by the classical siphon flow scenario.

An observationally-constrained model of strong magnetic reconnection in the solar chromosphere

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Carlos José Díaz Baso
Institute for Solar Physics, Stockholm University

The evolution of the photospheric magnetic field plays a key role in the energy transport into the chromosphere and the corona. In active regions, newly emerging magnetic flux interacts with the pre-existent magnetic field, which can lead to reconnection events that convert magnetic energy to thermal energy. We aim to study the heating caused by a strong reconnection event that was triggered by magnetic flux cancellation. We use imaging-spectropolarimetric data in the Fe I 6301A, Fe I 6302A, Ca II 8542A and Ca II K obtained with the CRISP and CHROMIS instruments at the Swedish 1-m Solar Telescope. This data was inverted using multi-atom, multi-line non-LTE inversions using the STiC code. The inversion yielded a three-dimensional model of the reconnection event and surrounding atmosphere, including temperature, velocity, microturbulence, magnetic file configuration, and the radiative loss rate. The model atmosphere shows the emergence of magnetic loops with a size of several arcsecs into a pre-existing predominantly unipolar field. Where the reconnection region is expected to be, we see an increase in the chromospheric temperature of roughly 2000 K as well as bidirectional flows of the order of 10 km s^{-1} emanating from the region. We see bright blobs of roughly 0.2 arcsec diameter in the Ca II K moving at a plane-of-the-sky velocity of order 100 km s^{-1} and a blueshift of 100 km s^{-1}, which we interpret as plasmoids ejected from the same region. This evidence is consistent with theoretical models of reconnection and we thus conclude that reconnection is taking place. The chromospheric radiative losses at the reconnection site in our inferred model are as high as 160 kW m^{-2}, providing a quantitative constraint on theoretical models that aim to simulate reconnection caused by flux emergence in the chromosphere.

Magnetic fields and plasma velocities in the chromospheric He I 1083 nm triplet during a solar filament eruption

Christoph Kuckein, Sergio J. González Manrique, Lucia Kleint and Andrés Asensio Ramos

Christoph Kuckein
Leibniz Institute for Astrophysics Potsdam (AIP)

We investigate the dynamics and magnetic properties of the plasma, such as line-of-sight velocity (LOS), optical depth, vertical and horizontal magnetic fields, belonging to an erupted solar filament. The filament eruption was observed with the GREGOR Infrared Spectrograph (GRIS) at the 1.5-meter GREGOR telescope on 2016 July 3. The Stokes I profiles were grouped using the machine learning k-means algorithm and then inverted with the inversion code HAZEL. The erupting-filament material presents: (i) ubiquitous upward motions with peak LOS velocities of about 73 km/s; (ii) predominant large horizontal components of the magnetic field, on average, in the range of 173-254 G, whereas the vertical components of the fields are much lower, on average between 39-58 G; (iii) optical depths in the range of 0.7-1.1. The analyzed filament eruption belonged to the fast rising phase, with total velocities of about 124 km/s.

Magnetic properties on the boundary of evolving pores

Jurcak, J., Bello González, N.

Marta García Rivas

Astronomical Institute of the Czech Academy of Sciences

Recent studies of sunspots have shown that there is a critical value (Bcrit) of the vertical component of the magnetic field (Bver) that triggers umbral mode of convection, i.e., only umbral convection is allowed in regions with Bver > Bcrit. We study the existence of a Bcrit in other magnetic structures, such as pores. The evolution of magnetic properties on the pore boundary during its lifetime shows their role on the stability of pores.

Understanding the type-II spicule contribution to coronal loops

Nived Vilangot Nhalil

Armagh Observatory and planetarium

We study the properties of coronal loop foot-point observations of type-II spicules in the chromosphere and their signature in EUV corona using CRisp Imaging Spectro-Polarimeter (CRISP) and co-aligned Solar Dynamic Observatory (SDO) observations. Aim of this work is to understand, why there is not always a one to one correspondence between type-II spicules and hot coronal plasma signature. We find that the number density of type-II spicules in a region close to the loop foot-point is an order of magnitude larger than that in the quiet Sun region. However, their properties such as velocity, lifetime are the same in both the region. We also find that an enhancement in RBE (Rapid blue-shifted excursion: On-disk counterpart of type 2 spicule) number appears as a local brightening in the AIA 171 light curve, which confirms the role of RBEs in heating the corona. We further confirm this by simulations of coronal loop hydrodynamics performed using ARGOS. Simulation run with 1.25 × 1024 erg/pulse (corresponding to ~9-10 RBEs contributing to a burst) manage to reproduce a DEM peak at 0.8Mk matching the observation very closely. This is a strong indication that type-II spicules could be responsible for the heating of coronal loops.

Stratification of physical parameters in a C-class solar flare using multi-line observations

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We present high-resolution and multi-line observations of a C2-class solar flare, occurred in NOAA AR 12740 on May 6, 2019. The rise, peak, and decay phases of the flare were recorded continuously and quasi-simultaneously in the Ca II K line with the CHROMIS instrument, the Ca II 8542 Å and Fe I 6173 Å lines with the CRISP instrument at the Swedish 1-m Solar Telescope. A non-LTE STiC inversion code was employed to infer the temperature, magnetic field, line-of-sight (LOS) velocity, and microturbulent velocity stratification in the flaring atmosphere. The temporal analysis of the inferred temperature at the flare footpoints shows that the flaring atmosphere from $\log(\tau) \sim -2.5$ to -3.5 is heated up to 7 kK, whereas from $\log(\tau) \sim -3.5$ to -5 the inferred temperature ranges between $\sim$ 7.5 kK and ~ 11 kK. During the flare peak time, the LOS velocity shows both upflows and downflows around the flare footpoints in the upper chromosphere and lower chromosphere, respectively. Moreover, the temporal analysis of the LOS magnetic field at the flare footpoints exhibits maximum change of ~ 600 G. After the flare, the LOS magnetic field decreases to the non-flaring value, exhibiting no permanent or step-wise change. Our analysis suggests that a fraction of the apparent increase in the LOS magnetic field at the flare footpoints may be due to the increase in the sensitivity of the Ca II 8542 Å line in the deeper layers, where the field strength is relatively stronger. The rest can be due to magnetic field reconfiguration during the flare. In the photosphere, we do not notice significant changes in the physical parameters during the flare and non-flare time. Our observations illustrate that even a less intense C-class flare can heat the deeper layers of the solar chromosphere, mainly at the flare footpoints, without affecting the photosphere.

A study of Flare induced Fast Propagating Waves and Coronal Loop Oscillations

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NIT Calicut

Coronal loops are bright, curving magnetic flux tubes that appear as arcs at coronal heights. We have analyzed the flare induced oscillations and fast propagating waves using high resolution observations provided by the Atmospheric Imaging (AIA) on board Solar Dynamic Observatory (SDO). We have reported a pre-flare phase which initiates the reconfiguration of magnetic field lines. This magnetic re-connection causes the main flare. The time series of the oscillation event across the coronal loop has been analyzed. The period of oscillation ranges from 5-7 minutes with damping time of 11-48 minutes. We have calculated the length of the coronal loop, speed of the fast propagating wave and the magnetic field of the loop.

Evidence of chromospheric molecular hydrogen emission in a solar flare observed by the IRIS satellite

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University of Glasgow

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

The Dynamic and Magnetic Evolution of Arch Filament Systems

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We study the dynamics of plasma along the legs of an arch filament system (AFS) observed with relatively high-cadence spectropolarimetric data from the ground-based solar GREGOR telescope (Tenerife) using the GREGOR Infrared Spectrograph in the He I 10830 Å range. The temporal evolution the plasma along an AFS was followed using the chromospheric He I 10830 Å triplet and Si I 10827 Å. Measurements of vector magnetic fields in the solar chromosphere, especially in AFS, are extremely scarce, but very important. The magnetic field configuration reveals how AFSs are sustained in the chromosphere and hints at their formation, evolution, and disappearance. The magnetic field in the AFS follows loop-like structures traced by chromospheric absorption lines. However, if magnetic field lines follow chromospheric threads as seen by filtergrams of Hα, Ca II, or He I is still not fully resolved. Previous studies have modeled AFS as multiple flux ropes with mixed signs of helicity consistently with the observed multiple filament bundles constituting AFS. Nevertheless, further spectropolarimetric observations are needed to address this issue. Many spectral lines are sensitive to the atmospheric parameters up to the upper chromosphere. Moreover, when combined with photospheric Zeeman sensitive spectral lines, one can infer the topology of the magnetic field from the bottom of the solar atmosphere to the chromosphere.In this study, we followed the nature of AFSs by reconstructing the magnetic field configuration of an EFR from the very beginning and follow its evolution and dynamics to support current AFS models. To that aim we used the spectropolarimetric data available at the upper photosphere (Si I) and the upper chromosphere.

Vortex Motion and Plasmoid Ejections in the Eruptive Polar Prominence

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Modern high-resolution observations reveals that the solar prominences are associated with the prosperous dynamics such as instabilities, waves, oscillation, counter-streaming flows, tornadoes-like motion, plasmoid ejection, large-scale vortex motion etc. on different spatio-temporal scales in the solar atmosphere. The tornado-like motion in prominences is evolved via two mechanisms i.e., the apparent rotational motion of the helical flux-rope and and oscillation or counter-streaming flows in the prominence spines or barbs. There is an active debate that whether the photospheric vortex motions are associated with the swirls/tornadoes-like motion in the solar prominence or not. We show a scientific case study in which the high-resolution EUV images of the SDO/AIA provide opportunity to explore the detailed internal and external dynamics of a prominence before and during the eruption. Several internal dynamics such as large-scale vortex motion, swirl-like motion, tornadoes-like motion, horns, cavity, etc. appear during the evolution of prominence. The apparent rotating motions of the prominence barbs might play an important role for the evolution and growth of the filament by transferring cool plasma and magnetic twist. Large-scale vortex motion is evident in the upper part of the prominence and consists of a swirl-like structure within it. The slow shearing motion at the footpoint twists the prominence legs oppositely and responsible for the two-stage of magnetic reconnection. The first stage of the reconnection is governed by the tearing mode instability, which triggers multiple plasmoid ejection along the elongated current sheet within the prominence. The estimated reconnection rate (0.05-0.2) is consistent with the Petscheck-type reconnection. The ejected plasmoid is destroyed the current sheet and responsible for the collapse of multiple magnetic arcades near the X-point. The external reconnection is initiated by the reconnection between collapsing magnetic arcades and overlying prominence, which leads to the eruption of the prominence.

