

# Solar Orbiter Energetic Particle Detector: Early Results and Science Data Center

F. Carcaboso-Morales<sup>1,7,8</sup>, Francisco Espinosa<sup>1</sup>, Ignacio Cernuda<sup>1</sup>, R. Gómez-Herrero<sup>1</sup>, J. Rodríguez-Pacheco<sup>1</sup>, Alberto Carrasco<sup>1</sup>, Laura Rodríguez-García<sup>1</sup>, Ángel del Pino Jiménez<sup>1</sup>, Robert F Wimmer-Schweingruber<sup>2</sup>, Nils Peter Janitzek<sup>2</sup>, Daniel Pacheco<sup>2</sup>, Glenn M Mason<sup>3</sup>, George C Ho<sup>3</sup>, Alexander Kollhoff<sup>2</sup>, Zigong Xu<sup>2</sup>, G Andrews<sup>3</sup>, Patrick Kühl<sup>2</sup>, Lars Berger<sup>2</sup>, Sandra Eldrum<sup>2</sup>, Nina Dresing<sup>6</sup>, David Lario<sup>7</sup>, Olga Malandraki<sup>4</sup>, Angels Aran<sup>5</sup>, Rami O Vainio<sup>6</sup>, Johan Lauritz Freiherr von Forstner<sup>2</sup>, Bernd Heber<sup>2</sup>, Sebastian Boden<sup>2</sup>, Stephan I Boettcher<sup>2</sup>, Manuel Prieto<sup>1</sup>, O Rodriguez Polo<sup>1</sup>, Sebastian Sanchez Prieto<sup>1</sup>, César Martín-García<sup>10</sup>, Ali Ravanbakhsh<sup>2</sup>, Christoph Terasa<sup>2</sup>, Charles E Schlemm<sup>3</sup>, Helmut Seifert<sup>3</sup>, Teresa Nieves-Chinchilla<sup>7</sup>

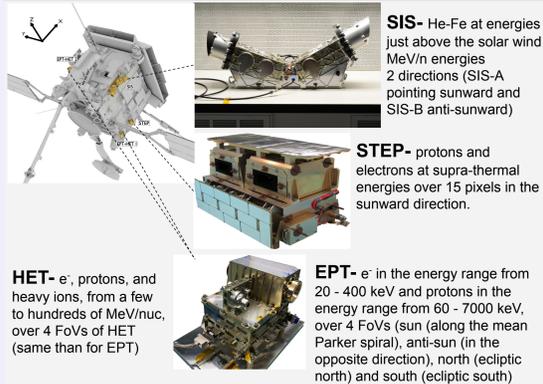
1. University of Alcalá 2. Christian-Albrechts Universität 3. Johns Hopkins University, APL 4. National Observatory of Athens, IAASARS  
5. Universitat de Barcelona 6. University of Turku 7. NASA/GSFC 8. Catholic University of America 9. Paradox Cat GmbH 10. German Aerospace Center (DLR)



## Abstract

The EPD onboard Solar Orbiter is a suite of multiple sensors (STEP, SIS, EPT, HET), which measure particle intensities over a wide range of energies (from suprathermal to relativistic energies) and for different species ( $e^-$ , protons, and heavy ions) in different directions. The EPD data center (<http://espada.uah.es/epd>) offers a prime venue to inspect the SEP activity, both to promptly check the most recent solar activity using quicklook plots based on low-latency data sets, and to perform deeper studies with data validated for scientific use. Among others, a series of plots and relevant information, such as the spacecraft maneuvers or sensor updates, are provided to the community. This facility gives access to all the data from the EPD sensors (also located in SOAr), including L2 and more elaborated L3 data in the near future, which have further processing. An application programming interface is also offered for accessing EPD data. Besides, during the first year and a half of observations, Solar Orbiter has completed three orbits, and EPD has measured several increases in particle fluxes, due to heliospheric and solar-origin events. Some of the events have been analysed and the flux enhancements have been tagged for future studies. This work aims to let the community know the availability of the instrument data products, and to explain how to properly use the provided data products and plots, as well as to summarise all the available studies published until now.

