IRENE Industry Days – ESA Perspective

Piers Jiggens [1], Ingmar Sandberg [2], Sigiava Aminalragia-Giamini [2], Constantinos Papadimitriou [2], Zafar Iqbal [2], Matteo Martucci [3], Fan Lei [4], Daniel Heynderickx [5], Pete Truscott [6], Hugh Evans [1], Francesco Cafagna[3], Roberta Sparvoli[3], Simon Clucas [1]

[1] ESA/ESTEC, The Netherlands
[2] Space Applications & Research Consultancy, Greece
[3] INFN, Italy
[4] RadMod Research, UK
[5] DH Consultancy, Belgium
[6] Kallisto Consultancy, UK

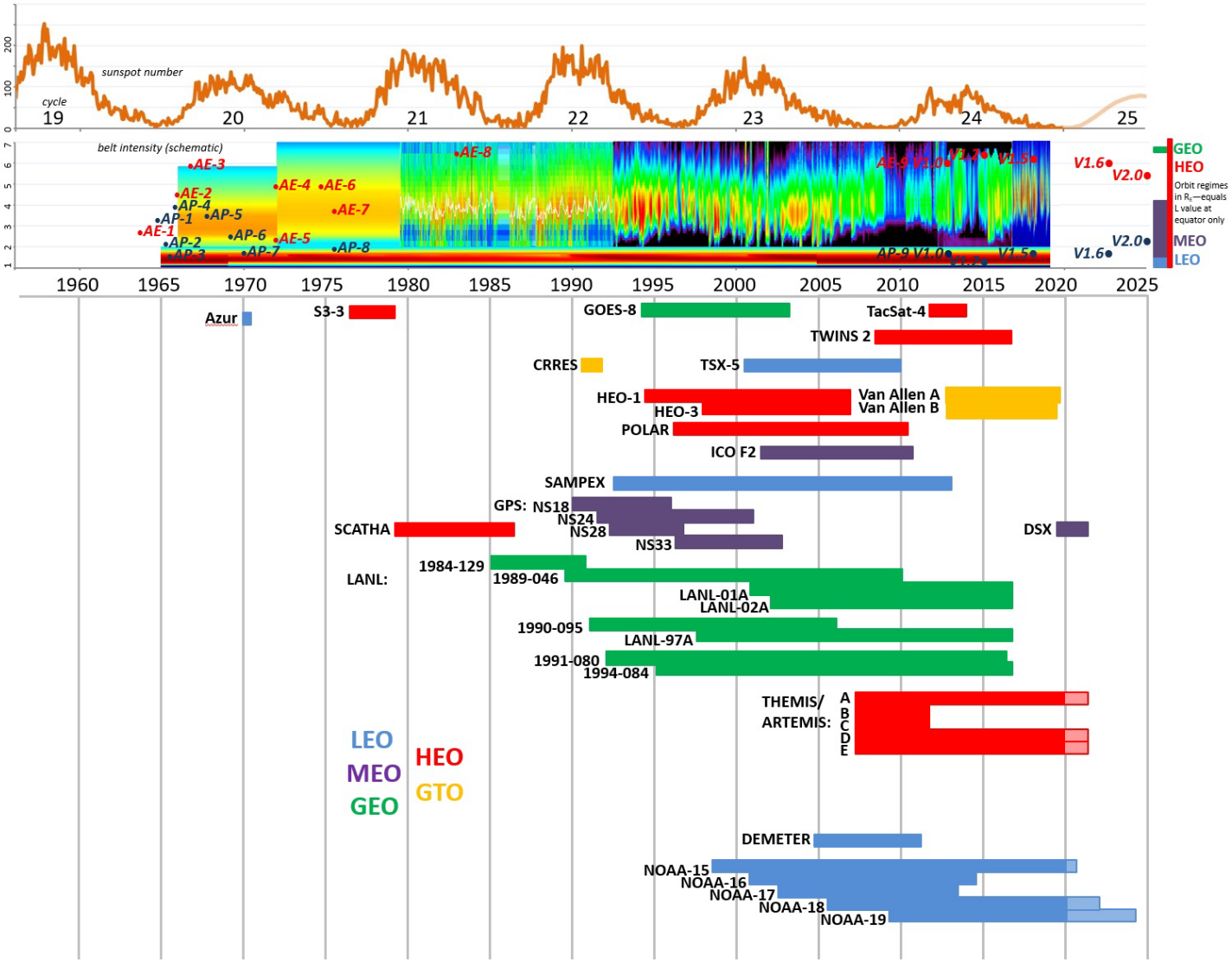
2023-03-01/02

Overview

- ESA is contributing to the IRENE development through contracts with its industry
- Primarily this has been focused on the ecIRENE (European Contribution to IRENE) contract with SPARC
- That contract has a global open source license condition allowing us to collaborate with our code on the development side
- It is envisioned that the code will be translated for the operational version of the tool and this will not therefore fall under that open source licence
- There are 4 main tracts that we follow for this collaboration:
    a) Dataset contributions from ESA and European missions (or missions with European contributions)
    b) “Complete” trapped electron model development made available so elements can be exploited in IRENE
    c) Lead for Solar Energetic Particle Model development (and associated magnetospheric shielding)
    d) Validation (and verification) Testing of IRENE models

Datasets in Present Version

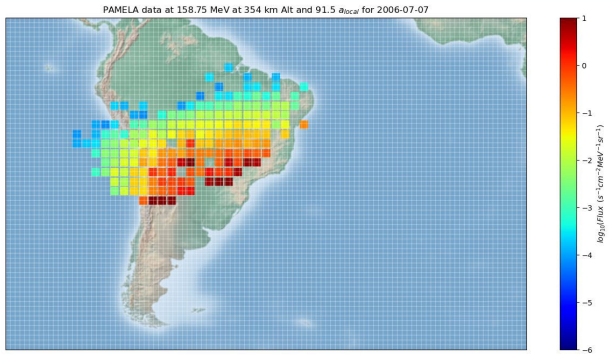
- Incorporates 45 data sets from 1976-2016
  - Chosen for high quality and coverage
- 330+ instrument-years of data
  - 10x more than AE8+AP8
- All solar cycle phases sampled:
  - 16 sets >10 years
  - 27 sets >5 years
- May be some gaps and coverage density can always be enhanced but high-quality processed data is desirable.



