Abstracts for the 2025 Flux Emergence Workshop, San Diego, CA

Monday 10:30-11:00 (remote)

Formation of magnetic flux concentrations in turbulent convection zones

A.S. Brun (Dept of Astrophysics DAp-AIM, CEA Paris-Saclay, France)
co-authors: **Q. Noraz** (RoCs, Norway), **A. Strugarek** (DAp-AIM, France)

We investigate the self-consistent generation of magnetic flux concentrations in a convective dynamo as a function of turbulent degree. By controlling the vigor of the convective motions in the context of the convective conundrum, we trigger in the dynamo the apparition of intense and relatively large magnetic flux concentrations that locally reach a new dynamical balance such that both the velocity and temperature field are impacted and inhibited by the presence of strong, super-equipartition magnetic fields. We follow the formation process of these intense magnetic bundles and their subsequent evolution and emergence at the surface of the simulations. We further study how such magnetic structures influence the operation of the global dynamo from which they genuinely emerge.

Monday 11:30-12:00

How much magnetic flux and energy do active regions carry away from the solar interior?

Sushant S. Mahajan (Stanford University), **Brian Welsch** (UW Green Bay)

The emergence of active regions is traditionally attributed to magnetic flux generated in the solar interior, which rises through the convection zone and escapes via the photosphere. In this scenario, active regions transport magnetic flux and energy from the deep interior to the solar surface. We investigate this process within the magnetic buoyancy framework of Parker (1955) to address a key question: how much of the magnetic flux and energy in the solar interior is carried away by active regions ascending through the convection zone? Using theoretical analysis and insights from prior studies, we study magnetic flux amplification, transport and dissipation processes and evaluate their implications for the solar dynamo. Our findings challenge conventional assumptions, suggesting the need for a paradigm shift in understanding the mechanisms governing magnetic flux transport and its role in the solar dynamo.

Monday 12:00-12:30

Testing Theories of the Origin of the Solar Hemispherical Helicity Rules

Nic Brummell (University of California Santa Cruz)

Magnetic helicity has always provided a significant constraint on the solar dynamo. Interestingly, observations of proxies for the magnetic helicity in active regions appearing at the solar surface seem to follow a distinctive chirality rule: negative helicity in the Northern hemisphere and positive helicity in the Southern. The origin of this ``rule'' may provide a window into the deeper interior. We investigate two potential theories via numerical simulations. The theories are very distinct. The perhaps best known theory, known as the ``Sigma effect'' [1], operates via the acquisition of magnetic helicity in a rising flux tube from buffeting by the rotationally-influenced turbulent convection through which it travels. A newer theory [2,3,4] operates instead via a selection mechanism which leads to the preferred rise of the ``correct'' helicity. On investigating both with numerical simulations of rising magnetic structures in convective turbulence, we find that the newer theory appears to be more robust.

[1] Longcope, D., Fisher, G., & Pevtsov, A., *Astrophys. J.*, **507**, 417, (1998),

[2] Manek, B., Brummell, N., & Lee, D., *Astrophys. J. Lett.*, **859**, L27, (2018)

[3] Manek, B., & Brummell, N., *Astrophys. J.*, **909**, 72, (2021)

Monday 14:00-14:30

Characterizing the Combined Effects of Diffusion Coefficients, Meridional Flow Profiles, and Flux Emergence Properties on the Buildup of the Polar Fields Using Surface-Flux Transport Modeling

Marc L. DeRosa (LMSAL), **Soumyaranjan Dash** (NSO), **Sushant Mahajan** (Stanford University)

Understanding the emergence, advection, and dispersal of photospheric magnetic flux on the Sun is key to understanding the long-term evolution of the polar fields, which are correlated with sunspot cycle amplitudes. In this work, the strength and timing of the formation of the polar fields are investigated using a one-dimensional (latitude vs time) evolving surface-flux transport model, in which the same list of bipolar magnetic regions (from sunspot cycles 24 and 25) are used as input for a series of models, but the flux dispersal and emergence properties, and meridional flow characteristics, are varied. We find that some combinations of these inputs have an outsized effect on the cancellation of magnetic flux across the equator, and consequently on the amount of magnetic flux advected poleward, as determined by examining the change in the axial magnetic dipole moment as a function of time.

<u>Monday 14:30-15:00</u>

Quantification of the Rate of Active Region Emergence on the Sun

Lisa A. Upton, **Bibhuti K. Jha** (SouthWest Research Institute)

The sunspot number (SSN) is widely accepted as the metric for quantifying the rise and fall of solar cycle activity. The official International SSN (R_i) originated in Zurich, Switzerland, but is now produced and preserved by the Sunspot Index and Long-term Solar Observations (SILSO) group at the Royal Observatory of Belgium. The SSN is an historical index that quantifies the activity of the Sun by counting the number of sunspot groups and the number of individual sunspots on the Earth-facing side of the Sun each day. These two numbers are added and then multiplied by a scaling factor that accounts for differences from observer to observer. Due to the nature of how it is created the SSN is a metric that quantifies the number of active regions (ARs) on one hemisphere of the Sun on a given day. A more useful metric for the purpose of simulating AR emergence and evolution in a model would be the rate of AR emergence. Here we present our efforts quantifying the rate of AR emergence as a function of the SSN. This is an essential component of our newly developed Synthetic Active Region Generator (SARG), a tool for generating synthetic AR catalogs as source terms for surface flux transport models such as the Advective Flux Transport (AFT) model. SARG relies solely on artificial sunspot cycle profiles, or the SSN itself,to generate a series of ARs with observed statistical properties (e.g., flux, location, and timing). SARG can be used to create many realizations that can be incorporated into the model to investigate the uncertainty due to the stochastic nature of AR emergence observed on the Sun. Here, we present the quantification of the AR emergence rate and describe SARG. We also show a use case scenario where SARG was used to create a historical reconstruction spanning Solar Cycles 1–24 (1755–2020) using AFT.

