Future Solar and Heliospheric Assets for Space Weather Prediction: Instruments, Modelling and Machine-Learning

Date, time: 22nd April 2022, 10:30 – 15:35 BST
Location: Virtual, hosted on Zoom

Meeting abstract

The UK has world leading heliophysics and space weather programmes with, for example, major involvement in operating space missions such as SOHO, STEREO and Solar Orbiter, ground-based facilities such as BISON and LOFAR, and the creation of the MET Office Space Weather Operations Centre. Notably, currently under development, is the ESA Vigil (formerly known as Lagrange) operational space weather mission to the Lagrange L5 point in which the UK has invested heavily via ESA's Space Safety Programme. In tandem with further L1 missions under development, Vigil will underpin a wave of new research opportunities aimed at increasing predictive capabilities for space weather forecasting.

As we enter the era of satellite mega-constellations and domestic rocket launches, and with the NASA/ESA Lunar Gateway Space Station due to be stationed outside the protective influence of the Earth's magnetic field, there is a strong need to better understand the fundamental link between solar and interplanetary space weather and the near-Earth environment. As we observe increasing solar activity in Solar Cycle 25, a community wide effort is required to coordinate and synergise current and future developments.

We invite contributions from academic and space weather communities on all aspects of solar- and helio-physics starting from the solar surface, extending out through the solar corona, into the solar wind, and out to Earth's orbit and beyond. The meeting will focus on three key themes:

- Space-, ground-based and in-situ observations of the photosphere, corona and inner heliosphere;
- Physical models which solve the relevant physics to make best use of sparse observations in space and to fill gaps where observations are unavailable; and
- Data assimilation and machine learning techniques which are now understood to be fundamental for many regimes of space weather forecasting.

Schedule

BST	Chairs: Ravindra Desai & Siegfried Gonzi	
10:30	Ravindra Desai	*Opening remarks*
10:35	Stefaan Poedts (Invited)	*Space Weather and the VSWMC*
11:00	Tony Arber	*Space weather predictions from solar magnetogram to satellite charging*
11:15	Robertus Erdelyi	*The Solar Activity Monitor Network - SAMNet*
11:30	Jasmina Magdalenić (Invited)	*Solar radio observations and the space weather*
11:55	Mario Bisi	*LOFAR4SpaceWeather (LOFAR4SW) – Increasing European Space-Weather Capability with Europe's Largest Radio Telescope: A Brief Summary*
12:10	Bernard Jackson	*High-Resolution Density Reconstructions of the Inner Heliosphere and the Challenge for Future Modeling Techniques*
12:25	**Lunch + Posters (*Gathertown)***	
	Chairs: Jackie Davies & Matthew Lang	
13:00	Eftyhia Zesta (Invited)	*Noise Eliminating Magnetometer Instrument in a Small Integrated System (NEMISIS) on the Heliophysics Environmental and Radiation Measurement Experiment Suite (HERMES) platform of the Lunar Gateway*
13:25	Giuseppe Mandorlo	*European Space Agency Space Weather Mission To L5*
13:40	Daniel Verscharen	*The Plasma Analyser (PLA) instrument for Vigil - Update and Progress*
13:50	Jonathan Eastwood	*In situ magnetic field measurements at L5 for space weather monitoring and prediction*
14:00	Arnaud Thernisien	*The CCOR-3 Compact Coronagraph for the ESA VIGIL Mission*
14:10	**Break**	
	Chairs: Matthew Lang & Ravindra Desai	
14:20	Enrico Camporeale (Invited)	*Reinventing Space Weather forecasts with Artificial intelligence: Current and future trends*
14:45	Edward Brown	*Attention-Based Machine Vision Models and Techniques for Solar Wind Speed Forecasting Using Solar EUV Images*
15:00	Harriet Turner	*Quantifying the effect of ICME removal and observation age for in situ solar wind data assimilation*
15:15	Craig DeForest	*NASA's PUNCH Mission: A Pathfinder to Better Space Weather Forecasting*
15:30	Siegfried Gonzi	*Closing remarks*
15:35	***Posters (Gathertown)***	

