

Results from the space-borne High Energy Particle Detector (HEPD-01) after 6 years in orbit

Alessio Perinelli^(1,2) *on behalf of the CSES-Limadou collaboration*

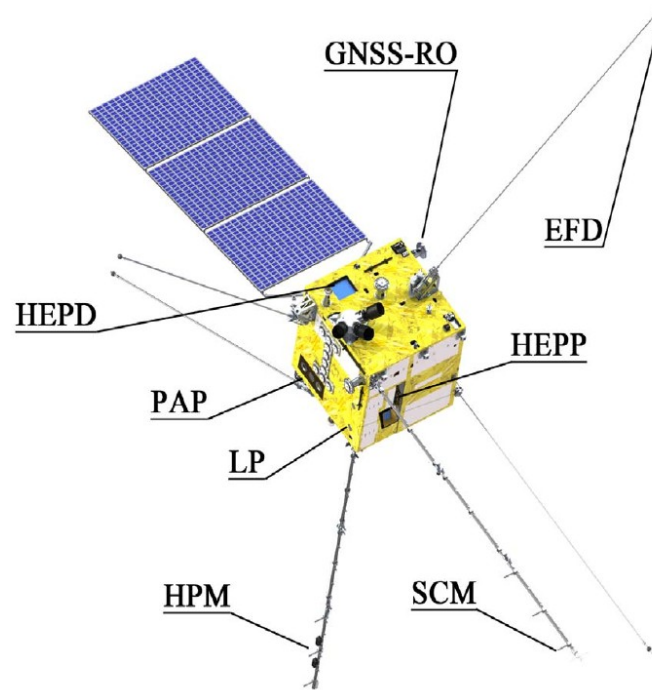
(1) Department of Physics, University of Trento, Italy

(2) Trento Institute of Fundamental Physics and Applications (TIFPA-INFN), University of Trento, Italy



CSES-01

China Seismo-Electromagnetic Satellite



- investigate the **ionosphere**
- **particles** and **plasma** perturbations
- **solar physics**
- **cosmic rays**

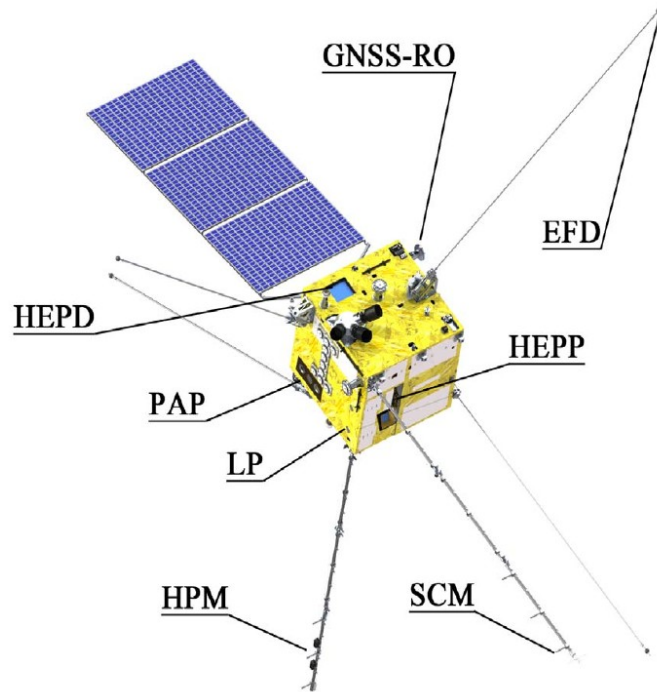
Launched Feb. 2018

Shen *et al.* (2018). The state-of-the-art of the China Seismo-Electromagnetic Satellite mission. *Sci. China Technol. Sci.* **61**:634.

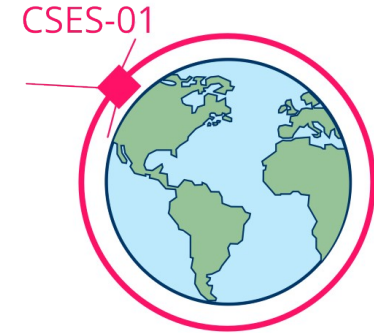
The CSES-01 satellite

CSES-01

China Seismo-Electromagnetic Satellite

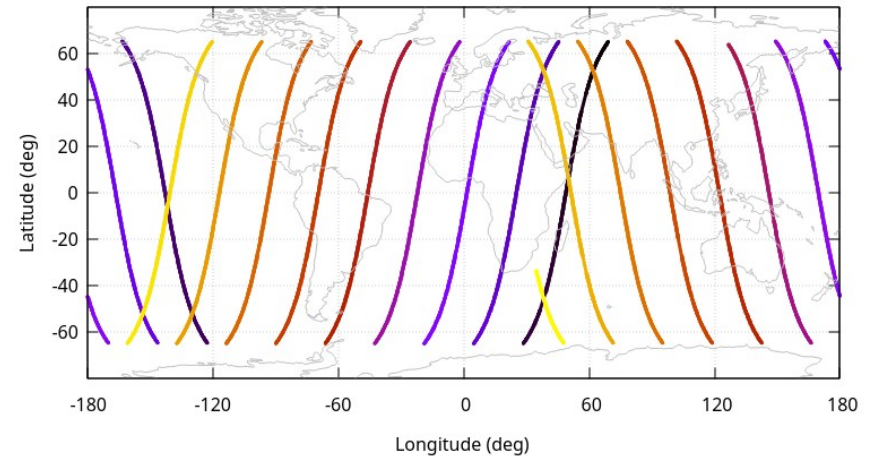


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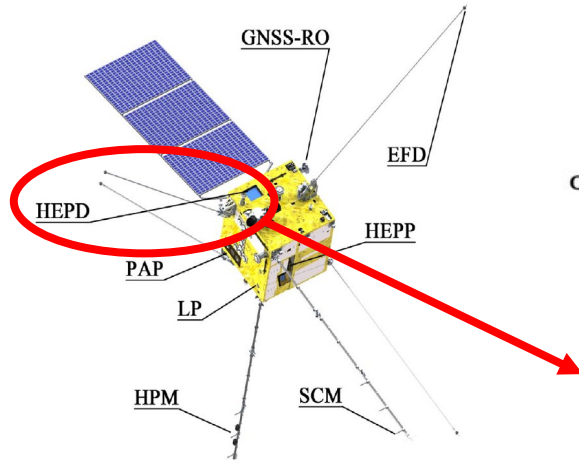


- **Sun-synchronous, 97° inclination (quasi-polar)**
- Altitude **~500 km**
- Period **~94 min**
- Return time **~5 days**

