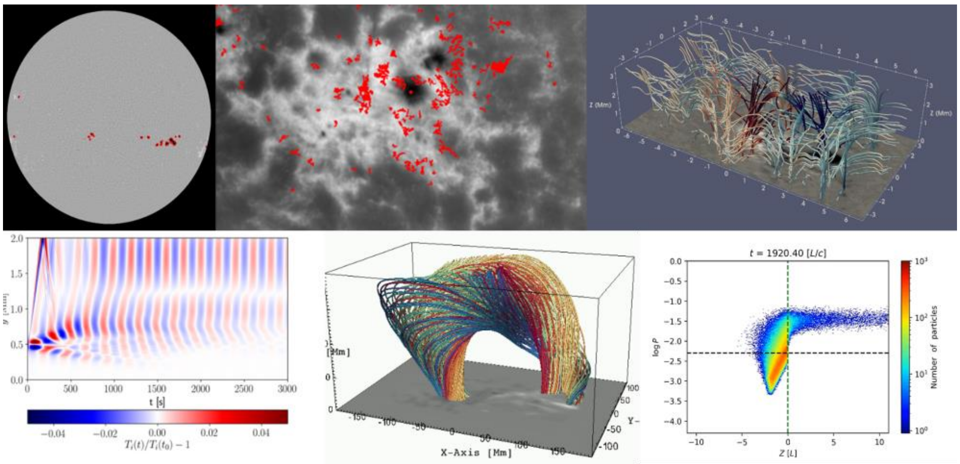

SWATNet NEWSLETTER

IN THIS ISSUE

Editorial
Teresa Barata, SWATNet Outreach leader

On behalf of the SWATNet team, I am delighted to send you this third newsletter, about the scientific progress of ours 12 PhD students. Our Early Stage Researchers (ESR)s have completed two years of intense learning, including a solar observation program, and are now deeply dedicated to science. During the project's first two years, we observed exciting interactions among our students, leading to scientific collaborations, publications, and conference presentations. In this newsletter, we will share the outcomes our ESRs produced in collaboration with their supervisors during the project's third year. It has been a great scientific year for the SWATNet team, and we hope you enjoy reading about the exciting science produced by our students.

1. The SWATNet Scientific Projects

SWATNet aims to tackle space weather issues by studying solar eruptions, modeling solar wind and shock dynamics, and understanding Solar Energetic Particles. It is divided into three Work Packages (WPs), each consisting of 3-5 research projects.

WP1 focuses on modeling and forecasting solar activity through 4 projects:

- **Pre-eruption magnetic configuration and eruption forecasting (project 1, by Augustin André-Hoffmann):** The approach used is innovative and focuses on Extreme Ultraviolet (EUV) images of active regions, which are hotspots of major flares and coronal mass ejections (CMEs). The aim is to identify distinct brightenings related to the energetic phenomena that occur before the onset of these events, as precursors for such events are typically elusive. We are using automated methods to identify and categorize brightenings. We have developed a technique to remove saturation effects in EUV observations, resulting in cleaned images, appropriate for further study. Our current focus is analyzing active regions to establish emission thresholds and statistical metrics for predicting solar eruptions. We are using data

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from the AIA and HMI telescopes onboard NASA's Solar Dynamics Observatory.

- **Assessment of the Near-Sun CME Magnetic Field (project 2, by Shifana Koya):** The idea here is to provide a well-educated magnetic field strength at the principal axes of CMEs, which is one of the key parameters that determine the CMEs' space weather impact on Earth's magnetosphere. Measuring coronal magnetic field is rare, and models for CME propagation start far from the Sun. Calculating helicity differences of active regions, prior to and after solar eruptions, helps constrain the CME helicity content and an axial magnetic field using forward modeling and a suitable CME magnetic flux rope model. The predictions are then propagated into the inner heliosphere using self-similar expansion. Results are validated at Earth's Lagrange 1 (L1) point where an in-situ spacecraft measure the CME magnetic field directly, but also elsewhere in the inner heliosphere, where more spacecraft may exist.

- **Three-dimensional solar flare forecasting (project 3, by Shreeyesh Biswal):** Another innovative approach is implemented here. Solar flares don't originate from the photosphere but slightly above it. A physics-based magnetic parameter has been implemented in the low corona by upward extrapolating the photospheric magnetic field. The result was powerfully simple: estimating the magnetic flux accumulated along the magnetic PIL gave several hours of additional early warning time for imminent flares. The project is taking this further with a much more systematic study to find distinguishing behavior between flaring and non-flaring regions. Another objective is to enhance early warning time and define it better. The study uses data from the HMI telescope onboard NASA's Solar Dynamics Observatory mission. Significant results have already been reached.