Presenter	Poster Title
Timothy Horbury	*New space weather monitoring opportunities: Solar Orbiter and IMAP*
Sanjay Gosain	*A Compact Doppler Magnetograph based on miniaturization of GONG instrument*
Craig DeForest	*Polarimeter to UNify the Corona and Heliosphere (PUNCH): Mission status and science update*
George Miloshevich	*Inverse cascade and magnetic vortices in kinetic Alfvén-wave turbulence*
Gordon J. Koehn	*Sun-to-Earth modelling of CME-CME interactions: How to create a perfect storm?*
Luca Giovannelli	*Sun CubE OnE: A Multi-wavelength Synoptic Solar Micro Satellite*
David Orozco Suárez	*CMAG: A Coronal MAGnetograph mission for studying the inner corona magnetic fields*
Sachin Reddy	*Predicting equatorial plasma bubbles with a random forest classifier*
Antony Soosaleon	*Limits of Coronal Abundances*
Tina Zhou	*Using Machine Learning to pre-prune ensembles of magnetogram synoptic maps.*
David Barnes	*Assessment and Validation of Daily Enlil and EUHFORIA Simulations During 2019–2021*

Abstracts

Space Weather and the VSWMC

Stefaan Poedts & the VSWMC-P3 team (Invited)

The ESA Virtual Space Weather Modelling Centre (VSWMC) project was defined as a long term project including different successive parts. Parts 1 and 2 were completed in the first 4-5 years and designed and developed a system that enables models and other components to be installed locally or geographically distributed and to be coupled and run remotely from the central system. A first, limited version went operational in May 2019 under the H-ESC umbrella on the ESA SSA SWE Portal. It is similar to CCMC but interactive (no runs on demand) and the models are geographically distributed and coupled over the internet.

The goal of the ESA project "Virtual Space Weather Modelling Centre - Part 3" (2019-2021) was to further develop the Virtual Space Weather Modelling Centre, building on the Part 2 prototype system and focusing on the interaction with the ESA SSA SWE system. The objectives and scope of this new project include maintaining the current operational system, the efficient integration of 11 new models and many new model couplings, including daily automated end-to-end (Sun to Earth) simulations, the further development and wider use of the coupling toolkit and front-end GUI, making the operational system more robust and user-friendly. The VSWMC-Part 3 project finished recently.

The 11 new models that have been integrated are Wind-Predict (a global coronal model from CEA, France), the Coupled Thermosphere/Ionosphere Plasmasphere (CTIP) model, Multi-VP (another global coronal model form IRAP/CNRS, France), the BIRA Plasma sphere Model of electron density and temperatures inside and outside the plasmasphere coupled with the ionosphere (BPIM, Belgium), the SNRB (also named SNB3GEO) model for electron fluxes at geostationary orbit (covering the GOES 15 energy channels >800keV and >2MeV) and the SNGI geomagnetic indices Kp and Dst models (University of Sheffield, UK), the SPARX Solar

Energetic Particles transport model (University of Central Lancashire, UK), Spenvis DICTAT tool for s/c internal charging analysis (BISA, Belgium), the Gorgon magnetosphere model (ICL, UK), and the Drag Temperature Model (DTM) and operations-focused whole atmosphere model MCM being developed in the H2020 project SWAMI. Many new couplings have also been implemented and a dynamic coupling facility has been installed. Moreover, Daily runs are implemented of two model chains covering the whole Sun-to-Earth domain. The results of these daily runs are made available to all VSWMC users.

We will provide an overview of the state-of-the-art, including the new available model couplings and daily model chain runs, and demonstrate the system.

Space weather predictions from solar magnetogram to satellite charging

Tony Arber

The talk will begin with a brief overview of the EU funded Prediction of Adverse effects of Geomagnetic storms and Energetic Radiation (PAGER) project which aims to run ensemble predictions from solar magnetograms through to satellite charging. Next a detailed description of the work at the University of Warwick which is responsible for predicting solar wind conditions at 1 A.U. from GONG data including real-time ensemble simulations of the quiet SW, methods for automated CME injection based on Gibson-Low flux tubes and Gaussian process optimisation and data assimilation.