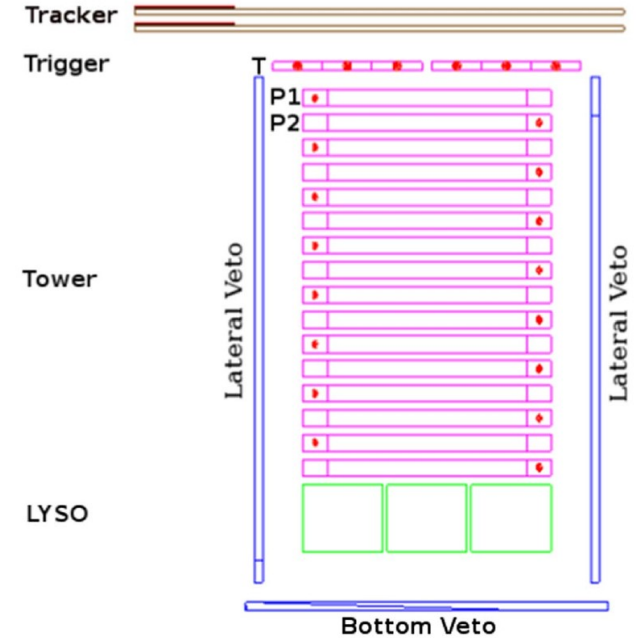
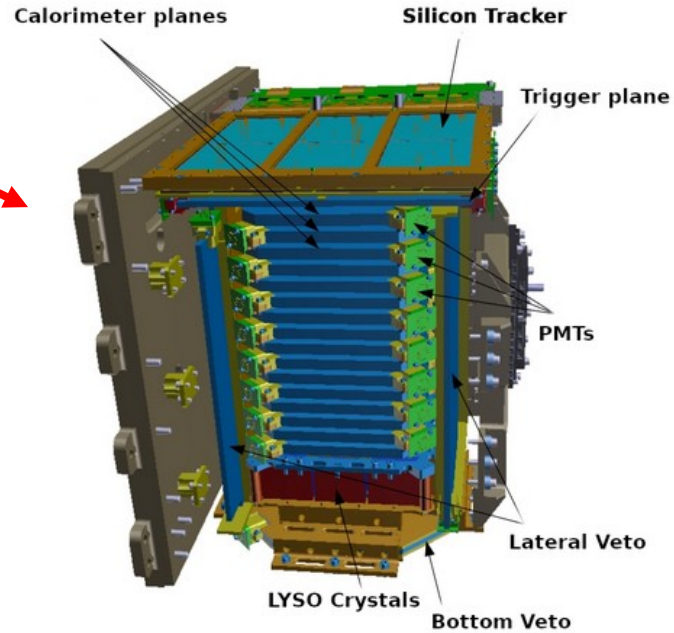
1-day footprint



Shen *et al.* (2018). The state-of-the-art of the China Seismo-Electromagnetic Satellite mission. *Sci. China Technol. Sci.* **61**:634.



HEPD-01 High-Energy Particle Detector

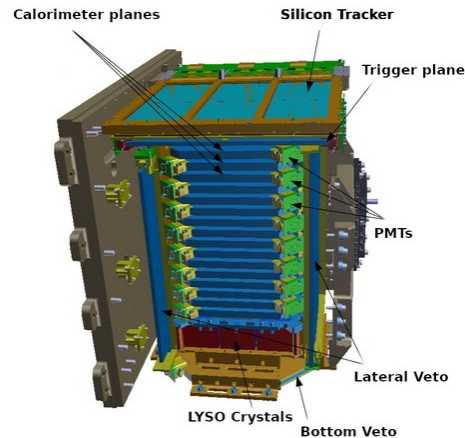


Picozza *et al.* (2019). Scientific goals and in-orbit performance of the high-energy particle detector on board the CSES-01. *The Astrophysical Journal Supplement Series*, **243**:16.

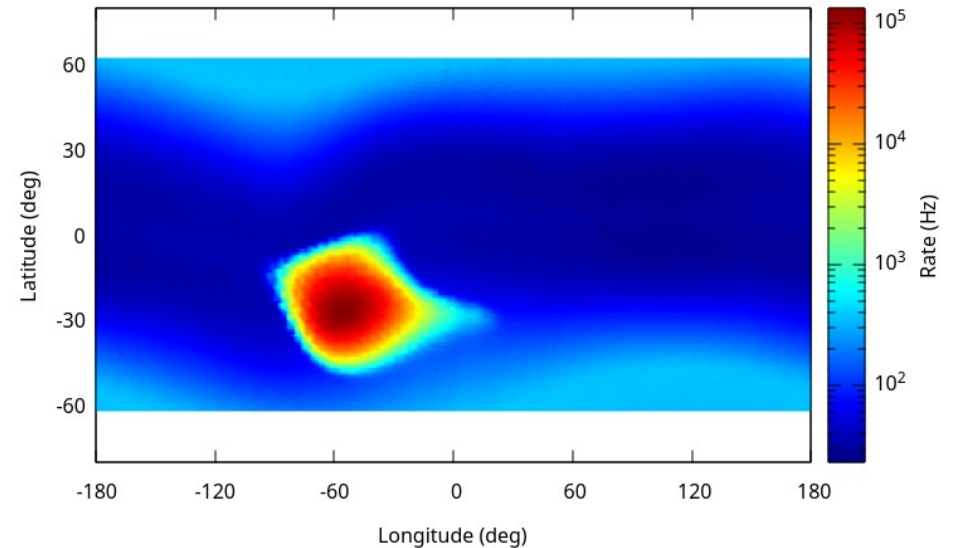
HEPD-01

High-Energy Particle Detector

- Electrons **3-100 MeV**
- Protons **30-300 MeV**
- Light nuclei up to few **100 MeV/n**
- Angular acceptance ~ 1 sr
- Geometric factor up to $300 \text{ cm}^2 \text{ sr}$



Trigger rate over the Earth

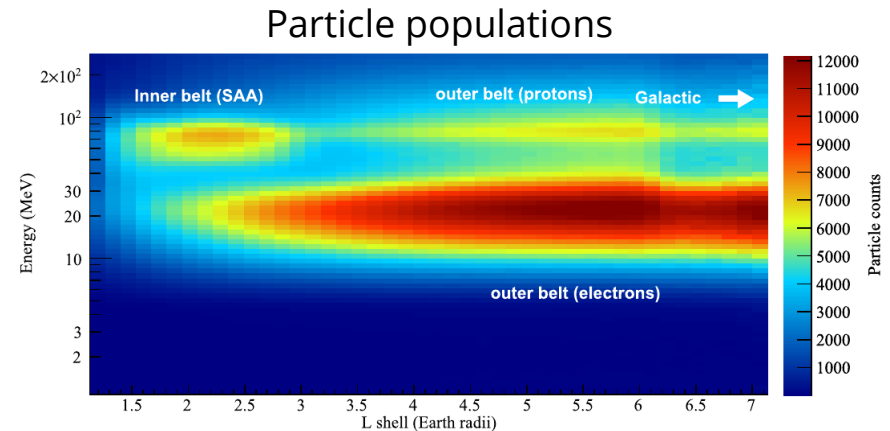
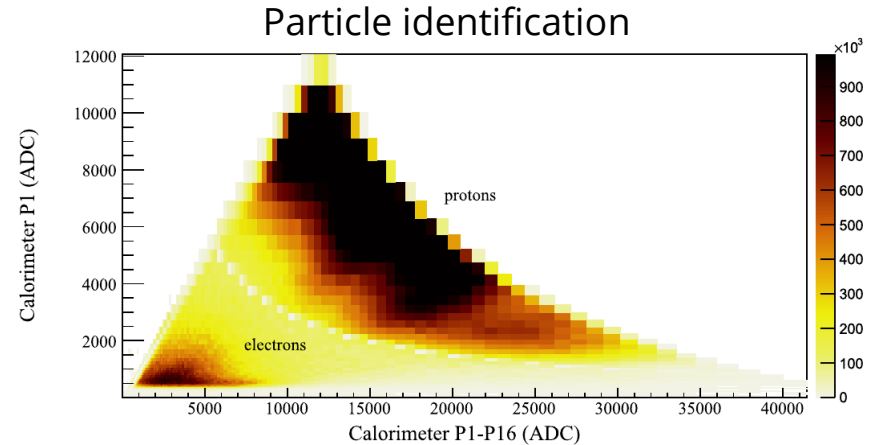
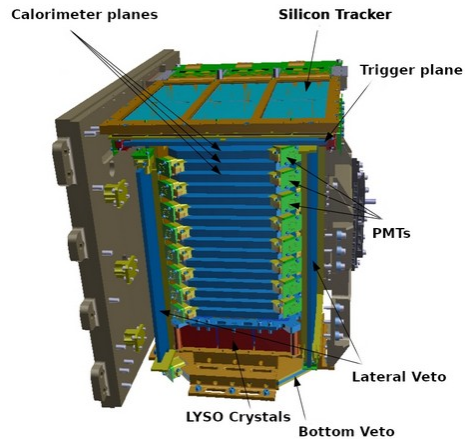


Picozza *et al.* (2019). Scientific goals and in-orbit performance of the high-energy particle detector on board the CSES-01. *The Astrophysical Journal Supplement Series*, **243**:16.