## The Energetic Particle Detector



## EPD Data Center

It can be found at the main EPD website (<http://espada.uah.es>) under DATA>EPD Data Portal. It contains the full set of published EPD data products at the SOAr (<http://soar.esac.esa.int>) in the form of daily CDF files. EPD data are published at most 3 months after they are received on ground.

Data files are organised by their processing:

- **Level 1** - received from EPD in uncalibrated units (i.e. detector counts).
- **Level 2** - main science product. Calibrated in physical units and validated by the EPD team.

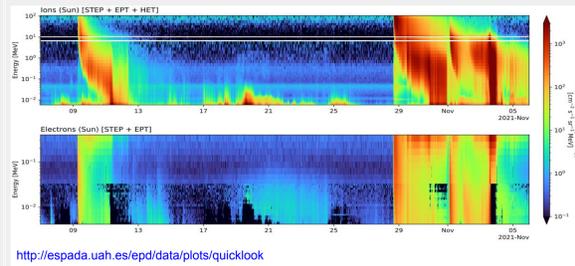
## Main Level 2 Data Products

- step-rates.**
- Species: Suprathermal particles: Ions+ $e^-$  (Integral), ions (magnet)
  - Energy range: from ~5 keV to ~80 keV averaged in 48 energy bins and per-pixel intensities with reduced energy resolution
  - Cadence: 10 s
  - Note: As of October 22, 2021 this product has been replaced by a new one containing per-pixel intensities with high energy resolution (32 bins) and 1 s cadence
- ept-[sun/asun/north/south]-rates.**
- Species: Energetic ion and  $e^-$  for the 4 telescopes.
  - Energy range:  $e^-$  from ~30 keV to ~500 keV in 34 bins. Ions from ~50 keV to ~6 MeV for ions in 64 bins
  - Note: Since March 24, 2021 the intensities are measured with a cadence of 1 s
- sis-[a/b]-rates-[slow/medium/fast].**
- Species: Ions (H--Fe) using *time-of-flight* analysis
  - Energy range: from ~50 keV/n to ~10 MeV/n (species dependent)
  - Cadence: slow (30 min), medium (30 s) and fast (3 s, since July 7, 2021)

## Quicklook plots

Automatically produced using low latency data. These data are sent to ground with the highest priority for monitoring purposes, but have lower quality than the final data products, that may arrive with long delays (up to several months).

4-day and monthly SIS browse plots are also provided showing higher quality data specific to the SIS instrument.



## Catalogue of Particle Enhancements

A list of electron and proton (ion) increases observed by EPD, showing at least a factor of 2 enhancements above the pre-event background is presented below.

This catalogue extends over two mission phases: commissioning and cruise. For the former, Solar Orbiter data is not fully publicly available as it was intended mainly for commissioning, during which the instrumental settings were changed multiple times