The Solar Activity Monitor Network - SAMNet

Robertus Erdelyi

The Solar Activity Magnetic Monitor (SAMM) Network (SAMNet) is an international consortium of ground-based solar telescope stations. SAMNet, at its full capacity, will continuously monitor the intensity, magnetic and Doppler velocity fields at multiple heights in the solar atmosphere from the photosphere to the upper chromosphere. SAMM sentinels are equipped with a cluster of identical telescopes each with different magneto-optical filter (MOFs) to take observations in K~I, Na~D and Ca~I spectral bands. A subset of SAMM stations will also have white-light coronagraphs and emission line coronal spectro-polarimeters. The objectives of SAMNet are to provide data for space weather research and forecast of flares and CMEs. The goal is to achieve an operationally sufficient lead time of e.g. flare warning of 2-8 hours, and provide much sought-after continuous synoptic maps (e.g., LoS magnetic and velocity fields, intensity) of the lower solar atmosphere with spatial resolution limited only by seeing or diffraction limit, and with a cadence of 10-min. The individual SAMM sentinels link into their master HQ hub where data received from all the slave stations are processed and flare warning is issued up to 26 hrs in advance.

Solar radio observations and the space weather

Jasmina Magdalenić (Invited)

Recent decades, the topic of space weather has attract a lot of attention. Numerous studies were performed, combining the observations and state of the art modeling with the aim to better understand drivers of the space weather and improve the accuracy of the space weather forecasting. The main drivers of space weather at Earth and the cause of the geomagnetic storms are the fast solar wind, coronal mass ejections (CMEs) and associated shock waves. Consequently, the accurate and fast prediction of arrival of these disturbances to Earth is very important in the space weather research.

The radio observations, in particular the one at metric to decametric wavelengths, are fast available and can provide important information about the associated eruption. The solar radio emission associated with the CME-driven shock waves is a unique mean for tracking the shocks all the way from the Sun to Earth. The radio observations can also provide unique information on the coronal parameters e.g. coronal magnetic field strength, coronal electron density and even the velocity of the background solar wind and CMEs, often needed as an input to different models.

In this talk I will present how the solar radio observations can be employed in the space weather studies and operational space weather forecasting. I will discuss different types of radio observations, such as ground based (e.g. LOFAR, MWA) and space based observations (STEREO/Waves and WIND/Waves). I will also address how the information obtained from the radio observations can be used as an input to the heliospheric models such as e.g. ENLIL and EUHFORIA.

LOFAR4SpaceWeather (LOFAR4SW) – Increasing European Space-Weather Capability with Europe's Largest Radio Telescope: A Brief Summary

Mario M. Bisi, Richard A. Fallows, René Vermeulen, Stuart C. Robertson, Mark Ruiter, Nicole Vilmer, Hanna Rothkaehl, Barbara Matyjasiak, Joris Verbiest, Eoin Carley, Peter T. Gallagher, Tobia Carozzi, Michael Lindqvist, Michael Olberg, Paulus Kruger, Maaijke Mevius, David Barnes, Oyuki Chang, and Carla Baldovin

Space Weather monitoring, operations, and the unpinning research are a very important topics in the global space-weather landscape. Knowledge of interactions in the Sun-Earth system, the physics behind observed space-weather phenomena, and its direct impact on modern technologies are key areas of scientific and technological interest.

The LOw Frequency ARray (LOFAR) pan-European radio-telescope system is presently the world's largest low-frequency radio telescope consisting of a dense core of 24 stations near Exloo in The Netherlands, an additional 14 stations spread across the northeast Netherlands, and a further 14 stations based internationally across Europe. These international stations are six across Germany, three in northern Poland, and one each in France, Ireland, Latvia, Sweden, and the UK. Further sites are being planned across Europe to include Italy and Bulgaria in the coming years.

The LOFAR For Space Weather (LOFAR4SW) project (see: http://lofar4sw.eu/) was a Horizon 2020 (H2020) INFRADEV design study to undertake the initial investigations, and complete a design study, into the upgrading of LOFAR across Europe. The project prepared a novel design pathway (with extensive documentation) which, when envisaged, will bring new and significant capabilities into the space-weather domain. The final design documents of LOFAR4SW are providing the building blocks of a comprehensive conceptual and technical description of the necessary LOFAR upgrades needed, and the pathways next to be taken, to enable simultaneous operation as a radio telescope for astronomical research as well as an infrastructure working for space-weather studies and monitoring. In this work we present a brief overview of the LOFAR4SW project, some examples of the envisaged capabilities, and a summary of the end of the project and where we expect/hope to go next.