HEPD-01

High-Energy Particle Detector

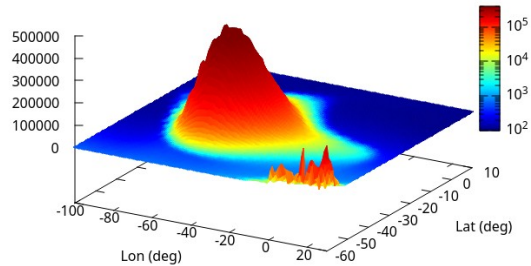
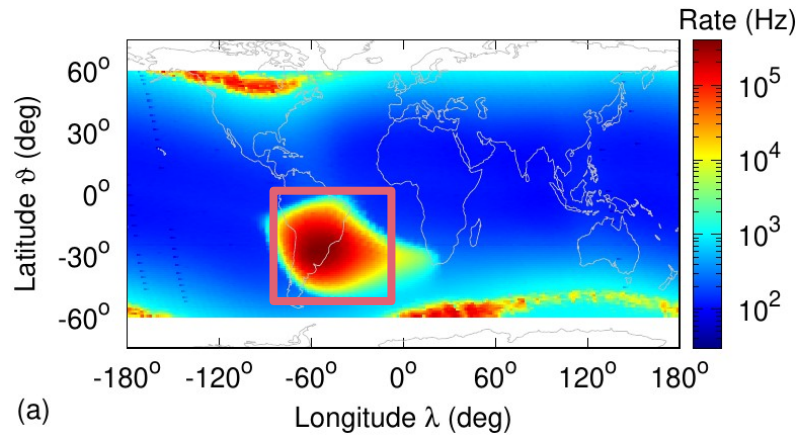
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Near-Earth environment - SAA characterization

Trapped particle population

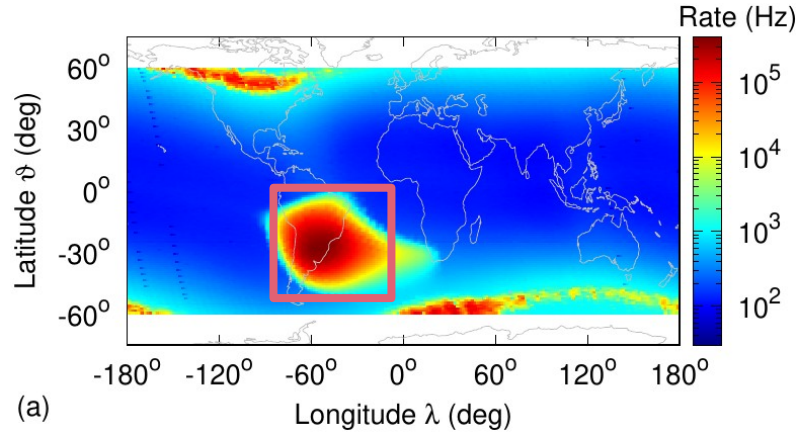


CSES-Limadou collaboration (2024). Mapping the South Atlantic Anomaly charged particle environment with the HEPD-01 detector on board the CSES-01 satellite. *In preparation*.

Martucci et al. (2022). New results on protons inside the South Atlantic Anomaly, at energies between 40 and 250 MeV in the period 2018–2020, from the CSES-01 satellite mission. *Phys. Rev. D* **105**, 062001

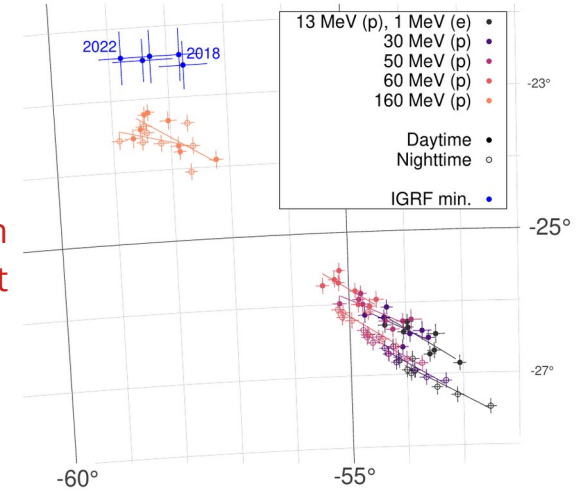
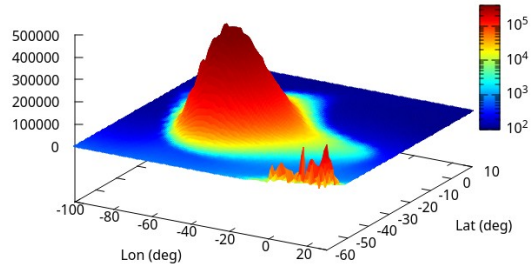
Near-Earth environment - SAA characterization

Trapped particle population



→ characterization of SAA drift

0.14 ± 0.02 deg/year North
 0.28 ± 0.03 deg/year West

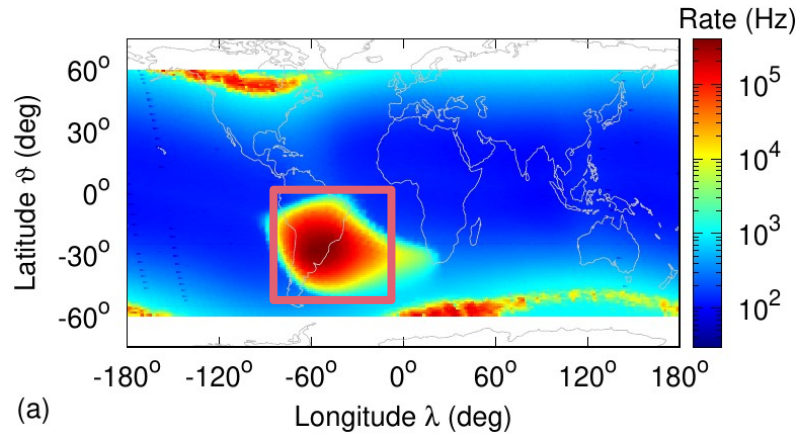


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Near-Earth environment - SAA characterization

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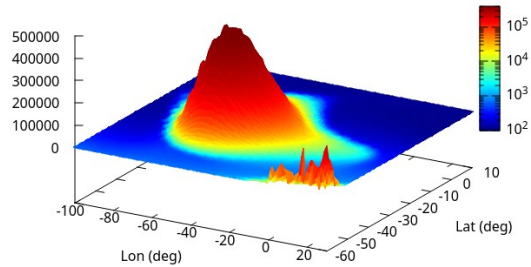
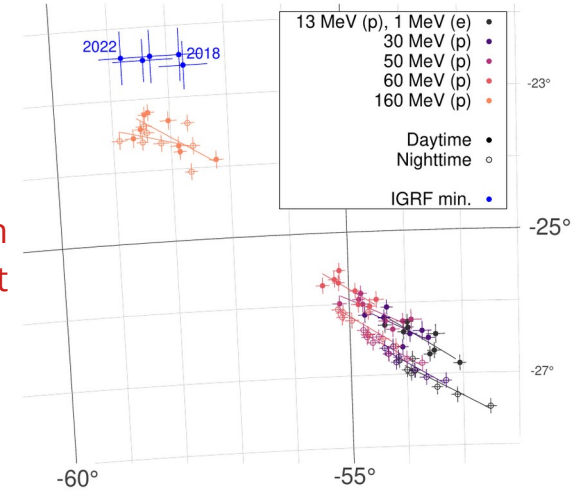