New datasets as part of European Contribution

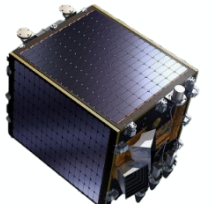
PAMELA

- Magnetic spectrometer for high-energy [80-4000 MeV]
- 244 day flux maps
- 20 (log) energy bins
- 2 degree lon-lat bins
- 62.25 km altitude bins

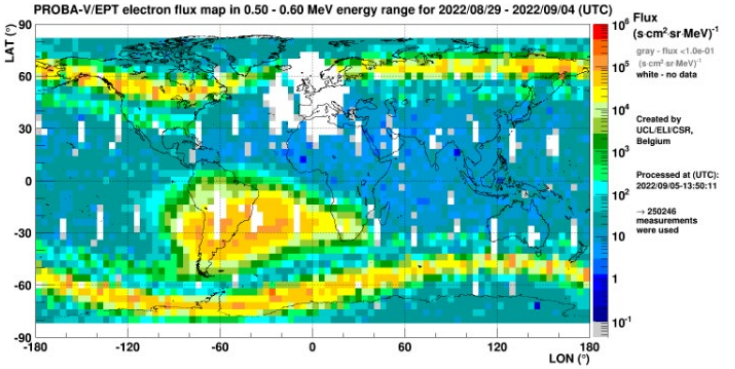


PAMELA: a Payload for Antimatter Matter Exploration and Light–nuclei Astrophysics

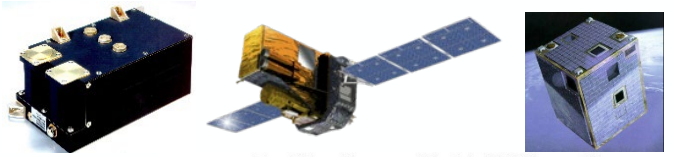
PROBA-V/EPT



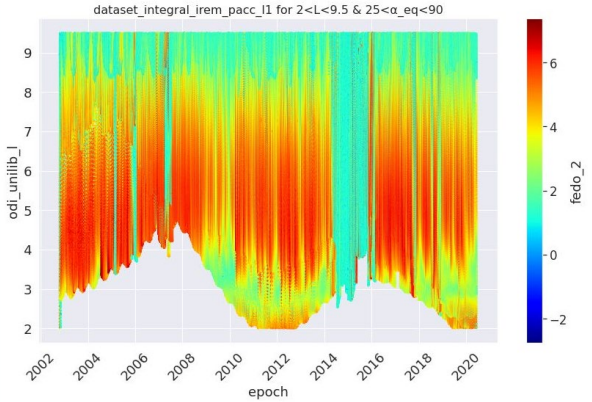
- Spectrometer for electrons, protons and helium
- With pitch angle information very relevant for SAA
- Operation in LEO since May 2013



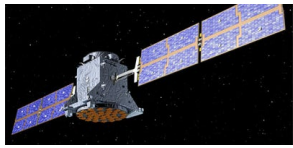
SREM/IREM



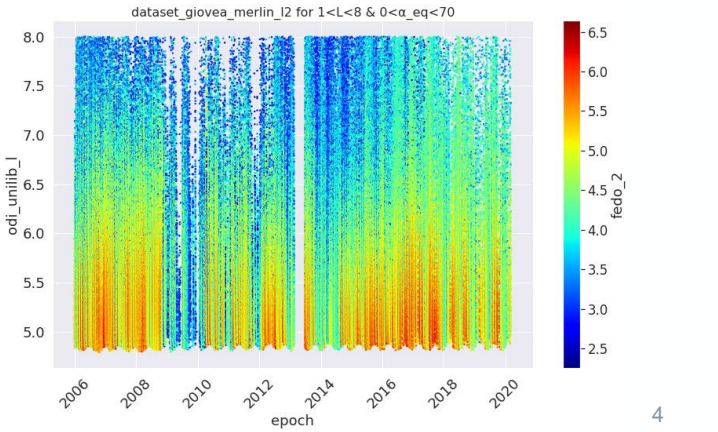
- Level-2 data from Integral and Proba-1
- 0.55 – 5.0 MeV electrons
- 15 (log) energy channels
- HEO, MEO and LEO orbits
- Over 2 decades of data



Merlin/SURF



- 3 omni-directional electron energy channels [0.76, 1.17, 1.65 MeV]
- MEO operating on-board GIOVE-A ~15 years
- Cross-calibrated with Arase/XEP data



ODI: Radiation Data Provisioning Requirements:

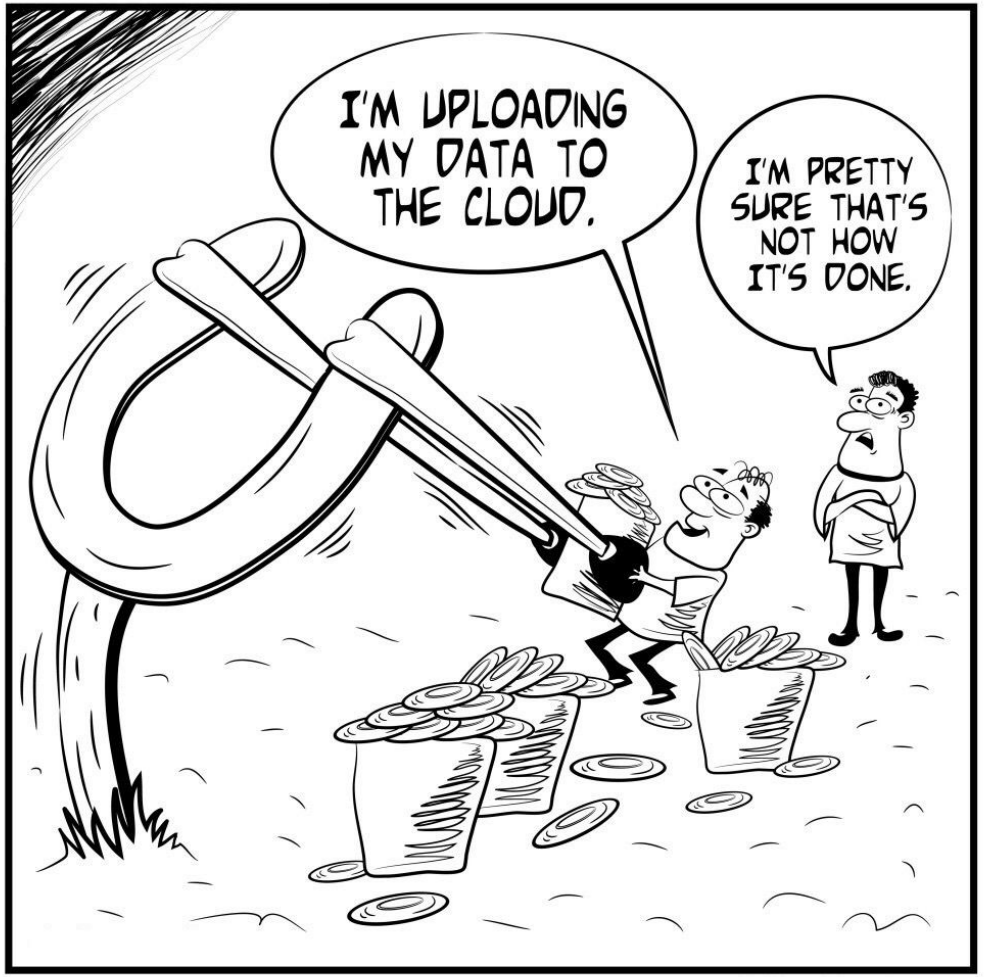
- **Philosophy**:

  "***Serve the user the data directly into their analysis tools***"

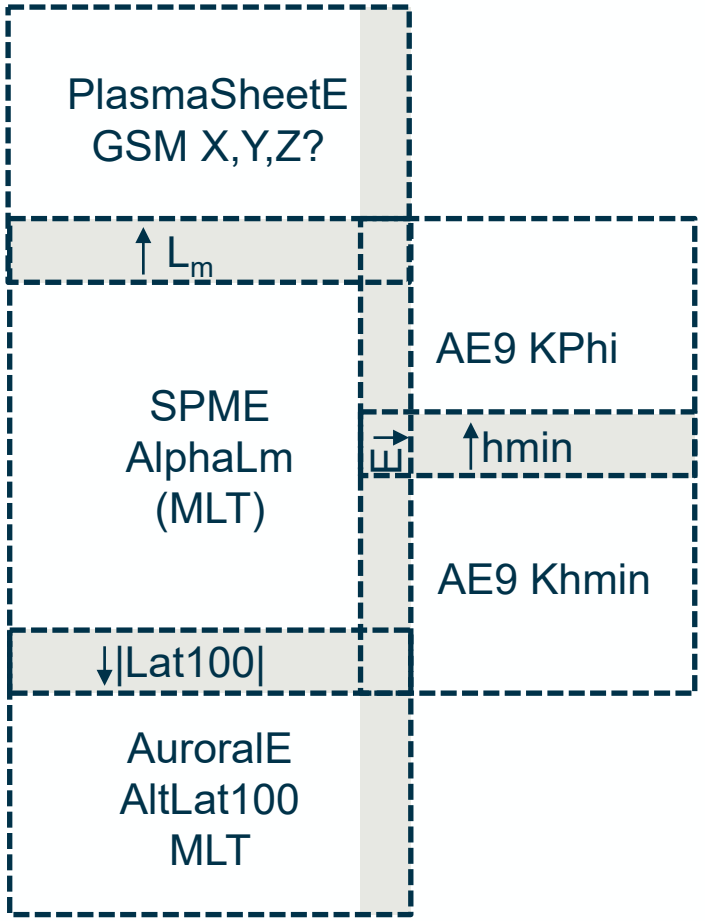
- **Requirements**:
  - **Consistent data model** for the data: consistent naming of data types (flux, energy);
  - Comprehensive **meta-data** description in dataset (self documenting datasets);
  - Storage in an **online system** that provides access via numerous tools (we chose MySQL);
  - Provide **multiple clients** for different tools (Python, IDL, matlab, …);
  - Dataset **extensibility** – can add metadata or additional variable to the datasets (ephemeris, magnetospheric coordinates);
  - Parse and ingest from many **data formats** (CDF, netCDF, text, JSON, CSV, FITS, …);
  - **Automated** downloading and ingestion of data (cron jobs);
  - **Regular updates** to dataset configurations – PIs regularly change the source URL, and the data format;
  - **Flexibility/Extensibility** – can add new functionality or build on existing functionality;
  - **Data processing** – can create new datasets 'on the fly' – Level 0 data processed to Level 2

Our Solution: Open Data Interface (ODI)

- A MySQL database – provides numerous interfaces to programming languages
- Data model based on the NSSDC/CDF file format tailored to COSPAR PRBEM dataset standard https://prbem.github.io/documents/Standard_File_Format.pdf
- ODI Client Interfaces include: Python, IDL, Matlab, PHP, Java
- Access to datasets via direct database socket/port or through a REST or HAPI (Heliospheric API, https://cdaweb.gsfc.nasa.gov/registry/hdp/hapi/) interface
- Processing chain “hooks” to provide dataset specific processing before/during/after data ingestion process
- ESA worldwide open source license
- Export datasets to CDF or netCDF files for dataset distribution
- God help us all, but there’s even an Excel interface