The fully-envisaged longer-term goal of enabling a LOFAR4SW update across the LOFAR system would make LOFAR/LOFAR4SW one of the world's most-comprehensive space-weather observing systems capable of shedding new light on several aspects of the space-weather system, from the Sun to the solar wind to Jupiter and Earth's ionosphere.

High-Resolution Density Reconstructions of the Inner Heliosphere and the Challenge for Future Modeling Techniques

Bernard V. Jackson, Lucas Cota, Matthew Bracamontes, Andrew Buffington, Jackie A. Davies, Mario M. Bisi, David Barnes, Munetoshi Tokumaru

Since the 1990s our group at UCSD has successfully used remotely-sensed data to reconstruct the heliosphere in three-dimensions (3-D) using a time-dependent analysis. This allows solar wind velocity, density, and magnetic field to be determined from archival data sets and can also provide forecasts at any location throughout the heliosphere. We have recently adapted UCSD's Solar Mass Ejection Imager (SMEI) iterative tomography analyses for use with STEREO Heliospheric Imager (HI) data to provide 3-D reconstructed plasma densities. These analyses can also include ground-based interplanetary scintillation (IPS) data from ISEE, Japan, and LOFAR IPS data to help provide comprehensive reconstructions of density and velocity from an Earth-based perspective. The STEREO HI analyses are of sufficient resolution to enable plasma densities at the spacecraft to be reconstructed at one-hour temporal resolution. In doing this, we have found that the reconstructed data show that the fronts for initially fast halo CMEs can appear spotty and non-uniform as they pass the spacecraft at 1 AU, presumably indicating that they are modified to appear this way by intervening plasma structure, solar wind flows, or both. Our current STEREO HI analysis system is also operated in near real time with a latency that can be anywhere from three to five days predicated by the time taken to download STEREO HI science data from the NASA Deep Space Net and process it at RAL Space. We currently re-run the analysis every six hours. While this is inadequate for most advance forecasting needs, it benchmarks computing requirements for high-resolution 3-D reconstruction analyses of this type. It also prototypes the forecasting capability for future similar spacecraft heliospheric imager instruments such as the NASA Small Explorer PUNCH, UCSD's the Vigil Heliospheric Imager, or UCSD's All Sky Heliospheric Imager (ASHI), which are intended to be operated with a shorter data latency.

Noise Eliminating Magnetometer Instrument in a Small Integrated System (NEMISIS) on the Heliophysics Environmental and Radiation Measurement Experiment Suite (HERMES) platform of the Lunar Gateway
Eftyhia Zesta (Invited), Mark Moldwin, Todd Bonalsky, Deirdre Wendel

There are two instrument suites on the Lunar Gateway. They are named after two of Artemis's half-siblings in Greek Mythology: ERSA, the goddess of dew, and HERMES, the messenger of the Olympian gods. ERSA, built by ESA, and HERMES, built by NASA, will be launched with the first two Gateway Vehicles, the Power and Propulsion Element (PPE) and the Habitation and Logistics Outpost (HALO), respectively, and will begin monitoring the lunar radiation environment and return data before crews begin to arrive.

NEMISIS is a multi-sensor magnetometer system comprised of one miniaturized fluxgate magnetometer at the end of a boom, and two platform-mounted magneto-inductive magnetometers in a collaboration between GSFC and University of Michigan. The full system along with algorithms enables the separation of scientific magnetic field measurements from those generated by magnetic noise source on the platform and vehicle. We discuss the status of NEMISIS, currently in instrument Phase D, and the scientific and Space Weather measurements that will be accomplished by the HERMES suite.

European Space Agency Space Weather Mission To L5
Cristina Bramanti & Giuseppe Mandorlo

The European Space Agency (ESA) mission to L5, known as VIGIL, is using a complementary perspective to L1 observations, will provide improved assessment of Coronal Mass Ejection (CME) motion and density, its arrival time (therefore speed/energy) and impact on Earth in order to support better protection of the critical infrastructure on ground and in space. The mission is planned to carry out also in-situ observations of the solar wind bulk velocity, density and temperature, and Interplanetary Magnetic Field (IMF) at L5, to provide enhanced detection and forecasting of high speed solar wind streams producing stream, and co-rotating interaction regions. The presentation will provide an overview of VIGIL mission, including mission objectives, the instrument suite and the consortium.