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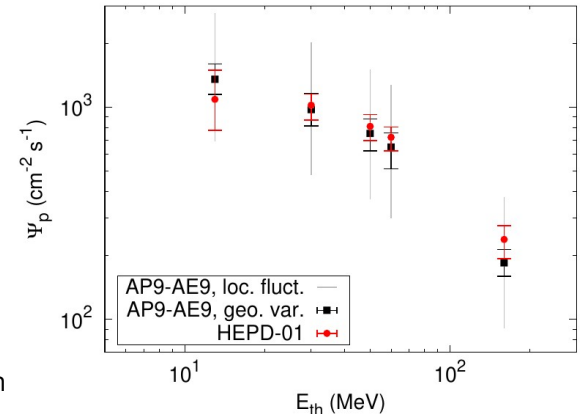
→ HEPD-01 estimate of integral proton flux

Validation of AP9-AE9



CSES-Limadou collaboration (2024). Mapping the South Atlantic Anomaly charged particle environment with the HEPD-01 detector on board the CSES-01 satellite. *In preparation*.

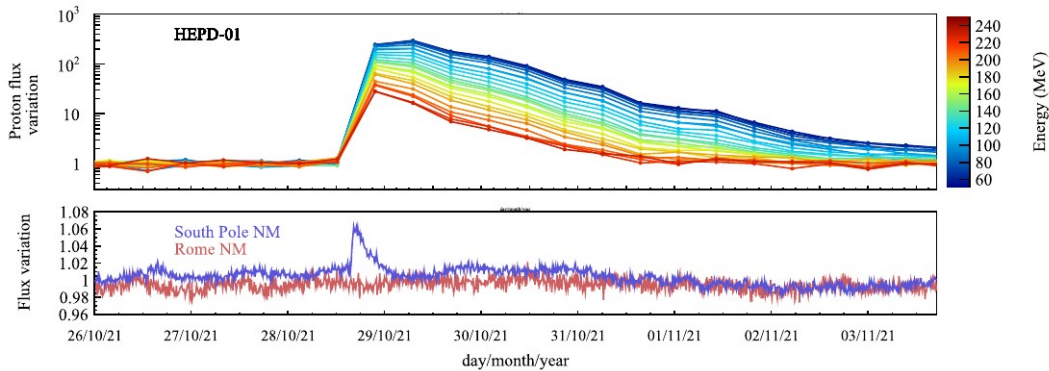
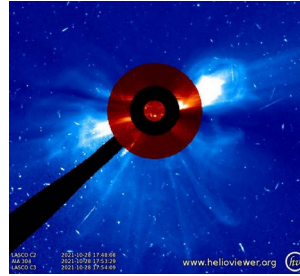
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28 October 2021:

Long X1-class flare + coronal mass ejection

→ **Ground Level Enhancement**

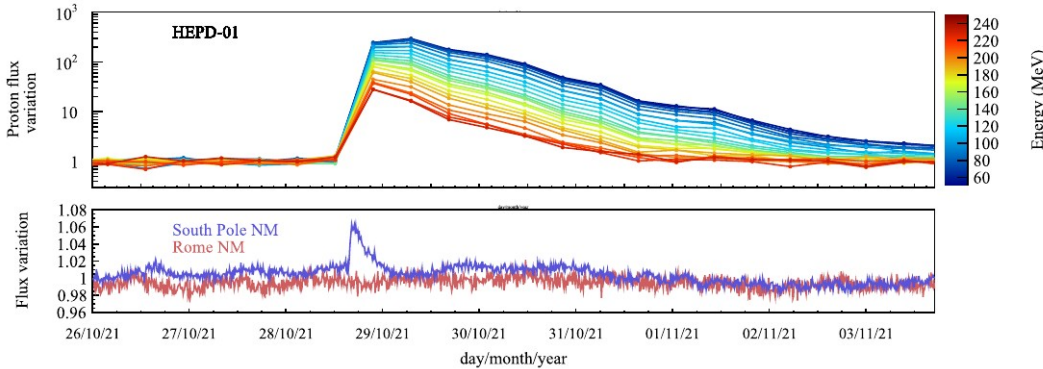


Martucci et al. (2023). The First Ground-Level Enhancement of Solar Cycle 25 as Seen by the High-Energy Particle Detector (HEPD-01) on Board the CSES-01 Satellite. *Space Weather* **21**, e2022SW003191

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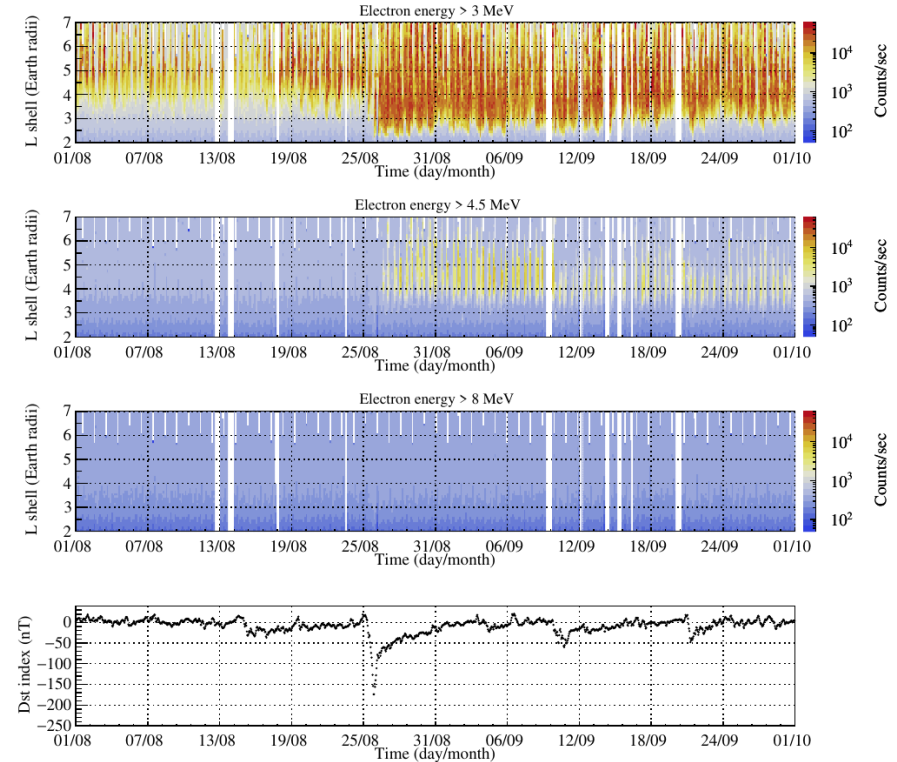
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20 August 2018:

coronal mass ejection → **large geomagnetic storm**



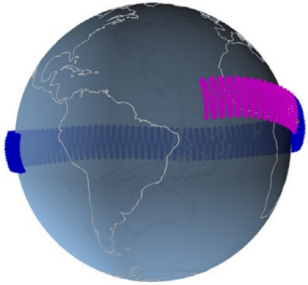
Palma et al. (2021). The August 2018 Geomagnetic Storm Observed by the High-Energy Particle Detector on Board the CSES-01 Satellite. *Appl. Sci.* **11**, 5680.