Chromospheric dynamics in Coronal holes and Quiet Sun

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Coronal Holes (CHs) are regions with subdued intensity with a net upflow of plasma in comparison to Quiet Sun (QS) regions, with at coronal temperatures. At transition region temperatures, a statistical net reduction of intensity and larger upflows are seen in CHs over QS. In this work, we use spectroscopic measurements of the Mg II and C II lines from Interface Region Imaging Spectrograph (IRIS), formed at chromospheric temperatures, to investigate the intensity, Doppler shift and line width variations with photospheric magnetic field measurements. We find, statistically, that the CH intensity is subdued when compared to QS in all features of Mg II and C II. Furthermore, the difference in intensities increases with increasing photospheric magnetic field strength. We also find, statstically, excess upflows and downflows in CH when compared to QS, and an increase in the difference in flow velocity between these two regions with increasing magnetic field strength. Finally, we find excess line widths of C II in CH over QS for the same magnetic field strength. These results are important for understanding the heating of the corona in CHs and QS, as well as the formation of solar wind.

Estimation of Fried’s Parameter from solar H-alpha data

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Vishnu Unni. C

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Estimation of the atmospheric coherence diameter (popularly known as the Fried’s parameter) is of paramount importance in characterizing any site. The possibility of estimating it from long exposure H-alpha telescope data has been previously demonstrated [1]. The large statistics of estimated values of Fried’s parameter from archival data from Merak H-alpha telescope is presented. References: [1] Sridharan Rengaswamy, B Ravindra, and Prabhu Kesavan, Measurement of astronomical seeing using long exposure solar images. Solar Physics, 294, 01 2019. doi: 10.1007/s11207-019-1393-y

Poster - Group II

Coronal Magnetism (Measurements, flares, CME’s and Space Weather)

Hydrodynamics of Hi-C brightenings

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Small transient brightenings that occur in the solar atmosphere may play a significant role in coronal heating. An accurate understanding of the energetics of such events observed in the corona will help us understand the physics of their origin and thereby address the problem of solar coronal heating. In this work, we have studied the energetics of some of smallest brightenings ever observed by Hi-C, using 0-D hydrodynamical simulations using the Enthalpy Based Thermal Evolution of Loops (EBTEL). We find that these brightenings can be modeled with physically reasonable hydrodynamic loops, of some lengths and heating budgets. We find conduction to be the dominant cooling mechanism for these events in their initial phase, similar to that for flares, microflares, and nanoflares. This is suggestive of similar underlying physical mechanism for these brightenings as the flaring events.

Solar X-ray Irradiance and Features Variability from Spatially Resolved Full-Disk Images from Hinode/XRT and comparing with GOES (1-8A) X-ray Flux

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Adithya H. N.

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Our Sun is the major energy source of all living beings on Earth and it is the driving force of all weather and climate on Earth. Understanding activity variation in the Sun in different wavelengths will lead to better understanding of Earth and Space weather. The variations in the X-ray irradiance are produced by surface manifestation of solar magnetic activity. Considering the variations in the solar X-ray flux may cause significant changes in the Earth's climate, understanding the physical origin of X-ray irradiance changes is an extremely important issue in Solar and Space Physics. In order to understand the solar X-ray irradiance variability, we have developed an algorithm in Python to segment the different coronal features such as active regions (ARs), coronal holes (CHs), X-ray bright points (XBPs) and background (BG). We have used the full-disk images from Hinode/XRT for the period: 2007 to 2020 and derived several parameters (such as intensity, area, full-disk intensity, contribution of all the features) of the X-ray image. In this paper we will be discussing the important results of the variations of intensity, area, full-disk intensity, the number variation of XBPs, and the contribution of all the features (ARs,CHs, XBPs and BGs) in comparison with GOES (1-8A) X-ray flux and solar magnetic cycle.

Impact of solar wind on planetary atmospheres with and without magnetospheres

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CESSI, IISER Kolkata

We present results of 3D compressible magnetohydrodynamic (MHD) simulations of the interactions between solar wind and weakly magnetized/non-magnetized planets hosting atmospheres, using the Star-Planet Interaction Module (CESSI-SPIM) developed at CESSI, IISER Kolkata. The structures of magnetopause and bow shock are found to be functions of the wind velocity, planetary dipole strength and orientation of IMF with respect to the planetary field. The atmospheric loss rate, which is important from the perspective of planetary habitability, varies with the wind strength. For studying a case analogous to the conditions of present-day Mars, a non-magnetized planet with no atmosphere is considered. The results are found to be in agreement with observations from Mars Global Surveyor (MGS) and Mars Atmosphere and Volatile EvolutioN (MAVEN) missions.

Multiwavelength Observations of Flare Triggering Mechanism: A Question Tether cutting or Emerging Flux”

Chandan Joshi
JECRC University

We present here multiwavelength observations of a X-Class flare to understand the triggering mechanism. The observations were carried out by Solar Dynamics Observatory and RHESSI. The results of observational study lead to a question whether the triggering mechanism was tether cutting or it favours the interaction of emerging flux with existing magnetic topology.

Deep Learning for heliophysics

channabasava chola

IIIT Kottayam

Heliophysics and Image processing are interconnected to each other to understand the activities of the sun, as we know in recent days deep learning based algorithms outperformed in robustness as well as accurate classification and detection of objects. In terms of heliophysics, we will be concentrating on the sun activity tracking.

Geoeffectiveness of DH-CMEs during solar cycle 24

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Kumaun University Nainital, Uttarakhand

This paper presents a detailed analysis of geoeffectiveness of CMEs associated with DH-type-II radio bursts during solar cycle 24. We have selected 119 DH-CME events from March 2008-December 2015. The levels of geomagnetic activity are categorized into two groups based on the observed minimum Dst index ≤ -50 nT, (1) Geoeffective events (2) Non-Geoeffective events. About 31% (37/119) of the DH-type-II radio bursts are associated with geomagnetic storm. We have found that the geoeffective events have high starting frequency, low ending frequency, wider bandwidth, long duration, slower drift rate than non-geoeffective events. The parameters are analyzed statistically and represented graphically. There exist a good correlation between CME speed and flare flux for geoeffective events (r=0.50) indicates that flares are responsible for producing geomagnetic storms. There exist a weak correlation between DST index and CME speed (R=0.09) and between CME acceleration and DST index (R=-0.12). The CME speed of geoeffective events are heigher than non-geoeffective events, shows that CME speed is the most important parameter for geoeffectiveness.

High fidelity spectroscopic imaging at low radio frequencies to estimate plasma parameters of solar coronal mass ejections at higher coronal heights

Devojyoti Kansabanik (NCRA-TIFR), Surajit Mondal (NCRA-TIFR),Divya Oberoi (NCRA-TIFR), Angelos Vourlidas (Applied Physics Laboratory, John Hpokins University, Laurel, USA)

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Coronal Mass Ejections (CMEs) are large-scale explosive eruptions of magnetised plasma from the Sun into the Heliosphere. Measuring the physical parameters of CMEs is crucial for understanding their physics and for assessing their geo-effectiveness. Radio observations offer the most direct means for estimating these plasma parameters when gyrosynchrotron (GS) emission is detected from the CME plasma. However, since the first detection by Bastian et al.2001, only a handful of studies have successfully detected GS emission from CME plasma. This is usually attributed to the challenges involved in obtaining the high dynamic range imaging required for observing this faint gyrosynchrotron emission in the vicinity of active solar emissions. The newly developed imaging pipeline (Mondal et al., 2019) designed for the data from Murchison Widefield Array (MWA) marks a significant improvement in metre wave solar radio imaging. Our work suggests that we should now be able to routinely detect GS emission from CME plasma. We present an example where we have successfully detected radio emission from CME plasma and modelled it as GS emission, leading to reliable estimates of CME magnetic field as well as the distribution of energetic electrons (Mondal et al. 2020). In a different example we are able to detect the radio emission from the CME plasma out to as far as 8.3 solar radii. We find that the observed spectra are not always consistent with simple GS models. This highlights that more complicated physics might be at play and points to the need for building more detailed models for interpreting these emissions. We hope that with the availability of polarimetric imaging capability, which we are in the process of developing, this technique will provide a robust way to routinely measure CME magnetic fields along with its other physical parameters. We note that these are the weakest detections of GS emissions from CME plasma reported yet.

Growth and decay of Sunspots and their associated radio emissions

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Abstract: Sunspots are studied over a long period using Kodaikanal Solar Observatory data. The radio emission is also associated with the growth and decay of sunspots. We report the variety of radio bursts and the duration with an emphasis to solar noise stroms.