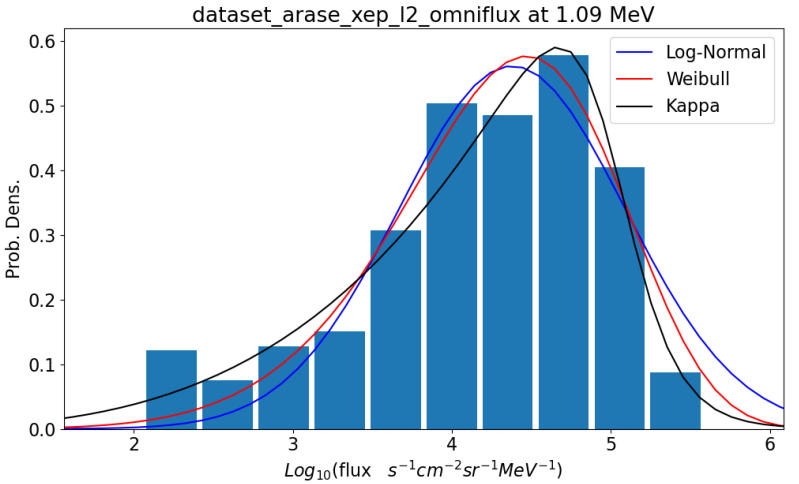


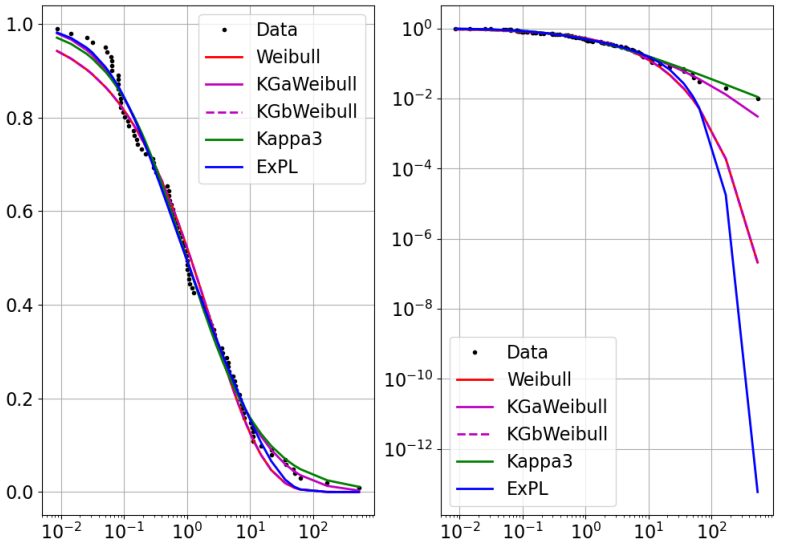
Trapped Particle Model Method Enhancements



Arrow indicates direction of increase of stitching variable

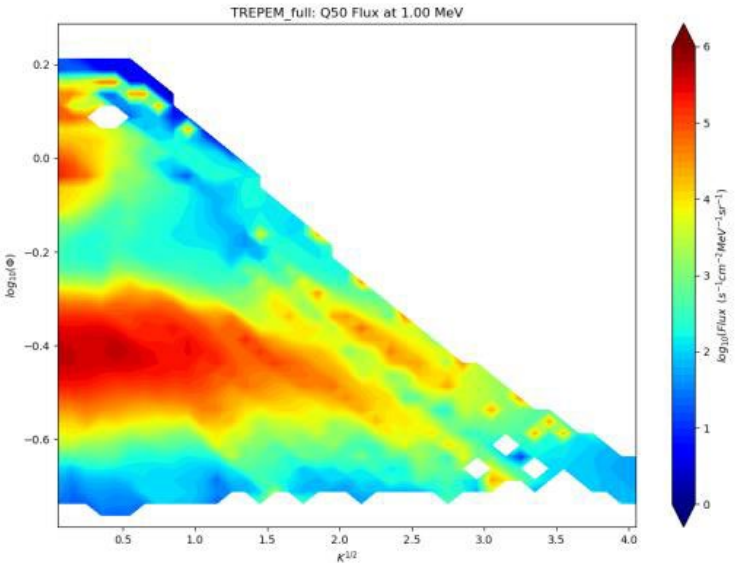
- AE9 uses Weibull distributions with 2 parameters, all others use LogNormal
- This creates discontinuities, stitched at run time
- Targeting a new framework to allow a smoother transition or alternatively merging distributions
- Model tracks uncertainty on the statistical parameters via error covariance
- Storing more data via a table-of-percentiles approach with a simplified error covariance may alleviate issue
- Also investigating other possible distributions which may be enhancing
- Performance is an issue, both in terms of number of parameters and speed of computation

