HENON

HEliospheric pioNeer for sOlar and interplanetary threats defeNce

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Overview

The HEliospheric pioNeer for sOlar and interplanetary threats defeNce (HENON) is a new mission concept conceived to address the widely recognized need to make a leap forward in the Space Weather (SWE) forecasting and science. The HENON baseline foresees one 12U CubeSat orbiting along a **Distant Retrograde Orbit** (DRO) of the Sun-Earth system, so that the HENON CubeSat will stay for a long period of time very far upstream of the Earth (well beyond L1 at least ~ 0.1 AU).

HENON will embark a state of the art radiation monitor, which will provide **high-resolution measurements of energetic particle spectra**, making HENON the first mission ever monitoring in near real time the particle radiation environment in the deep space. This will provide insight into the near-Earth spatial variations of SEP events giving rise to better boundary conditions for forecasting and nowcasting tools.

The HENON mission aims to embark additional payloads tailored for SWE interplanerobservations, namely **solar wind and/or interplanetary magnetic field measurements**, in order to pave the way for a significant improvement (several hours) of the forecasting horizons of geo-effective interplanetary structures.

HENON has important technological objectives, as well. As a matter of fact, HENON will demonstrate the capability of the CubeSat technologies in deep space to reach both scientific and operational goals through the first ever operation in unexplored DRO orbits. This will pave the way for a future fleet of such CubeSats equally spaced along the DRO, which could provide continuous near real-time measurements for space weather forecasting. HENON is in the A/B study phase that is being developed in the framework of the **ESA General Support Technology** Program (GSTP). *HENON is funded by the Italian Space Agency as part of the* ***ALCOR programme.***

Main HENON objectives

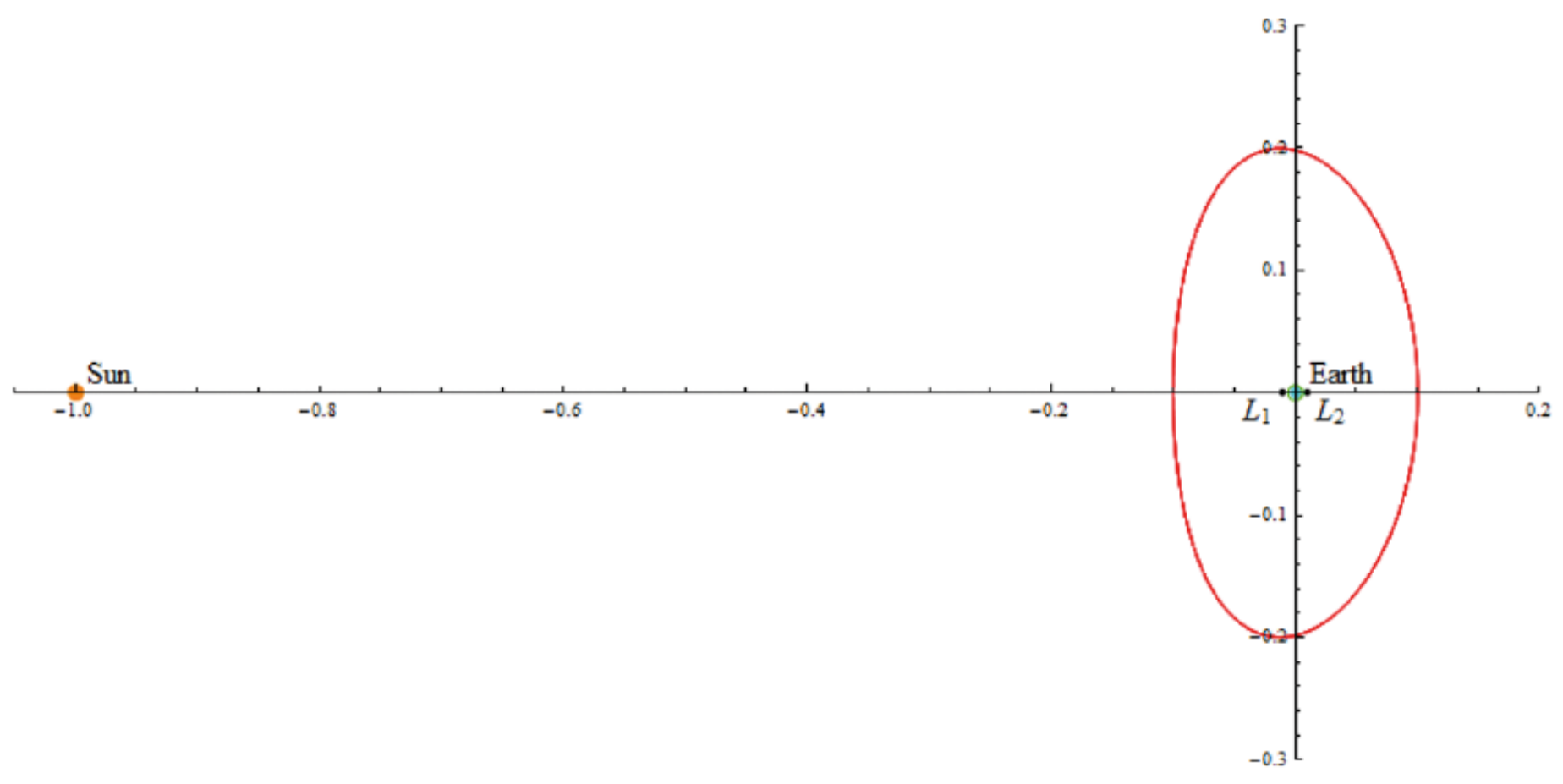
HENON objectives can be categorized in two types. The first type pertains to the realization of a quality leap in our capabilities to timely predict space weather effects; the second relates to the progress in the understanding of the fundamental plasma processes and space weather physical mechanisms.