Origin, activation and blowout expansion of pre-CME coronal arcade from the active region NOAA 11947

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We investigate the origin, evolution, and expansion of pre-CME coronal arcade from the active region (AR) NOAA 11947 on 08 January 2014 by implying the combined observations from Atmospheric Imaging Assembly (AIA) on board Solar Dynamics Observatory (SDO), Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI), and HiRAS radio emission. The EUV AIA 171 Å channel reveals the origin of the coronal pre-CME arcade during a prolonged period of ≈1 hour before the solar eruptive event. EUV images of the pre-CME arcade at high coronal temperatures indicate the presence of hot core overlaid by dense coronal loop system. A typical “arcade-to-bubble” like evolution of the coronal pre-CME arcade is observed which subsequently, undergoes through blowout expansion. Initially, the arcade undergoes through a slow rise evolution with speed of ≈3 km/s. The coronal loops transitioned from a slow rise state to fast rise state, accelerating to a speed of ≈420 km/s. The successful eruption of the hot channel leads to an M3.6 flare and a coronal mass ejection (with linear speed ≈643 km/s). During the impulsive phase of the flare, we observed the eruption of the filament from the AR and compact hard X-ray sources at energies up to ≈50 keV from its source region. The eruptive expansion of the hot channel is also accompanied by a type II radio burst in ≈50-500 MHz frequency band, suggesting propagation of CME associated shock at lower corona.

Magnetic jerk driven seismic emissions in sunspots accompanying major solar flares

Hirdesh Kumar and Brajesh Kumar

Udaipur Solar Observatory, Udaipur

Solar flares are the catastrophic events that take place in the solar atmosphere. Large solar flares have been observed to generate seismic waves in the Sun. We have studied seismic emission in sunspots accompanying M- and X-class flares from Helioseismic and Magnetic Imager onboard Solar Dynamics Observatory space mission. H alpha chromospheric intensity filtergrams from GONG and hard X-ray images from RHESSI spacecraft have been used to identify the locations of flare ribbons and hard X-ray foot points appearing during the flares. Fourier power maps in 2.5-4 mHz band have been constructed for the identification of seismic emission locations in the sunspots for pre-flare, spanning flare and post flare epochs. We have identified concentrated locations of acoustic power enhancements in sunspots accompanying these major flares. In the power maps, we have selected only those locations which are away from the flare ribbons and hard X-ray footpoints. These regions are believed to be free from any flare related artifacts in the observational data. Our investigation provides evidence that abrupt changes in the magnetic fields (known as 'magnetic-jerk') leading to impulsive changes in the Lorentz force could be the driving source for these seismic emissions in the sunspots during flares. Such seismic emissions in the sunspots are essential to study because these 'magnetic-jerk' driven seismic waves can propagate from the photosphere to higher solar atmospheric layers along the magnetic field lines in the form of magnetoacoustic waves and thereby can contribute to the heating of solar atmosphere.

The study of late recovery phase of an extreme geomagnetic storms

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University of Mumbai

Geomagnetic storms are crucial phenomena during severe space-weather conditions, which directly or indirectly affect communication, navigation, transportation, power grid and satellite electronic systems. They are usually caused by coronal mass ejections (CMEs) and corotating interaction regions (CIRs) of interplanetary space. Mostly, CMEs generating extreme magnetic storms recover within one or two days. However, we demonstrate a case study of a particular extreme geomagnetic storm caused by a CME that exhibits a longer recovery phase than usual. The present study suggests that the possible causal agent for such extended recovery of the storm is the Alfven wave. Further we have investigated recovery of 31 extreme geomagnetic storms that occurred in the last three decades. Each individual storm demonstrate two distinct features of recovery phase i.e. initial fast recovery and later on slow recovery. We have done fitting of all 31 storm recoveries by using exponential decay function, Hyperbolic decay function and Linear decay function. We noticed that fast recovery is well explained by exponential and hyperbolic decay functions. whereas extended slow recovery is well explained by linear decay function.

Are the compressive oscillations in hot coronal loops a manifestation of standing slow waves?

Krishna Prasad Sayamanthula

KU Leuven

Flare associated hot coronal loops often display compressive plasma oscillations with periods on the order of tens of minutes. They were initially discovered using spectroscopic observations in which a quarter period phase shift was found between the intensity and Doppler shift oscillations leading to their interpretation as standing slow magneto-acoustic waves. Recent observations using imaging telescopes reveal localized brightenings moving back and forth within a coronal loop termed as "reflected-propagating" or "sloshing" oscillations. These oscillations exhibit similar properties as that of standing slow waves although their spatio-temporal properties do not actually resemble a standing wave. Numerical simulations suggest that an impulsive flow pulse injected into a coronal loop would initially display a reflecting phase before setting up a standing wave. But the lack of evidence for this transition in observations imply that the sloshing oscillations are perhaps an independent class of oscillations. In this presentation, I will show some recent results highlighting the possible interpretation of these waves. I also present a technique to extract the wave properties from sloshing oscillations.

Successive occurrences of quasi-circular ribbon flares in a fan-spine-like configuration involving hyperbolic flux tube

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We present a comprehensive analysis of the formation and evolution of a fan-spine-like configuration that developed over a complex photospheric configuration where dispersed negative polarity regions were surrounded by positive polarity regions. This unique photospheric configuration, analogous to the geological “atoll" shape, hosted four homologous flares within its boundary. Computation of the degree of squashing factor (Q) maps clearly revealed an elongated region of high Q-values between the inner and outer spine-like lines, implying the presence of an hyperbolic flux tube (HFT). The coronal region associated with the photospheric atoll configuration was distinctly identified in the form of a diffused dome-shaped bright structure directly observed in EUV images. A filament channel resided near the boundary of the atoll region. The activation and eruption of flux ropes from the filament channel led to the onset of four eruptive homologous quasi-circular ribbon flares within an interval of ≈11 hours. During the interval of the four flares, we observed continuous decay and cancellation of negative polarity flux within the atoll region. Accordingly, the apparent length of the HFT gradually reduced to a null-point like configuration before the fourth flare. Prior to each flare, we observed localised brightening beneath the filaments which, together with flux cancellation, provided support for the tether-cutting model of solar eruption. The analysis of magnetic decay index revealed favourable conditions for the eruption, once the pre-activated flux ropes attained the critical heights for torus instability.

A case study of ground level enhancement event: GLE-70

Pranali Thakur, Dr.Anil Raghav(University of Mumbai), Gauri Datar(IIG), Zuber Shaikh(IIG)

Pranali Thakur

University of Mumbai

The sudden, short term enhancement in cosmic ray intensity is generally known as Ground Level Enhancement (GLE) event. They may be produced by some acceleration mechanism on surface of Sun or in interplanetary space. Actually, these GLEs are special class of solar energetic particles (SEP) events, which are recorded by ground based Neutron Monitors on the Earth surface. Their studies are important because it affect on satellite operations, dose degradation in spacecraft electronics, inhabited space missions, commercial aircraft operation, navigation & modern technology system. This GLE demonstrate distinguishable double hump structure in cosmic ray data. In literature it is expected that the first peak of the GLE is associated with the solar flare and second peak is associated with CME. Here, we investigate various local parameters such as Earth's day-night variations as well as magnetosphere coupling with solar wind (east & west side. Our main aim to find the origin of observed double hump structure & understand the factors that are responsible for converting a SEP event in a GLE.

A Statistical Study of Plasmoids associated with post-CME Current Sheet

Ritesh Patel, Vaibhav Pant, K. Chandrashekhar, Dipankar Banerjee

Ritesh Patel

IIA, ARIES

We investigate the properties of plasmoids observed in the current sheet formed after an X-8.3 flare followed by a fast CME eruption on September 10, 2017 using Extreme Ultraviolet (EUV) and white-light coronagraph images. The main aim is to understand the evolution of plasmoids at different spatio-temporal scales using existing ground- and space-based instruments. We identified the plasmoids in current sheet observed in the successive images of {\it Atmospheric Imaging Assembly} (AIA) and white-light coronagraphs, K-Cor and LASCO/C2. We found that the current sheet is accompanied by several plasmoids moving upwards and downwards. Our analysis showed that the downward and upward moving plasmoids have average width of 5.92 Mm and 5.65 Mm, respectively in the AIA field of view (FOV). However, upward moving plasmoids have average width of 64 Mm in the K-Cor which evolves to a mean width of 510 Mm in the LASCO/C2 FOV. Upon tracking the plasmoids in successive images, we observe that downward and upward moving plasmoids have average speeds of $\sim$272 km s^{-1} and $\sim$191 km s^{-1} respectively in the EUV passbands. We note that the plasmoids become super-Alfvénic when they reach at LASCO FOV. Furthermore, we estimate that the null-point of the current sheet at $\approx 1.15\ R_\odot$ where bidirectional plasmoid motion is observed. We study the width distribution of plasmoids formed and notice that it is governed by a power law with a power index of -1.12. Unlike previous studies there is no difference in trend for small and large scale plasmoids. The presence of accelerating plasmoids near the neutral point indicates a longer diffusion region as predicted by MHD models.

Insights from connecting 3D evolution of CMEs to their source regions

Satabdwa Majumdar, Vaibhav Pant, Ritesh Patel and Dipankar Banerjee.

Satabdwa Majumdar

Indian Institute of Astrohysics, Bangalore

A major shortcoming in the understanding of kinematics of Coronal Mass Ejections (CMEs) is regarding the information on kinematics in the inner corona (< 3RSUN) and despite a few recent studies reporting kinematics in the inner corona, most works either suffer from projection effects or inconsistencies arising from combining white light and Extreme Ultraviolet observations. To remove these discrepancies, we study, with the help of stereoscopic observations from COR-1 and COR-2 on-board STEREO-A/B, the complete 3D evolution of slow (≤ 400 km/s) and fast CMEs (≥ 400 km/s) in the inner and outer corona in white light data. We identify the source regions of these CMEs and classify them as Active Regions (ARs), Active Prominences (APs), and Prominence Eruptions (PEs). Combining the 3D acceleration and width evolution profiles, we find the observational evidence that it is Lorentz force that is responsible for both expanding and accelerating a CME. Further, we also show that statistically, the height of influence of this Lorentz force on the 3D kinematics of CMEs lies in the range of 2.5-3 RSUN. We find a broad range in the distribution of peak 3D speeds and accelerations, ranging from 396 to 2465 km/s and 176 to 10,922 m/s2 respectively, with a long tail toward high values coming mainly from CMEs originating from ARs or APs. Further, we find that the magnitude of true acceleration is inversely correlated with its duration with a power-law index of −1.19. We believe that these results will provide important inputs for the planning of upcoming space missions that will observe the inner corona and for models that study CME initiation and propagation.