Re-entrant albedo protons

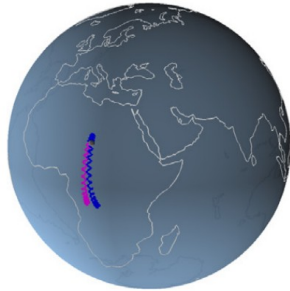
Secondary products of cosmic rays interacting with atmosphere → re-entrant = returning towards Earth

trajectory-tracing software → **classify** albedo protons into three populations

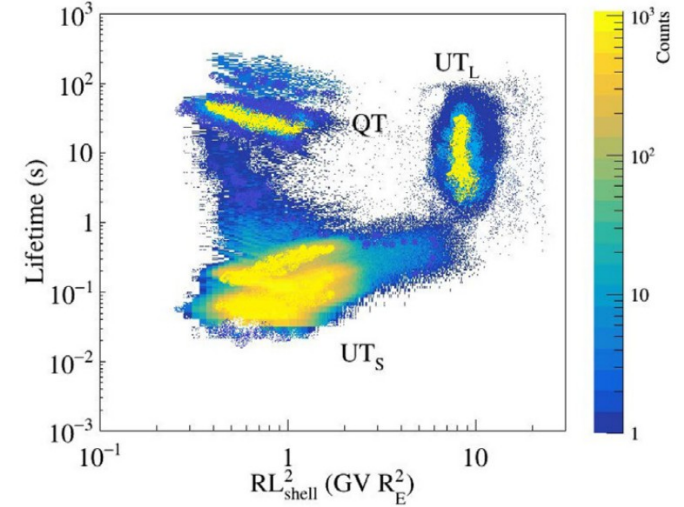
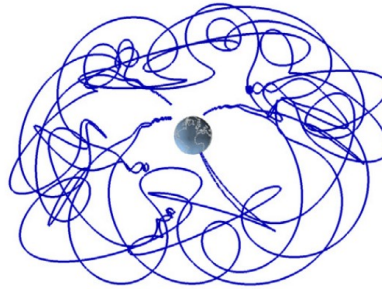
Quasi-Trapped



UnTrapped (short)



UnTrapped (long)

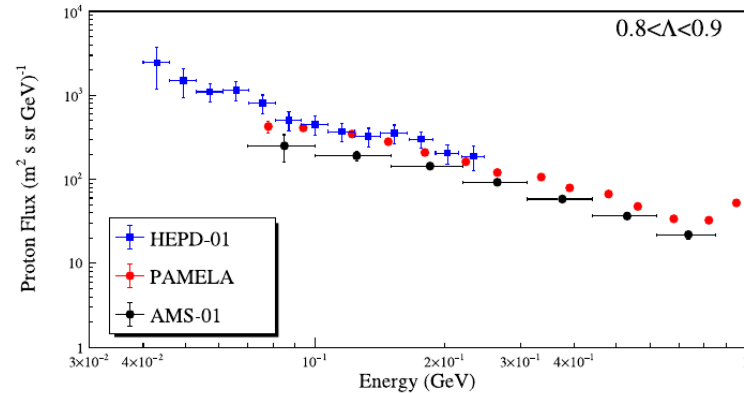
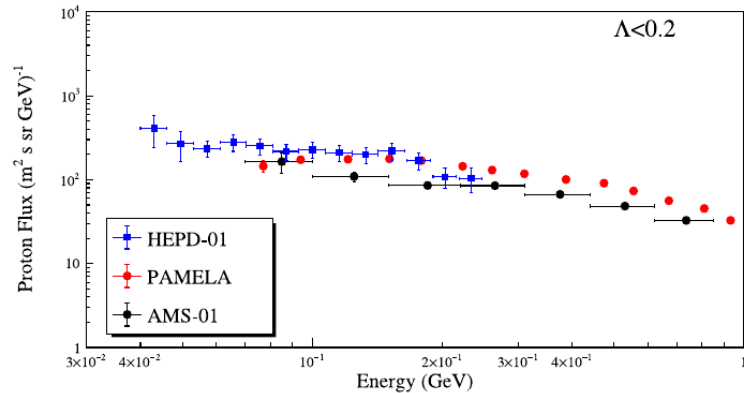


Martucci et al. (2024). Measurements of low-energy, re-entrant albedo protons by the HEPD-01 space-borne detector. *Astroparticle Physics* **162**, 102993

Re-entrant albedo protons

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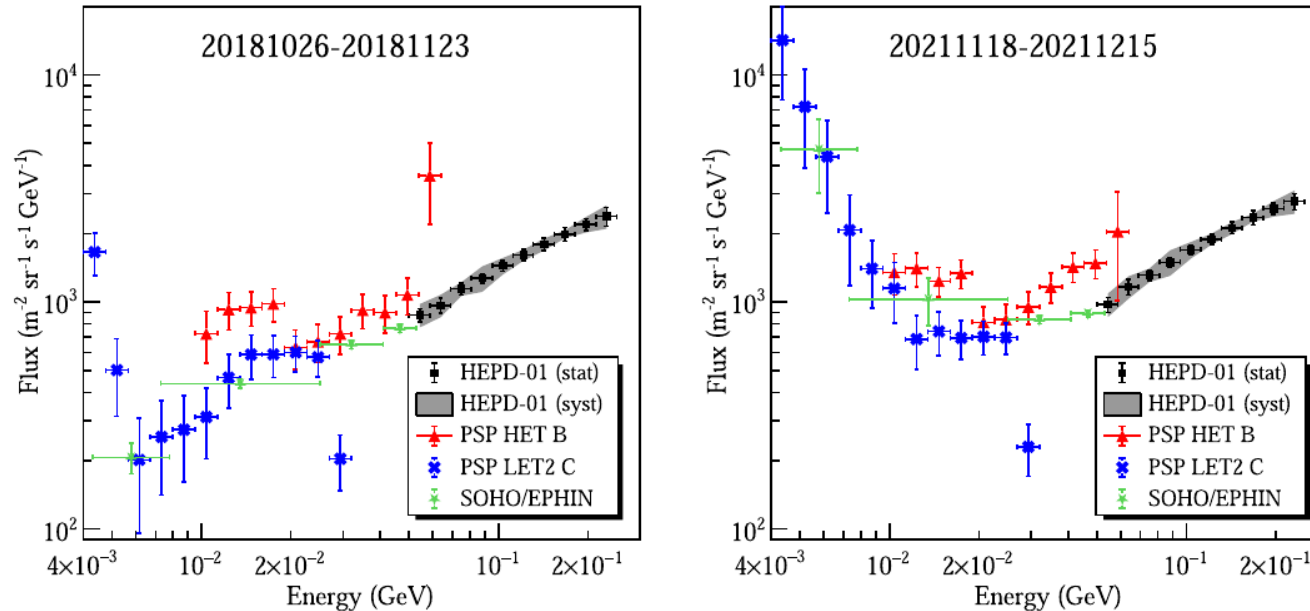
Extending AMS-01 and PAMELA ranges



Martucci et al. (2024). Measurements of low-energy, re-entrant albedo protons by the HEPD-01 space-borne detector. *Astroparticle Physics* **162**, 102993