More specifically, the main HENON objectives are:

- Provide the first real time monitoring of the particle radiation environment in the deep space for Space Weather tools and services.
- Enable provision of novel and timely real-time alerts for SEP events penetrating the near-Earth environment
- Provide for the first time detection of approaching interplanetary perturbations, such as HSSs and ICMEs/shocks, with significant increased warning times, through measurement of GCR flux variations.
- Achieve new insight of acceleration/transport of SEPs and furnish new constraints to models for the GCR short/mid-term modulation
- Pave the way for forecasting horizons of geo-effective interplanetary structures (ICMEs, HSSs) in the order of several hours leading for the first time to a quantum improvement of forecasting capability
- Enable the use of magnetic field and solar wind parameters to constrain the modelling of solar wind and ICME evolution and propagation through the heliosphere
- Provide observations of the solar wind plasma and/or magnetic field to enable studies of turbulence at large and medium scales, also studying the correlation with other spacecraft in L1.
- Enable provision of novel and timely real-time alerts for SEP events severity in the near-Earth environment by adapting the modified ESPERTA (Empirical model for Solar Proton Events Real Time Alert) model (Laurenza et al., 2018, DOI:10.3847/1538-4357) .

HENON concept

Orbit: In DRO orbits (originally studied by Michel Hénon, 1969) the combination of the motion of two bodies revolving around a common primary on orbits of identical period results in one of the two bodies apparently orbiting the other on a large quasi-elliptical retrograde orbit. In HENON the concept of DRO orbits is applied to one spacecraft and the Earth, orbiting around the Sun. The HENON nominal orbit will have an eccentricity of about 0.1 (see figure on the left, in the Sun-Earth rotating frame).



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When orbiting the DRO, HENON will remain for a **long time upstream of the Earth at a distance much larger than L1**, namely around 0.1 AU. The **nominal mission duration will be 1 year**, during which Henon will complete one revolution, **moving by about one degree per day** in the retrograde direction around the Earth.

