SWATNet School 2: Sun-Earth Interactions

26-28 September 2022 - Athens, Greece

The Abstract Book

Co-organisers of the event

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ΠΑΝΕΠΙΣΤΗΜΙΟ ΙΩΑΝΝΙΝΩΝ

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Description of the training

This School focuses on how space weather affects Earth, the solar activity leading to this interaction, the solar wind – magnetosphere coupling, radiation storms and substorms. The focus is on different time-scales and coupling of different domains, as well as the challenges this introduces to both modelling and forecasting. From our Partners e.g., HSPF and UoI will contribute by sharing their expertise on solar observations, and SAS by providing insight on modelling / forecasting challenges. Themes of the School relate to the SWATNet's main topics, namely Sun (S), Heliosphere (H), and Artificial Intelligence (AI), as well as Industrial Contribution (IC) and Specific Interest (SI) topics.

Programme

Link: https://swatnet.eu/school-2-sun-earth-interactions/

Format

The school will be primarily in-person, with a capability of virtual participation for students and lecturers. In the abstract book each lecture is marked correspondingly - **[P]** stands for in-person contributions and **[V]** stands for virtual lectures.

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26 September 2022 (DAY 1)

Space weather and Earth-affecting transients: solar flares [P]

Manolis K. Georgoulis, RCAAM of the Academy of Athens

Space Weather collectively implies the short-term, ever-changing conditions in the interplanetary space and the planetary magnetospheres in the solar system. It is predominantly attributed to the solar magnetic activity and, to a much smaller extent, to galactic cosmic rays. By ‘interplanetary conditions’ we mean plasma properties and electromagnetic radiation environment, modulated by the solar cycle and episodes of eruptive solar evolution. Here we will focus on an iconic, historically first-studied manifestation of explosive evolution of solar magnetic fields, namely, solar flares. We will start with the event phenomenology and then move on to briefly touch on the one and only known mechanism for flare triggering, namely, magnetic reconnection. We will discuss the statistics of flares that possibly provide a glimpse into their collective physics and offer seeds, as well as aphorisms, for their potential forecasting. Finally, we will very briefly describe why we should care about solar flares and their prediction for both near-Earth and cislunar environments, as well as for the interplanetary human exploration envisioned for this century.

Space weather and Earth affecting transients: CMEs and SEPs [P]

A. Papaioannou, IAASARS, National Observatory of Athens, Greece

Our host star, the Sun, is the dominant driver of energetic phenomena that structure the interplanetary environment, continuously influencing our near-Earth space with mass, magnetic field, and radiation energy in varying timescales. On top of this structured outflow from the Sun, the solar wind; transients such as: solar flares, coronal mass ejections (CMEs) - their interplanetary counterparts (ICMEs) - and solar energetic particles (SEPs) generate intense adverse effects on advanced technological systems of our human society. Therefore, it is critical to underpin the physics of Space Weather and implement concepts, tools and services that deliver predictions of the continuously changing conditions of the near-Earth space. In this talk recent knowledge on transients and their interconnection will be reviewed. In particular, CMEs, the in-situ characteristics of ICMEs as well as the kinematic models of CMEs that have been developed to interpret CME propagation in the heliosphere and to predict the arrival times at 1 AU will be discussed. Next SEPs will be presented in terms of their origin (e.g. flares vs CMEs), longitudinal spread and impact. Special focus will be given on the means and methods applied to treat the largely imbalanced problem of SEP prediction, based on the underlying physical connections to their progenitors. Finally, since CMEs and SEPs share an intimate physical connection, the particulars of a new integrated space weather prediction system that incorporates statistical concepts and delivers near real-time predictions of the evolving SEP time profile will be demonstrated. An outlook on the open issues and challenges for a robust holistic prediction of Earth-affecting solar transients concludes this talk.