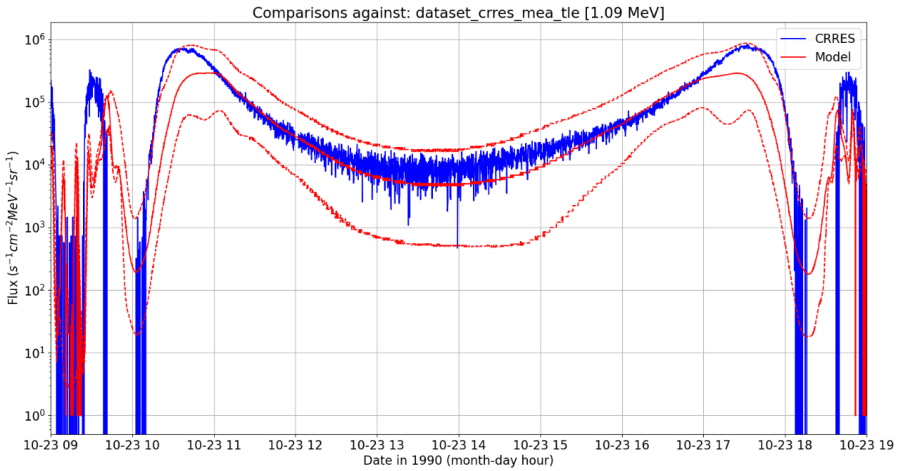


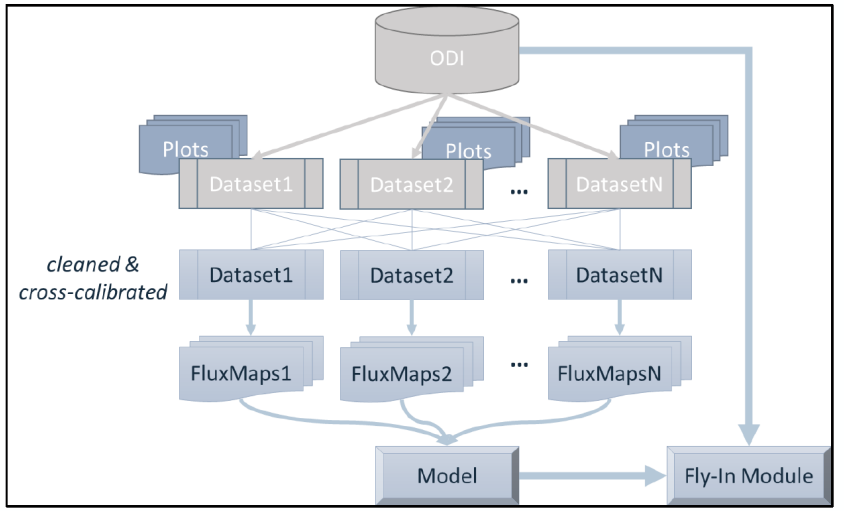


Trapped Particle Model - Data and Method Sensitivity

- The IRENE development code is in python
- An independent framework with a range of choices for model methods and distributions including cross-calibration, flux map production and merging, and fly-in modules has been developed
- This also allows studies to be performed using independent data sets both for model creation and validation
- Developments that are deemed enhancing can be fed into the IRENE development code for further testing
- Allows for realization of international component