The Plasma Analyser (PLA) instrument for Vigil - Update and Progress
Daniel Verscharen

The Vigil mission is the ESA's flagship operational space-weather mission. It will combine remote-sensing and in-situ measurements to enable accurate space-weather predictions from its unique vantage point at the fifth Sun-Earth Lagrange point. The Plasma Analyser (PLA) instrument will measure the solar wind at the location of the spacecraft over a wide dynamic range of plasma parameters. The data from PLA will predict high-speed solar wind streams headed towards Earth and support work to improve and validate inner heliosphere models that can be used to provide better predictions of the background plasma conditions through which Earth-directed coronal mass ejections propagate. PLA is an electrostatic plasma analyser that builds largely on the flight heritage of previous instruments designed by UCL/MSSL. In this presentation, we will give a status update of the PLA development and an outlook into the space-weather prediction capabilities enabled by PLA.

In situ magnetic field measurements at L5 for space weather monitoring and prediction
Jonathan Eastwood

Geomagnetic storms are a highly significant source of space weather effects, and are caused by the intense circulation of plasma and energy through the Earth's magnetosphere via magnetic reconnection and the Dungey cycle. This is ultimately controlled by the interplanetary magnetic field, and so accurate forecasting of the interplanetary magnetic field strength and orientation is crucial to develop advanced warning of storm conditions. Furthermore, energetic particle propagation through the heliosphere is intimately related to the interplanetary magnetic field and the connectivity of the solar wind.

In situ magnetic field measurements from the Sun-Earth Lagrange L5 point offer a natural way to extend our knowledge of the interplanetary magnetic field over a significant longitudinal fraction of the inner heliosphere, in a region that is particularly pertinent for space weather monitoring and prediction. In this presentation we review the utility of such measurements, starting with relatively well-explored use cases such as their relevance for understanding stream interaction regions, but also discussing their proposed use in data assimilation and constraining models of the solar wind, and providing ground truth about the structure of the interplanetary magnetic field. Moreover, we examine the importance of interplanetary magnetic field structure for predicting space weather conditions at the Lunar Gateway, which will be located outside the magnetosphere the majority of the time and which will be used for human exploration of the Moon where astronauts will have significant exposure to space weather impacts.

Numerous mission concepts have been presented centred on using measurements from L5 to understand and predict space weather, most recently the ESA Vigil mission. Here we also briefly discuss the unique requirements of real-time measurement compared to more traditional science missions, and the extent to which this informs the design of a proposed low-risk high-heritage instrument concept for L5 measurements.

The CCOR-3 Compact Coronagraph for the ESA VIGIL Mission
Arnaud Thernisien

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Reinventing Space Weather forecasts with Artificial intelligence: Current and future trends
Enrico Camporeale - Invited

Currently there is no single space weather forecasting model that has not been outperformed by a corresponding model based on machine learning (ML). Undoubtedly the future of space weather forecasting lies within the field of artificial intelligence. Yet, there are a number of challenges that need to be overcome before ML can become the mainstream tool for reliable, actionable and safe space weather forecasting. The challenge number one, however, is to make researchers understand what machine learning really is and what it can do for us.

In this talk I will touch upon the current state and the future perspectives of machine learning in space weather, showing examples of forecasting models for solar wind, geomagnetic indices, and ground magnetic perturbations.

Attention-Based Machine Vision Models and Techniques for Solar Wind Speed Forecasting Using Solar EUV Images
Edward Brown

Extreme ultraviolet images taken by the Atmospheric Imaging Assembly on board the Solar Dynamics Observatory make it possible to use deep vision techniques to forecast solar wind speed—a difficult, high-impact, and unsolved problem. At a 4 day time horizon, this study uses attention-based models and a set of methodological improvements to deliver an 11.1% lower RMSE and a 17.4% higher prediction correlation compared to the previous work testing on the period from 2010 to 2018. Our analysis shows that attention-based models combined with our pipeline consistently outperform convolutional alternatives. Our study shows a large performance improvement by using a 30 min as opposed to a daily sampling frequency. Our model has learned relationships between coronal holes' characteristics and the speed of their associated high-speed streams, agreeing with empirical results. Our study finds a strong dependence of our best model on the phase of the solar cycle, with the best performance occurring in the declining phase.