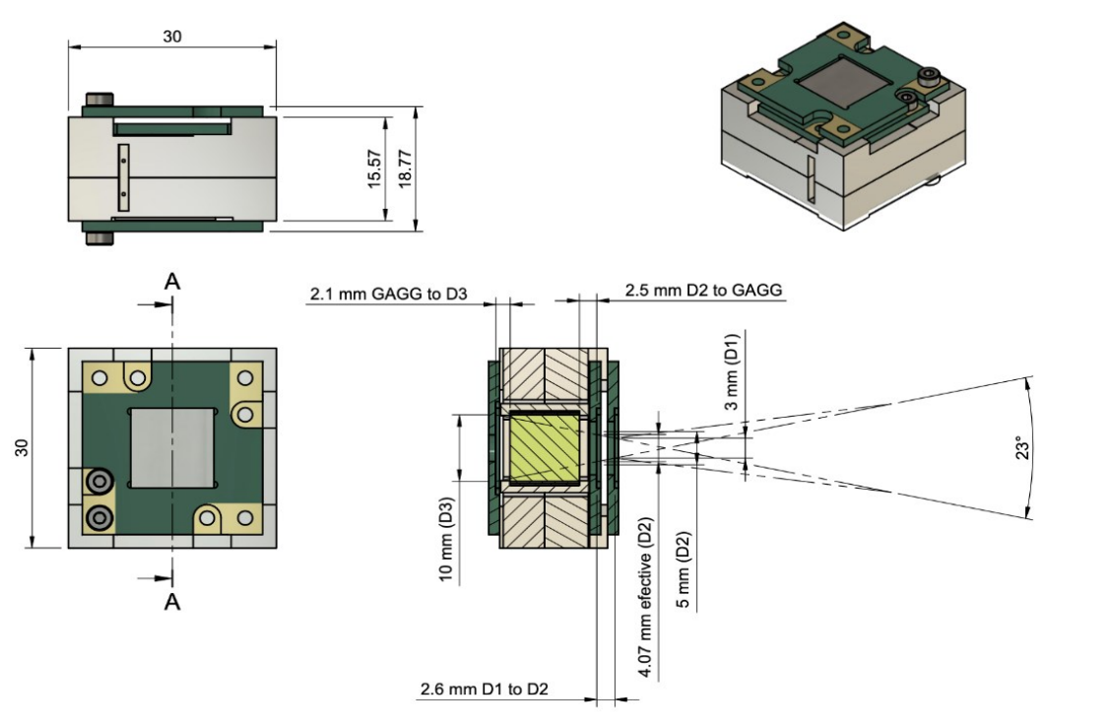
Spacecraft: One 12 U Cubesat based on the HAWK-12 platform by Argotec. The Cubesat is three axis stabilized. The Cubesat will be spinning for limited time periods during specific payload operation mode.

Payload: as a baseline HENON will embark the Relativistic Electron and Proton Experiment (REPE). HENON payload will be augmented by the MAGnetometer from Imperial College (MAGIC) and the faraday cup (FC) instruments (to be confirmed by the end of the Phase A/B study).

HENON Payload						
Instrument	Description	Measurement			Instrument Budgets	
		Quantity	Range	Time resolution (Hz)	Nominal mass [kg]	Nominal power [W]
REPE	Radiation Monitor	Energetic proton and electron fluxes	Ions Energy range 10-200 MeV Electrons Energy range 0.5-8 MeV Energy resolution: 40%	0.14	1	2.5
MAGIC	Magnetoresistive Magnetometer	Magnetic field	±2000 nT with a digital resolution of 2pT*	10	0.1	0.9
FC	Faraday Cup	Ion density, velocity and temperature	Velocity: 200 – 1000 km/s Density: 0.1 – 200 cm-3 Temperature: 0.1 – 100 eV**	0.33	>1.4	1.4

* The FC instrument can be operated in Turbulence mode, as well. In such a mode the FC can provide the ion flux vector with time resolution of at least 10 Hz.

REPE will be developed by the Space Research Laboratory of the University of Turku in collaboration with the Aboa Space Research Oy (ASRO) company and derives from the optimization of the RADMON instrument which flew in Aalto-1 3U CubeSat and will be part of the payload of the Finnish mission Foresail-2 to be launched in 2024.

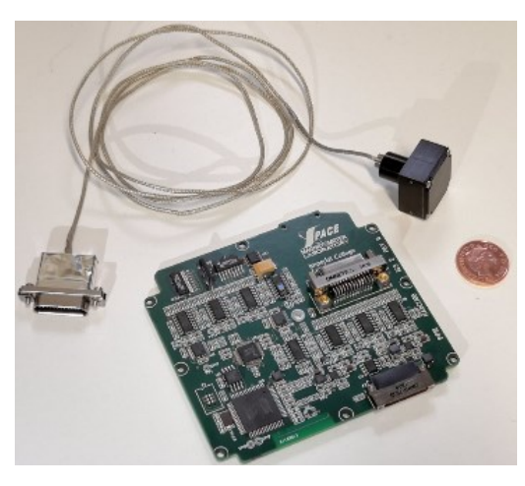


REPE detector overview. Courtesy of R. Vainio

FC will developed by Faculty of Mathematics and Physics at Charles University located in Prague. FC is based on the BMSW instrument that operated nominally onboard the Spektr-R spacecraft during the s/c lifetime (2011-2019), developed by Charles University in Prague and part of the BMSW-LG instrument of the Luna-Resurs-1 (LROA) mission.

