The background of the slide features a vibrant, artistic representation of the sun in the bottom-left corner, with bright orange and yellow rays emanating from it. In the upper center, a small, blue and white globe of Earth is visible against a light blue sky. The overall aesthetic is clean and scientific, with a focus on space-related imagery.

# Python Tools for Cosmic-Ray and Solar Particle Analysis with Metis and EPD/HET Data

Preliminary Results on Out-of-the-Ecliptic Observations: The Unique Detection of the SEP Event Dated August 21–24, 2025 with Metis

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# Outline

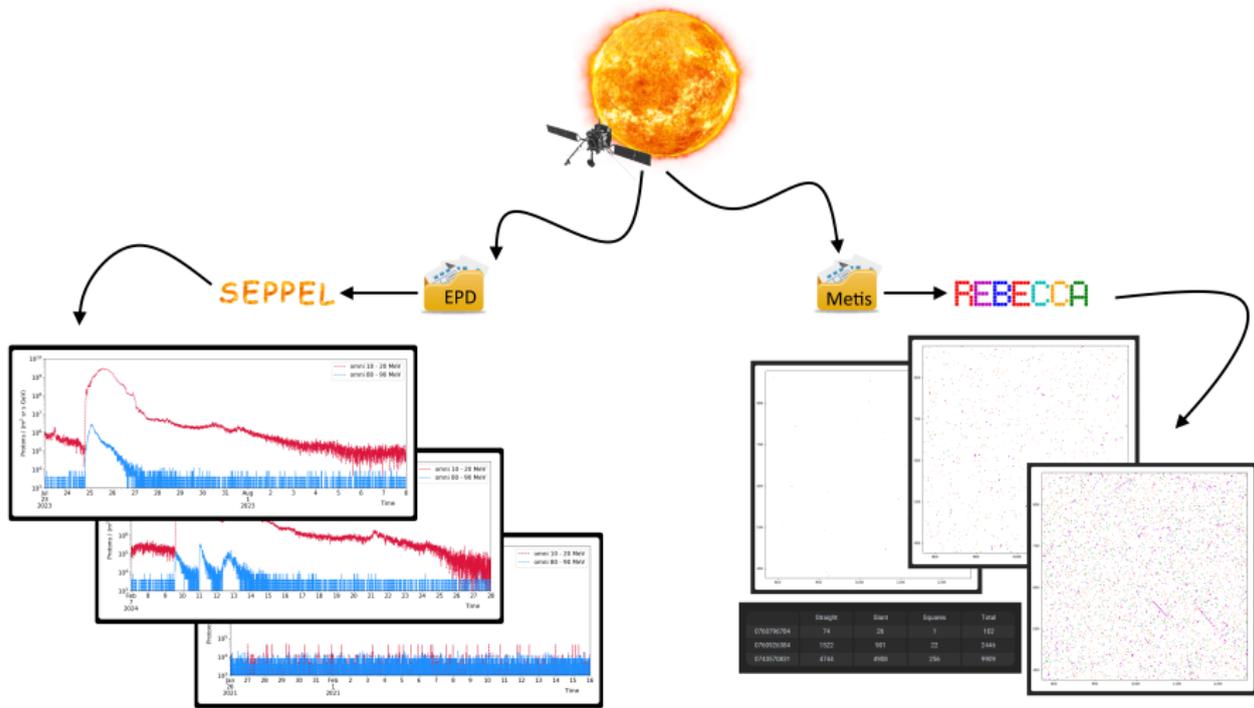
- 1 Overview
- 2 SEPPEL as a Visual Tool for Solar Energetic Particle Events
- 3 REBECCA to Automate the Cosmic-Ray Matrix Analysis
- 4 Case Study: The Strongest SEP Event of Solar Cycle 25
- 5 Conclusions

# Motivation

## Activity overview

- Monitoring galactic cosmic-ray variations and solar energetic particle events
- Necessity of correlating data from multiple instruments
- 👉 Solar Orbiter multi-instrument observations of X-ray, electron and proton fluxes of solar origin
- Study of the correlation of the overall particle flux outside and inside the spacecraft
- Development of dedicated tools for efficient data analysis and handling