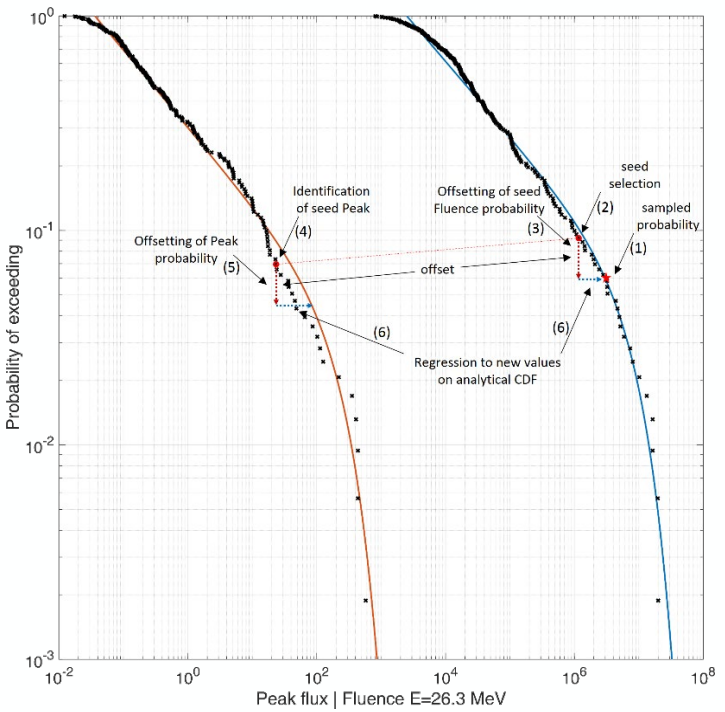




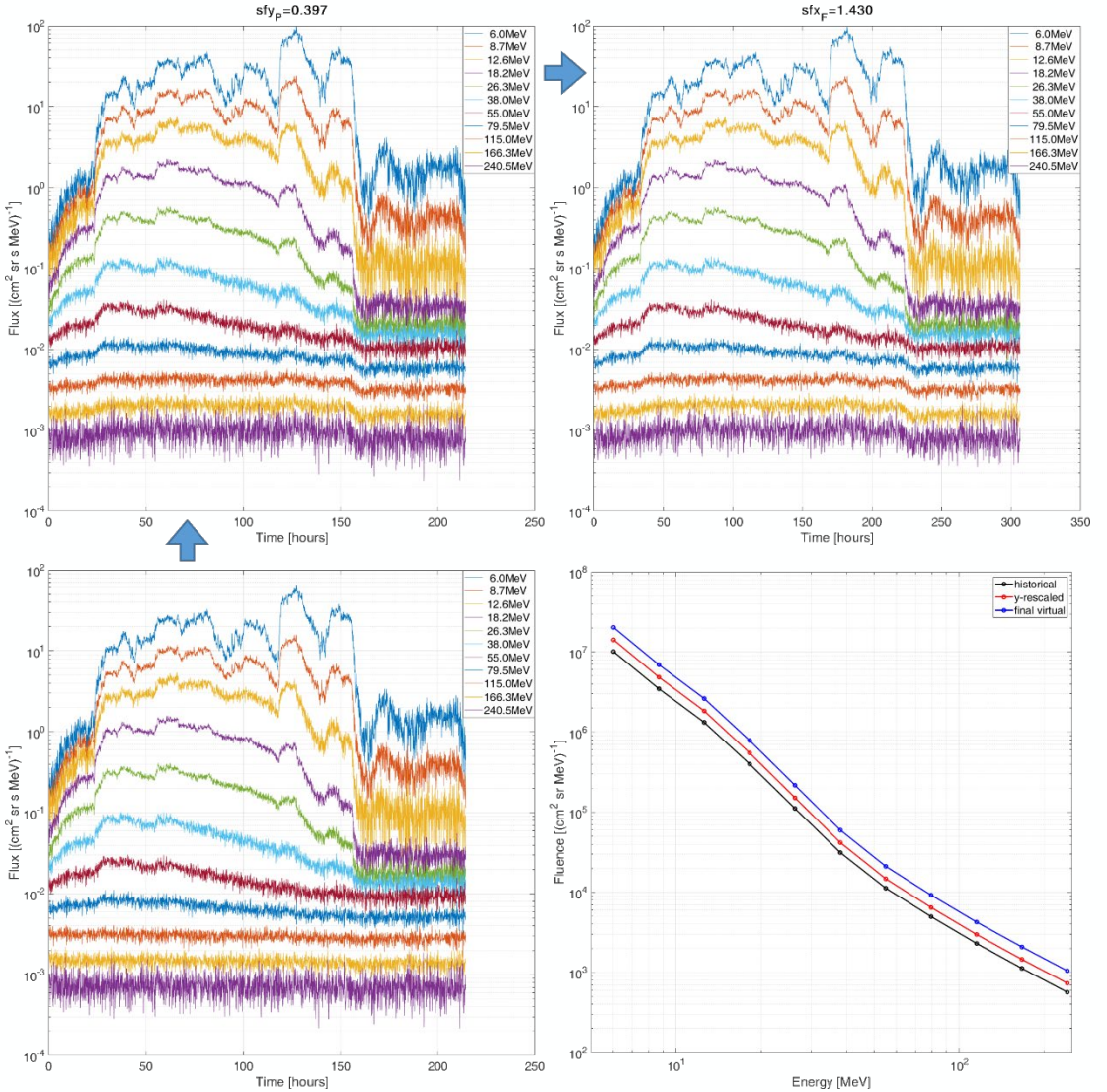


Solar Energetic Particles – SAPPHIRE-2S (S2S)

- SAPPHIRE-2S follows a virtual timelines approach with outputs of flux time series spectra for protons and helium via re-scaling of historical enhancements
- Retains spectral coherence in model outputs and allows time-varying effects calculation (e.g. SEE and interference)

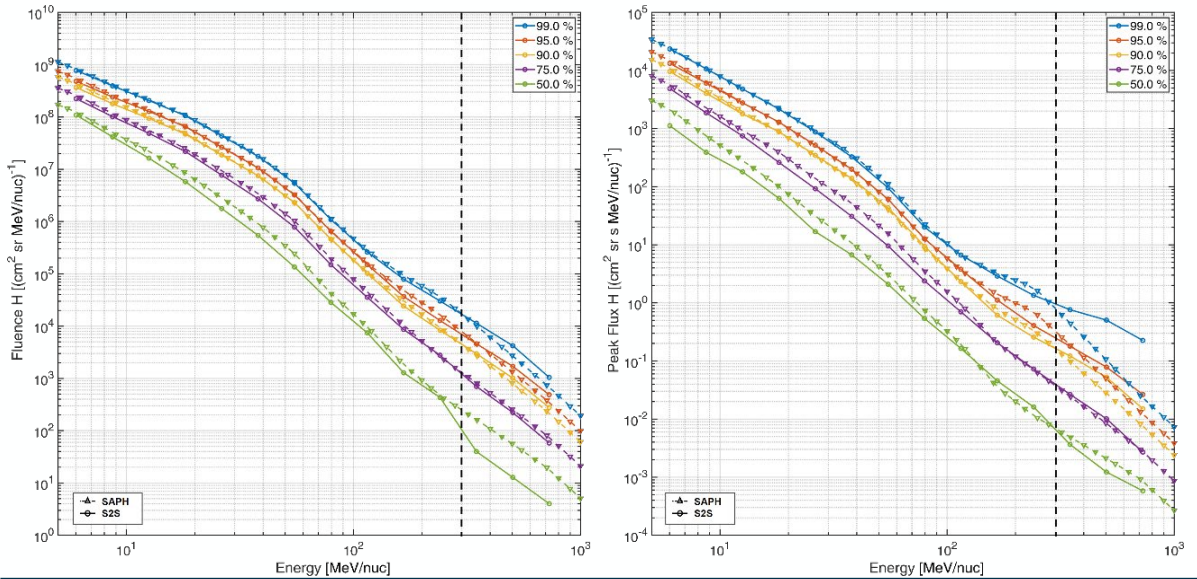


- Reference channel peak and fluence randomly sampled
- Model selects appropriate (historical) seed event based on flux/fluence
- Time series are scaled in flux to match the peak and time to match fluence
- All channels scaled, spectral coherence preserved



S2S Foreseen Implementation in IRENE

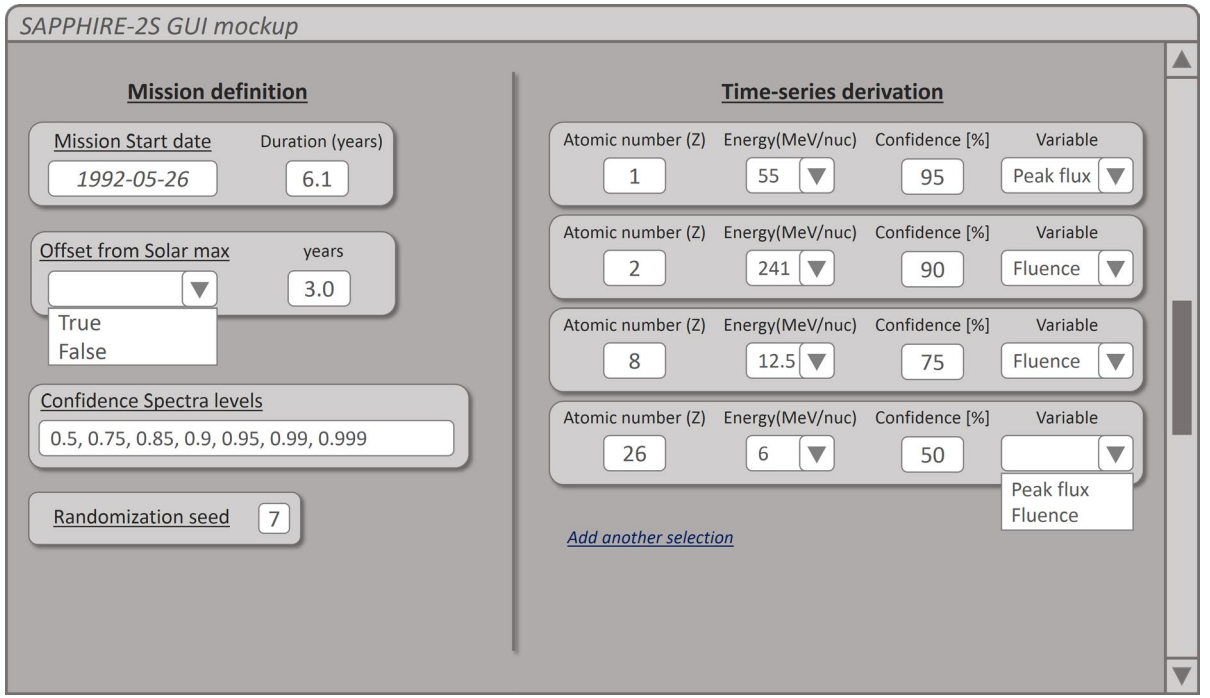
- SEP models (other than ESP fluence) are run as number large monte-carlo simulations/iterations from which confidence level outputs are extracted
- S2S model employs a 2-step process for speed-up:
  1. Pre-packaged 1 million years timeline of SEPs – VDS (Virtual Data Set)
  2. Operationally VDS is interrogated based on request