BMSW-LG-DOP for the LROA mission. Courtesy of Z. Němeček.

MAGIC The magnetic field sensor on HENON is based on the design of the MAGIC instrument (Brown+, 2012, Meas. Sci. Technol. 23 059501) which is part of RadCube, an ESA technology demonstration mission performed under the auspices of the GSTP programme.



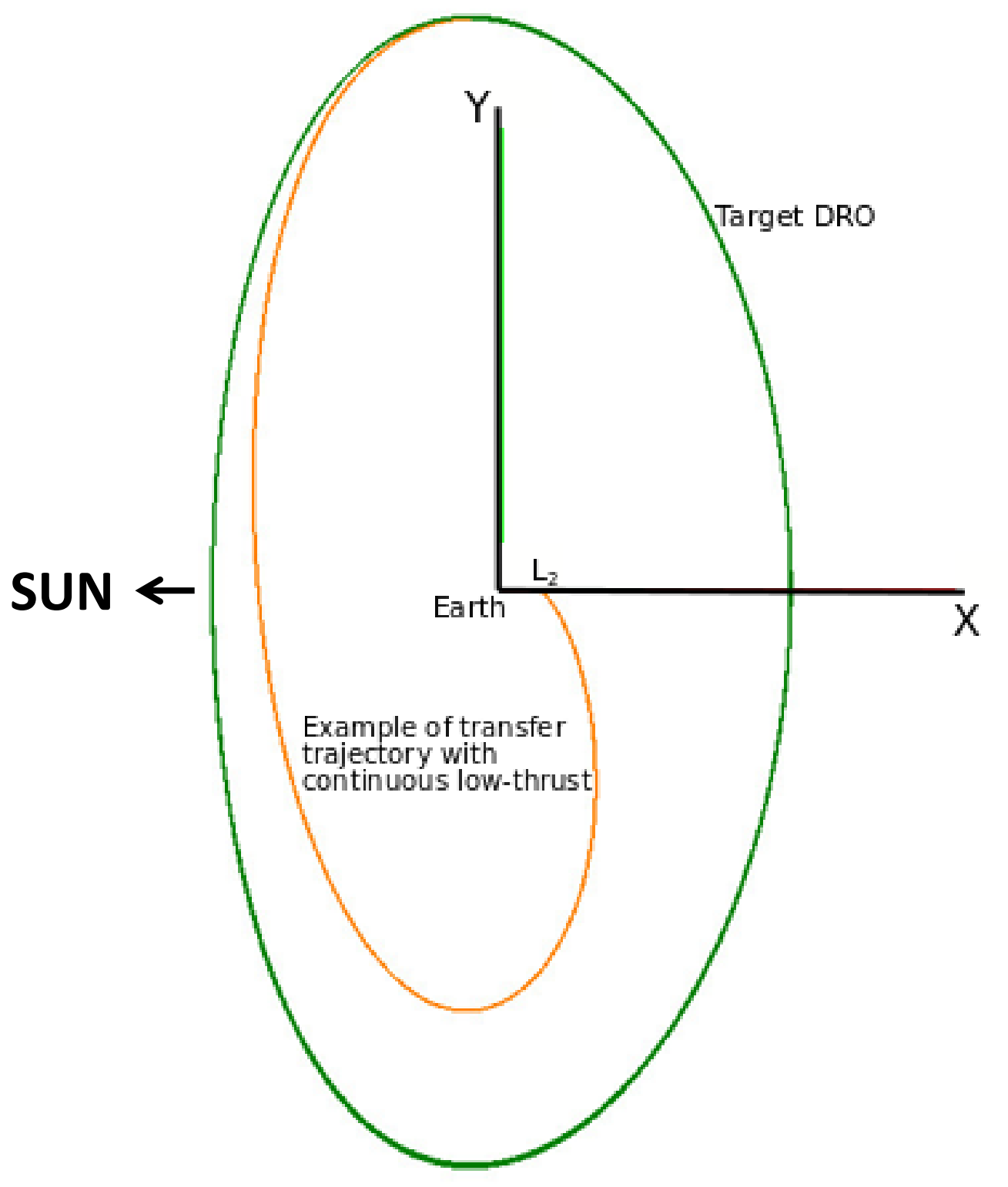
MAGIC. Courtesy of J. Eastwood (See also: Eastwood+, Sunjammer, 2015, Weather, doi:10.1002/wea.2438.