Solar magnetism influences Environment of the Earth

Saumitra Mukherjee

Jawaharlal Nehru University

Space Environment Viewing and Analysis (SEVAN) network node of Jawaharlal Nehru University has inferred the variability of solar cosmic-ray changes with the variations in planetary indices, Electron flux, Proton flux, and planetary indices recorded by the SOHO satellite. It is further noted that various environmental changes including snowfall, rainfall, changes in atmospheric temperature, and other perturbation of changes in man-made physical surroundings are linked with solar magnetism and variability.

Multi-wavelength Observations of Coronal Mass Ejections close to the Sun with Ground and Space-based Instruments

Shirsh Lata Soni

Awadhesh Pratap Singh University Rewa MP India

This present study is to upgrade our understanding of Coronal Mass Ejection and other phenomena associated with it. To follow the space-time observations of as event from near corona to large distances in the interplanetary medium we analyse the combination of data obtained from space-based experiments and ground based instruments as well. Here we report on the CME event occurred on 02 July 2012, this event associated with a type-II radio burst in metric and interplanetary domains. The dynamic spectral analysis that the burst have harmonic and fundamental components of emission with band splitting. Due to the interaction between the flanks of the two CMEs (~5:10UT) there was an enhancement seen in the Type II bursts. This also caused a sudden jump in the Type II burst. Various density model have been used to obtain shock speed, Alfven speed and Magnetic field from the Radio burst and was compared with the parameters obtained from STRERO.

Data Driven Models for Coronal Magnetic Field Prediction

Soumyaranjan Dash

Center of Excellence in Space Sciences India (CESSI)

Solar coronal magnetic field dynamics drive the spaceweather. Due to the bright photosphere and low coronal density it is difficult to measure the coronal magnetic field accurately. Data driven modelling of the coronal magnetic field is one of the ways to understand the onset of solar storms and predict them. For constraining these models it is essential to have observations of the solar corona which is only possible during total solar eclipses and space based coronagraphs. Employing the century-scale calibrated Surface Flux Transport (SFT) model and Potential Field Source Surface (PFSS) model we predicted the coronal magnetic field structure for several past solar eclipses. For modelling the polarization characteristics we utilized FORWARD model. Here we discuss the possible insights from such simulations.

Two Circular Ribbon Flares and Their Geo-effectiveness

Syed Ibrahim, Wahab Uddin, Bhuwan Joshi, Ramesh Chandra

Syed Ibrahim

Aryabhatta Research Institute of Observational Sciences

We discussed two eruptive circular ribbon flares which are associated with the Sun-Earth connecting Coronal Mass Ejections (CMEs). Many CMEs are erupted before and after these CMEs, but we carefully analyzed the initiation and propagation details of these events to establish the connection of corresponding CMEs-ICMEs and their near Earth consequences. Initial sunspot and its earlier evolution are observed by Helioseismic and Magnetic Imager (HMI). Eruption signatures from solar source region are confirmed by the Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics Observatory (SDO) at different wavelength observations and Aryabhatta Research Institute of Observational Sciences (ARIES) Hα filtergrams. For both the CMEs, original eruption were associated with same class of flares and were followed by moderate speed coronal mass ejections. The multi-channel SDO observations confirm that the eruptive flares and subsequent CMEs were intimately related to the filament eruption. After the flares, we observed moderate speed CMEs in Large Angle Spectrometric Coronograph (LASCO) field of view (FOV). Same event tracked up to Earth by Solar Terrestrial and Relational Observatory (STEREO) instruments. From near-Sun to near-Earth, CME/ICME have played an important role in the enhancement of the Geo-effectiveness from intense to moderate.

Regular and Oscillatory motion of Coronal Bright Points

Tsinamdzgvrishvili, T., Shergelashvili, B., Chargeishvili, B., Mghebrishvili, I., Mdzinarishvili, T. and Japaridze, D.

Tamar Tsinamdzgvrishvili

Ilia State University, Tbilisi, Georgia

Long-term automatic tracking of coronal bright points has made it possible to study their proper motions using data from the AIA 193 Å channel of SDO/AIA. Fits files for 95 visually long-lived bright points uniformly distributed in latitude have been chosen for processing. A specially developed program automatically fixes the heliographic coordinates of the centroid of the chosen coronal bright points in a series of Fits files. It was found that the proper motions of all the coronal bright points studied here have a distinct oscillatory character. The periods of the oscillations range from 5 to 60 h with an average of 20 h. Some tendencies in the latitudinal dependence of the oscillatory characteristics have been found. A possible explanation of these oscillations in terms of the propagation of helical waves along the magnetic loops that form the structure of the coronal bright points is pointed out. Linear trends in the latitudinal and longitudinal components of the motion of the coronal points are used to determine the rotational velocity and meridional migration of the coronal bright points. An analysis of the rotational velocities confirms the differential character of the latitudinal dependence. The problem of determining the direction and magnitude of the meridional migration is discussed.

Diagnosing the magnetic field structure of a coronal cavity observed during the 2017 total solar eclipse

Yajie Chen, Hui Tian, Yingna Su, Zhongquan Qu, Linhua Deng, Patricia R. Jibben, Zihao Yang, Jingwen Zhang, Tanmoy Samanta, Jiansen He, Linghua Wang, Yingjie Zhu, Yue Zhong, and Yu Liang

Yajie Chen
Peking University, china

We present an investigation of a coronal cavity observed above the western limb in the coronal red line Fe X 6374 Å using a telescope of Peking University and in the green line Fe XIV 5303 Å using a telescope of Yunnan Observatories, Chinese Academy of Sciences, during the total solar eclipse on 2017 August 21. A series of magnetic field models is constructed based on the magnetograms taken by the Helioseismic and Magnetic Imager on board the Solar Dynamics Observatory (SDO) one week before the eclipse. The model field lines are then compared with coronal structures seen in images taken by the Atmospheric Imaging Assembly on board SDO and in our coronal red line images. The best-fit model consists of a flux rope with a twist angle of 3.1π, which is consistent with the most probable value of the total twist angle of interplanetary flux ropes observed at 1 au. Linear polarization of the Fe XIII 10747 Å line calculated from this model shows a “lagomorphic” signature that is also observed by the Coronal Multichannel Polarimeter of the High Altitude Observatory. We also find a ring-shaped structure in the line-of-sight velocity of Fe XIII 10747 Å, which implies hot plasma flows along a helical magnetic field structure, in the cavity. These results suggest that the magnetic structure of the cavity is a highly twisted flux rope, which may erupt eventually. The temperature structure of the cavity has also been investigated using the intensity ratio of Fe XIII 10747 Å and Fe X 6374 Å.

Poster - Group III

Computational Solar Physics (MHD Simulations, Models and fitting of Observations)

Reconnection and Particle Acceleration in Presence of Shear Flows

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Magnetic reconnection is a ubiquitous phenomenon in laboratory and astrophysical plasma and is believed to be an essential process for particle acceleration in such environments. Systems with multiple current sheets in presence of velocity shears are expected to be present at various regions of interest such as tokamaks, solar flares and planetary magnetospheres. In particular, the double current sheet layer is of great interest owing to its ability to lead to an explosive non-linear instability growth. We have investigated the evolution of double tearing modes (DTM) of magnetic reconnection in very high Lundquist number plasmas in presence of a velocity shear using resistive Magnetohydrodynamic simulations. We have studied the (i) initial transient phase, (ii) the explosive phase emerging from a structure-driven secondary instability and (iii) the final relaxation phase which is dominated by turbulence. Our results show a deviation in the reconnection rate from the theoretical scaling for DTM systems further confirming the dependence of the reconnection rates on the structure of the magnetic islands. We have subsequently investigated the process of particle acceleration in such systems. The results from our test particle simulations also demonstrate the effects of various mechanisms such as magnetic island merger and island contraction in acceleration of particles in a manner to produce a power-law spectrum of the non-thermal population of accelerated particles. In summary, I will highlight the integral role played by fast reconnection in accelerating particles and its relevance in generation of solar energetic particles due to flares and production of flux transfer events in the magnetosphere.

Impact of Hall MHD on Magnetic Reconnection on the Sun

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Kamlesh Bora

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Observations have revealed the diffusive nature of solar coronal plasma in the form of solar flares, coronal mass ejections, jets--manifestation of magnetic reconnections (MRs). The onset of reconnection in a near-perfectly conducting plasma like the solar corona requires the generation of small scales in consequence of large scale dynamics, eventually leading to a locally reduced characteristic length scale of the magnetic field variability. At such small scales, the standard magnetohydrodynamics is not valid and the Hall-magnetohydrodynamics (Hall MHD) takes over. Hall MHD gives the faster reconnection as well as resolves the details of dynamics at small scales. To explore the reconnection in Hall MHD, we have successfully extended the computational model EULAG-MHD to include the Hall forcing and reported the evolution of three-dimensional (3D) coherent magnetic structures recently. Simulations of evolution of a magnetic flux rope from solar corona like sheared magnetic arcades in the presence and absence of the Hall forcing have revealed that the rope evolves through intermediate complex structures, ultimately breaking locally because of reconnections in the presence of Hall forcing. Interestingly, the breakage occurs earlier in the presence of the Hall term, signifying faster dynamics leading to magnetic topologies favorable for reconnections.

