Measurements and results using data collected with the HEPD-01 on board the China Seismo-Electromagnetic Satellite

12th Cosmic Ray International Seminar - CRIS 2022, 12-16 September 2022

F.M.Follega on behalf of the Limadou-HEPD collaboration
University of Trento and INFN-TIFPA

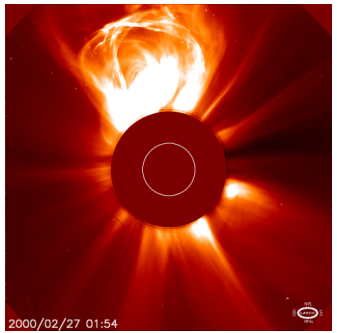
CRIS 2022
12th Cosmic Ray International Seminar
Naples, Italy, September 12 -16, 2022

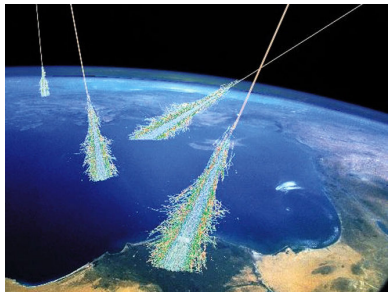
The CSES scientific mission

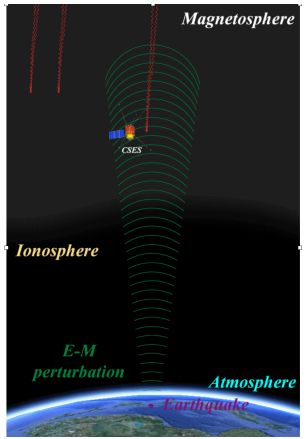
The **CSES mission** is a scientific collaboration between Italy and China.

Scientific goals:

- **Investigate the ionosphere** and gather world-wide data;
- Measure the particles and plasma **perturbations of the atmo/iono/ magnetosphere** (natural sources and anthropic emitters);
- Study solar-terrestrial interactions and solar physics phenomena: CMEs, SEPs, solar flares;
- Study **low energy cosmic rays;**



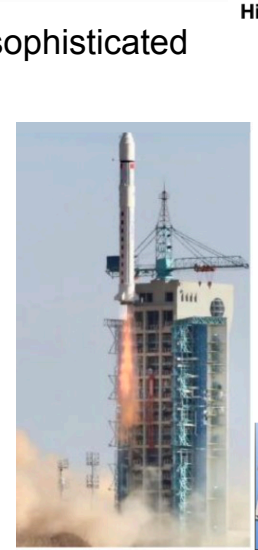


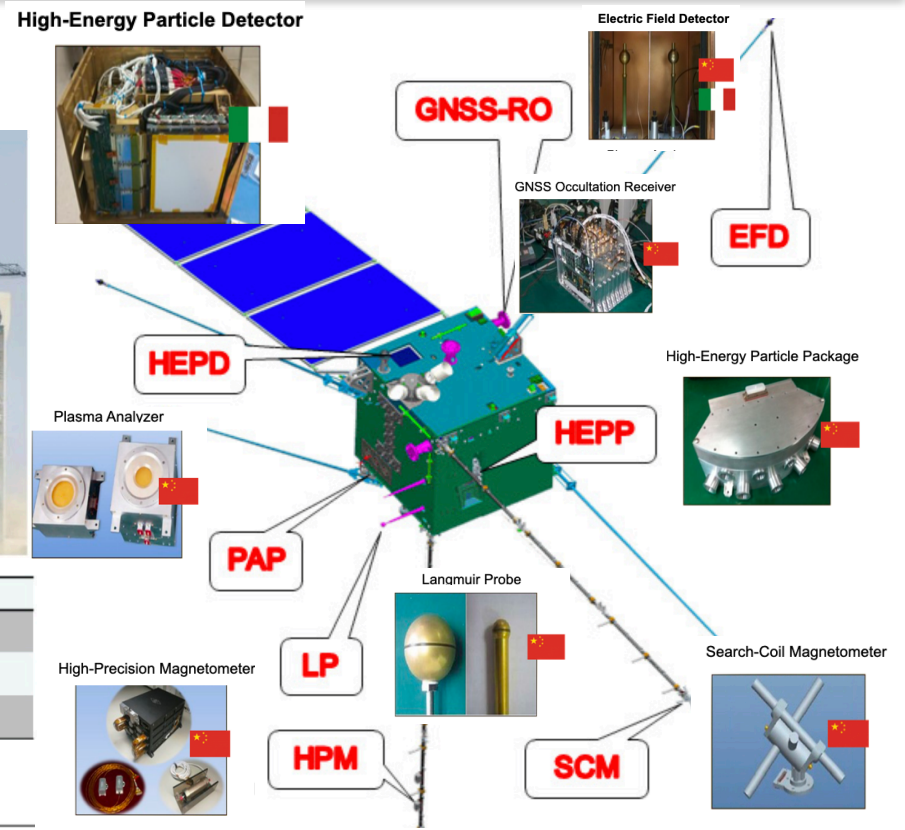


The CSES-01 Satellite

The China Seismo-Electromagnetic Satellite is a sophisticated multi-channel space observatory.