Monday 15:30-16:00

Formation and energetics of shocks in a 3D flux emergence simulation

Angelos Giannis and **Vasilis Archontis** (University of Ioannina)

The million-degree solar corona requires efficient mechanisms to convert magnetic and flow energy into heat, yet the role of viscous shock dissipation in emerging flux regions has not been systematically addressed. We aim to couple viscous dissipation to MHD shock waves in flux-emergence-driven heating events and to study the energetics and thermal impact of these shocks in the corona. We perform a three-dimensional (3D) compressible, resistive MHD simulation with the Lare3d code, which uses a Lagrangian–Remap scheme on a staggered grid and includes both explicit Ohmic resistivity and viscous shock heating for accurate shock capturing. A burst of slow shocks driven by early plasmoid ejections is initially reported, yielding profound transient heating and sharp entropy jumps in the corona. Reconnection in the current sheet results in fast shocks as plasmoids collide with the ambient field. During the first blowout jet we identify an interface shock as the flux rope material collides with the ambient field, a termination shock atop the post-eruption flare loops, and slow shocks flanking the loops, each coinciding with peaks in viscous dissipation. Global diagnostics reveal that shock heating is highest during the initial plasmoid-driven shocks and the blowout jets—notably the first blowout jet. These events coincide with peaks in kinetic and enthalpy fluxes. Shocks produce the most entropy in the experiment's cooler, early phases. Magnetic flux emergence drives transient events that account for substantial viscous dissipation in the solar corona, and we demonstrate here that this dissipation occurs primarily via MHD shocks. Our analysis identifies the first blowout jet as the most energetic event, revealing several shock structures that, to our knowledge, have as yet received no notice in 3D simulations of emerging flux regions.

Monday 16:00-16:30

Effects of Twist Parameter Variations on the Emergence of Magnetic Flux Tubes

V. Agalianou and **V. Archontis** (University of Ioannina)

Magnetic flux emergence from the solar convection zone into the solar atmosphere is an important mechanism for a wide range of solar phenomena, including sunspots, flares, and coronal mass ejections. We study the impact of variations in the magnetic twist parameter on the evolution of emerging magnetic flux tubes. We employ 3D resistive MHD simulations using the LareXd code to model the rise and emergence of flux tubes with constant, increasing and decreasing twist profiles. Our results demonstrate that the initial twist distribution can influence the geometry of the emerging field, the formation and eruption of magnetic flux ropes, and the overall magnetic topology in the corona. Non-uniform twist cases exhibit both ejective and confined eruptions, with significant differences in the buildup and release of magnetic helicity. We observe the formation of complex photospheric magnetic field morphologies, ranging from simple bipolar to multipolar configurations, and discuss their potential association with localized plasma heating at low heights.

Tuesday 10:00-10:30

A novel method to measure and track the magnetic flux in solar active regions

Georgios Chintzoglou (Lockheed Martin Solar and Astrophysics Laboratory)

Measuring the magnetic flux, Φ, from photospheric magnetograms requires defining a Gaussian surface, either closed (encompassing the entire solar sphere) or open (restricted to a sub-region such as an active region; AR). While straightforward in principle, in practice ARs and their constituent bipoles often emerge and evolve in close proximity, complicating the definition of consistent Gaussian surfaces. Flux can leak across evolving boundaries, and adjusting surface areas over time introduces systematic uncertainties that hamper reliable flux tracking.
In this talk, I will present a new method that circumvents these difficulties by exploiting the integral form of Maxwell-Faraday's law of induction. From sequences of photospheric magnetograms, we derive electric field maps ("electrograms") via an un-curling operation. This reformulation reduces the flux-tracking problem to following the polarity inversion lines (PILs) that serve as natural integration contours. Computing the contour integral of the induced electric field along these PILs directly yields the magnetic flux. In effect, the dimensionality of the flux measurement problem is reduced from a 3D/2D surface integral to a robust 1D line integral. This approach simplifies flux tracking and provides a powerful new tool for studying magnetic flux emergence, cancellation, and the dynamics of solar active regions.

Tuesday 10:30-11:00

Moderate Nesting: A New Look at the Distribution of the Sun's Active Regions

Aimee Norton (Stanford University)

Activity nests, also known as active longitudes, are locations where active regions repeatedly emerge over a period of months or years. The Sun shows moderate active region nesting behavior with ~30-40% of active region magnetic flux found in nests that are short-lived (4 months) and ~10% found in nests that are long-lived (2 years). Nests show strong North-South hemispheric asymmetry with the hemispheres alternating times of hosting long-lived nests. In addition to commonly hosting flares and CMEs, activity nests are interesting because they inform us about the non-axisymmetric nature of the solar dynamo. We report on nesting observed during Solar Cycle 24 and the start of Cycle 25 as studied using HMI/SDO magnetic synoptic maps. Lower-order m = 1, 2 modes dominate early and late in the cycle whereas m = 4, 6 modes appear at solar maximum. The physical mechanism that causes nests is unknown but could be due to an instability acting on the interior magnetic field or due to flow fields such as giant convection cells causing preferred locations of flux emergence. We discuss these issues as well as report on the average characteristics such as lifetimes, rotation rates and amount of magnetic flux contained in the observed nests.