Electron Events (36)							Ion Events (29)						
1	2	3	4	5	6	7	1	2	3	4	5	6	7
Start date	Onset time	Peak date	Peak time	Peak intensity	Max energy	dt-Telescope	Onset date	Onset time	Peak date	Peak time	Peak intensity	Max energy	dt-Telescope
(dd/mm/yyyy)	(UTC)	(dd/mm/yyyy)	(UTC)	(cm <sup>2</sup> s <sup>-1</sup> sr MeV <sup>-1</sup> )	(keV)	(min)	(dd/mm/yyyy)	(UTC)	(dd/mm/yyyy)	(UTC)	(cm <sup>2</sup> s <sup>-1</sup> sr MeV <sup>-1</sup> )	(keV)	(min)
11/07/2020	02:31	11/07/2020	02:44	6.99e2	154-167	1	18/04/2020	02:55	18/04/2020	04:25	3.75e1	187-202	10
19/07/2020	10:47	19/07/2020	14:37	1.29e2	78-85	5	20/04/2020	09:57	20/04/2020	10:27	4.50e1	151-162	5
20/07/2020	20:47	20/07/2020	21:27	3.78e2	130-142	5	07/06/2020	19:27	08/06/2020	01:07	8.51e1	187-202	5
21/07/2020	01:27	21/07/2020	01:42	2.24e2	78-85	5-Omni	19/06/2020	03:02	19/06/2020	04:03	1.31e3	411-446	1
21/07/2020	03:07	21/07/2020	03:58	1.72e3	53-58	1	19/06/2020	10:37	19/06/2020	11:02	1.05e2	274-298	5
21/07/2020	04:56	21/07/2020	04:58	1.24e3	199-218	1	11/07/2020	17:07	11/07/2020	17:17	4.19e1	218-235	5-Omni
21/07/2020	06:36	21/07/2020	06:42	1.59e3	257-281	1	12/07/2020	03:07	12/07/2020	17:30	7.00e1	218-235	5
21/07/2020	07:16	21/07/2020	07:40	3.07e3	218-237	1	21/07/2020	02:47	21/07/2020	21:12	4.63e2	4100-4400	5
21/07/2020	08:02	21/07/2020	08:05	4.52e3	1020-2400 <sup>(1,2)</sup>	1	23/10/2020	07:32	23/10/2020	12:57	1.03e2	804-873	5
22/07/2020	23:44	22/07/2020	23:51	1.73e3	119-130	1	23/10/2020	22:12	23/10/2020	23:52	9.75e1	804-873	5
22/10/2020	12:53	22/10/2020	14:37	1.87e3	237-257	1	13/11/2020	01:09	13/11/2020	01:12	3.75e2	202-218	1-South
23/10/2020	02:32	23/10/2020	02:37	3.49e2	78-82	5	14/11/2020	14:09	14/11/2020	15:45	1.50e2	235-254	1-South
26/10/2020	17:52	26/10/2020	18:22	2.03e2	167-183	5	15/11/2020	23:45	15/11/2020	13:05	7.19e1	298-321	10-Omni
28/10/2020	13:17	28/10/2020	13:27	1.38e2	85-93	5	18/11/2020	03:15	18/11/2020	09:35	9.63e1	298-321	10
14/11/2020	10:15	15/11/2020	07:15	1.29e2	62-67	30	19/11/2020	00:55	19/11/2020	03:45	1.45e2	950-1030	10
07/11/2020	09:43	07/11/2020	10:26	4.26e3	1020-2400 <sup>(1)</sup>	1	24/11/2020	19:03	25/11/2020	15:59	1.37e3	4870-5310	2-Omni
17/11/2020	14:45	17/11/2020	14:53	9.43e2	85-93	2	26/11/2020	12:21	26/11/2020	13:57	1.19e3	1220-1340	2
17/11/2020	18:37	17/11/2020	18:45	1.96e3	73-78	1	29/11/2020	14:22	29/11/2020	15:52	7.09e1	522-572	15
18/11/2020	12:09	18/11/2020	12:17	5.75e2	73-78	1	30/11/2020	02:02	30/11/2020	04:27	1.85e2	522-572	5
18/11/2020	13:29	18/11/2020	13:39	1.31e3	85-93	1	30/11/2020	09:01	30/11/2020	10:15	7.25e2	5830-6130	2
18/11/2020	14:35	18/11/2020	14:42	1.57e3	85-93	1	02/12/2020	23:52	02/12/2020	00:52	3.58e1	202-218	15-Omni
18/11/2020	18:39	18/11/2020	22:07	8.02e2	93-101	1	03/12/2020	14:07	03/12/2020	15:52	7.00e1	202-218	5-North
18/11/2020	12:09	18/11/2020	12:17	5.75e2	58-62	1	09/12/2020	10:35	09/12/2020	03:55	9.26e1	5830-6130	10
19/11/2020	06:13	19/11/2020	06:47	1.12e3	78-85	2	10/12/2020	04:39	10/12/2020	05:01	4.50e2	676-739	1
20/11/2020	20:15	20/11/2020	22:01	2.37e3	1020-2400 <sup>(1)</sup>	1	11/12/2020	09:45	11/12/2020	19:25	5.40e2	5830-6130	10
24/11/2020	06:51	24/11/2020	11:00	4.78e2	93-101	2	14/12/2020	12:27	14/12/2020	21:01	6.13e2	411-446	2
24/11/2020	13:21	24/11/2020	13:52	1.10e3	101-110	1	15/12/2020	11:22	15/12/2020	11:22	1.33e2	141-151	5
24/11/2020	19:32	24/11/2020	21:25	1.17e3	434-471 <sup>(1)</sup>	1	19/12/2020	21:32	19/12/2020	23:47	3.79e1	162-174	5-Omni
29/11/2020	13:38	29/11/2020	18:02	8.22e3	5990-17980 <sup>(1)</sup>	1	20/12/2020	04:05	20/12/2020	05:01	1.61e2	254-274	2-Omni
09/12/2020	05:22	09/12/2020	05:57	3.02e2	78-85	5	02/02/2021	15:30	02/02/2021	16:30	1.96e1	141-151	60
10/12/2020	08:06	10/12/2020	08:14	1.73e3	78-85	1	04/02/2021	14:30	04/02/2021	17:30	2.31e1	202-218	60
10/12/2020	23:43	10/12/2020	23:59	9.92e4	1020-2400 <sup>(1)</sup>	1	15/02/2021	21:25	16/02/2021	00:25	7.37e1	235-254	10
11/12/2020	08:33	11/12/2020	09:07	6.81e2	101-110	2	21/02/2021	22:35	22/02/2021	03:05	1.59e2	321-349	10
12/12/2020	09:45	12/12/2020	10:25	2.43e2	67-73	10							
13/12/2020	10:05	13/12/2020	10:53	6.86e2	110-119	2							
15/02/2021	13:37	15/02/2021	14:03	6.75e2	101-110	2							
20/02/2021	21:45	21/02/2021	02:35	1.61e2	119-130	10							