Fluxes of **cosmic ray protons** ~50 – 250 MeV

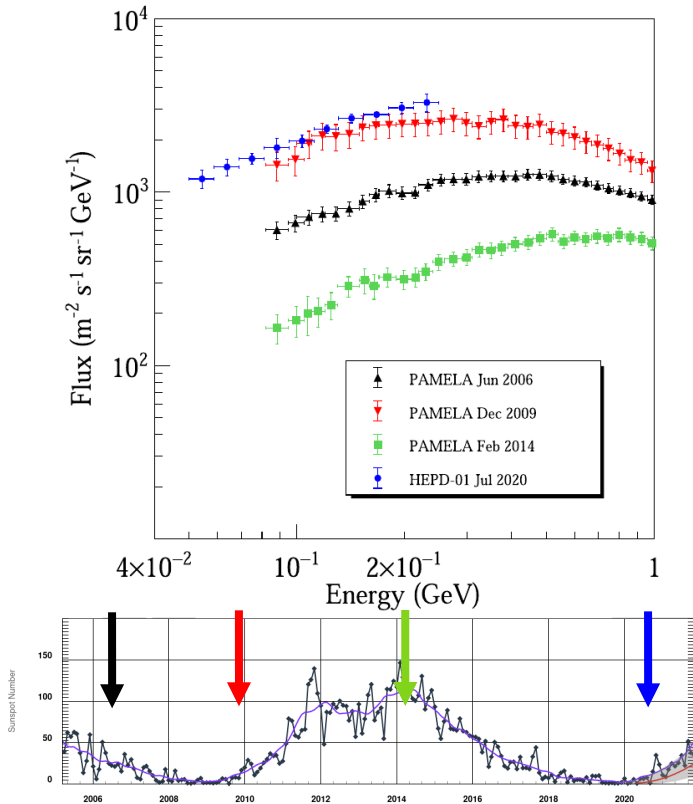
- Rigidity cut-off > 0.26 GV
- $L > 7$, excluding geomagnetic storms, flares, SEP events



Bartocci et al. (2020). Galactic Cosmic-Ray Hydrogen Spectra in the 40–250 MeV Range Measured by the High-energy Particle Detector (HEPD) on board the CSES-01 Satellite between 2018 and 2020. *Astrophys. J.* **901**, 8

Martucci et al. (2023). Time Dependence of 50–250 MeV Galactic Cosmic-Ray Protons between Solar Cycles 24 and 25, Measured by the High-energy Particle Detector on board the CSES-01 Satellite. *Astrophys. J. Lett.* **945**, L39

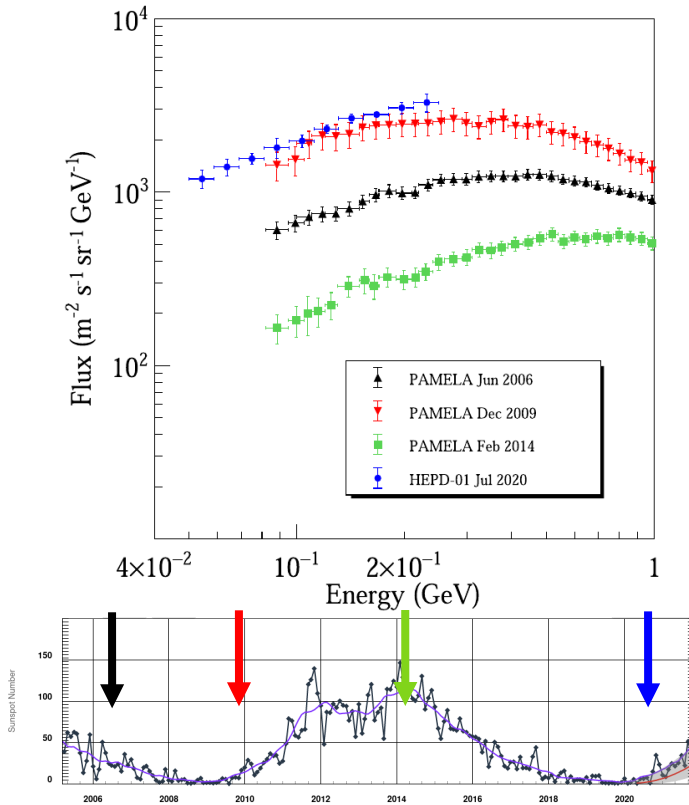
Time modulation of cosmic ray proton flux 2018-2022



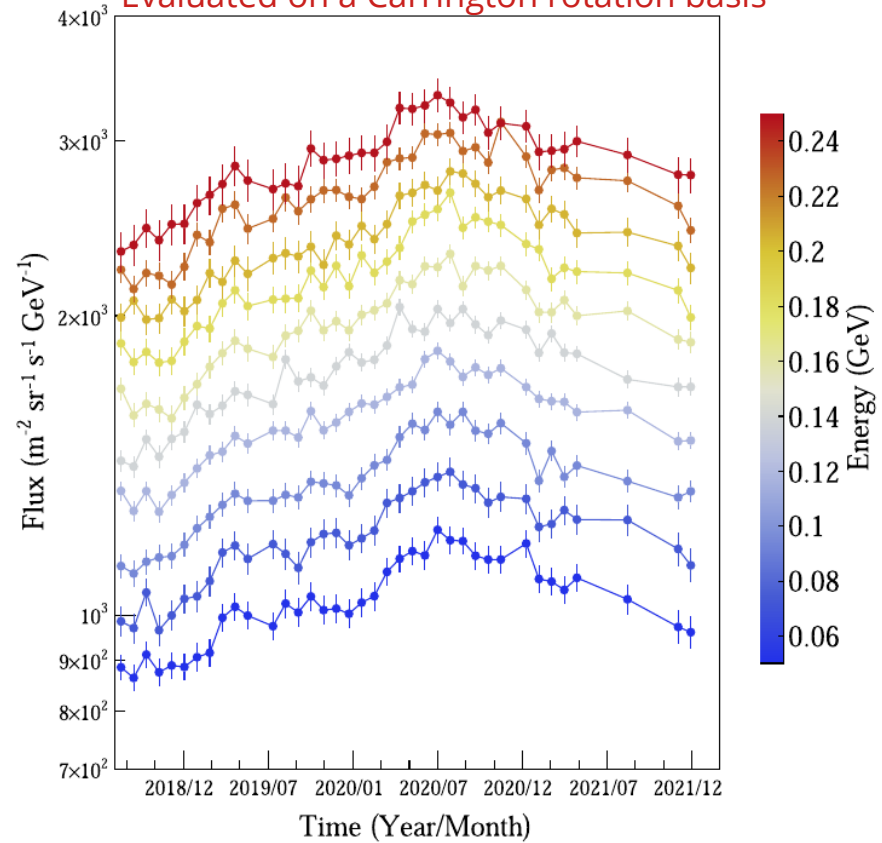
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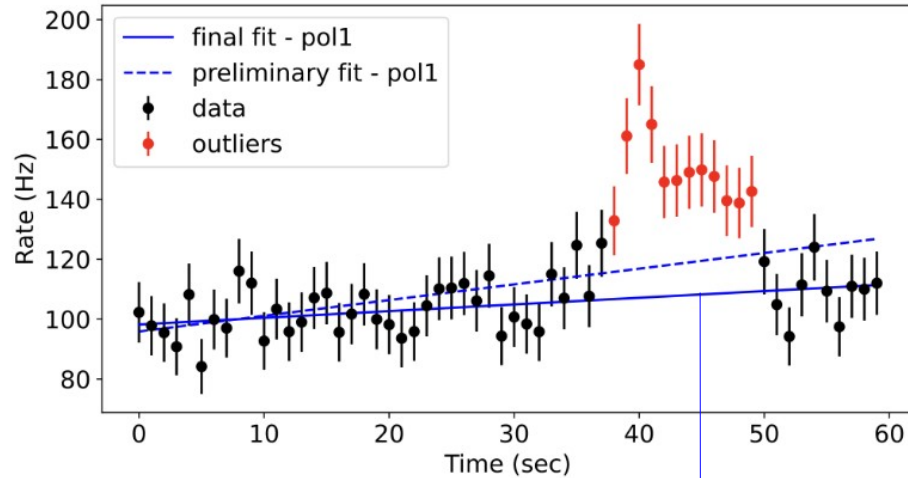