- **Modelling periodic and quasi-periodic variations in solar activity (project 4, by Guilherme Nogueira):** The ongoing research aims to investigate relations between different solar active region parameters that can be extracted from magnetograms, such as magnetic flux, latitude, longitude and initial dipole moment. The primary objective is to investigate relations between these parameters, look at available data sets, and cross-check to use them an excellent tool to understand both the underlying theory and the observed data regarding active region formation and the contribution of bipolar active regions. The project also wants to explore the behavior of active regions, test the hypothesis that anti-Joy active regions can be considered a different data set, and study the importance of nonlinear deterministic feedback mechanisms and stochastic fluctuations in determining intercycle variations of solar activity.

There are 5 projects covered by WP2, which is titled "Coronal and heliospheric modeling and forecasting":

- **Global MHD coronal model (project 5, by Mayank Kumar):** The heating of the solar chromosphere, the associated plasma outflows, and the origin of the solar wind are key issues in heliophysics. In a recently submitted paper, we provide a new perspective on their connection to the propagation and dissipation of waves generated by solar granulation. Our numerical simulations using the JOANNA code reveal that naturally evolving convection generates waves, and dissipation of these waves due to ion-neutral collisions leads to heating in the chromosphere and plasma outflows. This phenomenon may play a role in the generation of the solar wind and the accompanying heating.

- **CME evolution in the corona (project 6, by Andreas Wagner):** Constructing magnetic field lines from active region modelling data is essential to comprehend the mechanisms that cause eruptions. We have introduced a magnetic flux rope extraction tool for solar coronal magnetic field modelling data to achieve this. This tool is an improved version of the methodology presented by Wagner et al. (2023), offering more options and fewer assumptions about the flux rope shape, resulting in a more accurate set of field lines. Our modelling results were verified with observations.

- **Particle acceleration at coronal shocks (project 7, by Lydia John):** Our aim is to study the effects of magnetic field gradient-induced adiabatic focusing on the coronal acceleration of SEPs. We used Monte Carlo simulations for a one-dimensional oblique shock model to show that adiabatic focusing can lead to a steady state momentum spectrum at a shock and far upstream. This effect can also be produced in a non-focused simulation by introducing a free-escape boundary. This approach can lead to the development of efficient codes for modeling particle emission from shocks self-consistently.

- **Particle transport in interplanetary medium (project 8, by Edin Husidic):** We developed the Icarus+PARADISE model as an improvement over the previous EUHFORIA+PARADISE model. Icarus uses adaptive mesh refinement (AMR) and grid stretching to model solar wind configurations, while PARADISE propagates energetic particles through these configurations. We validated the model by reproducing previous results and demonstrated increased particle acceleration with higher levels of AMR in the shock region.

- **Forecasting CME arrival in the whole heliosphere (project 9, by Ronish Mugatwala):** To better predict impulsive events and reduce the risk to our tech-driven society, we must evaluate forecasting models' performance. To this end, the quality and availability of suitable data are of paramount importance. We built a database of CME properties to evaluate forecasting models. We used the drag-based model DBM) to determine the propagation of CMEs and explored the parameter space for drag parameters and solar wind speed. Our dataset provides validation of DBM and yields further insight into CME features. However, there are possible CME events where DBM approximation requires more investigation.

Three projects are related with WP3, entitled "Forecasting Space Weather with Artificial Intelligence", namely:

- **Forecasting solar activity with deep learning (project 10, by Grégoire Francisco):** Our Patch-Distributed CNN (PCNN) is a novel deep learning framework designed for forecasting solar flares. Its unique architecture offers precise flare risk predictions for different regions of the solar disk with accurate position estimations obtained through gradient tracking. The PCNN eliminates the need for prior feature extraction and active region detection, presenting operational advantages with minimal human intervention and reduced reliance on external systems (figure 1). We propose a new approach involving the use of time-windows labeled based on the sum of flares' fluence, which proves to be a more effective characterization of solar activity for extended time-windows.

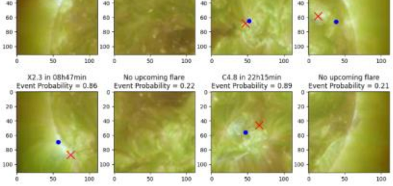

Figure 1 – C+SPCNN – EUV forecast and position estimations.

- **CME arrival modelling with Machine Learning (project 11, by Simone Chierichini):** The project uses Machine Learning to predict and understand CME behavior. In the first phase of our project, we expand the CAT-PUMA tool, employing Supervised Learning techniques with Supervised Learning techniques to improve CME transit time predictions and assess their impact on Earth and use SHAP values for model interpretation to understand their limitations. Subsequently, we approached the problem from a different angle, the Probabilistic Drag-Based Model (P-DBM) employed with Monte Carlo Markov Chains (MCMC) to derive probability distribution functions for DBM parameters. Two distinct approaches—ensemble and individual—are explored for predicting CME arrival times. The individual approach shows promising results, with a mean absolute error of 9.86 ± 4.07 hours, advancing our understanding of space weather forecasting (figure 2).