Quantifying the effect of ICME removal and observation age for in situ solar wind data assimilation
Harriet Turner

Accurate space weather forecasting requires advanced knowledge of the solar wind conditions in near-Earth space. Data assimilation (DA) combines model output and observations to find an optimum estimation of reality and has led to large advances in terrestrial weather forecasting. It is now being applied to space weather forecasting. Here, we use solar wind DA with in-situ observations to reconstruct solar wind speed in the ecliptic plane between 30 solar radii and Earth's orbital radius. This is used to provide solar wind speed hindcasts. Here, we assimilate observations from the Solar Terrestrial Relations Observatory (STEREO) and the near-Earth dataset, OMNI. Analysis of two periods of time, one in solar minimum and one in solar maximum, reveals that assimilating observations from multiple spacecraft provides a more accurate forecast than using any one spacecraft individually. The age of the observations (in terms of the last time the target Carrington longitude was observed) also has a significant impact on forecast error, whereby the mean absolute error (MAE) sharply increases by up to 23% when the forecast lead time first exceeds the corotation time associated with the longitudinal separation between the observing spacecraft and the forecast location. It was also found that removing coronal mass ejections from the DA input observations and verification time series acts to reduce the forecast MAE by up to 10% as it removes false streams from the forecast time series. This work highlights the importance of an L5 space weather monitoring mission for near-Earth solar wind forecasting and suggests that an additional mission to L4 would further improve future solar wind DA forecasting capabilities.

NASA's PUNCH Mission: A Pathfinder to Better Space Weather Forecasting
Craig DeForest

The Polarimeter to UNify the Corona and Heliosphere (PUNCH) is a NASA Small Explorer mission that will image space weather effects in 3D as they cross the corona and inner heliosphere. The PUNCH flight assets are four small LEO satellites with deeply baffled visible-light cameras. The cameras operate together to form a "virtual coronagraph" with a 90° field of view centered on the Sun. A single "Narrow Field Imager" coronagraph duplicates the SOHO/LASCO-C3 field of view, and three "Wide Field Imager" heliospheric imagers, with mutually overlapping fields of view, work together to achieve the wide dynamic range and field of view needed for PUNCH science. PUNCH will produce linearly-polarized image sequences of the entire inner heliosphere, once every four minutes for a two-year nominal mission starting in 2025, allowing the mission to track space weather events in three dimensions as far as 1 AU from the Sun. This has the potential to revolutionize space weather forecasting by enabling direct tracking of CMEs and CIRs, sidestepping the current need to extrapolate solar observations, via modeling, across the inner heliosphere.

New space weather monitoring opportunities: Solar Orbiter and IMAP
Timothy Horbury

Solar Orbiter, in its science phase, returns data once a day from a complex orbit through the inner solar system. This includes magnetic field data: we discuss how it can be used to test and constrain real-time solar wind models. IMAP, launching in 2025, will travel to L1 and carry the most comprehensive real-time solar wind monitoring payload to date. We discuss how IMAP can contribute to multi-point L1 monitoring to improve the timing and accuracy of near-time forecasting.

A Compact Doppler Magnetograph based on miniaturization of GONG instrument
Sanjay Gosain

We describe a concept for a compact Doppler magnetograph based upon the miniturization of highly successful GONG instrument. GONG was designed for helioseismology measurements from a network of identical ground based instruments distributed geographically. The simplicity of GONG measurements make this instrument very robust for space based measurements of fulldisk Doppler and magnetic maps. The data reduction is very simple and can be performed onboard thereby reducing the need for high telemetry. At its heart the instrument utilizes highly proven solid polarizing Michelson cubes which can be easily optimized for a given spectral line and offera very large acceptance angles, thereby allowing compact designs. Further, the Michelson can be made athermal such that the instrument drift with temperature is minimal. We show proof of concept of the design and pressent key characteristics that make it a potential low cost magnetograph for deep space missions.