Evaluated on a Carrington rotation basis



Bartocci et al. (2020). Galactic Cosmic-Ray Hydrogen Spectra in the 40–250 MeV Range Measured by the High-energy Particle Detector (HEPD) on board the CSES-01 Satellite between 2018 and 2020. *Astrophys. J.* **901**, 8

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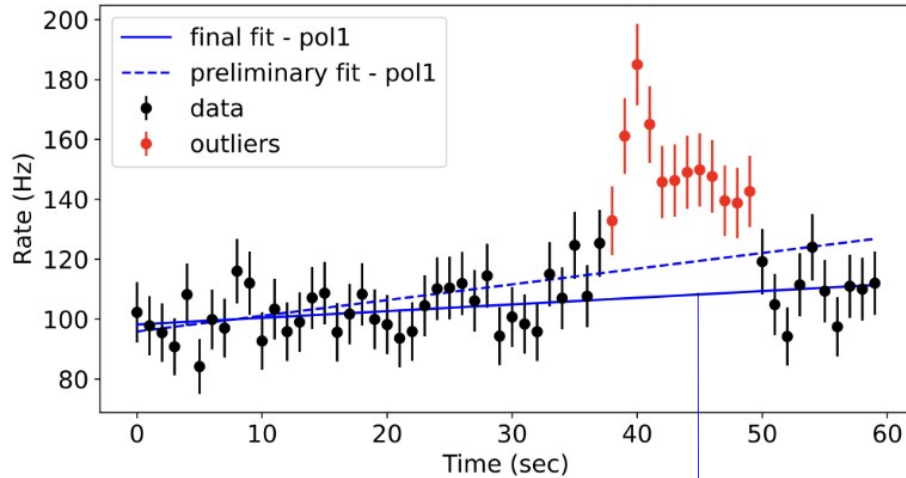
T trigger rate time series → blind outlier search

Background **polynomial degree** “learned”
from previous orbits at the same location

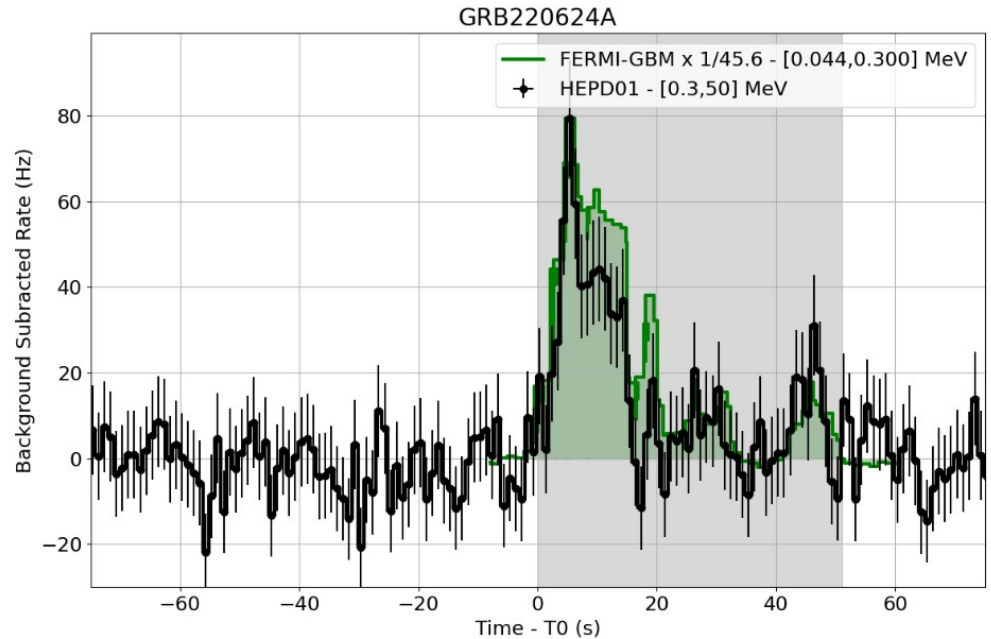
Palma et al. (2020). Gamma-Ray Burst Observations by the High-Energy Particle Detector on board the China Seismo-Electromagnetic Satellite between 2019 and 2021. *Astrophys. J.* **960**, 21

CSES-Limadou collaboration (2024). The catalogue of Gamma-Ray Bursts observations by HEPD-01 in the 0.3-50 MeV energy range. Under review in *Astrophys. J.*

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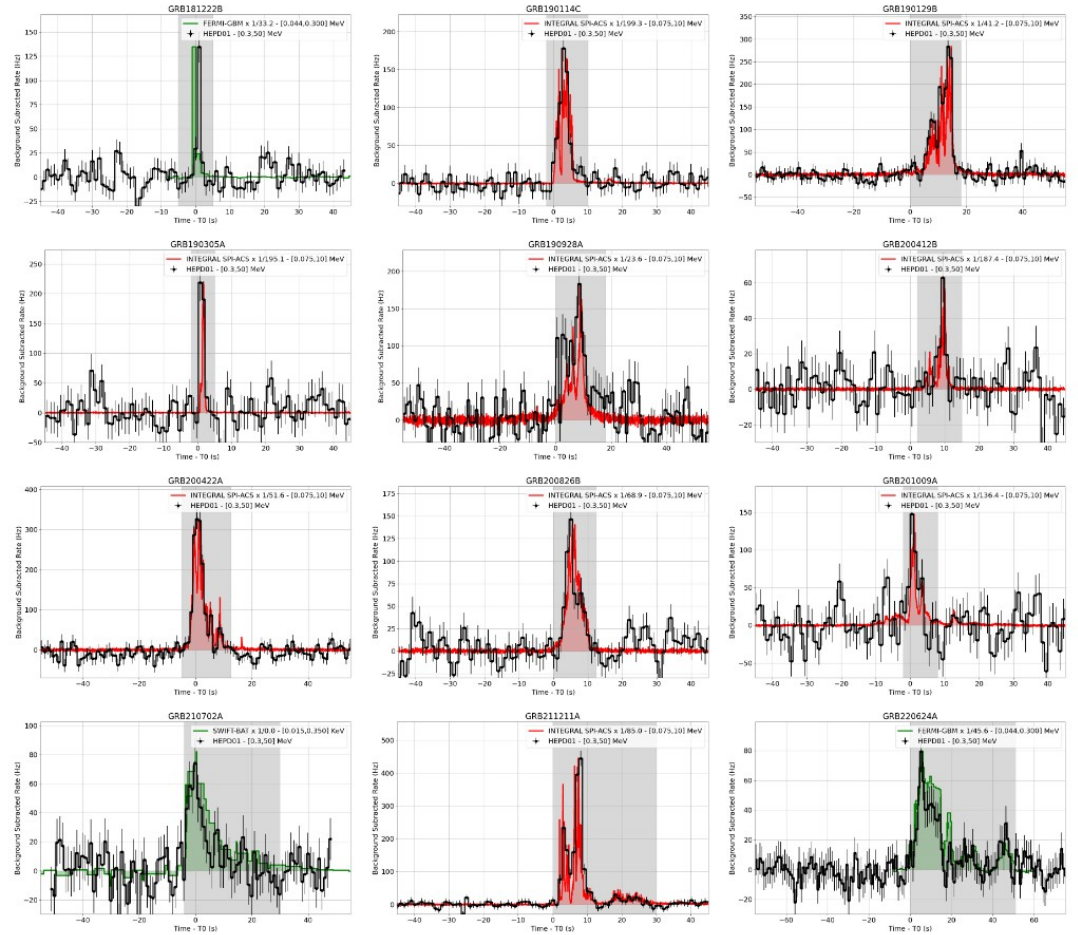