CME modeling [V]

Stefaan Poedts, KU Leuven, Belgium

EUHFORIA is a heliospheric wind and CME evolution model. The first version contained only a cone CME model. This is a simple spherical plasma blob with increased pressure and density that is injected through the inlet boundary. It was developed to model the CME shock waves and predict their time of arrival at Earth. We know, however, that the impact of a CME, its “geo-effectiveness”, is determined by the orientation of its internal magnetic field upon arrival at Earth. Therefore, more advanced CME models have been integrated in EUHFORIA, like the spheromak model and the Fri3D model, and more models are being developed and integrated, like the (half-) torus models based on a Soloviev and Miller-Turner solutions. These will be discussed.

Time scales of solar energetic particle fluxes: from seconds to decades [V]

Rami Vainio, University of Turku, Finland

The different processes affecting solar energetic particle emission from the Sun and the subsequent transport of particles in the heliosphere will be discussed. The lecturer will start from the scales related to acceleration in the impulsive phase of the flare, then proceed to time scales of particle transport and acceleration in the interplanetary space, and, lastly, discuss the time scales of solar rotation and solar magnetic activity that affect the SEPs in scales from months to decades and beyond. He will also present some models that can address the dynamics of the SEP radiation environment at Earth at different time scales.

Radiation belt variability connection to solar/interplanetary and magnetospheric drivers at various time-scales [P]

Ioannis A. Daglis, Department of Physics, National & Kapodistrian University of Athens and Hellenic Space Center, Greece

Electrons in the outer Van Allen belt occasionally reach relativistic energies and therefore become a hazard for spacecraft operating in geospace, leading to significant potential risks. The energy and flux of these electrons can vary over time scales of years (related to the solar cycle), seasons (semi-annual variation), hours (magnetic storms), minutes (sudden storm commencements). Electric fields and plasma waves are the main factors regulating the electron transport, acceleration and loss. Both the fields and the plasma waves are driven directly or indirectly by disturbances originating at the Sun, propagating through interplanetary space and impacting the Earth. We review our current understanding of the response of outer Van Allen belt electrons to solar eruptions and their interplanetary extensions, i.e. interplanetary coronal mass ejections and high-speed solar wind streams and the associated stream interaction regions. We also discuss the magnetospheric processes that link interplanetary drivers with geospace electrons.

An overview of the history of the observations and theories of coronal mass ejections [V]

Russell A. Howard, Johns Hopkins University Applied Physics Laboratory, USA

Since the discovery of coronal mass ejections about 50 years ago, the concept of what they are and their significance has been evolving. Coronal transients close to the Sun were well known from ground-based observations, but the idea of a massive (10^12 kg) object escaping solar gravity was not expected. For example, erupting solar prominences were common but the mass in them was thought to drain back to the Sun and not escape. In the mid-1960s, two rocket-borne coronagraphs were launched a day apart and observed a dramatic change in the streamer pattern. This change was used to justify including a coronagraph on an orbiting satellite to perform routine observations every day. Thus, NASA launched the Orbiting Solar Observatory #7 on September 29, 1971 to study the evolution of the corona. Two months later the coronagraph captured a new type of coronal transient, what we now call a coronal mass ejection. This illustrates that to answer one question, other questions pop up.

Since then, seven more orbiting coronagraphs (or the similar heliospheric imager) have been sent to space. Each of them has provided improved observations (resolution, sensitivity, field of view and cadence) resulting in improved insights and theories into the phenomenon. This overview will provide an overview of the observations and theoretical changes over the last five decades.

27 September 2022 (DAY 2)

High Speed Streams: the "Veniamin" of space weather drivers [P]

Eleanna Asvestari, University of Helsinki, Finland

Although solar eruptions are considered to be the primary drivers of space weather, high speed streams (HSS) and their associated stream interaction regions (SIR) are also key players. From sculpting the interplanetary space through which solar eruptions and solar energetic particles travel, to directly interacting with the Earth's magnetic field, their contribution to space weather is often non-negligible and rather important. During this lecture we will go on a journey through the spatial and temporal timescales of HSS. We will start from their sources at the Sun and how they contribute to the space weather effectiveness of HSS. We will proceed in the interplanetary space to learn about how they interact with the slower solar wind forming SIR and find out how and why some become corotating interaction regions (CIR). Our journey will end at the Earth's magnetosphere learning how HSS directly impacts it. Living in an era of growing space weather forecasting methods and models, we will have a look into the state-of-the-art and the less computationally expensive alternatives and learn about their success and their failures in forecasting the arrival and the strength of HSS.