# Solar Energetic Particle Event Analysis



## SEPPEL

SEPPEL
- □ ×

<input type="checkbox"/> 10 - 20 MeV	<input type="checkbox"/> 15 - 25 MeV	<input type="checkbox"/> 20 - 30 MeV	<input type="checkbox"/> 30 - 40 MeV	<input type="checkbox"/> 40 - 50 MeV	<input type="button" value="← Select"/>
<input type="checkbox"/> 50 - 60 MeV	<input type="checkbox"/> 60 - 70 MeV	<input type="checkbox"/> 70 - 80 MeV	<input type="checkbox"/> 80 - 90 MeV	<input type="checkbox"/> 15 - 20 MeV	<input type="button" value="← Select"/>
<input type="checkbox"/> 30 - 50 MeV	<input type="checkbox"/> 30 - 90 MeV	<input type="checkbox"/> 50 - 70 MeV	<input type="checkbox"/> 70 - 90 MeV	<input checked="" type="checkbox"/> 10 - 90 MeV	<input type="button" value="← Select"/>

<input type="checkbox"/> sun	<input type="checkbox"/> asun
<input type="checkbox"/> north	<input type="checkbox"/> south
<input checked="" type="checkbox"/> omni	

<input type="button" value="Reset energies"/>	<input type="button" value="Reset detectors"/>
<input type="button" value="All energies"/>	<input type="button" value="All detectors"/>



SEPPEL

Solar Energetic  
Particle event  
Plot ELaboration

Time window	days
- 2021-10-06 12:00 +	- 9 +
GCR background	days
- 2021-10-07 00:00 +	- 2 +
Onset	minutes
- 2021-10-09 07:00 +	- 120 +
Peak	minutes
- 2021-10-09 11:00 +	- 60 +
Decay	minutes
- 2021-10-09 21:40 +	- 60 +

Public data up to  $\sim 100$  MeV available on SOAR  
 (<https://soar.esac.esa.int/>)

Higher-energy data kindly provided by the EPD/HET Collaboration to study the particle impact both inside and outside the spacecraft

Federico Sabbatini (UniUrb, INFN)

SEPPEL & REBECCA

February 12, 2026

5 / 19

## SEPPEL

SEPPEL

Select event

10 - 20 MeV 15 - 25 MeV 20 - 30 MeV 30 - 40 MeV 40 - 50 MeV <-- Select  
50 - 60 MeV 60 - 70 MeV 70 - 80 MeV 80 - 90 MeV 15 - 20 MeV <-- Select  
30 - 50 MeV 30 - 90 MeV 50 - 70 MeV 70 - 90 MeV 10 - 90 MeV <-- Select

sun asun  
north south  
omni

Reset energies Reset detectors  
All energies All detectors

SEP catalogue (local file)

**SEPPEL**  
Solar Energetic  
Particle event  
Plot ELaboration

Time window days  
2021-10-06 12:00 9  
GCR background days  
2021-10-07 00:00 2  
Onset minutes  
2021-10-09 07:00 120  
Peak minutes  
2021-10-09 11:00 60  
Decay minutes  
2021-10-09 21:40 60

> Zoom in <  
< Zoom out >  
<< Back  
Forth >>

Save  
Plot  
Details

## SEPPEL

SEPPEL

Select event

<input type="checkbox"/> 10 - 20 MeV	<input type="checkbox"/> 15 - 25 MeV	<input type="checkbox"/> 20 - 30 MeV	<input type="checkbox"/> 30 - 40 MeV	<input type="checkbox"/> 40 - 50 MeV	<- Select
<input type="checkbox"/> 50 - 60 MeV	<input type="checkbox"/> 60 - 70 MeV	<input type="checkbox"/> 70 - 80 MeV	<input type="checkbox"/> 80 - 90 MeV	<input type="checkbox"/> 15 - 20 MeV	<- Select
<input type="checkbox"/> 30 - 50 MeV	<input type="checkbox"/> 30 - 90 MeV	<input type="checkbox"/> 50 - 70 MeV	<input type="checkbox"/> 70 - 90 MeV	<input checked="" type="checkbox"/> 10 - 90 MeV	<- Select