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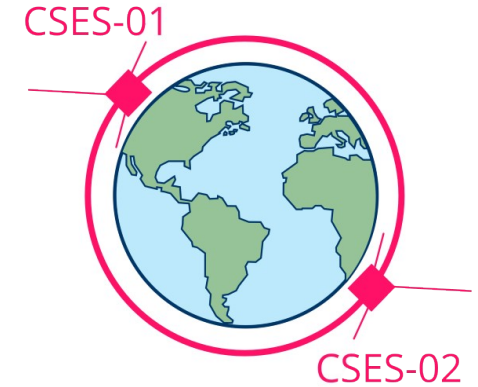
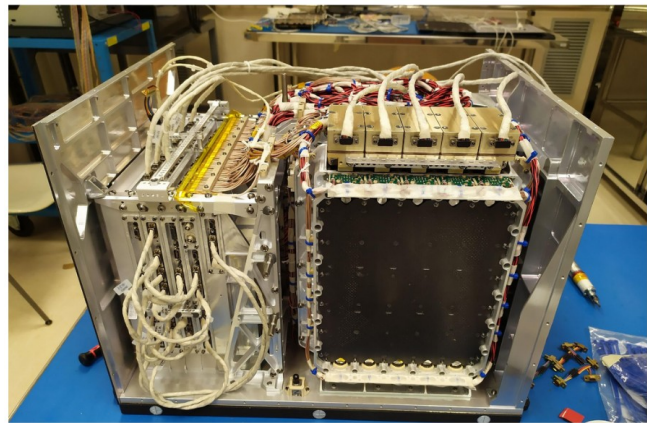
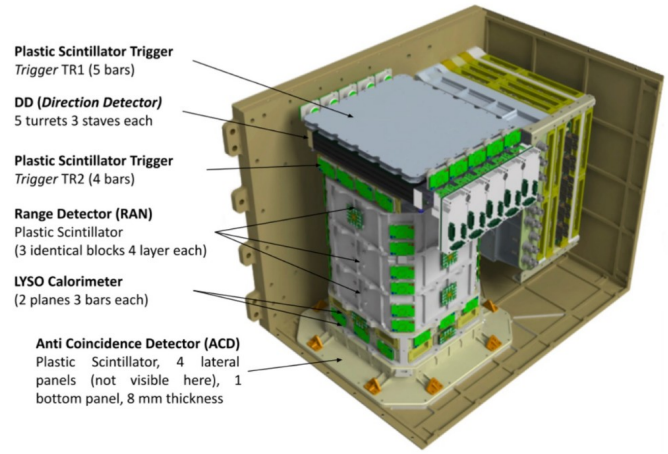
HEPD-01 GRB catalogue

- **12 GRBs** matched with dedicated instruments
- T₀, rate / light-curve correlation



CSES-Limadou collaboration (2024). The catalogue of Gamma-Ray Bursts observations by HEPD-01 in the 0.3-50 MeV energy range. Under review in *Astrophys. J.*

The second generation instrument, **HEPD-02** on board **CSES-02**...

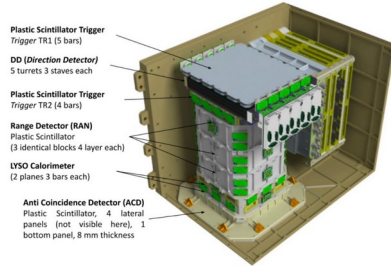


CSES constellation era begins
Launch schedule: December 2024



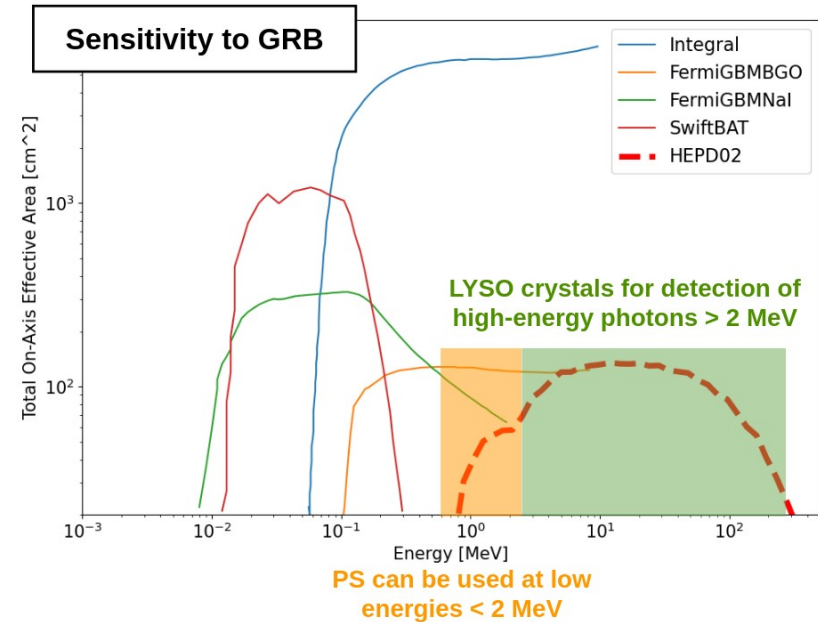
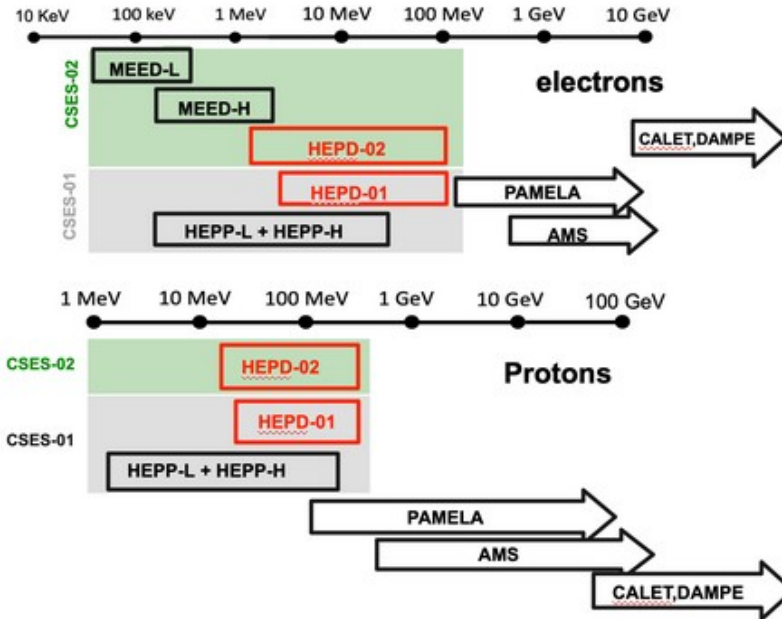
Simultaneous two-instrument observations

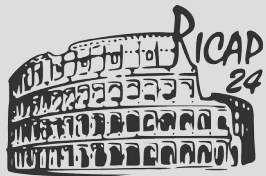
The second generation instrument, **HEPD-02** on board **CSES-02**...



- Pixel tracker (MAPS)
- Double trigger T1, T2
- 46 12 planes
- 6 LYSO bars
- prescaled triggers
- dedicated GRB trigger

- **lower E threshold**
- **better sensitivity**





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