Tracking the solar wind from L1 to near-Earth space and coupling to the magnetosphere-ionosphere-thermosphere system [V]

Mike Lockwood, Reading University, UK

Satellites in halo orbits around the L1 Lagrange point give us a good, but not perfect, idea of the solar wind conditions that impinge upon Earth's magnetosphere. In addition, many years of space-weather research has given us an understanding of how energy, mass and momentum is transferred into and through the coupled magnetosphere-ionosphere-thermosphere system. This talk will outline that understanding and study the correlations between "coupling functions", combinations of parameters designed to quantify the influence of the solar wind, and how they depend on the location of the upstream monitor, the timescale of interest and on which aspect of space weather they are designed to predict.

Space weather, geomagnetic disturbances and geomagnetically induced currents [V]

Ari Viljanen, Finnish Meteorological Institute, Helsinki, Finland

In the end of the solar-terrestrial interaction chain, geomagnetically induced currents (GIC) provide a concrete example of space weather. GIC flow in technological conductor systems such as power grids and oil or gas pipelines. They are a consequence of Faraday's law of induction: temporal variations of the geomagnetic field are always associated with an electric field. This geoelectric field in turn produces currents in all conductors as stated by Ohm's law. The practical motivation to study GIC is the harmful effects that they may have especially on power grids. This lecture concentrates on the physical aspects of GIC. The basic method to model GIC from the Maxwell equations is also described to provide general understanding of geomagnetic induction. As an example of topical research, a short overview of extreme geomagnetic storms is presented.

Using AIDA tool for data mining and space weather forecasting [V]

Giovanni Lapenta, KU Leuven, Belgium

The EU project Aida developed a number of tools for space weather and space science. The output of the project AIDA (www.aida-space.eu) has been organised in two main contributions: the AidaPy and AidaDb. AidaPy is a python-based suite of tools for data analysing and machine learning applied to space data from missions and from simulations. A critical novelty is that the same analysis can be applied to datasets from observation and from synthetic data produced by simulations. The AidaPy tools cover methods of interest to space mission design and operation, to space science discovery and investigation and to space weather forecasting. Many of the tools developed are based on machine learning, focusing on both supervised and unsupervised methods for a range of different applications. AidaDb is a database of high level data (e.g. trained neural network) and sample data sets made available to reproduce the results of AIDA and learn how to follow the examples AIDA provide. We will review the tools and focus especially on the analysis of velocity distribution functions from simulations and the MMS space mission. The question we want to answer is how do we detect extreme events (e.g, reconnection) using the tools of AIDA.

Performance verification and validation of space weather forecasting methods [V]

Ioanna Tsagouri, Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing, National Observatory of Athens, Greece

Space weather forecasts are crucial for both scientific and operational purposes; they reflect progress in our understanding of space weather causes and consequences and contribute to the mitigation of related impact on modern technological systems. In addition, the development of space weather forecasting tools remains always among the key challenges in the field, since the research community has to address a series of dynamically changing needs. In this framework, space weather forecasting capabilities are subject to continuous assessment that aims to quantify forecasting ability and track progress over time. This task is fundamentally driven by verification and validation of space weather forecasting methods' performance. Relevant activities include the comparison of the forecasts with ground-truth evidence and should be carefully designed by considering the nature, the specificity and the space-time domain of the forecasts, as well as the availability and the quality of ground-truth resources. A set of skill scores is also available for the evaluation of specific forecasting ability aspects with respect to the requirements (e.g., accuracy, precision or detection ability). Indeed, there are several approaches available to serve any validation need, but also key governing principles to formulate a consistent validation plan. This presentation aims to outline a general methodology that can support the development and implementation of such a plan according to international standards, including examples of the adoption of the proposed methodology by the space weather community.

28 September 2022 (DAY 3)

Student presentations [P]

No lectures will be taking place on Day 3 of the School.