



First Results from Solar Orbiter's Energetic Particle Detector

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How do solar eruptions produce energetic particle radiation that fills the heliosphere?

- This can be broken down into several key topics:
 - 1. SEP seed populations
 - 2. Injection, acceleration and release processes of SEPs
 - 3. SEP transport

What do we need?

- Get close to the Sun
- Comprehensive energetic particle instrumentation with:
 - Broad energy range and composition coverage (including suprathermals)
 - High temporal resolution
 - Directional information
- Supplementary remote sensing measurements



EPD System Architecture







EPD Accommodation on the Spacecraft:







Temporal Resolution:

- STEP: SupraThermal Electrons and Protons. Up to 1s
- SIS: Suprathermal Ion Spectrograph. Up to 3s
- EPT/HET: Electron Proton Telescope/High Energy Telescope. Up to 1s



EPD Fields of View







EPD Energy Range



Wide energy/composition coverage to study different heliospheric particle populations









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STIX synoptic measurements

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Solar Orbiter

solar orbiter

- Launched February 9th, 2020
- Ten instruments: 6 remote and 4 in situ
- Closest perihelion 0.28 au
- Out of the ecliptic measurements
- Cruise phase until Nov. 2021
- Only in situ instruments and STIX are currently switched on during cruise phase



EPD long-term spectrum





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EPD long-term spectrum





EPD papers I: CIRs & Quiet times

Suprathermal Particles from Corotating Interaction Regions During the First Perihelion Pass of Solar Orbiter Allen et al. [Accepted by A&A Lett]

- Six CIR events are investigated with observations from SolO SIS and ACE ULEIS
- Spectra show little modulation between ACE (1 au) and SolO (down to 0.54 au)
- Events are very weak compared to CIRs during more active times.
 - Spectral slopes are more similar to higher energy (>1 MeV) ions during active times
- Radial intensity gradient similar to Van Hollebeke et al. (1978)



EPD papers I: CIRs & Quiet times

Quiet-time Low Energy Ion Spectra Observed on Solar Orbiter During Solar

Minimum

Mason et al. [accepted by A&A Lett]

- Study of the energetic ion spectra and composition over the range ~0.1->100 MeV/nucleon during "quiet-times" and "super quiettime" periods
- SIS + HET data
- Spectra measured during the quiet period showed transitions from GCR(> 50 MeV/nucleon) to ACR (~few to ~50 MeV/nucleon) to a steeply rising "turn-up" spectrum below a few MeV/nucleon whose composition resembled impulsive, 3He-rich SEP events
- The radial dependence of 4.4 MeV/nucleon 4He and O had large uncertainties but was consistent with a small gradient
- During the super-quiet interval the ~flat low energy 4He spectrum extended downwardreaching ~300 keV/nucleon







EPD papers II: CMEs related

Radial Evolution of the April 2020 Stealth Coronal Mass Ejection between 0.8 and 1 AU A Comparison of Forbush Decreases at Solar Orbiter and Earth von Forstner et al., accepted by A&A

- First CME seen at SolO on April 19, associated with Forbush decrease (FD) in EPD/HET data
- Slow, stealth CME (~350 km/s, no clear SDO/AIA signatures), but relatively strong magnetic field
- HET C detector counters: high time resolution measurements of the FD (amplitude: 3%)
- Multispacecraft event:
- seen at Earth on April 20 close longitudinal alignment (1% FD in neutron monitors and 2% at LRO/CRaTER)
- Also hit BepiColombo (close to Earth), and possibly Venus
- STEREO-A remote-sensing observations
- Modeling efforts predict a smaller FD.
 Possible explanation: CME may have been compressed by the following SIR.





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EPD papers II: CMEs related

Energetic proton enhancement in the sheath of an interplanetary coronal mass ejection

Emilia K. J. Kilpua et al., Accepted by A&A

- Study about role of the CME sheath region in the particle acceleration process
- Multi-point in-situ observations of a sheath region ahead of a CME on April 19-21 2020
- Energetic protons enhancements in the sheath but at different locations in L1 and SolO
- At L1, the proton flux enhancement is associated with the HCS crossings, while at Solar Orbiter the proton enhancement is channelled within a small-scale flux rope
- Substructures that are swept from the upstream solar wind and compressed into the sheath can efectively act as the acceleration sites



Energetic ion observations by EPD/EPT within a mini flux rope

EPD papers II: CMEs related

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Study of two interacting Interplanetary Coronal Mass Ejections encountered by Solar Orbiter during its first , perihelion passage