sun  asun  
 north  south  
 omni

Reset energies    Reset detectors  
All energies    All detectors

Energy ranges locally defined in custom file

**SEPPEL**  
Solar Energetic  
Particle event  
Plot ELaboration



Time window    days  
- 2021-10-06 12:00 + - 9 +

GCR background    days  
- 2021-10-07 00:00 + - 2 +

Onset    minutes  
- 2021-10-09 07:00 + - 120 +

Peak    minutes  
- 2021-10-09 11:00 + - 60 +

Decay    minutes  
- 2021-10-09 21:40 + - 60 +

> Zoom in <  
< Zoom out >  
<< Back  
Forth >>

Save  
Plot  
Details

## SEPPEL

SEPPEL

Select event

10 - 20 MeV  15 - 25 MeV  20 - 30 MeV  30 - 40 MeV  40 - 50 MeV <-- Select  
 50 - 60 MeV  60 - 70 MeV  70 - 80 MeV  80 - 90 MeV  15 - 20 MeV <-- Select  
 30 - 50 MeV  30 - 90 MeV  50 - 70 MeV  70 - 90 MeV  10 - 90 MeV <-- Select

sun  asun  
 north  south  
 omni

Reset energies Reset detectors  
All energies All detectors

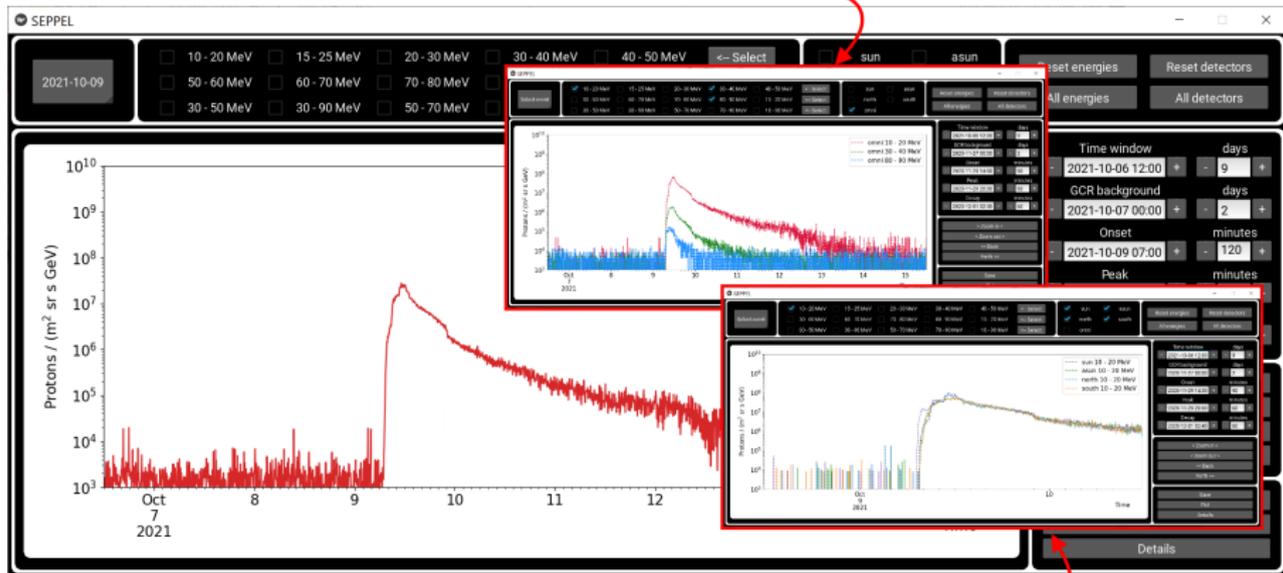
Time window days  
- 2021-10-06 12:00 + 9 +  
GCR background days  
- 2021-10-07 00:00 + 2 +  
Onset minutes  
- 2021-10-09 07:00 + 120 +  
Peak minutes  
- 2021-10-09 11:00 + 60 +  
Decay minutes  
- 2021-10-09 21:40 + 60 +

> Zoom in <  
< Zoom out >  
<< Back  
Forth >>

Save  
Plot  
Details

Available detectors / fields of view

## SEPPEL



Rodríguez-Pacheco+, A&A 642, A7, 2020  
 Grimani+, A&A 645, A15, 2021  
 Grimani+, A&A 677, A45, 2023

Grimani+, A&A 686, A74, 2024  
 Grimani+, A&A 705, A103, 2026

# SEPPEL

## Main features

- Flexible and customisable via user-defined files
- Complete workflow
  - 1 Data download from SOAR
  - 2 CDF pre-processing
  - 3 Time series visualisation
  - 4 Plot customisation
  - 5 Local saving
- Implemented in Python
  - Standard modules + kivy
- 👉 Available upon request
- 👉 Release on GitHub after proper cross-platform validation