Tuesday 11:30-12:00

Beyond J_r: Using Gauss's Separation Method to study the evolution of 3D current structures in the solar corona

Johnathan R. Stauffer (NRL/NRC), **Mark G. Linton** (NRL), **Peter W. Schuck** (NASA/Goddard)

While electrical currents are thought to play an important role in the generation of solar flares and coronal mass ejections (CME's), they remain difficult to directly study as only the normal current density, J_r, can be calculated directly from observations. Indirect information about the 3D structure of atmospheric currents can be obtained by studying the magnetic fields they generate in the solar photosphere, but are often obscured by the stronger field signatures generated by currents in the solar convection zone. These contributions to the solar surface magnetic field (as well as the contribution from the surface-threading current J_r) can be separated through the application of Gauss's separation algorithm, allowing for more detailed study of coronal current systems in the lead-up to solar flares.

We demonstrate the utility of this method by applying Carl's Indirect Coronal Current Imager (CICCI; a publicly available implementation of Gauss's separation method) to observations of NOAA Active Region 11158, which hosted a number of CME-productive flares between 2/13 and 2/18/2011. By combining CICCI diagnostics of the surface-threading (i.e., radial) and coronal current distributions, we observe the emergence of several twisted flux ropes prior to the start of flaring activity. Application of this technique to a larger selection of active regions shows that significant pre-flare evolution can be seen in most cases, suggesting that CICCI can be a powerful tool for studying the role of currents in solar flare onset.

This work was supported by the Office of Naval Research, and the NASA Living with a Star program.

Tuesday 12:00-12:30

Pivot of the Emerging Bipolar Magnetic Region in the Birth of Sigmoidal Solar Active Regions

Ronald L. Moore (University of Alabama Huntsville), **Sanjiv K. Tiwari**, **Navdeep K. Panesar**, **Alphonse C. Sterling**, and **Talwinder Singh**

We present an augmentation to longstanding evidence from observations and MHD modeling that (1) every solar emerging bipolar magnetic region (BMR) is made by an emerging Ω-loop flux rope, and (2) twist in the flux-rope field makes the emerged field sigmoidal. Using co-temporal full-disk coronal EUV images, magnetograms, and continuum images from Solar Dynamics Observatory (SDO), we found and tracked the emergence of 42 emerging single-BMR sigmoidal active regions (ARs) that have sunspots in both polarity domains. Throughout each AR's emergence, we quantified the emerging BMR's tilt angle to the east-west direction (the x-direction in SDO images) by measuring in the continuum images the tilt angle of the line through the (visually located) two centroids of the BMR's opposite-polarity sunspot clusters. As each AR emerges, it becomes either S-shaped (shows net right-handed magnetic twist) or Z-shaped (shows net left-handed magnetic twist) in the coronal EUV images. Nineteen of the ARs become S-shaped and 23 become Z-shaped. For all 42 ARs, in agreement with published MHD simulations of the emergence of a single-BMR sigmoidal AR from a subsurface twisted flux rope, if the AR becomes S-shaped, the emerging BMR pivots counterclockwise, and if the AR becomes Z-shaped, the emerging BMR pivots clockwise. For our 42 ARs, the pivot amount roughly ranges from 10° to 90° and averages about 35°. Thus, at the onset of the emergence of our average emerging Ω-loop flux rope, the magnetic field's twist pitch angle at the flux rope's top edge is plausibly about 35°.

Tuesday 14:00-14:30

Towards a Robust Estimate of the Solar Photospheric Poynting and Helicity Flux

Xudong Sun, **Jiayi Liu** (University of Hawaii),
Peter Schuck (NASA Goddard Space Flight Center)

The observed magnetic fields and Doppler velocities are frequently used to quantify the Poynting and helicity flux through the solar photosphere. Multiple methods have been developed for this purpose, but their consistency with one another is not warranted. Here we evaluate the performance of three methods (PDFI, DAVE4VM, DAVE4VMwDV) on NOAA active region 12673. We find that the accumulated magnetic energy and helicity differ significantly between these methods, even in signs. Using Helmholtz-Hodge decomposition, we show that Doppler velocity can contribute significantly through the non-inductive (curl-free) electric field. The different, ad hoc treatments of the Doppler and transverse velocities in these methods are directly responsible for the discrepancies. We discuss a possible post-processing procedure and the desired future observations that can better constraint these methods.

Tuesday 14:30-15:00

Polarity Inversion Line helicities and solar eruptivity

Kostas Moraitis (University of Ioannina)

We examine the relation of the relative helicity that is contained around the polarity inversion line (PIL) of the magnetic field, and its respective current-carrying component, with solar eruptivity. For this, we study the evolution of the PIL helicities in a sample of ~40 solar active regions which exhibited 220 flares above the M1.0 class. The computation of the PIL helicities is accomplished with the help of the respective relative field line helicities, the recently-developed proxies for the densities of the corresponding helicities, after first extrapolating for the 3D coronal magnetic field with a nonlinear force-free method. We find that, on average, for the stronger flares (above the M5.0 class) the relative helicity of the PIL experiences important decreases, >10%, during eruptive flares, while mixed changes are observed for confined flares. The PIL current-carrying component of relative helicity shows higher-magnitude decreases in both strong and weak flares, reaching >20% average changes during the stronger eruptive flares. Moreover, the PIL current-carrying helicity's flare-related variations exhibit the largest differences between eruptive and confined flares, thus strengthening the value of the PIL current-carrying helicity as an eruptivity indicator.