Mission Analysis. During the Phase A/B study particular attention is being dedicated to the study of different modes to reach the operative orbit. Two options are being considered:

1.Using an on-board propulsion system - electric propulsion would provide the required ΔV to reach a DRO orbit from an Earth-Sun Lagrangian point.

2.Using a carrier vehicle - this kind of service reduces the mission complexity, allowing for a reduced LEOP time.

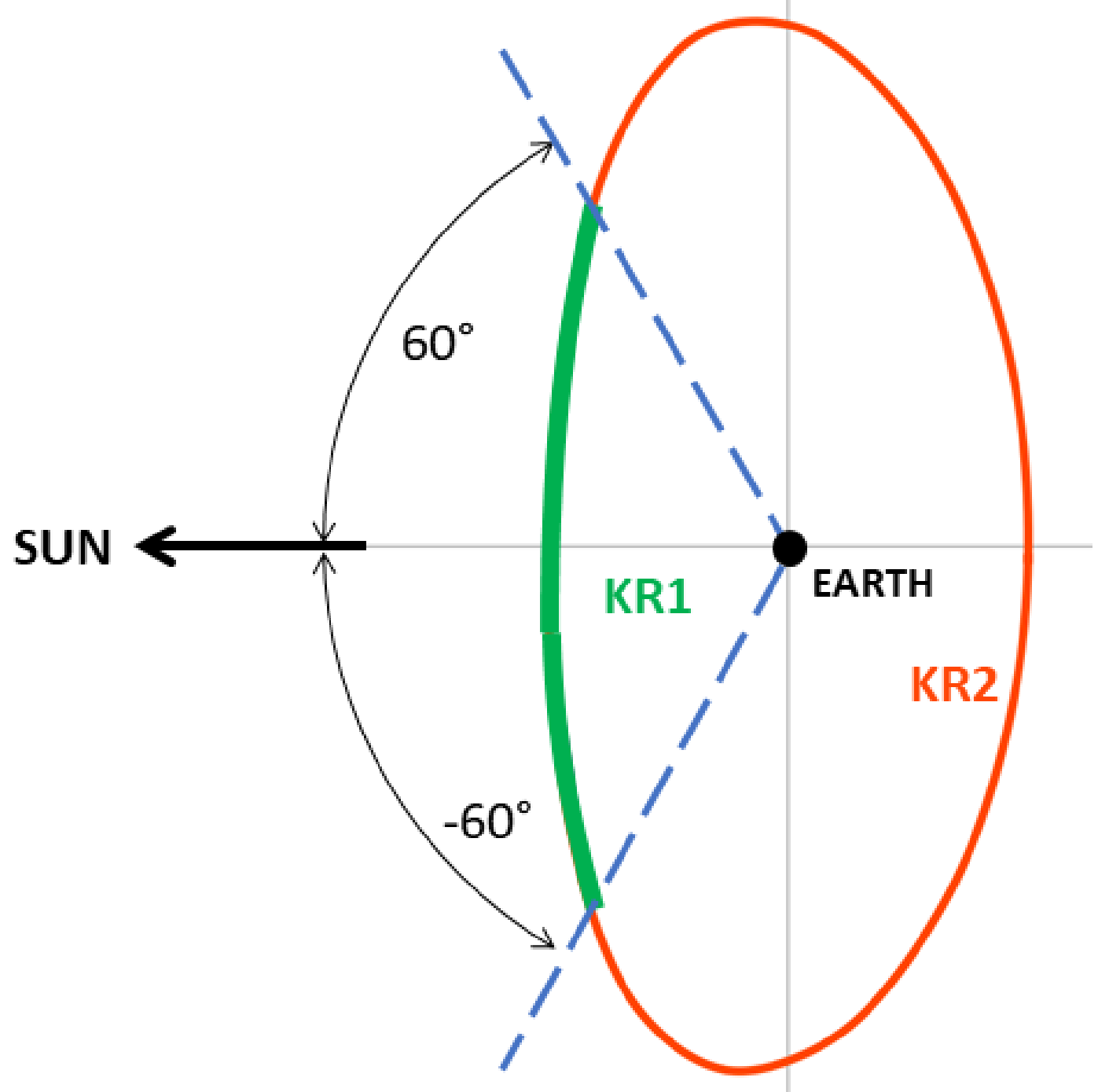
The figure on the right shows an example of transfer trajectory from L2 to the desired DRO, employing continuous low-thrust provided by a suitable on-board electric propulsion system.