## REBECCA



VL matrices only. Same performance (spurious pixels)

## REBECCA

REBECCA

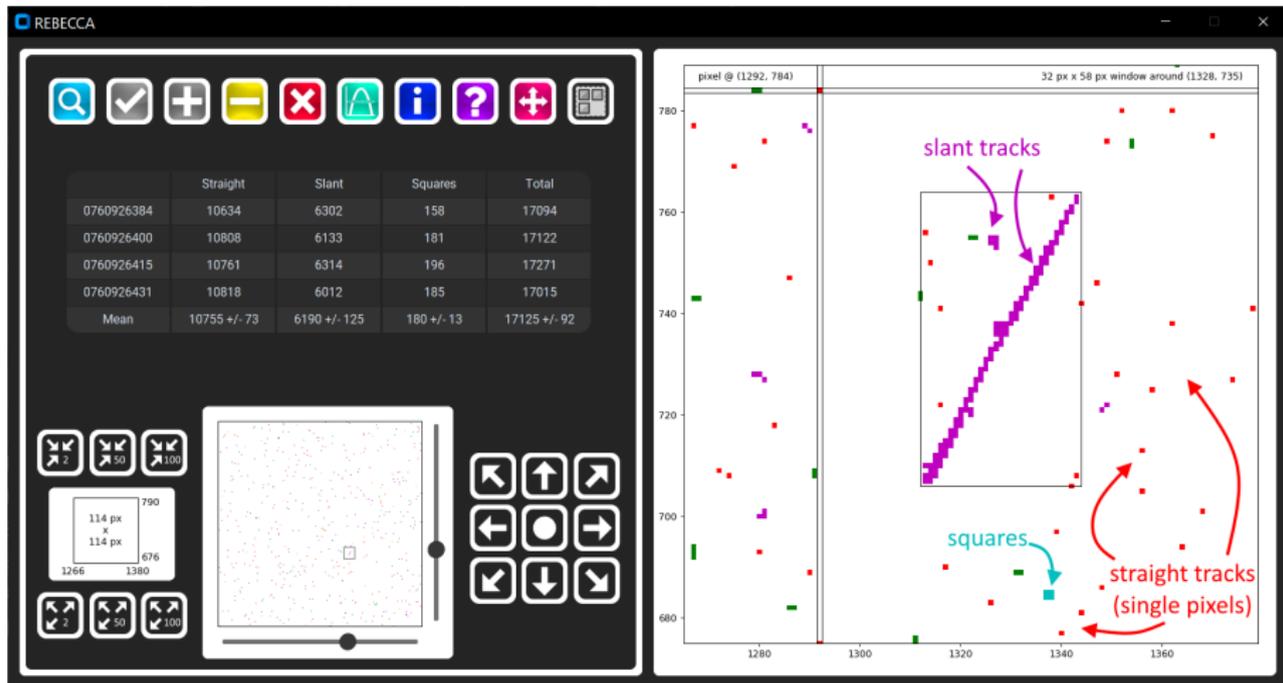
-  Search and open. Find a fits file and open it
-  Confirm. Noisy rows and columns are removed, the percentage of fired pixels is calculated and shown
-  Add. The cosmic-ray matrix is added to the table, if not already present
-  Remove. Select a row from the table, then use this button to delete the corresponding matrix from the table
-  Reset. Remove all cosmic-ray matrices from the table
-  Statistics. Calculate the average values and the standard deviation for the matrices in the table
-  Info. Select a row from the table, then use this button to get the metadata of the corresponding matrix
-  Quick guide. Open this help window
-  Drag mode. Left click + drag to navigate the matrix. Right click on a pixel to set the center of the matrix
-  Select mode. Left click + drag to select a submatrix. Right click to navigate the matrix