Notes. <sup>(1)</sup> Maximum energy range for electrons as observed by HET. <sup>(2)</sup> Possible heavier-species contamination.

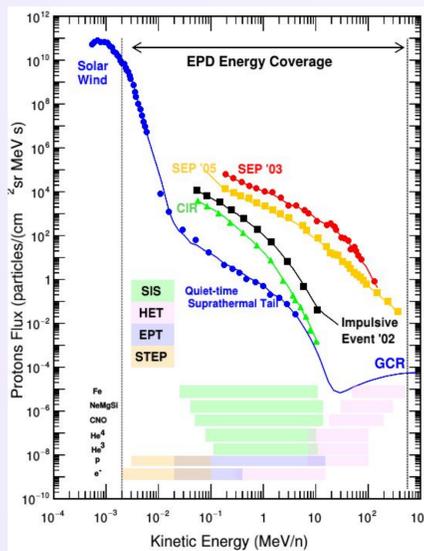
## Columns explanation

- 2- $\sigma$  onset date (1) and time (2)
- Peak date (3), time (4) and intensity (5) for 53-85 keV electrons and 132-220 keV ions, respectively
- Maximum energy observed (6), defined as the last energy channel reaching at least a factor of 2 higher than the background intensities. For electrons, when the enhancement was also observed by HET, the highest energy bin of HET that fulfilled the criterion is shown instead.
- Time resolution and looking directions used (sunward by default) (7)

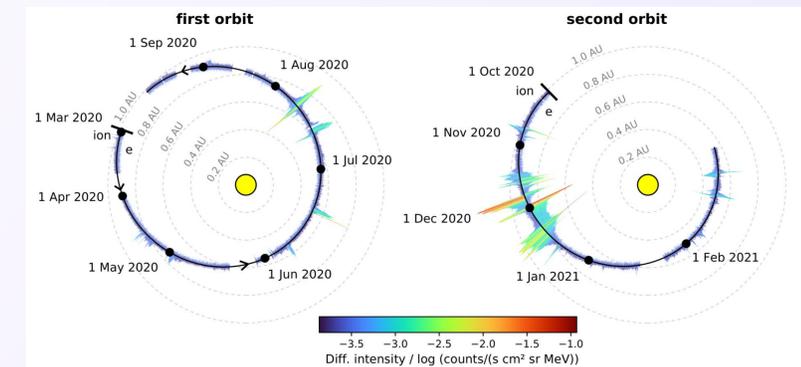
## Application Programming Interface (API)