Polarimeter to UNify the Corona and Heliosphere (PUNCH): Mission status and science update
Craig DeForest

PUNCH is a NASA Explorer mission to image the outer solar corona and inner heliosphere as a single unified system. PUNCH will image the corona, solar wind, and features such as coronal mass ejections and stream interaction regions once every four minutes continuously for its complete two-year mission. PUNCH data are highly relevant to space weather forecasting, as they enable (via polarization of Thomson scattered light) 3-D tracking of solar ejecta across the inner solar system. PUNCH is currently slated to launch on a ride-share with NASA's SPHEREx mission, with prime science measurements starting in 2025. This talk will cover the essential structure and current status of the mission, recent updates to the science planning, and information on how to get involved with the PUNCH mission.

Inverse cascade and magnetic vortices in kinetic Alfvén-wave turbulence
George Miloshevich

A Hamiltonian two-field gyrofluid model for kinetic Alfvén waves (KAWs) in a magnetized electron–proton plasma, retaining ion finite-Larmor-radius corrections and parallel magnetic field fluctuations, is used to study the inverse cascades that develop when turbulence is randomly driven at sub-ion scales. In the directions perpendicular to the ambient field, the dynamics of the cascade turns out to be non-local and the ratio , the ratio of the KAW to the Alfvén frequencies displays a local minimum. At the corresponding transverse wavenumber, a condensate is formed, and the cascade towards larger scales is then inhibited. Depending on the parameters, a parallel inverse cascade can develop, enhancing the elongation of the ion-scale magnetic vortices that generically form.

Sun-to-Earth modelling of CME-CME interactions: How to create a perfect storm?
Gordon J. Koehn & Ravindra T. Desai

Coronal mass ejections (CMEs) are the largest type of eruption seen on our Sun and the primary cause of geomagnetic disturbances and storms when they arrive at the Earth. Most geomagnetic storms are created by the impact of single CME yet in a significant fraction of cases CMEs interact with other CMEs which can significantly increase their geo-effectiveness. In this paper we implement a spheromak CME description within a 3-D heliospheric MHD model and self-consistently model their interactions with the pre-existing solar wind and with one another. We assess their geo-effectiveness at 1 AU through quantification of the relevant solar wind variables and an empirical measure of the Disturbance Storm Time index based upon solar wind-magnetosphere coupling functions. We show how the orientation and handedness of a given CME can have a significant impact on its geoeffectivness due to a prolonged conservation of toroidal flux caused by differential interplay with the Parker Spiral, and how a large range of possible CME-CME interactions can produce a diverse range of geophysical impacts at the Earth.

Sun CubE OnE: A Multi-wavelength Synoptic Solar Micro Satellite
Luca Giovannelli

The Sun cubE onE (SEE) is a 12U CubeSat mission in LEO that will investigate Gamma and X-ray fluxes and UV solar emission to support studies in Sun-Earth interaction and Space Weather. SEE's primary goal is to monitor the emission from soft-X to Gamma ray energy range and the solar activity in the Mg II doublet at 280 nm. The Gamma and X-ray fluxes will be studied with unprecedented temporal resolution and with a multi-wavelength approach thanks to the combined use of silicon photodiode and SiPM based detectors. The flare spectrum will be explored from the KeV to the MeV range of energies by the same payload, and with a cadence > 10 kHz (advanced goal 1 MHz) to unveil the sources of the solar flares. SiPM detectors are a novel approach in the field of Solar Physics but are designed and built on the heritage of instruments that had outstanding scientific results in space (see e.g. PAMELA and MINI-EUSO). Given its UV imaging capabilities, SEE will be a key space asset to support detailed studies on solar activity, especially in relation to ultraviolet radiation which strongly interacts with the upper layers of the Earth's atmosphere, and in relation to space safety, included in the field of human exploration. SEE data will be used together with space and ground-based observatories that provide Solar data (e.g. Solar Orbiter, IRIS, GONG, TSST), high energy particle fluxes (e.g. GOES, MAXI, CSES) and geomagnetic data in a multi-instrument/multi-wavelength/multi-messenger approach.