Zoom in

Zoom out

Go to the center of the matrix or move towards the direction of the arrow

## REBECCA



Antonucci+, A&A 642, A10, 2020  
 Fineschi+, Exp. Astron. 49, 239, 2020

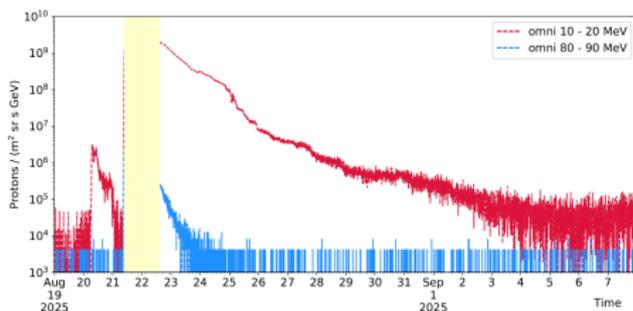
Romoli+, A&A 656, A32, 2021  
 Grimani+, A&A 705, A103, 2026

# REBECCA

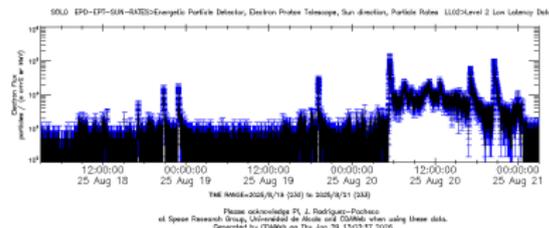
## Main features

- Lightweight computation
- ✗ Matrix files to be manually supplied after human quality check
- Automated count based on lessons learned with previous viewers
- Topology identification based on colours
- Complete and fast analysis over multiple matrices (few seconds)
  - Prior visual analysis only possible on small sub-matrices (many hours)
- Implemented in Python
  - Standard modules + CustomTkinter
- 👉 Available upon request
- 👉 Release on GitHub after proper cross-platform validation

# The SEP Event Dated August 21–24, 2025

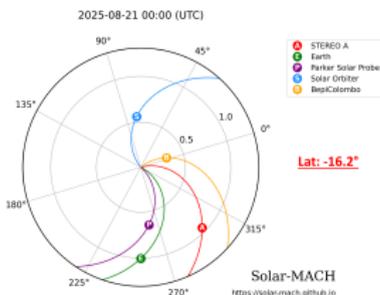


EPD/HET proton data (SEPPEL)

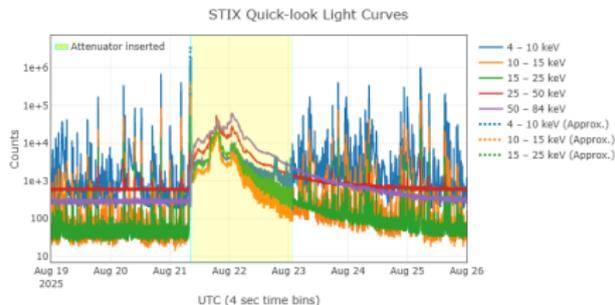


EPD/EPT electron data

<https://cdaweb.gsfc.nasa.gov/>



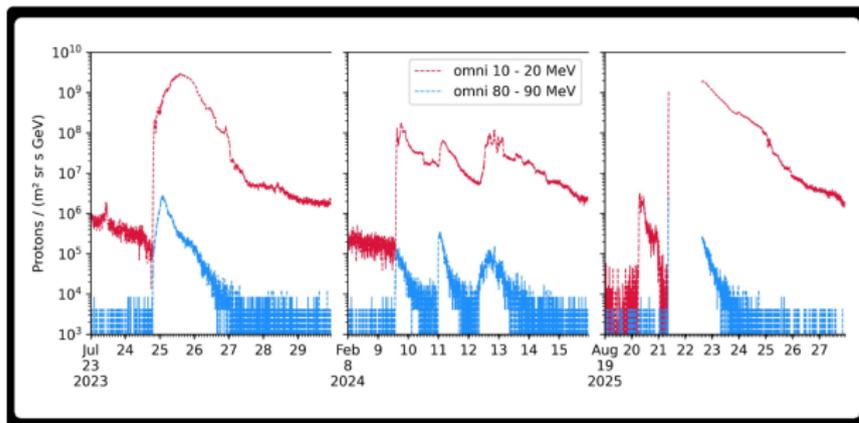
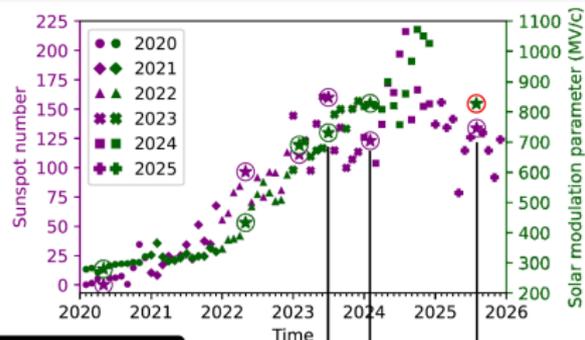
<https://solar-mach.streamlit.app/>