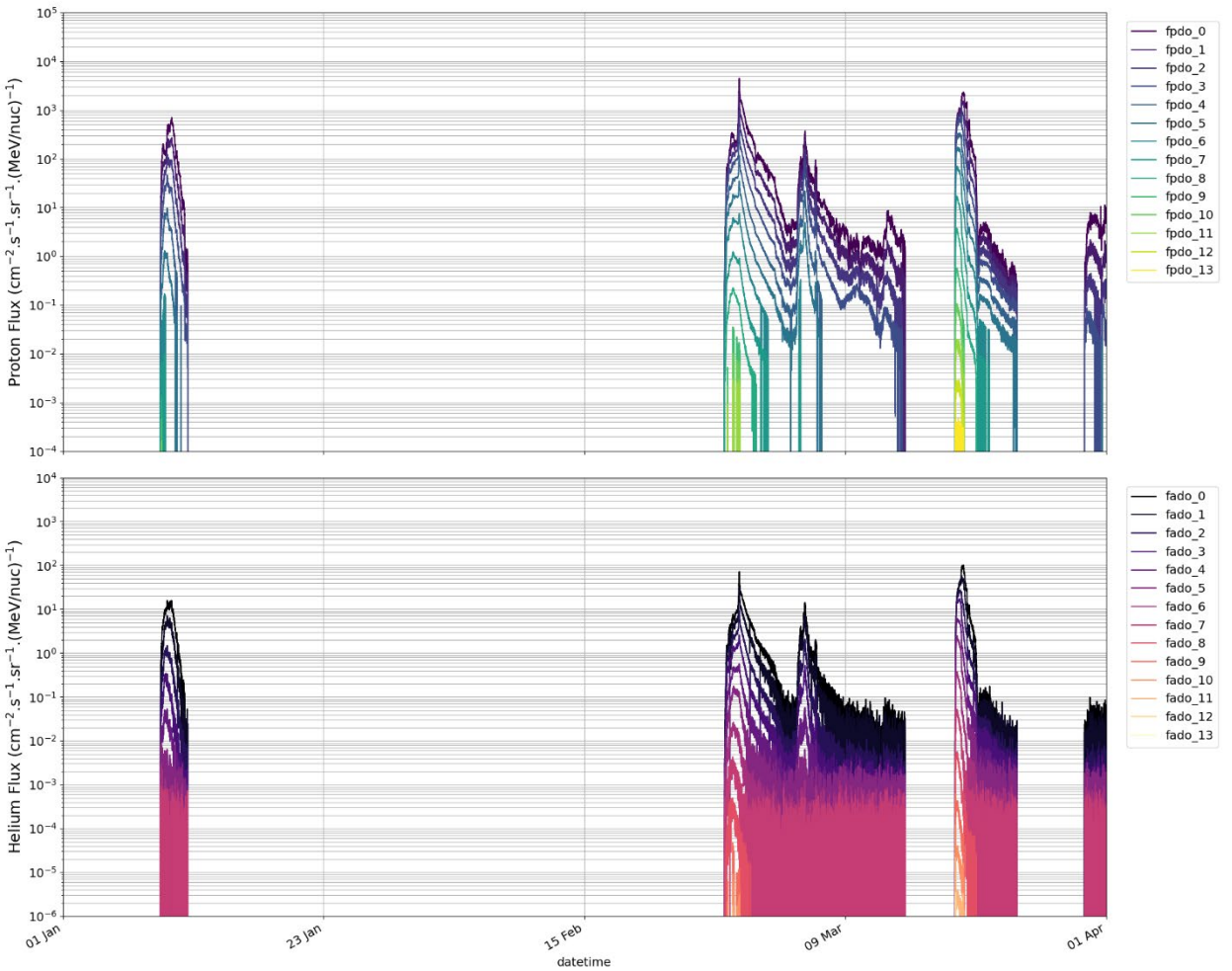


- Standard synoptic SEP model inputs:
  - Mission duration (and optionally orbit)
  - Solar conditions (per segment)
  - Confidence level(s)
- Standard synoptic SEP model outputs
  - "Envelope spectra" at confidence levels (e.g. proton fluence and flux shown)
  - Z = 1 to 92 (if requested)
- Additional user inputs for time-series production:
  - Energies (fixed @ RDSv3), species, confidence
- Additional output:
  - Time-series which satisfy user's selections
- Orbit input allows for geomag. shielding application
  - Applied on the time-series level

Example SAPPHIRE-2S inputs/outputs

- This is a 3-month snippet from a longer model output for a single iteration
- The tool will be able to return times series for given modes of user inputs or spectra outputs such as on the last slide
- Will also be possible to combine with MSM





NoM: Network of Models – Goals

Single **python client** API to run all NoM models

- Easier discovery of models and data
- Less custom scripting and validating of data

Lightweight, general facade to convert any model into a **NoM server**

- Can retro-fit existing projects
- Simple interface spec for new projects
- More time on model development
- Less requirement to create custom API

Standardise on model description:

- Model docs
- Model meta data (version, provider etc.)
- Input provision format
- Output formats
- Dynamic model GUI creation

- Single-authoritative source of model information

Standardise on data types:

- Spectra, time series, data maps, images …
- Particle fluxes, LET, dose-depth …

- Model interoperability and pipelining
- Simplifies data analysis
- Simplifies plotting
- …