CMAG: A Coronal MAGnetograph mission for studying the inner corona magnetic fields

David Orozco Suárez

The study of the Sun's inner coronal magnetic fields is one of the technological challenges of solar physics today. Inferring magnetic fields in the corona requires measuring the four Stokes components in forbidden coronal emission lines whose polarization signals can differ orders of magnitude in their amplitude. Here we present the CMAG mission, aimed to observe the full Stokes vector of the corona down to 1.02 solar radius. CMAG is a space mission designed to obtain maps of the coronal magnetic fields with unprecedented spatial and temporal resolutions by means of a dedicated imaging spectropolarimeter whose external occulter is placed about 400 meters away, between the science instrument and the Sun. Baseline consists of two different spacecraft in formation flight. The first one is meant to act as an external occulter by carrying a dedicated disk. The second one would be a small satellite with a refracting telescope and an internal occulter to image the solar inner corona at a spatial resolution of 2.5 arcseconds. CMAG uses a lithium niobate (LiNbO3) Fabry-Perot etalon for the spectral analysis and two nematic liquid crystal variable retarders and a linear polarizer as the analyzer to measure all four Stokes parameters at given wavelength samples of selected coronal emission lines: Fe XI @ 530, Fe XIV @ 789 nm and Fe XIII @ 1074 nm. The goal is to obtain a full map of the vector magnetic field and the line-of-sight (and plane-of-the-sky) velocities of the inner corona, between 1.02 to 2.5 solar radius, from space and for long periods of time with the required stability and a cadence of one minute to follow the solar structures in their evolution, as never done, nor planned before.

Predicting equatorial plasma bubbles with a random forest classifier

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In the post-sunset ionosphere rising plumes of low-density plasma known as equatorial plasma bubbles (EPBs) can form. EPBs can degrade GNSS signals and, communications between ground stations and spacecraft. As our dependence on space-based assets continues to grow, there is an ever-pressing need to better understanding and ultimately forecast EPB events.

SWARM is a 3-satellite LEO mission that launched into a near polar orbit in 2013 at an altitude of 460 and 540km. We first create a labelled dataset of EPB’s using a Savitzky-Golay smoothing filter. Comparing it to the existing EPB-labeller on-board SWARM we see the classification accuracy improves from 75% to 81%.

We then feed the labelled set into a random forest classifier (RFC) using longitude, spacecraft potential, plasma density and ion temperature as features. The former is the most important feature identified by the RF and the longitudinal dependence of EPBs has long been reported. Potential was the second most pertinent feature and the link between spacecraft charging and EPBs does not appear to have been previously reported. Spacecraft charging is primarily the product of electron temperature and density. Therefore, it can be viewed as a naturally occurring engineering feature for the model, thus explaining its importance in the RF. The model recall is 95% which is a respectable performance as our objective is to detect EPBs and therefore to minimize false negatives. The F1 score is 88% and we also deem this acceptable. Future work will extend the study into forecasting EPBs and integrating additional data.

Assessment and Validation of Daily Enlil and EUHFORIA Simulations During 2019–2021

David Barnes

We present a study of the assessment of daily simulations using both the European Heliospheric Forecasting Asset (EUHFORIA) and Enlil solar wind models over a period of almost three-years, during 2019-2021. This is achieved by driving both models with the same inputs, GONG magnetograms and cone CMEs parameterised using observations from coronagraphs on STEREO and SOHO. The output of models is compared to existing catalogues of Coronal Mass Ejections (CMEs) and High-Speed Streams (HSSs) recorded at both STEREO-A and DSCOVR. We employ the established methodology of contingency tables, and their associated skill scores. We find success ratios for CME prediction of 0.56 (Enlil) and 0.51 (EUHFORIA). Hit rates of 0.67 for both models suggest that they are capable of predicting two out of every three Earth-impacting CMEs. Our results are dominated by correct rejections because we are operating at solar minimum when CME occurrence is rare. Mean absolute error in Enlil and EUHFORIA predictions of CME arrival at Earth is 13.3h and 16.5h respectively. Similar results are found for CMEs arriving at STEREO-A, with hit rates of 0.75 and 0.77 for Enlil and EUHFORIA, respectively, and an MAE of 15.6h and 12.4h. Analysis of HSSs at Earth is performed in the same way, however, it is less informative because of their high frequency and difficulty in determining their arrival time precisely.