STIX photon data

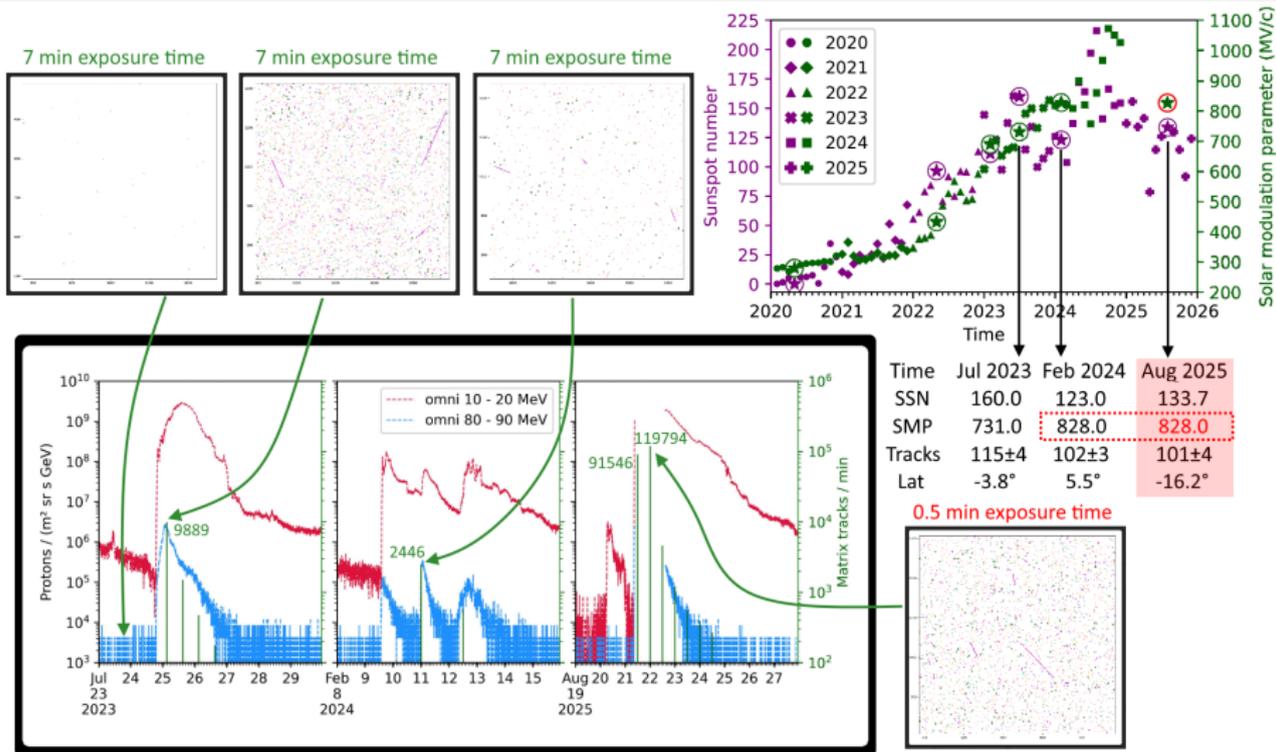
<https://datacenter.stix.i4ds.net/>

# The SEP Event Dated August 21–24, 2025



Time	Jul 2023	Feb 2024	Aug 2025
SSN	160.0	123.0	133.7
SMP	731.0	828.0	828.0
Tracks	115±4	102±3	101±4
Lat	-3.8°	5.5°	-16.2°