Turbulence characteristics of Solar Prominences due to Rayleigh Taylor Instabilities

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Madhurjya Changmai

Centre for mathematical Plasma-Astrophysics, KU Leuven

The purpose of our study is to deepen our understanding on the turbulence that arises from Rayleigh Taylor Instabilities in quiescent solar prominences. Quiescent prominences in the solar corona are cool and dense condensates that show internal dynamics over a wide range of spatial and temporal scales. These dynamics are dominated by vertical flows in the prominence body where the mean magnetic field is predominantly in the horizontal direction and the magnetic pressure suspends the dense prominence material. We perform numerical simulations using MPI-AMRVAC (http://amrvac.org) to study the Rayleigh Taylor Instability at the prominence-corona transition region using the Ideal-magnetohydrodyamics approach. High resolution simulations achieve a resolution of ∼23 km for ∼21 min transitioning from a multi-mode perturbation instability to the non-linear regime and finally a fully turbulent prominence. We use statistical methods to quantify the rich dynamics in quiescent prominence as being indicative of turbulence.

PARTICULAR SOLUTION OF THE MAGNETODYNAMIC TRANSPORT EQUATIONS FOR ONE-FLUID PLASMA OF ANISOTROPIC SOLAR WIND

Mirnamik, Bashirov Mirakhmedaqa
Azerbaijan

The MHD theory for a single particle solar wind is considered, taking into account the anisotropy of the heat flux and thermal pressure of the plasma. The equation is given a new form. The radial dependences of the solar wind speed and thermal velocities are investigated for one particular case, and an expression for the velocities is found, which can be used for further investigation of space plasma.

Statistical spectroscopic analysis of quiescent prominence observed in Lyman lines by SoHO/SUMER and MgII h&k lines by IRIS

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Pavol Schwartz

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A quiescent prominence was observed on October 22, 2013 at NW limb quasi-simultaneously and nearly co-spatially in the Lyman line series of hydrogen by SoHO/SUMER and in the MgII h&k UV lines by IRIS. In this contribution we analyze the dense and compact structure of the prominence because this part is quiet and therefore suitable for non-LTE modeling. This part of the prominence is also well visible in H_alpha filterogram images. Spectroscopical analysis of the Lyman line and MgII h&k profiles is done using following profile characteristics: integral intensities, depth of the central absorption (so-called reversal) and asymmetry of the peaks. Distributions of the profile chracteristics within the studied area of the prominence are statistically analyzed using histograms. The profile characteristics are now defined only for profiles with one peak (called as purely emissive) or with two peaks. There exist also profiles with more peaks in the observed data from both instruments, thus, statistical analysis of occurrences of different type of profiles one-, two-, three-, four-and-more-peak profiles a d peculiar profiles is also made. Results of the statistical analysis of observed data will be later compared with the similar statistical analysis of synthetic profiles obtained using non-LTE models of the fine structure of prominences. Currently, we compare the results, with with other modeled prominences.

Torsional fan magnetic reconnections at the three-dimensional coronal magnetic nulls

Sanjay Kumar, Sushree S. Nayak, Avijeet Prasad, Ramit Bhattacharyya

Sanjay Kumar

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Three-dimensional (3D) magnetohydrodynamic simulation is performed to explore the process of magnetic reconnection at the 3D coronal magnetic nulls. The initial magnetic field is constructed analytically by superposing uniform vertical magnetic fields of two different magnitudes on a linear force-free field. The initial field is characterized by the presence of a pair of 3D nulls along with quasi-separatrix layers (QSLs). The topology of the 3D nulls, complete with the spine axis and the dome-shaped separatrix surface, is similar to the ones expected in the solar corona. The simulated evolution documents the movement of the field lines of the separatrix surface to be different than the field lines located in the vicinity of the surface. This generates favorable contortion in the field lines to develop current sheets, which are localized to the separatrix surface --- giving rise to the torsional fan magnetic reconnections at the 3D nulls. Additionally, the reconnections are also found to occur at the QSLs. However, the strength of the currents near QSLs is smaller than the strength at the fan surfaces of the 3D nulls, which indicates the reconnections near QSLs to be less energetically efficient than the 3D nulls.

NUMERICAL SIMULATION OF ERUPTIVE EVENTS

SATYAM AGARWAL
PHYSICAL RESEARCH LABORATORY

The unavailibility of routine measurements for chromospheric and coronal magnetic fields motivates the use of magnetic field extrapolation models. The broad spectrum of physical assumptions and numerical techniques involved in different extrapolation methods demands a critical analysis of their usefulness in the context of solar observations. We note that the influence of extrapolation models on the simulated dynamics of magnetofluids in solar atmosphere is not well understood. We have used the NLFFF and NFFF extrapolation methods to explore this problem. We have considered two scenarios to simulate the eruptive flare from NOAA AR 11977 on 17 February 2014 using EULAG MHD code. In one case, we use the NFFF extrapolated magnetic field as input for MHD code where non zero Lorentz force drives the plasma dynamics. In another case, we use the NLFFF extrapolated magnetic field as input for MHD code where a suitably chosen flow drives the plasma dynamics.

Modelling the Impact of Magnetic Storms on Planetary Environments

Souvik Roy, Dibyendu Nandy

SOUVIK ROY

Center of Excellence in Space Sciences India (CESSI), IISER Kolkata

Coronal mass ejections (CMEs), large scale transient eruptions observed in the Sun, are thought to also be spawned by other magnetically active stars. The magnetic flux ropes intrinsic to these storms, and associated high speed plasma ejecta perturb planetary environments creating hazardous conditions. To understand the physics of CME impact and consequent perturbations in planetary environments, we use 3D compressible magnetohydrodynamic simulation of a star-planet module (CESSI-SPIM) developed at CESSI, IISER Kolkata based on the PLUTO code architecture. We explore magnetohydrodynamic processes such as the formation of a bow-shock, magnetopause, magnetotail, planet-bound current sheets and atmospheric mass loss as a consequence of magnetic-storm-planetary interactions. Specifically, we utilize a realistic, twisted flux rope model for our CME, which leads to interesting dynamics related to helicity injection into the magnetosphere. Such studies will help us understand how energetic magnetic storms from host stars impact magnetospheres and atmospheres with implications for planetary and exoplanetary habitability.

On the magnetohydrodynamics of an X-class flare on 2014 March 29

Sushree Sangeeta Nayak, Ramit Bhattacharyya, Sanjay Kumar

Sushree Sangeeta Nayak

Udaipur Solar Observatory, Physical Research Laboratory, India

We have explored the dynamics of an X-class flare on 2014 March 29 at~17:30 UT. For this purpose, we have performed a data-constrained simulation initiated by a non-force-free-field (NFFF) extrapolated coronal magnetic field with a motionless state. In the extrapolated field,we find a three-dimensional (3D) magnetic null, a pair of magnetic flux ropes, and a set of sheared arcades (overarching the filaments)in the vicinity of the flaring location. The simulated evolution shows that magnetic reconnection is initiated near the magnetic null point.The charged particles traverse through the spine and fan field lines of the 3D null and hit the lower atmosphere and may result in the chromospheric brightening. The sheared arcades are seen to rise and take part in the reconnection near the null point. Under favorable Lorentz force, the two flux ropes lose their twist and become nearly potential loops. These post-reconnection loops are well agreeing with the loops observed in 94 A channel of Atmospheric Imaging Assembly (AIA) onboard Solar Dynamics Observatory (SDO). We have also estimated the energy released (~ 6.8x10^{31} ergs) during this process which is in congruent with the corresponding observational value---showing efficacy of the simulation.

Generation and dissipation of magnetic structure on photosphere of sun

Tridib Roy & R. T. Gangadhara

Indian Institute of astrophysics

The lower solar atmosphere is a partially ionized plasma consisting of electrons, ions, and neutral atoms. We have treated solar plasma as a three-componemt fluid system, whose outcomes are interpreted in terms of three nonlinear effects over here such as: Hall effect, which arises from the treatment of the electrons and ions as two separate fluids and the ambipolar diffusion arises from the inclusion of neutrals as the third fluid. The Hall effect and ambipolar diffusion have been shown to be actively operating in a region beginning from near the photosphere up to the chromosphere. In a partially ionized plasma, the magnetic induction is subjected to ambipolar diffusion and the Hall drift in addition to the usual resistive or ohomic dissipation. These nonlinear effects create sharp magnetic structures which then undergoes themselves to various relaxation mechanisms. We have derived nonlinear coupled partial differential equations in terms of electron density scale height for three-fluid system and thereafter by truncating higher order nonlinear term associated with the magnetic field variation in z direction and using other suitable approximation, we are able to obtain analytic solution to the magnetic induction equation in a stationary state. In general we have considered the following effects which includes the Hall effect, ambipolar diffusion, and ohmic dissipation. The temporal evolution of the magnetic field is also planned to investigate under the combined as well as the individual effects of the Hall drift and ambipolar diffusion to demonstrate the formation of steep magnetic structure. These structures have just the right features for the release of magnetic energy into the solar atmosphere. We emphasize that the aforementioned nonlinear plasma processes are responsible for generating short scale current density structure, which subsequently undergoes through reconnection process and dissipate in terms of heat energy. We speculate that, these processes might have some implications on the well famous coronal heating problem.

Damping mechanism of longitudinal large-amplitude oscillations in solar prominence in the high-resolution simulation

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We report 2D MHD simulations of the longitudinal large-amplitude oscillations (LALOs) in the solar prominences performed using MHD code Mancha 3.0. The main idea of this work is to study the damping mechanism using the high-resolution simulations and find the physical reason for the damping of LALOs that could be hidden under the numerical dissipation. We studied the damping mechanism of LALOs using a simple configuration that contains a dipped magnetic field with a dense prominence plasma loaded in the region of the dips. In order to generate LALOs, we used a perturbation directed along the magnetic field. The obtained results indicate that the high-resolution simulations give more details about the damping behavior in the different prominence layers. Thus, we have found that the LALOs are strongly damped in the region where the magnetic field is more curved (in the center and bottom of the prominence). We obtained almost the same damping time at the prominence center for the two highest resolution considered. This means a physical mechanism works in the prominence center that is more efficient than the numerical dissipation. The oscillations in the shallower lines at the upper prominence part last for a longer time. Moreover, during the first 150 minutes, the oscillatory velocity is slightly amplified compared to an initial amplitude. This effect is even more pronounced when we use a higher spatial resolution. The damping and amplification mechanisms involved in our experiments can be important for explaining the observed strong damping of LALOs and, in some cases, their enhancement.