Tuesday 15:30-16:00

Active regions' pre-solar-storm global patterns and local dynamics

Mausumi Dikpati (NSF, NCAR, HAO), **Aimee Norton**, **Subhamoy Chatterjee**, **Kiran Jain** & **Scott McIntosh**

Magnetogram observations indicate that surface distribution of active regions (ARs) can be derived in the form of tight-fit global toroid patterns. ARs emerging in a certain longitude-range of the north and/or south toroids, which are "tipped-away" from each other are most prone to producing intense solar activity leading to biggest flares often associated with CMEs. We studied so far about ten cases of AR toroid patterns, including Halloween storms in cycle 23 and the Mother's Day superstorms in cycle 25, both of which created multiple biggest X-flares. Despite small statistics, in all these cases global toroid patterns show similar features before intense storms. Often multiple flux-emergences occur in the same location enabling complex interactions among the emerged ARs and leading to various local dynamics that can predict eruptions and upcoming storms with several hours lead time. We show that combining the study of the local dynamics of complex active regions and their evolution in global toroid patterns could provide good indicators for upcoming intense solar storms not just several hours but a few weeks ahead.

Tuesday 16:00-16:30

What are the Causes of Super Activity of Solar Active Regions?

Suman Dhakal (George Mason University)

Flare productivity varies among solar active regions (ARs). This study analyzed 20 ARs of contrasting sunspot areas and flare productivities to understand the super flare productivity of ARs. We used the flare index (FI) as an indicator of flare activity. We examined the pattern of morphological evolution of magnetic features. Further, we derived a set of magnetic feature parameters to quantitatively characterize ARs. Our study found that the correlation coefficient is the highest ($r = 0.78$) between FI and the length of the strong gradient polarity inversion line (SgPIL), while the coefficient is the lowest ($r = 0.14$) between FI and the total unsigned magnetic flux. This study also found that the super flare productive ARs have SgPILs (R value) longer (greater) than 50Mm (4.5). These results suggest that flare productivity is mainly controlled by the size of the subregion that comprises close interaction of opposite magnetic polarities and is weakly correlated with the size of the whole ARs. Further, even though magnetic flux emergence is important, this study shows that it alone is insufficient to increase flare productivity. New emergence can drive either the interaction of like or opposite magnetic polarities of nonconjugate pairs (i.e., polarities not from the same bipole). In the former case, the magnetic configuration remains simple, and flare productivity would be low. In the latter case, the convergence of opposite magnetic fluxes of nonconjugate pairs results in a magnetic configuration with long SgPIL and an increase in flare productivity.

Wednesday 10:00-10:30

Recurrent jets from an arch filament system

Reetika Joshi (NASA/GSFC and George Mason University)
Co-authors: **Luc Rouppe van der Voort**, **Brigitte Schmieder**, **Fernando Moreno-Insertis**, **Avijeet Prasad**, **Guillaume Aulanier**, and **Daniel Nóbrega-Sivero**

Solar jets are observed as collimated plasma ejections along magnetic field lines in both hot (EUV jets) and cool (chromospheric surges) temperature diagnostics. Utilizing the observations from the Swedish 1-m Solar Telescope (SST), along with Solar Dynamics Observatory (SDO) data, we analyzed a sequence of solar jets that originated from a mixed-polarity region located between the leading and following sunspots of an active region. This mixed-polarity region had formed over an extended period of approximately 24 hours through persistent magnetic flux emergence. Chromospheric SST observations identified this region as an arch filament system (AFS). Within this area, negative polarities were surrounded by positive polarities, creating a fan-shaped magnetic surface with a null point located at a height of 6 Mm, also revealed by magnetic field extrapolation. SST observations in the Hβ spectral line captured a large moving flux rope situated above the AFS, which triggered successive EUV and cool jets. The high-resolution SST data (0″.038 per pixel) resolved the presence of AFS at the base of the jet eruptions with an extended cool jet, which may be the result of a peeling-like mechanism of the AFS.

Wednesday 10:30-11:00

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

Navdeep K. Panesar[1,2], **Alphonse C. Sterling**[3], **Ronald L. Moore**[3,4], **Sanjiv K. Tiwari**[1,2], **Viggo H. Hansteen**[1,2,5,6], **David Berghmans**[7], **Mark Cheung**[8], **Daniel Müller**[9], **Frederic Auchere**[10], **and Andrei Zhukov**[7,11]

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

Wednesday 11:30-12:00

Parametric simulations of the propagation of solar jets: investigating the solar origin of switchbacks

E. Pariat (CNRS), **J. Touresse, C. Froment, V. Aslanyan, P. Wyper**

The recent discovery of the ubiquitous existence of switchbacks, localized magnetic deflections in the nascent solar wind, by Parker Solar Probe has spurred investigations into their origin. One prominent theory suggests they originate in the lower corona thanks to magnetic reconnection and that solar jet-like events are the progenitor of switchbacks. Jets are ubiquitous impulsive phenomena observed at various scales observed in the different layers of the solar atmosphere, associated with the release of magnetic twist/helicity. But can these helical magnetic structures be transported up until the inner heliosphere? Is it possible to demonstrate a causal relationship between a given solar jet and a switchback signature? Numerical modelling of solar jets has matured over the last 20 years, with 3D magnetohydrodynamics simulations enabling the analysis and understanding of multiple observational properties. Over the last few years, some efforts have been initiated to model the propagation of solar jets in the upper corona and into the inner heliosphere. During the presentation, I'll present new simulations aiming at understanding the propagation and possible signature of individual jet events to the solar wind discussing their possible role as switchbacks progenitors.