# The SEP Event Dated August 21–24, 2025



Only Metis followed the whole event dynamics

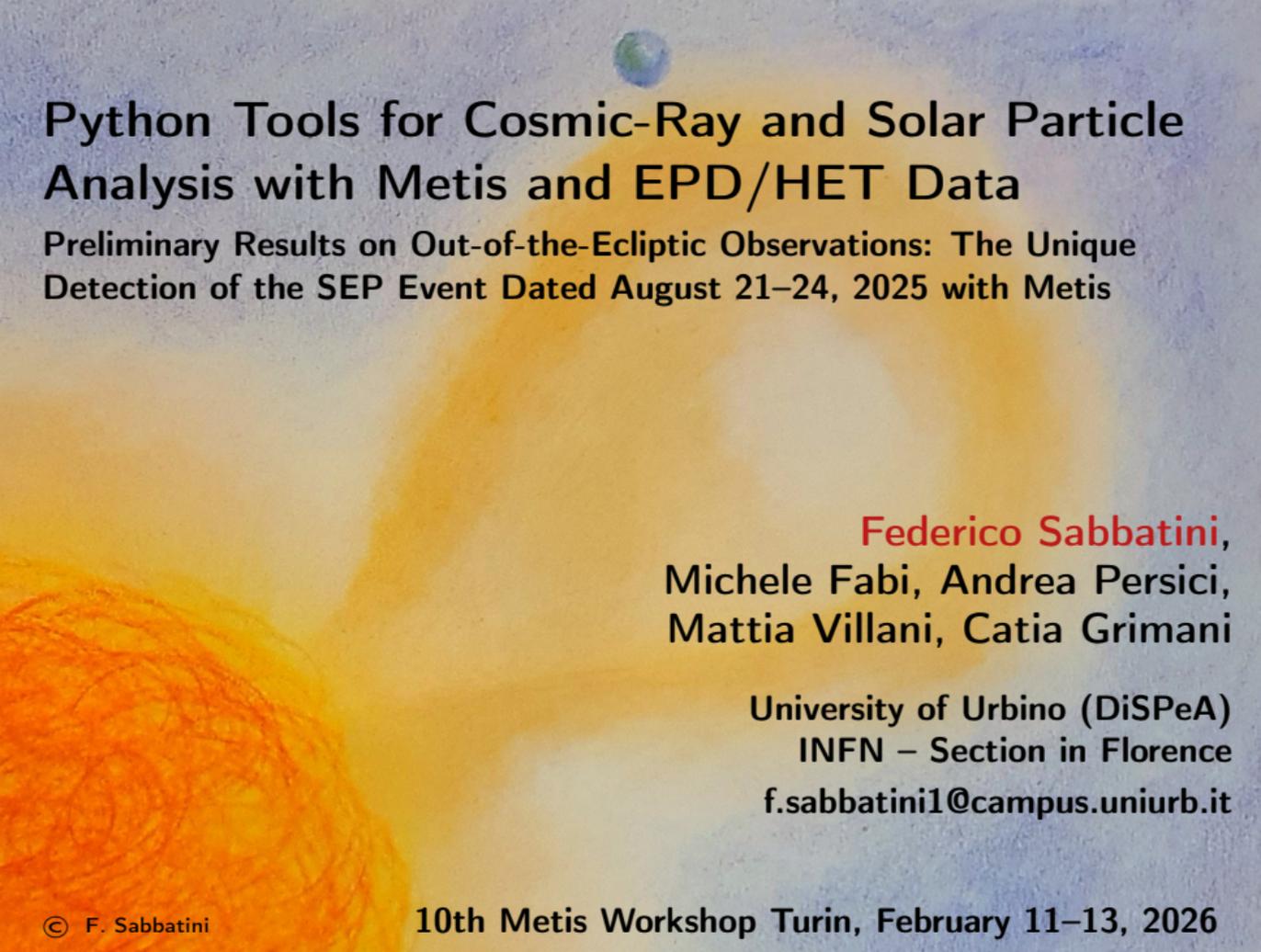
# Conclusions & Next Steps

## Current achievements

- Visual tool for galactic and solar particles → SEPPEL
- Automated analysis of cosmic-ray matrices → REBECCA
- Current results suggest a solar modulation parameter for August 2025 similar to that of February 2024
- Metis allowed a unique study of the strongest SEP event of Solar Cycle 25

## Next steps

- Release SEPPEL + REBECCA
- Reconstruct the August 2025 event by simulating varying proton fluxes to obtain results aligned with the matrix tracks and the observed decay

The background of the slide features a stylized, artistic representation of the sun in the bottom-left corner, rendered in vibrant orange and yellow colors with a textured, scribbled appearance. In the upper center, a small, realistic image of the Earth is visible against a light blue sky. The overall background has a soft, painterly texture with a gradient from light blue at the top to a pale yellow/orange at the bottom.

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