Seismic studies of solar prominences

Veronika Jercic

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Solar prominences, also known as solar filaments are cold, dense structures nested in the hot and tenuous solar corona. The main elements that make up a prominence are thread-like structures (also known as fibrils) characterized by counter-streaming flows. Such characteristics are confirmed by multiple observations [1, 2]. In a number of cases, prominences also exhibit oscillatory behaviour [3]. Understanding the exact interplay of mechanisms that cause prominence oscillation provides enormous insight into the solar corona. However, the exact mechanisms are still unknown. Numerous numerical simulations and studies have been conducted [4, 5, 6] in order to analyze the exact mechanisms governing prominence characteristics and their behavior. Yet, more details are still needed in order to properly model solar prominences, their finer structure and their oscillations. We aim to study causal relations between a localized energy release and a remote prominence oscillation. Varying the location and energy content of the perturbation can result in oscillations with different properties and damping. Hence, there is a great number of possible parameters governing the oscillations we observe. With this research we are addressing the problem of oscillations with an diabatic, 2D numerical model using an open-source MHD simulation code, MPI-AMRVAC [7]. We exploit the advantages of adaptive mesh refinement (AMR) to investigate how multiple threads react due to a realistic source perturbation. The grid we employ consists effectively of 4160×800 cells, which allows us to resolve lengths of 36 × 7:5 km. Additionally, this study has a direct impact on interpreting observations and on our understanding of unexplored, fundamental processes governing the corona and its heating. References: [1] O. Engvold. Observations of Filament Structure and Dynamics (Review). In David F. Webb, Brigitte Schmieder, and David M. Rust, editors, IAU Colloq. 167: New Perspectives on Solar Prominences, volume 150 of Astronomical Society of the Pacific Conference Series, page 23, January 1998. [2] P. F. Chen, L. K. Harra, and C. Fang. Imaging and Spectroscopic Observations of a Filament Channel and the Implications for the Nature of Counter-streamings. Astrophys. J., 784(1):50, March 2014. [3] M. Luna, J. Karpen, J. L. Ballester, K. Muglach, J. Terradas, T. Kucera, and H. Gilbert. GONG Catalog of Solar Filament Oscillations Near Solar Maximum. Astrophys. J. Suppl. Ser, 236(2):35, June 2018. [4] Yu-Hao Zhou, C. Xia, R. Keppens, C. Fang, and P. F. Chen. Three-dimensional MHD Simulations of Solar Prominence Oscillations in a Magnetic Flux Rope. Astrophys. J., 856(2):179, April 2018. [5] L. Y. Zhang, C. Fang, and P. F. Chen. Damping Mechanisms of the Solar Filament Longitudinal Oscillations in the Weak Magnetic Field. Astrophys. J., 884(1):74, October 2019. [6] V. Liakh, M. Luna, and E. Khomenko. Numerical simulations of large-amplitude oscillations in flux rope solar prominences. Astron. Astrophys., 637:A75, May 2020. [7] C. Xia, J. Teunissen, I. El Mellah, E. Chan´e, and R. Keppens. MPI-AMRVAC 2.0 for Solar and Astrophysical Applications. Astrophys. J. Suppl. Ser, 234(2):30, February 2018.

Poster - Group IV

Solar Interior, Seismology, Dynamo and Solar Cycle

Modeling Helioseismic Signatures of Differential Rotation and Meridional Circulation

Andrey Stejko

New Jersey Institute of Technology, USA

We use the new 3D linearized pseudo-spectral code GALE (Global Acoustic Linearized Euler) to create simulations of acoustic rays traveling throughout the solar interior. We use a randomized source model to mimic realization noise present in solar observations and perform deep-focusing methods in order to measure travel times in differential rotation and meridional circulation profiles derived from mean-field models of solar interior flow.

A New Formula for Predicting Solar Cycles

Gopal Hazra and Arnab Rai Choudhuri

Gopal Hazra

Trinity College Dublin

A new formula for predicting solar cycles based on the current theoretical understanding of the solar cycle from flux transport dynamo is presented. Two important processes---fluctuations in the Babcock-Leighton mechanism and variations in the meridional circulation, which are believed to be responsible for irregularities of the solar cycle---are constrained by using observational data. We take the polar field near minima of the cycle as a measure of the randomness in the Babcock-Leighton process, and the decay rate near the minima as a consequence of the change in meridional circulation. We couple these two observationally derived quantities into a single formula to predict the amplitude of the future solar cycle. Our new formula suggests that the cycle 25 would be a moderate cycle. Whether this formula for predicting the future solar cycle can be justified theoretically is also discussed using simulations from the flux transport dynamo model

Helioseismic Detection of Emerging Magnetic Flux

Stefan, J. T., Kosovichev, A. G., Stejko, A. M.

John Stefan

New Jersey Institute of Technology

A time-distance helioseismic technique, similar to the one used by Ilonidis et al (2011), is applied to two independent numerical models of subsurface sound-speed perturbations to determine the spatial resolution and accuracy of phase travel time shift measurements. The technique is also used to examine pre-emergence signatures of several active regions observed by the Michelson Doppler Imager (MDI) and the Helioseismic Magnetic Imager (HMI). In the context of similar measurements of quiet sun regions, three of the five studied active regions show strong phase travel time shifts several hours prior to emergence. These results form the basis of a discussion of noise in the derived phase travel time maps and possible criteria to distinguish between true and false positive detection of emerging flux.

IRIS view of the solar cycle 24: variability of the Mg II k & h lines

Julius Koza (1), Stanislav Gunar (2), Pavol Schwartz (1), Petr Heinzel (2), Wenjuan Liu (2); (1) Astronomical Institute, Slovak Academy of Sciences, Tatranska Lomnica, Slovakia (2) Astronomical Institute, The Czech Academy of Sciences, Ondrejov, Czech Republic

Julius Koza

Astronomical Institute, Slovak Academy of Sciences, Tatranska Lomnica, Slovakia

We present observations of variability of the emission cores of Mg II k & h lines in the solar cycle 24 and their center-to-limb variations acquired by the Interface Region Imaging Spectrograph (IRIS) in the years 2013-2020. We use 91 full-Sun NUV IRIS mosaics covering the raising phase, maximum, decline, and the end of the solar cycle 24. For this analysis, the solar disk is divided into ten concentric equiareal zones. Data averaged over the zones represent the center-to-limb variation of Mg II k & h line cores. The time series of IRIS spectral irradiance correlates well with the UV indices (Bremen Composite Magnesium II Index and the Composite Solar Lyman-alpha Index) with the correlation coefficients of 0.90 - 0.94, thus verifying the long-term stability of IRIS radiometric calibration. The Mg II k & h emission cores show significant center-to-limb variation. Their wavelength-integrated intensities decrease toward the limb suggesting overall limb darkening. However, broadening of the emission cores toward the limb invokes the limb brightening in narrow wavelength intervals where the intensities are higher than in the disk center. The time series of calibrated full-Sun IRIS mosaics allows also to answer a question whether the quiet areas of the solar atmosphere change over the solar cycle 24 at chromospheric layers. Another possible application of the IRIS mosaics is to supply missing measurements of the Mg II spectral irradiance from the SOLSTICE instrument on-board the SORCE mission in the period of its temporary shut down from July 13, 2013 to February 25, 2014 when IRIS acquired four full-Sun mosaics.

THE POLAR PRECURSOR METHOD FOR SOLAR CYCLE PREDICTION: COMPARISON OF PREDICTORS AND THEIR TEMPORAL RANGE

PAWAN KUMAR, MELINDA NAGY, ALEXANDRE LEMERLE, BIDYA BINAY KARAK AND KRISTOF PETROVAY

PAWAN KUMAR

IIT BHU

Solar activity affects our space environment, thereby influencing various aspects of human life. Hence, it is vitally important to develop capabilities for predicting strengths of the 11-year cycles of solar activity. The polar precursor method is widely considered to be the most robust physically motivated method to predict the strengths of an upcoming solar cycle. It uses the magnetic field concentrated near the poles around sunspot minimum. I will present an extensive performance analysis of various such predictors, based on both observational data like (WSO magnetograms, MWO polar faculae counts and Pulkovo A(t) index) and outputs (polar cap magnetic flux and global dipole moment) of various existing flux transport dynamo models. We calculate Pearson correlation coefficients (r) of the predictors with the next cycle amplitude as a function of time measured from solar cycle maximum and polar field reversal. Setting $r = 0.8$ as a lower limit for acceptable predictions, we find that observations and models alike indicate that the earliest time when the polar predictor can be safely used is 4 years after polar field reversal. This is typically 2 to 3 years before solar minimum and about 7 years before the predicted maximum i.e. considerably extending the usual temporal range of the polar precursor method. Re-evaluating the predictors another 3 years later, at the time of solar minimum, further increases the correlation level to $r > 0.9$. As an illustration of the result, we determine the predicted amplitude of Cycle 25 based on the value of the WSO polar field at the official minimum date of December 2019 as 126 ± 3. A forecast based on the value in early 2017, 4 years after polar reversal would have only differed from this final prediction by a few percent.