<u>Wednesday 12:00-12:30</u>

<u>Solar Orbiter observations and Bifrost simulations</u>

Daniel Nóbrega-Siverio (Institute of Astrophysics of the Canary Islands), **Reetika Joshi**, **Eva Sola-Viladesau**, **David Berghmans**, **Daye Lim**

Coronal jets are ubiquitous, collimated million-degree ejections that contribute to the energy and mass supply of the upper solar atmosphere and the solar wind. Solar Orbiter provides an unprecedented opportunity to observe fine-scale jets from a unique vantage point close to the Sun.

We aim to (1) uncover thin jets originating from Coronal Bright Points (CBPs), revealing previously unresolved contributions to coronal upflows; and (2) improve our understanding of plasmoid-mediated reconnection and its observable signatures.

We analyze eleven datasets from the High Resolution Imager 174 Å of the Extreme Ultraviolet Imager (HRIEUV) onboard Solar Orbiter, focusing on narrow jets from CBPs and signatures of magnetic reconnection within current sheets and outflow regions. To support the observations, we compare with CBP simulations performed with the Bifrost code.

We have identified thin coronal jets originating from CBPs with widths ranging from 253 km to 706 km: scales that could not be resolved with previous EUV imaging instruments. Remarkably, these jets are 30–85% brighter than their surroundings and can extend up to 22 Mm while maintaining their narrow form. In one of the datasets, we directly identify plasmoid-mediated reconnection through the development within the current sheet of a small-scale plasmoid that reaches a size of 332 km and propagates at 40 km/s. In another dataset, we infer plasmoid signatures through the intermittent boomerang-like pattern that appears in the outflow region. Both direct and indirect plasmoid-mediated reconnection signatures are supported by comparisons with the synthetic HRIEUV emission from the simulations.

The high spatial and temporal resolution of HRIEUV enables the detection of previously unresolved narrow jets and plasmoid-mediated reconnection signatures from CBPs. These findings highlight Solar Orbiter's unique capability and motivate future statistical studies to assess the role of such fine-scale phenomena in coronal dynamics and solar wind formation.

Wednesday 12:30-13:00

Insights into solar eruption dynamics and energy distribution through MHD + test-particle simulations

A. Strugarek (CEA Paris-Saclay), **M.V. Sieyra**, **A. Wagner**, **A. Prasad**, **P. Démoulin**, **F. Moreno-Insertis**, **E. Buchlin**, **A.S. Brun**, **M. Janvier**, **A. Finley**

With the advent of multi-view observations of the Sun, we can gain a better understanding of the three-dimensional structure of the solar eruptive events and identify the various energetic processes involved. To fully grasp the physics behind these phenomena, it is essential to develop innovative simulations that complement these observations. To this end, we hve developed a numerical framework based on the PLUTO code to model the evolution of active regions (ARs) using non-force-free magnetic field extrapolation, based on a magnetogram taken close to the onset of a flare, along with a stratified atmosphere. This presentation highlights the results of a solar eruption that occurred in NOAA AR 12241 on December 18, 2014.

Our simulation shows that a flux rope forms and then rises self-consistently in the same direction as the observed eruption, without any arbitrary assumptions regarding the flux rope structure. With the aid of an algorithm that identifies and tracks the magnetic flux rope, we examine the dynamics of this structure and determine its kinematic properties. Additionally, we calculate synthetic extreme ultraviolet (EUV) emissions from different perspectives, allowing us to make direct comparisons with observations.

Finally, we also incorporate test particles into the model to identify particle acceleration sites and anticipate the location and shape of non-thermal emissions. Furthermore, we quantify the energy proportion that is transferred into heating, eruptions, and particle acceleration.

Thursday 10:00-10:30

Synergies in High-Resolution Observations of the Solar Atmosphere to Unveil Small-Scale Energy Release during Flux Emergence

Salvo Guglielmino (Italian National Institute for Astrophysics)

Progress in high-resolution observations is leading us into a new era for understanding the complex interplay between magnetic flux emergence and energy release in the solar atmosphere.

Taking advantage of data acquired by the SDO, IRIS, and Hinode missions, we combine these observations with ground-based spectro-polarimetric measurements from SST and GREGOR. This coordinated approach allows us to track the evolution of magnetic fields from the photosphere to the corona and to investigate small-scale energy release events. The latter appear to be driven by processes such as magnetic reconnection and flux cancellation, contributing to atmospheric heating and—possibly—to solar wind acceleration.

Here, we report on events observed by IRIS in the ultraviolet that led to increases in Si IV and O IV line intensities—by factors of 100–1000 relative to quiet Sun levels—and significant line broadening (up to ±150 km/s), indicative of bi-directional plasma flows resulting from magnetic reconnection. SDO/AIA imaging often reveals bright counterparts across multiple channels, highlighting the upper atmospheric response. High-resolution spectro-polarimetry in the photosphere and chromosphere provides detailed insight into the magnetic configuration during flux emergence and decay.
Our findings demonstrate the crucial role of coordinated multi-instrument campaigns in addressing key challenges in the study of flux emergence dynamics. They pave the way for future investigations with advanced facilities such as the upcoming IBIS2.0 instrument—which we will present in more detail—, the European Solar Telescope (EST), and the Solar-C and MUSE satellites.