Forms the new back-end for SPENVIS

NoM: Network of Models - Models

Types of models running on https://nom.esa.int

- Binary executables using input files (SD2, IRENE …)
- Binary executables + command line arguments (DLR GCR …)
- Python models (abundances …)
- Docker/containerised models (G4SpaceApps (GRAS, SSAT, MULASSIS))
- WebAPI/RestAPI/RPC models (ODI …)
- Composite, complex models using a combination of several models (SPLEEM, SEU Time Series Tool …)
- Models on other NoM Servers (soon)

Made possible because all models are wrapped by two simple interfaces:

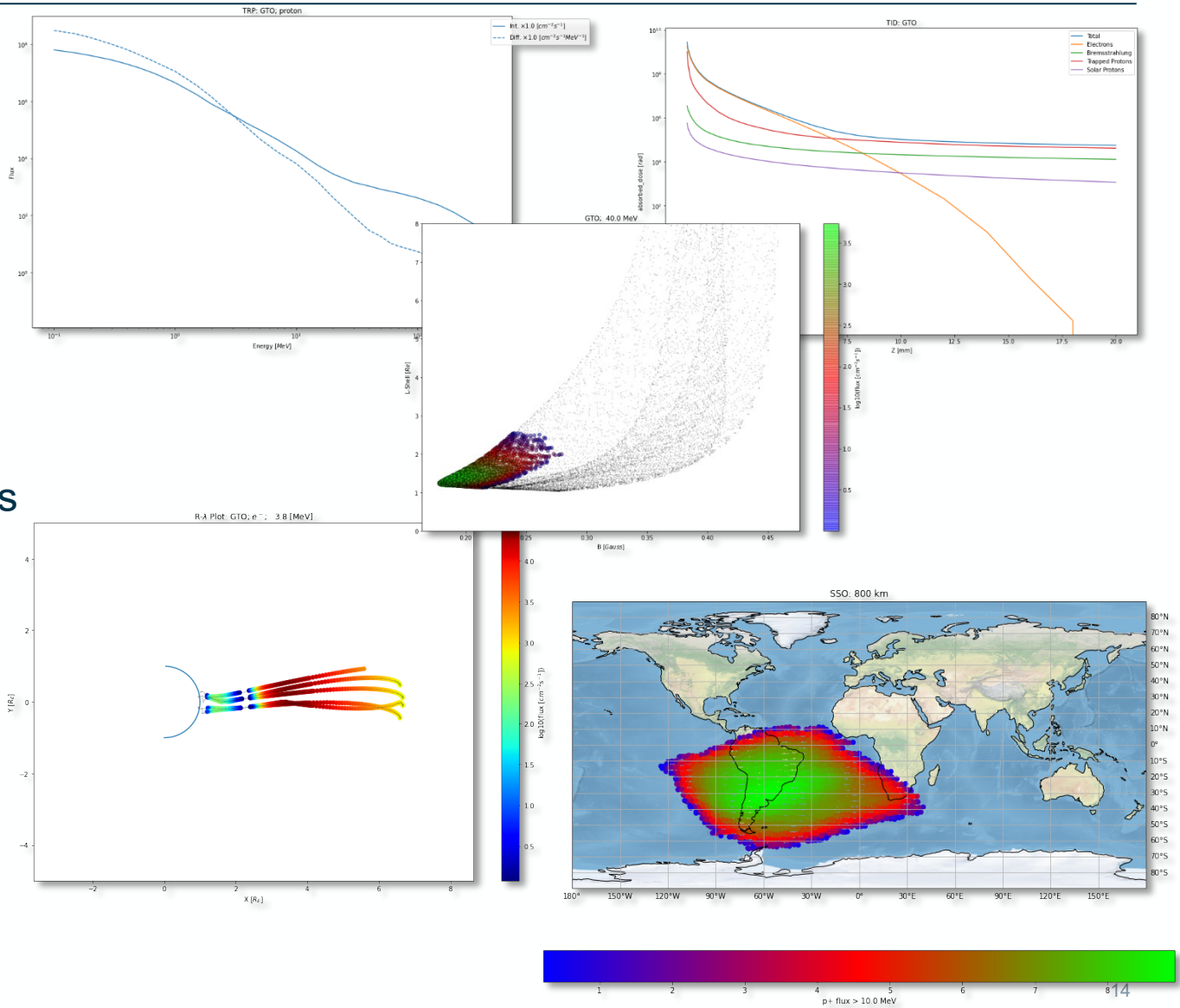
- ModelImplementation
- OutputReader

Model providers need only create two python classes implementing the above interfaces to allow their model to be run through NoM

Network Of Models: https://nom.esa.int

Libraries built on top of NoM:

- **nomplotlib**
  - Series of plotting functions to quickly and easily generate standardised plots of the NoM models for a radiation environment specification
- **nomanalysis**
  - A wrapper class to abstract away the details of performing a NoM analysis
  - Includes methods for outputting tables in CSV, HTML format, and integrates nomplotlib for plotting
  - Extensions include outputting an ECSS compliant Rad. Specification in MS-Word automatically



Useful links:

- ODI download via ESSR (ESA worldwide open source licenses)
  - Server Software: https://essr.esa.int/project/odi-open-data-interface-server
  - Client Software: https://essr.esa.int/project/odi-open-data-interface-client
  - ODI project site: https://spitfire.estec.esa.int/trac/ODI
  - TEC-EPS external servers:
    - REST https://spitfire.estec.esa.int/OdiREST/odi/api/v0.1
    - HAPI https://spitfire.estec.esa.int/hapi/
    - Dataset listing https://spitfire.estec.esa.int/ODI/show_datasets.php
    - SREM plots https://spitfire.estec.esa.int/ODI/dplot_SREM.html
- NOM: https://nom.esa.int/
- SPENVIS: https://spenvis.eu/
- Space Safety Programme: https://swe.ssa.esa.int/

The appearance of external hyperlinks does not constitute endorsement by the United States Department of Defense (DoD) of the linked websites, or the information, products, or services contained therein. The DoD does not exercise any editorial, security, or other control over the information you may find at these locations.