Magnetic Fields and Sub-photospheric Flows of Solar Active Regions

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Solar active regions (ARs) are three dimensional magnetic structures extending from the interior below the photosphere to coronal heights. The solar photosphere is an excellent conductor where frozen-in-field condition may be satisfied. Over a period of time, near the photosphere, plasma may evolve with magnetic field lines, and may play crucial role in solar activities. Therefore, one can expect that the near surface plasma and magnetic field lines must show some relationship in their topology. For this, we have studied the topological parameters such as kinetic and magnetic helicities in sub-photospheric flows and photospheric magnetic fields, respectively, over entire areas of several ARs observed during peak to decay phase of the solar cycle 23. We have found the hemispheric trend in the kinetic helicity of sub-photospheric flows averaged over the depth range of 2.5-12 Mms. The kinetic helicity shows a significant signature of the hemispheric trend, as 69%(67%) ARs in the northern (southern) hemisphere show negative (positive) helicity. Further, we derived magnetic helicity parameters for the ARs by using photospheric vector magnetic field observations to examine correlation with corresponding kinetic helicities. We found 68%(67%) ARs in the northern hemisphere with negative (positive) magnetic helicity in agreement with earlier reports. However, we did not find any significant association between the two helicity parameters. We also found that the hemispheric preference of all the parameters increases with the field strength of ARs. The topology of photospheric magnetic fields and near-surface sub-photospheric flow fields did not show good association but the correlation between them enhances with depths, which could be indicating more aligned flows at deeper layers of ARs.

Inferring solar differential rotation through normal-mode coupling

Samarth G Kashyap, Srijan Bharati Das, Shravan Hanasoge, Martin Woodard, Jeroen Tromp

Samarth G Kashyap

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Normal-mode helioseismic data analysis uses observed solar oscillation spectra to infer perturbations in the solar interior due to global and local-scale flows and structural asphericity. Differential rotation, the dominant global-scale axisymmetric perturbation, has been tightly constrained primarily using measurements of frequency splittings via

Understanding the subsurface dynamics of Active Regions

S.Pillai, M.Svanda

Shaktivel Pillai

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The principal factor responsible for the heliospheric disturbances is the formation of Active Regions (AR). These AR are a consequence of the magnetic fields generated by the dynamo action in the convection zone. They are the key drivers of solar variability and factors contributing to space weather predictions. Thus understanding the emergence and the evolution of AR will lead to concrete interpretation of the extreme conditions in space. We strongly believe that understanding the dynamics of AR will reveal the subsurface play of the magnetic fields.

Graphical study of the Solar Cycles and the Sunspots

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The turbulence of the Solar Plasma and the magnetic reconnection in the Sun's atmosphere are linked to the occurrence of the Sunspots. The 11 year quasi-periodicity in sunspots and the flipping of large-scale dipolar (north-south) magnetic field component of the Sun leads to the difference in the strength of the Solar Cycle, as it moves regularly from the solar minimum, that is, when the number of sunspots and the solar activities tend towards low values, followed up by the Solar maximum, when the solar activities rise to high noticeable values, and again, fading back to the Solar Minimum, thus, completing up a journey of one solar cycle. The solar activities are at peak during the maximum of the solar cycle, leading to the Solar Flares, and the Coronal Mass ejections- the most important drivers of the Space Weather, resulting in the geomagnetic storms on the Earth and the occurrence of the Auroras, while also causing up disruptions with the technology and the satellites. The solar wind and Solar Energetic particles, which occurs as a consequence of the Solar Phenomenon travels supersonically to escape the Sun's gravitational pull and propagates towards the heliosphere, where they reduce to the subsonic speeds as they reach the termination shock on the way to the heliopause, driving a shock wave, producing an electron beam ahead of it, and drives electron plasma oscillations termed as Langmuir waves, at the local electron plasma frequency via a beam plasma instability. Such shock related plasma oscillations produce radio emissions via non-linear mode coupling process at the two frequencies, plasma frequency, Fp and its harmonic. The radio emissions occur 3-4 years after the maximum of a particular Solar Cycle, succeeding the Forbush Decrease, which occurs 400 days prior to the onset of the radio emission events. The 2-3 kHz radio emissions emerged as the strongest in the Solar System, establishing the fact that the heliosphere is a well known radio emitter. In this project, the Solar Cycle 1 to Solar Cycle 24 have been studied graphically, by the use of data for the Sunspots number, Solar Wind Proton Density, 10.7cm solar flux and the number of coronal mass ejections along with the important phases such as Geomagnetic Storms, Solar Flares which occurred during the particular Solar Cycle. Also, the frequency of 2-3 kHz heliospheric radio emissions is calculated for the Solar Cycle 24, with the use of the formula: Fp= 8980(ne) 1/2 Hz, where ne is the local electron number density per cubic centimeter.

Inclination Dependence of Solar Ca II H & K Emission

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The emission in the near ultraviolet Ca II H & K lines, often quantified via the S-index, has been serving as a prime proxy of solar and stellar magnetic activity. Despite the broad usage of the S-index, the link between the coverage of a stellar disk by magnetic features and Ca H & K emission is not fully understood. To address this aspect, we developed a physics-based model to calculate the solar S-index. We made use of the distributions of the solar magnetic features derived from the simulations of magnetic flux emergence and surface transport, together with the Ca II H & K spectra synthesized using a non-local thermodynamic equilibrium (non-LTE) radiative transfer code. We show that the value of the solar S-index is influenced by the inclination angle between the solar rotation axis and the observer's line-of-sight, i.e. the solar S-index values obtained by an out-of-ecliptic observer are different from those obtained by an ecliptic-bound observer. This is important for comparing the magnetic activity of the Sun to other stars. We computed the variations of the S-index as they would be observed at various inclinations dating back to 1700. We find that depending on the inclination and period of observations, the activity cycle in solar S-index can appear weaker or stronger than in stars with a solar-like level of magnetic activity. We show that the solar chromospheric emission variations is absolutely normal in the context of stars with near-solar magnetic activity.

The Effect of Lorentz Stresses on the Solar Frequency Spectrum

Srijan Bharati Das, Tuneer Chakraborty, Shravan Hanasoge, Jeroen Tromp

Srijan B. Das

Princeton University

Departures from standard spherically symmetric solar models, in the form of perturbations such as global and local-scale flows and structural asphericities, result in the splitting of eigenfrequencies in the observed solar spectrum. Here we describe new theoretical developments that enable the computation of sensitivity kernels for frequency splittings (a coefficients) due to general Lorentz stresses in the Sun. We draw from theoretical ideas prevalent in normal-mode coupling theory in geophysical literature to build these kernels. We plot the Lorentz-stress kernels and estimate the a-coefficients arising from a combination of deep-toroidal and surface-dipolar fields (although we note that this could equally well be substituted by another choice of Lorentz stresses). These results pave the way to formally pose an inverse problem, and infer magnetic fields from the measured even a-coefficients.

Quiet-sun hydrogen Lyman-alpha line profile derived from SOHO/SUMER solar-disk observations and its variation with solar cycle

S. Gunár, P. Schwartz, J. Koza and P. Heinzel

Stanislav Gunar

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The solar radiation in the Lyman-alpha spectral line of hydrogen plays a significant role in the illumination of chromospheric and coronal structures, such as prominences/filaments, spicules, chromospheric fibrils, cores of coronal mass ejections, or solar wind. Moreover, it is important for the investigation of the heliosphere, Earth ionosphere, and the atmospheres of planets, moons and comets. We use SOHO/SUMER Lyman-alpha raster scans obtained without the use of the SUMER attenuator in various quiet-sun regions on the solar disk to derive a reference quiet-sun Lyman-alpha spectral profile. This reference profile is representative of the Lyman-alpha radiation from the solar disk during a minimum of solar activity. The solar radiation in the Lyman lines is not constant over time but varies significantly with the solar cycle. We use the LISIRD Composite Lyman-alpha index to adapt the incident radiation Lyman line profiles (Lyman-alpha and higher lines) to a specific date. Moreover, we estimate how the change of the incident radiation influences the synthetic spectra produced by the radiative transfer modelling. To do so, we use a 2D prominence fine structure model. The analysis of the influence of the change of the incident radiation shows that the synthetic spectra are strongly affected by the modification of the incident-radiation boundary condition in the Lyman lines. The most pronounced impact is on the central and integrated intensities of the Lyman lines. There, the change of the synthetic spectra can often have the same amplitude as the change of the incident radiation itself. The impact on the specific intensities in the peaks of reversed Lyman-line profiles is smaller but still significant. Interestingly, the hydrogen H-alpha line can be also affected considerably, even though the H-alpha radiation from the solar disk does not vary with the solar cycle.

Improved Measurements of the Sun's Meridional Flow and Torsional Oscillation from Correlation tracking on MDI \& HMI magnetograms

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The Sun’s axisymmetric flows, differential rotation and meridional flow, govern the dynamics of the solar magneticcycle and variety of methods are used to measure these flows, each with its own strengths and weaknesses. Flow measurements based on cross-correlating images of the surface magnetic field have been made since the 1970s whichrequire advanced numerical techniques that are capable of detecting movements of less than the pixel size in imagesof the Sun. We have identified several systematic errors in addition to the center-to-limb effect that influence previousmeasurements of these flows and propose numerical techniques that can minimize these errors by utilizing measurementsof displacements at several time-lags. Our analysis of line-of-sight magnetograms from theMichelson Doppler Imager(MDI) on the ESA/NASASolar and Heliospheric Observatory(SOHO) andHelioseismic and Magnetic Imager(HMI)on the NASASolar Dynamics Observatory(SDO) shows long-term variations in the meridional flow and differential rotation over two sunspot cycles from 1996 to 2020. These improved measurements can serve as vital inputs for solar dynamo and surface flux transport simulations.