Thursday 10:30-11:00

Comparing Bifrost models of flux emergence with solar observations

Viggo Hansteen (SETI, Lockheed Martin Solar and Astrophysics Laboratory), **Milan Gosic**, **Bart De Pontieu**, **Alberto Sainz Dalda**, **Luc Rouppe van der Voort**

Studying the emergence of magnetic fields is essential for understanding the physical mechanisms behind various phenomena in the solar atmosphere. Most importantly, the emerging fields offer valuable insights into how energy and mass are transferred to the upper solar atmosphere. As a result, they have garnered significant attention from both observational and theoretical perspectives. We present models of quiet Sun-like magnetic fields generated by the Bifrost code. We compare these models with observations from the Swedish 1-meter Solar Telescope (SST) and the Interface Region Imaging Spectrograph (IRIS). By tracking magnetic features in both the SST and Bifrost data, we determined the similarities and differences between the fields identified in the models and those observed. We conduct a quantitative comparison of various properties, such as flux content, flux densities, horizontal and line-of-sight velocities, lifetimes, sizes, and surface interactions. Additionally, we identify and analyze the properties of the largest emerging bipoles in the SST and Bifrost data. Our findings indicate that magnetic bipoles in the Bifrost simulations are generally stronger than those observed with the SST. However, a qualitative comparison of the chromospheric and transition region responses to the emerging fields in the Bifrost models, SST, and IRIS observations shows similar heating processes occurring above and around the emerging fields.

Thursday 11:30-12:00

Exploring magnetic flux cancellation from the solar photosphere to the corona

F. Moreno-Insertis[1,2], **V. H. Hansteen**[3,4,5,6], **D. Nóbrega-Siverio**[1,2,5,6]

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Magnetic flux cancellation is often understood as the direct meeting at low atmospheric levels of magnetic patches with opposite polarity, accompanied by a simultaneous reduction in their magnetic flux — and, in some cases, the complete disappearance of one or both of them from magnetograms. Observational studies of this process over the past decades have primarily relied on magnetograms and Doppler maps derived from photospheric or chromospheric spectral lines. A smaller number of studies have employed spectropolarimetric data inversions.

In parallel, theoretical investigations have been conducted using either analytical approaches or idealized, purely coronal MHD numerical models. Radiation-MHD models that incorporate self-consistent subphotospheric convection have also been explored; however, these typically extend only up to the low chromosphere and assume geometrically simple initial magnetic field configurations.

In this lecture, I will present recent results from a radiation-MHD simulation performed with the Bifrost code. This model spans from the uppermost layers of the solar interior to the corona; in it multiple episodes of magnetic flux emergence and cancellation take place. We analyze the temporal evolution of a few cancellation events, compute observational proxies, and investigate the fascinating magnetic topology at and around the cancellation site. Our study provides a three-dimensional picture of the events taking place above a cancellation site, and offers a perspective beyond the traditional dichotomy of Ω-loop retraction versus U-loop rise often used to interpret observations.

Thursday 12:00-12:30

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

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Solar coronal EUV/X-ray bright points (CBPs) are believed to be major contributors to quiet solar coronal heating. Solar Orbiter's EUI/HRI_{EUV} observations of an emerging flux region (a typical CBP) in 174 Å, emitted by the coronal plasma at ~1 MK, reveals the presence of numerous tiny bright dots. These dots are roundish with a diameter of 675±300 km, a lifetime of 50±35 seconds, and an intensity enhancement of 30% ±10% from their immediate surroundings. About half of the dots remain isolated during their evolution and move randomly and slowly (<10 km s^{-1}). The other half show extensions, appearing as a small loop or surge/jet, with intensity propagations below 30km s^{-1}. Many of the bigger and brighter HRI_{EUV} dots are discernible in SDO/AIA 171 Å channel, have significant EM in the temperature range of 1–2 MK, and are often located at polarity inversion lines observed in HMI LOS magnetograms. The Bifrost MHD simulations of an emerging flux region do show dots in synthetic Fe IX/X images, although dots in simulations are not as pervasive as in observations. The dots in simulations show distinct Doppler signatures – blueshifts and redshifts coexist, or a redshift of the order of 10 km s^{-1} is followed by a blueshift of similar or higher magnitude. The synthetic images of O V/VI and Si IV lines, which form in the transition region, also show the dots that are observed in Fe IX/ X images, often expanded in size, or extended as a loop, and always with stronger Doppler velocities (up to 100 km s^{-1}) than that in Fe IX/X lines. Our results, together with the field geometry of dots in the simulations, suggest that most dots in emerging flux regions form in the lower solar atmosphere (at ≈1 Mm) by magnetic reconnection between the emerging and pre-existing/emerged magnetic field. The dots are smaller in Fe IX/X images (than in O V/VI, and Si IV lines) most likely because only the hottest counterpart of the magnetic reconnection events is visible in the hotter emission. Some of these dot-like heating events might be manifestations of magneto-acoustic shocks (driven from the lower atmosphere) through the line formation region of Fe IX/X emission. Because these fine-scale heating events carry magnetic energy of the order of 10^{26} erg, they contribute significantly to a CBP's heating, and mark where exactly the heating happens within CBPs.

Thursday 14:00-14:30

Is Small-Scale Chromospheric Activity Driven by Dynamic Photospheric Magnetic Fields?

Vasyl Yurchyshyn (New Jersey Institute of Technology)

Small-scale jets and upflows in the quiet Sun, such as Type II spicules, are thought to play a vital role in chromospheric-coronal mass and energy transport. However, their formation mechanisms and relationship to photospheric magnetic field dynamics are poorly constrained. This presentation examines recent progress in elucidating the nature of Type II spicules, particularly their association with emerging magnetic flux. Evidence from various observational and analytical approaches indicates that these events are likely products of magnetic reconnection driven by the rapidly evolving, small-scale magnetic fields inherent in the turbulent solar photosphere. Clarifying this connection is pivotal for understanding coronal heating and mass balance.

