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The HESPERIA HORIZON 2020 Project and Book on Solar Particle Radiation Storms Forecasting and Analysis

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Abstract This article presents the High Energy Solar Particle Events forecasting and Analysis (HESPERIA) project, supported by the HORIZON 2020 programme of the European Union (Project 637324) as well as the resultant recently published book entitled *Solar Particle Radiation Storms Forecasting and Analysis, The HESPERIA HORIZON 2020 Project and Beyond*, edited by Malandraki and Crosby, Springer, Astrophysics and Space Sciences Library, 2018, ISBN 978-3-319-60051-2. The book reviews the results of the HESPERIA project as well as our current understanding of solar energetic particle physics.

Solar energetic particles (SEPs), ranging in energy from tens of keV to a few GeV, constitute an important contributor to the characterization of the space environment. They are emitted from the Sun in association with solar flares and coronal mass ejection-driven shock waves. SEP radiation storms may have durations from a period of hours to days or even weeks and have a large range of energy spectrum profiles. These events pose a threat to modern technology strongly relying on spacecraft, are a serious radiation hazard to humans in space, and are additionally of concern for avionics and commercial aviation in extreme circumstances. The High Energy Solar Particle Events forecasting and Analysis (HESPERIA) project, supported by the HORIZON 2020 programme of the European Union (Project 637324), has furthered our scientific understanding and prediction capability of high-energy SEP events by developing new European capabilities for SEP forecasting and warning while exploiting novel as well as already existing data sets.

The 2-year HESPERIA project, successfully completed in April 2017, led by the National Observatory of Athens, and with Project Coordinator Dr. Olga E. Malandraki, constituted a consortium of nine European teams that also collaborated during the project with a number of institutes and individuals from the international community. The complementary expertise of the teams made it possible to achieve the main objectives of the HESPERIA project:

1. To develop two novel real-time SEP forecasting systems based upon proven concepts
2. To develop SEP forecasting tools searching for electromagnetic proxies of the gamma-ray emission in order to predict large SEP events
3. To perform systematic exploitation of novel high-energy gamma-ray observations of the FERMI mission together with in situ SEP measurements near 1 AU
4. To provide for the first time publicly available software to invert neutron monitor (NM) observations of relativistic SEPs to physical parameters that can be compared with space-borne measurements at lower energies
5. To perform examination of currently unexploited measurements for SEP forecasting (e.g., radio emission)
6. To provide recommendations for future SEP forecasting systems

The results of the HESPERIA project as well as our current understanding of SEP physics are reviewed in the recently published book entitled *Solar Particle Radiation Storms Forecasting and Analysis, The HESPERIA HORIZON 2020 Project and Beyond*, edited by Malandraki and Crosby, Springer, Astrophysics and Space Sciences Library, 2018, ISBN 978-3-319-60051-2.

In Chapter 1, the book provides a historical overview on how SEPs were discovered back in the 1940s and how our understanding has increased and evolved since then. Current state of the art based on the unique SEP measurements analyzed in the three-dimensional heliosphere and the key SEP questions that remain to be answered in view of the forthcoming missions Solar Orbiter and Parker Solar Probe that will explore the solar corona and inner heliosphere are also presented. This is followed by an introduction to why SEPs are studied in the first place describing the risks that SEP events pose on technology and human health. Chapters 2 through 6 serve as background material covering solar activity related to SEP events such as

solar flares and coronal mass ejections; particle acceleration mechanisms; and transport of particles through the interplanetary medium, Earth's magnetosphere, and atmosphere. Furthermore, ground-based NMs are described. The last four chapters of the book are dedicated to and present the main results of the HESPERIA project. This includes relativistic SEP-related gamma-ray and radio data comparison studies, modeling of SEP events associated with gamma-rays and the inversion methodology for NM observations that infers the release timescales of relativistic SEPs at or near the Sun, and the two real-time HESPERIA SEP forecasting tools that were developed.

The HESPERIA UMASEP-500 tool makes real-time predictions of the occurrence of >500 MeV and ground level enhancement (GLE) events from the analysis of soft X-ray flux and high-energy differential proton flux measured by the GOES satellite network. An important finding is that the use of proton data alone allowed this tool to make predictions before any NM station's alert. Regarding the prediction of GLE events for the period 2000–2016, this tool had a probability of detection of 53.8% and a false alarm ratio of 30.0%. For this period, the tool obtained an advanced warning time of 8 min taking as reference the alert time from the first NM station; using the time of the warning issued by the GLE Alert Plus tool for the aforementioned period as reference, the HESPERIA UMASEP-500 tool obtained an advanced warning time of 15 min (Núñez et al., 2017). Based on the Relativistic Electron Alert System for Exploration (REleASE) forecasting scheme (Posner, 2007), the HESPERIA REleASE tools generate real-time predictions of the proton flux (30–50 MeV) at the Lagrangian point L1, making use of relativistic electrons ($v > 0.9c$) provided by the Electron Proton Helium Instrument on the SOHO spacecraft and near-relativistic ($v < 0.8c$) electron measurements from the Electron Proton Alpha Monitor aboard the Advanced Composition Explorer. An analysis of historic data from 2009 to 2016 has shown that the HESPERIA REleASE tools have a low false alarm ratio (~30%) and a high probability of detection (63%).

In summary, the goal of the presented HESPERIA tools has been to improve mitigation of adverse effects both in space and in the air from significant solar radiation storms, providing valuable added minutes of forewarning to users of space weather services. Both HESPERIA SEP forecasting tools are operational through the project's website (http://www.hesperia.astro.noa.gr) at the National Observatory of Athens. It is noteworthy that this book is published with open access under a CC BY 4.0 license and is freely available to the whole community at https://www.springer.com/de/book/9783319600505.

References

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