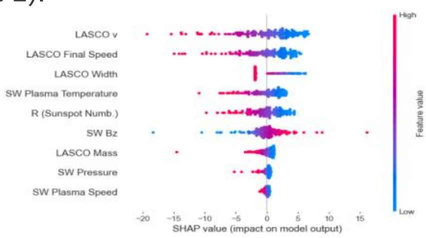

Figure 2 – Impact on model output (SHAP values).

- **Development of mathematical morphology algorithms to characterize the solar activity (project 12, by Slava Bourgeois):** We used mathematical morphology (MM) image processing to identify solar features such as sunspots contours and coronal structures in SDO images from 2012 to 2014.The results were compared with two reference sunspot catalogues and found similar results, validating the MM method. Currently, we are using MM to detect off-limb coronal structures in SDO/AIA 304 Å images from 2010 to 2021 and generate statistics on them. As an example, we plot the Carrington latitude of 50,000 of these events (randomly selected) as a function of time and observe in blue the zones with high density of coronal structures (figure 3). We also seek to identify solar jets using a MM dynamical approach based on sequences of images to track their evolution.

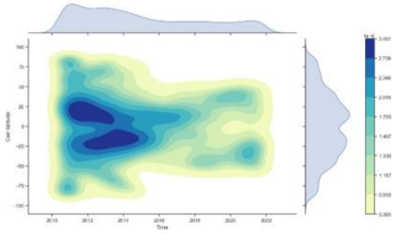

Figure 3 – Carrington latitude as a function of time.

2. Scientific Results

Since the start of our project, we have been thrilled to present the results of our research at various national and international conferences and workshops (https://swatnet.eu/dissemination/). To date, we have given approximately **30 presentations**, which have offered us an excellent opportunity to showcase our work to a broader audience and gather valuable feedback from experts in the field. Moreover, we are proud to announce that our research has resulted in the publication of **7 papers**, with 1 more paper currently in press and **4 others submitted** to peer-reviewed journals in the field. Our ESRs collaborate with each other on their projects, sharing knowledge and ideas. This interdisciplinary approach leads to exciting research outcomes and helps achieve our goals efficiently.

3. Training Activities

This year we had fewer activities, which is normal since our ESRs are more involved in their research. The following events occurred:

- Workshop 5: Mini-MBA, 23-24 March 2023, University of Sheffield, United Kingdom: https://swatnet.eu/workshop-5-mini-mba/
- School 3: Space Weather and our Technological Society, Budapest, 12-14 June, Hungary: https://swatnet.eu/school-3-space-weather-and-our-technology-based-societyschool-3/
- Workshop 6: Entrepreneuralism in Space Physiscs, 15-16 June 2023, Budapest,

Hungary: https://swatnet.eu/workshop-6-entrepreneurship-in-space-physics/

Throughout this third year, the ESRs of SWATNet also had the opportunity to participate in various international conferences and events, as shown in the next figures:

During the annual meeting, March 2023.

At the Gyula Bay Zoltan Solar Observatory (GSO) Gyula, Hungary, August 2023.

Dinner in Toulose, during the European Space Weather Week, 20-24 November 2023.

4. Outreach Update

SWATNet is a project that aims to raise awareness about space weather by effectively communicating its activities and results to the public and other audiences.

SWATNet participants have conducted various events as part of their initiative, such as taking part in the **European Researchers' Night** at multiple locations, such as the University of Helsinki, Academy of Athens & University of Ioannina, University of Coimbra, and Hungarian Solar Physics Foundation / Eötvös Loránd University. Our blog page contains more details about this activity (https://swatnet.eu/blog/).

SWATNet has recently joined the Horizon Results Booster program (HRB) to increase its visibility within the scientific community. After availing of "Module 1 - Portfolio Dissemination & Exploitation Strategy service", SWATNet has received a final recommendation suggesting applying to the next phase, " Module 1 B - Helping projects from the portfolio to design and execute a portfolio dissemination plan".

5. Upcoming Events

- 8-9 April 2024 – 3rd Annual Project Meeting
- 10-11 April 2024 – "Careers Workshop"
- ...and more!

To stay updated on what is happening in the SWATNet project we invite you to follow us on Twitter (https://twitter.com/SWATNetProject) and LinkedIn (https://www.linkedin.com/groups/12623482/) and visit the project website https://swatnet.eu/. We would very much appreciate if you spread the word about the SWATNet project in your channels!