Thursday 14:30-15:00

A Hypothesis for Creating and Sustaining the Chromosphere and its Chromospheric Fibrils

Sara F. Martin (Helio Research, La Crescenta, CA)

The primary two sources of emerging magnetic flux on the Sun are the active regions of the solar cycle and the intranetwork magnetic fields within supergranules. Active regions include the largest accumulations of magnetic flux on the Sun and the intranetwork magnetic flux reveals the smallest. Both relate to flows that force their magnetic fluxes to come into contact. Observations over the past 4-5 decades have consistently revealed patterns of specific magnetic interactions independent of the magnitude of the magnetic fluxes. Two patterns are: (a) Opposite-polarity magnetic fluxes cancel (disappear from the observed line-of-site component) when flows force them together, (b) Same polarity magnetic fluxes merge; their merged fluxes are the sum of the previous fluxes. In 1999, cancelling magnetic fluxes in filament channels were interpreted by Litvinenko and Martin as photospheric magnetic reconnection, the mechanism which forms filaments (prominences). This category of magnetic reconnection has subsequently been called "magnetic flux cancellation reconnection" by other authors. In classic magnetic reconnection, the mutual inflow of opposite-polarity magnetic fluxes (moving toward each other) are perpendicular to the center of a broad angle of outflows from the same site. This implies the conversion of magnetic energy to kinetic energy. In the case of filaments, the inflows are the opposite polarity magnetic moving together. The outflows are the counterstreaming threads seen in H-alpha images precisely above the narrow boundary cancelling fluxes in the photosphere. However, if the cancelling magnetic fluxes are in a cluster of small, opposite-polarity fluxes, such as at the vertices between three supergranules, the observed outflows are the radial patterns of fibrils sometimes called "rosettes." The different appearance of outflows between filaments and fibrils are due mainly to different configurations that magnetic flux has when flux cancelling reconnection occurs. I conclude that flux-cancelling reconnection is a candidate mechanism for producing fibrils in the chromosphere as well as filaments in filament channels. The organization of the outflows are variable and complex. The ever-present supergranules play a strong role in the continuous organization of the small clumps of magnetic flux of opposite polarity which undergo flux-cancelling reconnection and whose outflows become the fibrils of the chromosphere. We are reminded that flux- cancelling reconnection occurs readily between all adjacent separate sources of magnetic fields of opposite polarity. It is such a ubiquitous source of outflows that I am prompted to offer the general hypothesis that flux-cancelling reconnection at the photosphere is the primary mechanism that creates and sustains the chromosphere and its chromospheric fibrils.

Thursday 15:00-15:30

SO/PHI: A novel perspective to boundary conditions for coronal models

G. Valori (Max-Planck-Institut für Sonnensystemforschung)
and the **SO/PHI team**

Solar Orbiter (SO) is a joint ESA-NASA encounter mission launched in 2020 on a strongly eccentric orbit around the Sun with closest perihelia at 0.28 AU. The Polarimetric and Helioseismic Imager (PHI) onboard Solar Orbiter is composed of 2 telescopes: The Full-Disc Telescope (FDT) imaging the entire solar disk at any point of SO's orbit, and the High-Resolution Telescope (HRT), observing a smaller part of the solar disk at high resolution. For both telescopes, the temporal cadence can be as short as 60 seconds.

With an orbit of about six months around the Sun, SO/PHI is the first magnetograph providing maps of the photospheric vector magnetic field from viewpoints away from the Sun-Earth line, including the far side of the Sun and the first direct measurements of the polar field. This opens new opportunities for novel boundary conditions for data-driven and data-inspired numerical simulations.

For instance, by combining subsequent observation periods from SO/PHI and Earth-bound observatories, individual active regions can be followed for much longer periods of time than from single viewpoints, significantly extending studies of flares and coronal mass ejections that monitor the formation, evolution, and destabilization of coronal structures. Similarly, synoptic maps are widely used as boundary conditions to global models of the magnetic coronal field for space weather applications. Using SO/PHI observations of the far side of the Sun, synoptic maps can be built by combining data taken within just two weeks instead of the usual 27 days, which is expected to significantly improve the temporal consistency of the coronal models. Finally, the stereoscopic view of a same area on the Sun allows for a purely geometrical resolution of the 180-degree ambiguity, thereby removing one of the intrinsic sources of error in vector magnetograms by using observations only.

Starting from spring 2025, SO started to rise significantly above the ecliptic, providing full spectropolarimetric observations of the solar poles for the first time. Such information, of great relevance for solar dynamo studies as well as for coronal heating and solar wind models, will also be crucial for the quantitative constraint of the magnetic field in heliospheric models. Finally, SO/PHI is also the forerunner of the Photospheric Magnetic-field Imager (PMI) onboard the forthcoming L5 mission Vigil, which will provide some of the above applications as routinely data products.

Friday 10:00-10:30

Data driven simulations of emerging and eruptive active regions: validating against a ground truth flux emergence simulation.