The website also offers a basic API for programmatic access to the EPD data. It allows to search for specific products and dates, e.g.: <http://espada.uah.es/epd/data/api/search?level=12&product=ept-rates&from=2021-06-01&to=2021-06-30>

will return a list of files for the ept-rates product for June 2021. A given file in the list can be then downloaded as [http://espada.uah.es/epd/data/api/file/soLo\\_L2\\_epd-ept-sun-rates\\_20210607\\_V01.cdf](http://espada.uah.es/epd/data/api/file/soLo_L2_epd-ept-sun-rates_20210607_V01.cdf)



Timeline of Solar Orbiter mission events from Feb 2020 to Dec 2021. Key events include: Launch 10<sup>th</sup> Feb 2020; Commissioning (2020 Feb 10th 04:03 UTC -- 2020 June 14th 17:55 UTC); Cruise (2020 June 14th 17:55 UTC -- 2021 Dec 27th 00:00 UTC); Perihelium (2020 June 15th); VGAM (2020 Dec 27th 12:39 UTC). Various scientific highlights are marked with QR codes, such as: In situ multi-spacecraft and remote imaging observations of the first CME detected by Solar Orbiter and BepiColombo; Solar Origins of a strong stealth CME detected by Solar Orbiter; Evidence for local particle acceleration and the first recurrent Galactic Cosmic Ray depression observed by Solar Orbiter; Unusual enhancement of ~30 MeV proton flux in an ICME sheath region; Solar Orbiter's first Venus Flyby; MAG observations of structures and waves associated with the induced Venusian magnetosphere; Energetic Ions in the Venusian System: Insights from the First Solar Orbiter Flyby; The first widespread solar energetic particle event observed by Solar Orbiter on 20 November 2020; First near-relativistic solar electron events observed by EPD onboard Solar Orbiter; Solar Orbiter's encounter with the tail of comet C/2019 Y4 (ATLAS): magnetic field draping and cometary pick-up ion waves; Study of two interacting ICMEs encountered by Solar Orbiter during its first perihelion passage; The long period of <sup>3</sup>He-rich solar energetic particles measured by Solar Orbiter on November 17 - 23.



EPT intensities of 124 - 218 keV for ions and 54 - 101 keV for  $e^-$ .

## Articles of Longer Periods

- The first year of energetic particle measurements in the inner heliosphere with Solar Orbiter's EPD
- Quiet-time Low Energy Ion Spectra Observed on Solar Orbiter During Solar Minimum
- <sup>3</sup>He-rich Solar Energetic Particle Events Observed on the First Perihelion Pass of Solar Orbiter
- In-flight verification of the engineering design data for the EPD on board the ESA/NASA Solar Orbiter mission
- Cosmic-ray flux predictions and observations for and with Metis on board Solar Orbiter
- Suprathermal Particles from CIRs During the First Perihelion Pass of Solar Orbiter



API - Application Programming Interface  
CDF - Common Data Format  
EPD - Energetic Particle Detector  
EPT - Electron Proton Telescope  
 $e^-$  - Electron  
FoV - Field of View  
HET - High Energy Telescope  
SEP - Solar Energetic Particle  
SIS - Suprathermal Ion Spectrograph  
SOAr - Solar Orbiter Archive  
STEP - Suprathermal Electrons Protons



## Acknowledgements

We acknowledge the financial support by the Spanish MINECO projects PID2019-104863RB-I00/AEI/10.13039/501100011033, ESP2017-88436-R and its FPI predoctoral grant. We also acknowledge the STEREO instrument teams, especially SWEA instrument and B. Lavraud for his help, and the STEREO Science Center for providing the data used in this poster.