Daniele Telloni et al., Submitted for publication A&A

- Investigation of two successive CMEs separated by HCS encountered by Solar Orbiter during first perihelion, from both an observational and modeling perspective
- MAG and EPD data
- HeliosphericUpwind eXtrapolation (HUX), 3D COronal Rope Ejection (3DCORE) and EUropean Heliospheric FORecasting Information Asset (EUHFORIA)
- Compelling evidence that the two CMEs are interacting with each other (and possibly also with the HCS), via magnetic reconnection, during their propagation
- EPD data and EUHFORIA simulations seem to indicate that the two CMEs dynamically collide exactly at the location of Solar Orbiter
- Future work: multi-spacecraft observations of the same event at different distances from the Sun: SolO + MAVEN



In-fight verification of the engineering design data for the Energetic Particle Detector on board the ESA/NASA Solar Orbiter mission. Manuel Prieto Mateo et al., Submitted for

publication Acta Astronautica

- EPD engineering performance based on the housekeeping data received during its 1y in orbit, by comparison with the initial estimations and test results during EPD development.
- Power, thermal, radiation exposure and straylight are the main topics discussed as key indicators to ascertain that the design, manufacturing and qualification of the EPD units on ground were successful, which is confirmed thanks to this study.

EPD papers III: Technical









EPD papers IV: Venus & Comet Atlas

Energetic Ions in Venus System during SO flyby Robert C. Allen et al, A&A submitted Mar 2021

- STEP observed bursty suprathermal ion enhancements during the first SolO Venus GAM
- These enhancements correspond with likely ion acceleration processes of:
- Current sheets
- Upstream ionization and pick-up of exospheric neutrals
- The HET C detector observed obstruction of GCRs by
 Venus





EPD papers IV: Venus & Comet Atlas

Solar Orbiter's first Venus Flyby: MAG observations of structures and waves associated with the induced Venusian magnetosphere. Martin Volwerk et al., Submitted to A&A

- Study of the large scale structure and activity of Venus induced magnetosphere and high frequency plasma waves
- MAG , RPW and EPD/STEP data used
- Tail region downstream of the bow shock and planet shows evidences of structures such as flux-ropes and reconnection sites
- Evidences of Doppler-shifted IC waves that may suggest acelerated plasma flow in the magnetosheath.



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MAG, RPW and EPD/STEP data of Dec. 27th 2020

³He-rich Solar Energetic Particle Events Observed on the First Perihelion Pass of Solar Orbiter

Mason et al. [accepted by A&A Lett]

- 5 small 3He events observed by SIS 0.52 0.96 au. Sources not seen (beyond West limb)
- 18 June event: large anisotropies
- 20 July event:
 - Probably 2 injections
 - Fluence >30x larger than other events; Heavy ion rich
 - ³He/⁴He = 0.61±0.01, highest of all 5 events
 - Accompanying electron injections seen by EPT/STEP



First near-relativistic solar electron events observed by EPD onboard Solar Orbiter

Gómez-Herrero et al [accepted by A&A Lett]

- First electron events observed by EPD
- Associated with type III radio bursts and EUV jets
- Multipoint event on July 11 (Wind+SolO)
- July 22 events:
 - Excellent energy coverage by STEP and EPT. Velocity dispersion
 - Very good pitch-angle coverage by STEP and EPT. Strong anisotropy
 - Langmuir waves observed. Good connection to the source requires further investigation



The First Widespread Solar Energetic Particle Event Observed by Solar Orbiter on 2020 November 29

Alexander Kollhoff et al., . (Submitted to A&A)

- Multi-spacecraft observations of November 29 event
- Relativistic electrons as well as protons with energies >50MeV were observed by SolO, PSP, STEREO-A and multiple near-Earth spacecraft.
- EUI wave intersection with magnetic foot-points does not explain particle onset times
- Isotropic particle injections seen at all S/C → injection over wide longitudinal range (>230°!)



The Low-Energy Ion Event on 19 June 2020 Measured by Solar Orbiter Aran el al. (Submitted to A&A)

- FOCUS: Study the different SEP intensitytime profiles, especially those seen by the 4 FOVs of EPT and the FD seen by > 17-20 MeV ions detected by HET.
- How are these particles affected by the interplanetary magnetic structures crossing SolO?
- Is there a solar source for these particles that explains the clear difference of the sun-ward anti-sunward FOV intensities?



Radoslav Bucik et al. et al. The long period of 3He-rich solar energetic particles measured by Solar Orbiter on 2020 November 17–23 Submitted to A&A

- Study of the long period of 3He-rich SEP event observed during 17-23 November 2020
- At least 5 SEP injections identified
- SEP activity related to recurrents brightenings and jets in a large and complex sunspots group in 2 AR.
- The configuration of these 2 AR may be favorable for the recurrent particle injections and their longitudinal extensión (40^o) favors to maintain the connection with SolO.





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The first year of energetic particle measurements in the inner heliosphere with Solar Orbiter's Energetic Particle Detector

R. F. Wimmer-Schweingruber el al. (Submitted to A&A)

- Overview of initial results from the first year of operations
- First assessment of the instrument in flight performance
- A "must read" if you want to use the EPD data





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