A trade-off analysis is also going on in order to confirm the eccentricity of the operative DRO. Higher eccentricities imply a larger distance from the Earth and closer distance from the Sun, thus a larger time between the detection of a solar storm and its arrival to the Earth (provided the S/C is close to perihelion), which is beneficial for space weather purposes. On the other hand, higher eccentricities imply a larger delta-V required for the insertion to the final orbit starting from L1/L2, thus they are more costly solutions.

HENON Science Operations

Two different key region are identified along the nominal orbit. In the KR1 region, the HENON payload will be operated in such a way to provide *in situ* measurements of the radiation and plasma environment that will be used to generate near real time alerts to the ground. The KR2 region is defined as the part of orbit complementary to KR1. In such a region it is not useful to provide alerts, since in this case hazardous and/or geoeffective phenomena would have already or at least simultaneously reached Earth, and measurements will be used for scientific studies.



Using the REPE measurements, near real time novel alerts for SEP events and Forbush Decreases (FD) occurrence in the KR1 shall be provided to the Earth ground stations.

Moreover, it will be possible to take advantage of the SEP high quality measurements provided by REPE by using the ESPERTA. Such model had been adjusted to provide early forecasts of the largest radiation storms which are produced by ≥100 pfu SEP events, once the >10 MeV proton flux crosses the 10 pfu threshold at the Earth. It is worthwhile to note that few operational forecasting tools currently provide alerts of SEPs together with a quantification of their expected radiation level (e.g., the COMESEP SEP Forecasting tool); NOAA Space Weather Alerts and Warnings), but ESPERTA is the only model tested to predict ≥100 pfu (from moderate to extreme) SEP events with a very good performance including a warning time of about 2hr).

As far as interplanetary perturbations are concerned, in the case that HENON payload will include the FC and MAGIC instruments, KR1 observations can be used to predict the effects of ICMEs with a lead time from approximately 4 to 10 hours, in the case the ICMEs are moving at the high speed of 1000 km/s or at lower speed of 400 km/s, respectively. This implies a warning time which is ten time the current warning time based on in situ observations at L1. It is also important to note that HENON will provide in situ observations of the internal structure of the interplanetary perturbations largely in advance with respect to their arrival at Earth allowing us to ultimately ascertain the geoeffectiveness of the interplanetary structures (e. g. determining whether and for how long a southward directed interplanetary magnetic field will interact with the magnetosphere).

Impacts

The HENON mission will satisfy the urgent need for a pathfinder mission demonstration on novel and unexploited orbits especially suited for Space Weather monitoring, forecasting and science that will provide the paramount measurement of the energetic particle spectra and an unprecedented early detection of ICMEs and HSSs. Moreover, HENON will be the first European Space Weather dedicated mission providing real time particle measurements in deep space, having high angular and energy resolution to advance both Space Weather forecasting and science. Indeed, such measurements will also benefit current SEP forecasting models, foster the development of novel GCR based forecasting tools for interplanetary perturbations, and allow us a more detailed assessment of the accumulated radiation impact on future missions (e. g. manned missions to Moon and Mars). Moreover, HENON baseline can be enhanced to include a suite of instruments for measuring other fundamental parameters for the Space Weather operational aims and Space Weather science study, namely solar wind and interplanetary magnetic field observations. The combination of these data can further increase CME/shock arrival warning times and improve the accuracy of the predictions. For instance, space-weather CME/shock forecasting models rely on MHD modelling to propagate source-surface (generally solar surface or low corona) observations to 1AU, but do not yet use interplanetary observations beside L1 to constrain propagation through the heliosphere. HENON would fill these gaps in an unprecedented fashion, while providing insights in Space Weather science and complementing new and existing heliophysics missions. Furthermore, since Space Weather stems from the complex interplay of a variety of physical mechanisms which have to be characterized through the measurements of numerous quantities of different type and in diverse locations in the heliosphere, HENON will enrich the existing Space Weather datasets allowing us to deepen our knowledge in the field. In particular, HENON measurements will augment the datasets of the ASI Space weather InfraStructure (ASPIS) within the ASI Space Science Data Center, that is being developed to provide to the scientific community high-quality interdisciplinary data and global information relevant to Space Weather science. Finally, the HENON success will lead to the realization of a future fleet of CubeSats that will provide continuous near real-time measurements for operational space weather forecasting .