Sub-critical dynamos and hysteresis in the Babcock-Leighton type kinematic dynamo models

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In the Sun and other stars, a large-scale magnetic cycle is possible as long as the large-scale shear and helicity of the plasma flow in their convection zones are sufficiently strong. Hence, for each star, there is a critical dynamo number for the operation of a large-scale dynamo. As a star slows down, it is expected that the large-scale dynamo ceases to operate above a critical rotation period. In our study, we explore the possibility of the operation of the dynamo in the sub-critical region using the Babcock-Leighton type kinematic dynamo model. In some parameter regimes, we find that the dynamo shows hysteresis behavior, i.e., two dynamo solutions are possible depending on the initial parameters---decaying solution if started with weak field and strong oscillatory solution (sub-critical dynamo) when started with a strong field. The sub-critical dynamo mode, however, is unstable in some parameter regimes. Therefore, our work suggests the possible existence of sub-critical dynamo in some stars.

Poster - Group V

Synoptic Solar Physics

A Study of Correlation Between Angular and Meridional Velocities of Sunspot Groups

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We analyzed the combined 142 years sunspot-group data from Greenwich Photoheliograpic Results (GPR) and Debrecen Photoheliographic Data (DPD) and determined the yearly mean residual rotation and the meridional motion of sunspot groups in different 5 degree latitude intervals. We find that there exists a considerable latitude-time dependence in both the residual rotation and the meridional motion. However, there is no clear migratory character of torsional oscillations. The residual rotation is found to be -120 m/s to 80 m/s. In a large number of solar cycles the rotation is somewhat weaker during maxima than that of during minima. There exist alternate bands of equatorial and poleward merdional motions suggesting that the equaterward motion is dominant mostly around the maxima of cycles with velocity 8--12 m/s, whereas the poleward motion is dominant mostly around minima of cycles but with a relatively weak velocity, only 4--8 m/s. A statistically significant anticorrelation exists between the meridional motion and residual rotation. The corresponding linear-least-square best-fit is found to be reasonably good (slope, -0.28 + or - 0.09, is about 3.1 times larger than its standard deviation). The significant negative value of the slope indicates the existence of a strong angular momentum transport toward equator by meridional flows. We get a statistically significant anticorrelation between the slope determined from the data in 3-year moving time intervals and yearly mean sunspot number (SN), suggesting that there exists a relationship between the slope and activity during solar cycles. There is a suggestion that the slope leads SN by about four years and SN leads the slope by about 40 years. However, the correlation between the cycle-to-cycle modulations in the slope and amplitude of cycle is found to be insignificant, indicating that there is no relationship between the slope and strength of activity on a long-time scale (longer than a 11-year period).

Probable solar processes responsible for variations of solar activity

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The process of Solar magnetic field evolution is highly complex. It has been found that this evolution has strong control on the overall solar activity. Solar activity cycle characteristics vary from cycle to cycle and it makes the prediction of the nature of future activity cycles a major challenge. The evolution of magnetic field is also found to be varying from cycle to cycle, exhibiting many spatio-temporal trends and irregularities therein. In this context, exploring characteristics of various periodicities in the long-term evolution of solar activity cycles will enhance understanding of the magnetic field evolution. In this study, the periodicities in solar activity within different solar cycles (7-24) have been identified by applying wavelet analysis on daily sunspot numbers from year 1818 to 2019. The analysis reveals two aspects. One, there are periods that mimic the solar cycle averaged strength of activity throughout the interval of analysis i.e. solar cycles 7 to 24. Two, there are periods that do not display the above mentioned similarity, except for some cycles. Further, based on the characteristics of the above mentioned periods, 16 different groups of periods could be identified, periods in each group displaying similar behaviour. It is inferred that these distinct groups of periods are an indication that each owes their presence to a different causative mechanism on the Sun. A comprehensive investigation of these periods and their underlying causative mechanisms has been done. This paper aims at presenting the results of this investigation in detail.

The Influence of Solar Activity on the Rainfall over Kerala, India

Elizabeth Thomas and Noble P. Abraham

Noble P Abraham

Mar Thoma College, Tiruvalla

In this work we study the correlative effects of solar activity on the occurrence of rainfall over Kerala, India. We use 116 years data (1901-2016) for sunspot numbers from World Data Center SILSO, Royal Observatory of Belgium, Brussels and monthly rainfall data for the state of Kerala in mm from Indian Institute of Tropical Meteorology, Pune, India [Kothawale D.R. and Rajeevan M., Monthly, Seasonal and Annual Rainfall Time Series for All India, Homogeneous Regions and Meteorological Subdivisions: 1871-2016, IITM Research Report No. RR-138, August 2017]. In each of the solar cycles during the period of study, we compute the correlation coefficients for the different seasonal months of Jan-Feb (JF), Mar-May (MAM), June-Sept (JJAS) and Oct-Dec (OND) and the annual mean data. We observe that the rainfall in Kerala is correlated with the sunspot activity, with varying significance. Though the overall correlation of rainfall with sunspot is not discernible, seasonal rainfall, especially during JF and JJAS, show appreciable correlation with sunspot numbers. Keywords: rainfall, sunspots, Kerala, correlation coefficient

Solar-Cycle Characteristics in Kodaikanal Sunspot Area: Phase Distribution and Gnevyshev Gap

B.Ravindra, Partha Chowdhury & J.Javaraiah

Partha Chowdhury

Calcutta University

Solar activity is asymmetric in the two hemispheres in almost all cycles. This asymmetry is observed both in cycle amplitude and period. We have used about 90 years of sunspot-area data from the Kodaikanal Solar Observatory to study the phase distribution and Gnevyshev Gap between the opposite hemispheres. The northern hemisphere activity led by 12, 15, and 2 months in Solar Cycles 20, 21, and 22, respectively. No significant phase difference is found between the two hemispheres in Solar Cycles 16, 17, 18, 19, and 23. The Gnevyshev gap was found in both the hemispheric data in Solar Cycles 16, 18, 21, 22, and 23. These results are consistent with the earlier reported characteristics in sunspot-area data. These results suggest that the Kodaikanal Observatory data complement the existing sunspot data from other observatories to study solar activity over long and short periods.

Study of long term properties of filaments from synoptic maps

Rakesh Mazumder

ARIES, Nainital

Like sunspots, filaments are also one of the main indices of solar activity. However, filaments unlike sunspots being observed in high latitude carry magnetic field information in high latitude which is otherwise unavailable in historical data.

Similar to white light observation (which gives century-long sunspot data) H-alpha observation is also made regularly in synoptic mode observation e.g. in Kodaikanal Solar Observatory (KSO) from 1914 to 2007 or in Mauna Loa Solar Observatory (MLSO) from 1997 to 2010 and more recently NSO/GONG network BBSO (1988-2013). Also from hand-made Carrington map archives like Meudon synoptic maps, McIntosh synoptic maps one get valuable information about properties of filaments and long-term variation of it. In this talk, I will discuss the results of my two works on long-term properties of filaments (one from McIntosh database and another from the Meudon database), showing the potential of these kinds of statistical studies.

Along with the usual 11-years cyclic variation (which becomes more prominent for active region filament and less prominent for quit region filament) filament also, shows clear poleward migration (popularly known as "rush to the pole") which co-indices with polar field reversal making it important for solar cycle prediction. Also, our recent findings of anomalous tilt angle distribution of filaments in two hemispheres shed new light on the mechanism of origin of filaments.

Global Solar Magnetic Field and Interplanetary Scintillations During the Past Four Solar Cycles

K. Sasikumar Raja, P. Janardhan, Susanta Kumar Bisoi,Madhusudan Ingale, Prasad Subramanian, K. Fujiki, Milan Maksimovic

Sasikumar Raja Kantepalli
Indian Institute of Astrophysics, Bangalore

The extended minimum of Solar Cycle 23, the extremely quiet solar-wind conditions prevailing and the mini-maximum of Solar Cycle 24 drew global attention and many authors have since attempted to predict the amplitude of the upcoming Solar Cycle 25, which is predicted to be the third successive weak cycle; it is a unique opportunity to probe the Sun during such quiet periods. Earlier work has established a steady decline, over two decades, in solar photospheric fields at latitudes above 45° and a similar decline in solar-wind micro-turbulence levels as measured by interplanetary scintillation (IPS) observations. However, the relation between the photospheric magnetic fields and those in the low corona/solar-wind are not straightforward. Therefore, we have used potential-field source-surface (PFSS) extrapolations to deduce global magnetic fields using synoptic magnetograms observed with National Solar Observatory (NSO), Kitt Peak, USA (NSO/KP) and Solar Optical Long-term Investigation of the Sun (NSO/SOLIS) instruments during 1975 - 2018. Furthermore, we have measured the normalised scintillation index [m] using the IPS observations carried out at the Institute of Space-Earth Environment Research (ISEE), Japan during 1983 - 2017. From these observations, we have found that, since the mid-1990s, the magnetic field over different latitudes at 2.5 Rsun and 10 Rsun (extrapolated using the PFSS method) has decreased by ~ 11.3 - 22.2%. In phase with the declining magnetic fields, the quantity m also declined by ~ 23.6%. These observations emphasise the inter-relationship among the global magnetic field and various turbulence parameters in the solar corona and solar-wind.

Calibration of sunspot area records

Sudip Mandal, Natalie Krivova, Sami Solanki, Nimesh Sinha, Dipankar Banerjee

Sudip Mandal

Max Planck Institute for Solar System Research

Long and consistent sunspot area records are important for our understanding of the long-term solar activity and variability, providing insights to solar dynamo models. Multiple observatories around the globe, such as Royal Observatory of Greenwich in England, Debrecen Observatory in Hungary, Kodaikanal Observatory in India, etc have regularly recorded sunspot areas, but such individual records only cover restricted periods of time. Moreover, there are systematic differences between them, so that these records need to be cross-calibrated before they can be reliably used for further studies. In this talk, I will present a brief overview of these records and how to calibrate them to generate a long, consistent and calibrated sunspot area catalogue. Further, I will talk about various applications of such a catalogue, e.g. in getting the distribution of individual spots areas, latitude distributions, area filling factor of groups etc, that are important for our understanding of solar (and stellar) dynamos.