- **Launched** on the **2nd of February 2018**;
- Sun-Synchronous orbit at 500 km;
- Equipped with 9 instruments, among them the **High-Energy Particle Detector (HEPD-01)**
- Payload operation range: -65°/65° lat

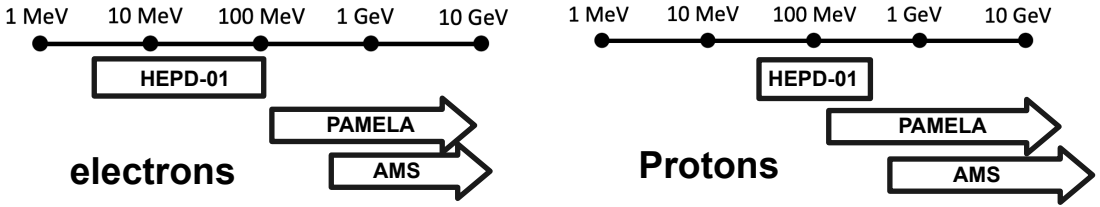


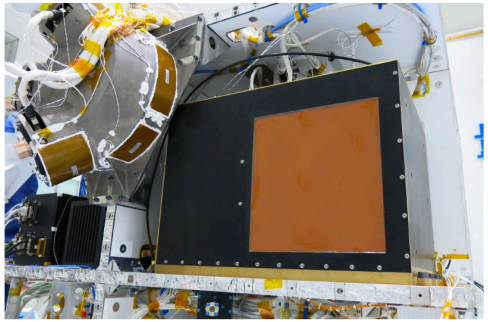


Category	Payload Name	Observation Targets
Electro-Magnetic Field	Electric Field Detector	Electric Field: DC ~ 3.5MHz
	High Precision Magnetometer	Magnetic Field: DC ~ 15Hz
	Search Coil Magnetometer	Magnetic Field: 10Hz ~ 20kHz
Energetic Particle	Italian HEPD(INFN Prod.) High Energy Particle Package	Proton： 2MeV~200MeV Electron： 100keV~100MeV

The High Energy Particle Detector HEPD-01

HEPD-01 is designed to measure fluxes of charged particles: mostly electrons (3-100 MeV) and protons (40-250 MeV)





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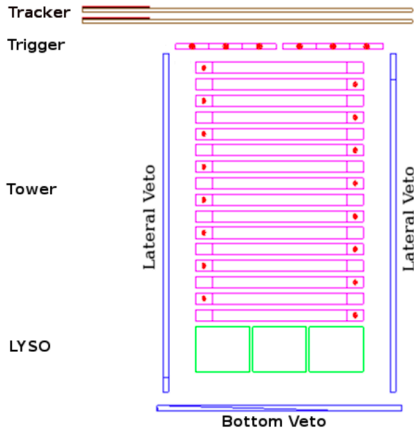
Detector subsystem:

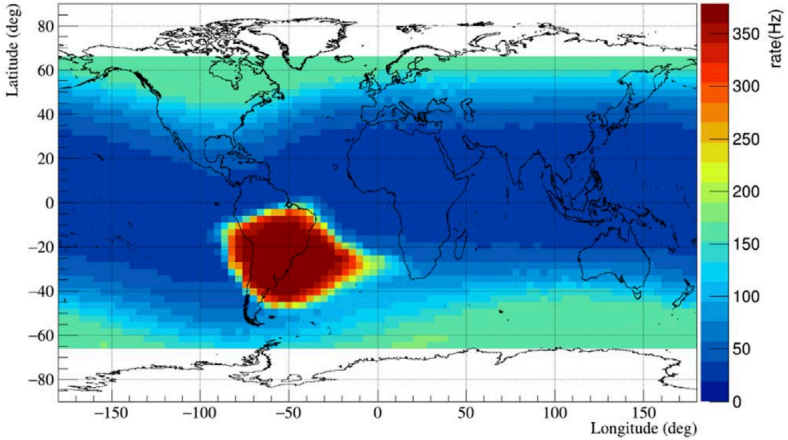
- **the tracker system -** two layers of double-sided silicon strips
- **the trigger plane -** 6 plastic scintillator bars
- **the calorimeter -** plastic scintillator tower (16 planes) + a final layer of LYSO inorganic crystals
- **the veto system** - 5 scintillator planes



Event acquisition and reconstruction

From the launch HEPD-01 is constantly acquiring data and monitoring near Earth environment.