Lucas Tarr (NSO), **James Leake** (GSFC), **Dylan Kee** (GSFC), **Mark Linton** (NRL), **Pete Schuck** (GSFC)

Recent theoretical and computational advances have made data driven models of emerging active regions possible. Here we discuss the validation of our new method, based on the MHD characteristics, using synthetic observations generated from a ground truth flux emergence simulation. Our simulations include gravity and a stratified atmosphere, and the driven simulation starts at the ground truth simulation's photosphere and extends into the corona. Our method solves a minimization problem at each numerical cell and at each timestep in the driven boundary to determine the allowed update, under the magnetohydrodynamic equations, of the cell's state vector that most closely matches an update estimated by other means, i.e., by temporal interpolation between two known boundary states. We find that the driven simulation accurately reproduces the emergence of a twisted flux tube through the photosphere, the formation of key topological features in the corona, and a coronal mass ejection, according to numerous metrics, e.g., the temporal evolution of mass flux, magnetic flux, and Poynting flux at various heights. This allows fruitful comparison to a variety of multi-wavelength observational diagnostics at a large range of heights above the driven lower boundary.

Friday 10:30-11:00

Simulation of X-Flare resulting from collisional shearing in a setup inspired by AR 11158

M. Rempel (NSF, NCAR, HAO) **G. Chintzoglou**, **M.C.M. Cheung**

The NOAA active region AR 11158 is a well-studied flare productive AR that led to the occurrence of more than 30 flares including one X and multiple M flares. A characteristic feature of AR 11158 was the formation of a collisional polarity inversion line (cPIL) in response to the emergence of 2 bipolar active regions in proximity and their interaction during the emergence process. We present a simulation of this collisional shearing process by moving sunspots in a quadrupolar configuration along the centroid positions extracted from AR 11158. This process builds up free energy in the corona exceeding 4x10^32 erg, out of which about 2x10^32 erg are released in a X-flare followed by a series of smaller flares in the B to M range. The 4 strongest flares are associated with coronal mass ejections. About an hour prior to the X-flare, we see the formation of a magnetic flux rope (MFR) located above the cPIL. About 5 minutes before the flare, we see an upflow at chromospheric heights associated with a slow rise of the MFR. At the time when the first signatures of the starting eruption are visible in synthetic EUV emission, parts of the MFR enter regions with a decay index larger than 1.5, indicating that the flare initiation is consistent with the torus instability. Comparing the series of flares in this simulation to properties of observed flares, we find a comparable trend between flare energy and GOES X-ray flux, but flare duration falls into the short end of the solar range. As a consequence, energy fluxes into the flare ribbons can be substantial, reaching 10^13 erg/cm^2/s for the simulated X-flare.

Friday 11:30-12:00

Solar Eruptions Triggered by Flux Emergence

T. Török (PSI), **M. G. Linton**, **J. E. Leake**, **Z. Mikic**, **R. Lionello**, **V. S. Titov** and **C. Downs**

Observations have shown a clear association of filament/prominence eruptions with the emergence of magnetic flux in or near filament channels. Magnetohydrodynamic (MHD) simulations have been employed to systematically study the conditions under which such eruptions occur. These simulations to date have modeled filament channels as two-dimensional (2D) flux ropes or 3D uniformly sheared arcades. Here we present MHD simulations of flux emergence into a more realistic configuration consisting of a bipolar active region containing a line-tied 3D flux rope. We use the coronal flux-rope model of Titov et al. (2014) as the initial condition and drive our simulations by imposing boundary conditions extracted from a flux-emergence simulation by Leake et al. (2013). We identify three mechanisms that determine the evolution of the system:
(i) reconnection displacing foot points of field lines overlying the coronal flux rope,
(ii) changes of the ambient field due to the intrusion of new flux at the boundary, and
(iii) interaction of the (axial) electric currents in the pre-existing and newly emerging flux systems. The relative contributions and effects of these mechanisms depend on the properties of the pre-existing and emerging flux systems. Here we focus on the location and orientation of the emerging flux relative to the coronal flux rope. Varying these parameters, we investigate under which conditions an eruption of the latter is triggered.

Friday 12:00-12:30

Parametric study of scenarios of eruptions triggered by flux emergence in a non-zero beta environment

Alexis Blaise (CEA Paris-Scalay)

Our current understanding of the triggering mechanism of solar eruptions is based on many different processes. One of them plays a prominent role in their evolution: Magnetic Flux Emergence (MFE) is thought to be a key phenomenon to explain the evolution of active regions and also for the triggering scenarios of transient events (especially for CMEs; Feynman and Martin, 1995). Flux emergence primarily occurs near strong and complex active regions (Schrijver and Zwaan, 2008). This process can destabilize these regions through Lorentz forces and magnetic reconnection, causing a stable region to reconfigure and release free magnetic energy. This release often manifests as transient and energetic events, such as solar flares or coronal mass ejections. Feynman and Martin (1995) introduced the idea that the relative orientation of MFE with respect to pre-existing flux has a strong impact on eruptivity. MFE was considered favorable when its polarity facilitates magnetic reconnection with the preexisting arcade.

Török et al. (2024) conducted simulations that reproduce a twisted, stabilized, current-carrying flux rope (based on a semi-analytical model called TDm; Titov et al., 2014) and using a magnetic flux emergence simulation with the Lare3D code by Leake et al. (2014). They identified interaction between opposite polarity emerging magnetic flux and the overarching confining magnetic field, causing a magnetic reconnection restructuring the magnetic topology. The results confirmed the influence of nearby emergence flux as a driver of solar eruptions processes but questioned the hypothesis that emergence flux is favorable to the reconnection scenario as theorized in Feynman and Martin (1995).

In this work we built upon the ideas of Török et al. (2024) and extend them in a non-zero beta environment. We consider a stratified atmosphere and a non-zero plasma beta environment and in a near future particle acceleration effects. We will present the parameters influencing the eruptivity of the relaxed TDm and explore the phenomenology. In particular, we assess the effect of the duration of the emergence, amount of emerging magnetic flux, orientation, and the type of emerging structures (with or without current carrying structures).