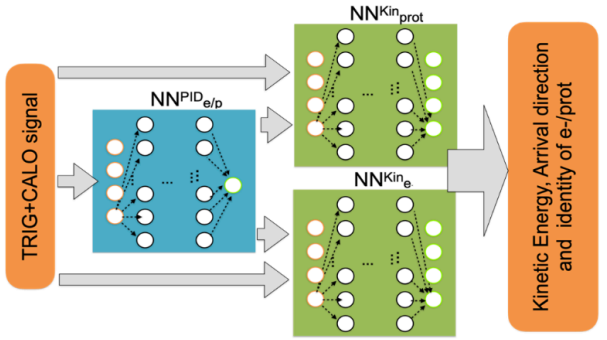
Acquisition with several trigger masks:
- T -> rate studies @ low energies
- T & (P1&P2) -> standard DAQ mask

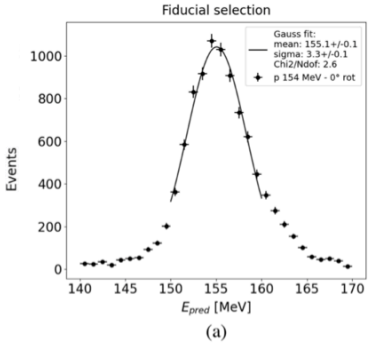


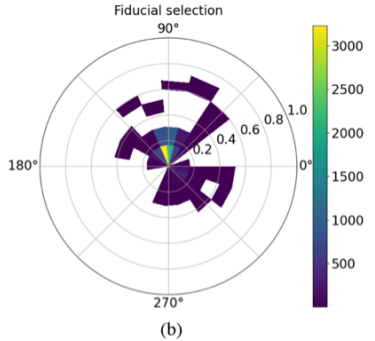
Event acquired also in SAA

Full DL event reconstruction for HEPD-01

powered by deepPP







Phys. Rev. D 105, 022004

Galactic Cosmic-Ray Hydrogen Spectra

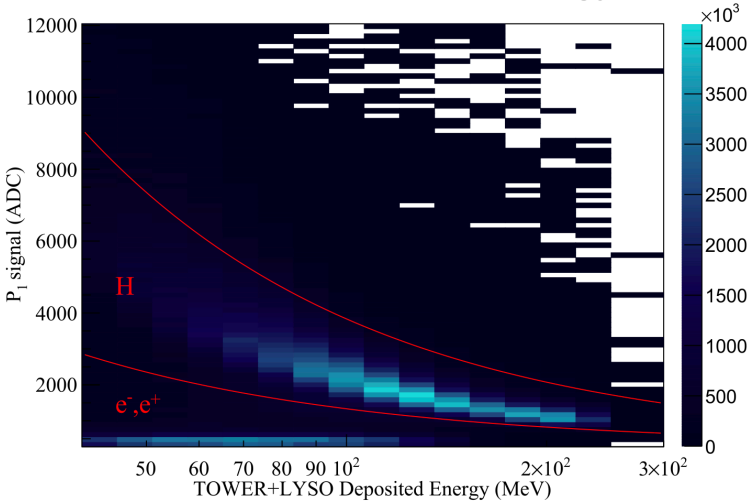
Proton Selection

Event selection:
- Trigger mask: T & (P1&P2)

Quality selection:
- Containment in the calo for energy reconstruction;
- No trigger multiplicity
- Plane continuity
- LYSO multiplicity cut

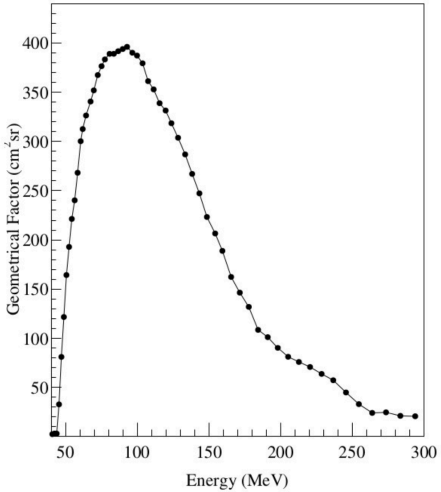
Proton selection:
- PID based on dE/dx vs Edep

Proton selection strategy



Proton selection band determined on MC with > 90% efficiency

Geometrical factor

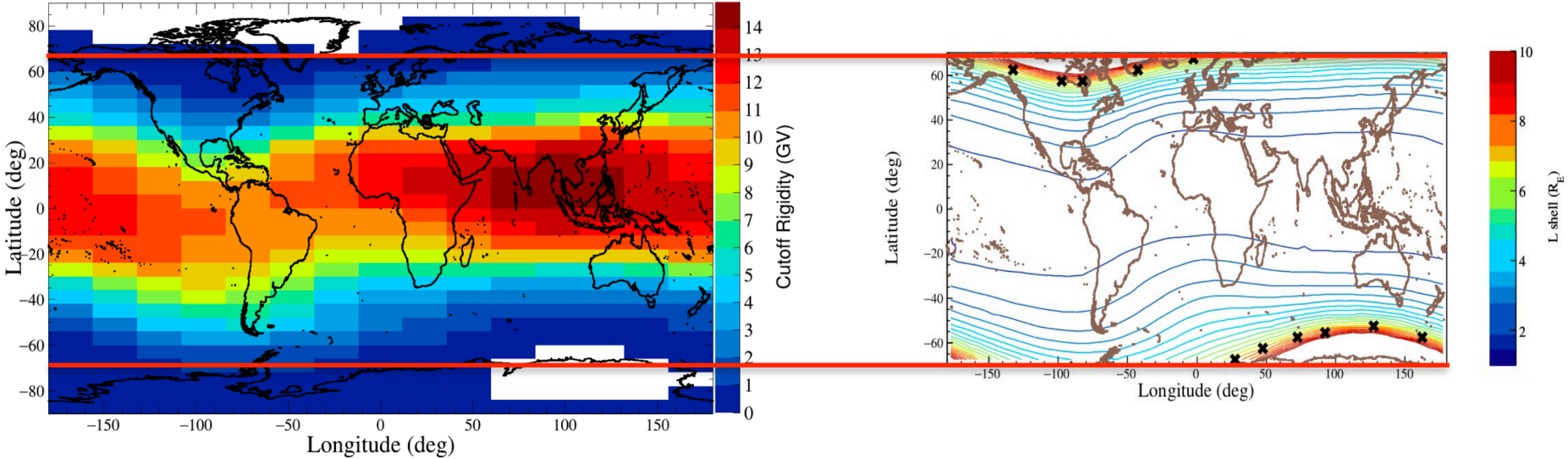


Very large geometric factor evaluated using a MC

(*) S. Bartocci et al 2020 ApJ 901 8

GCRs analysis - Proton Selection

To separate primary cosmic ray protons from albedo protons population the following strategy was adopted:

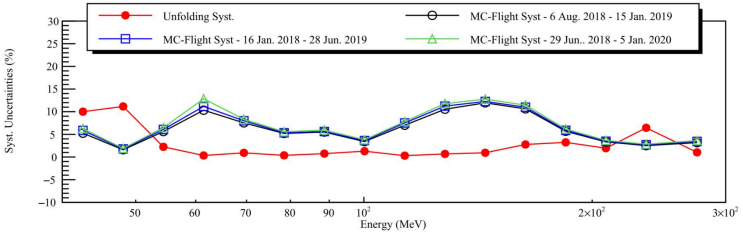


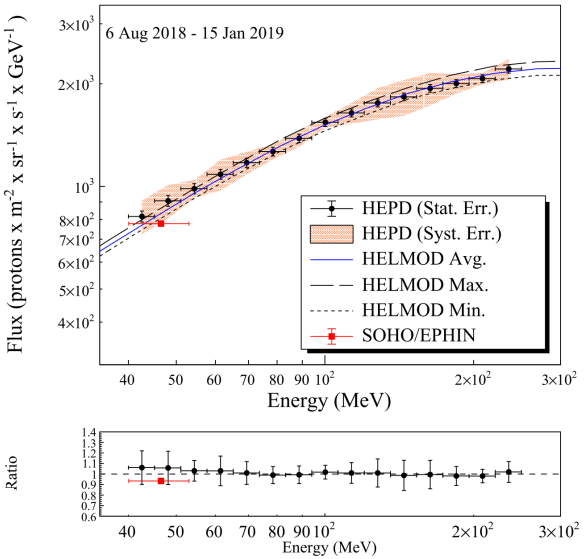
- Static **rigidity cut-off map / L-shell map**;
- Map is obtained with quiet periods of 2018 @ ~500 km altitude;
- Use data only from regions where CSES is above the rigidity cutoff for the energy threshohld of the analysis (0.26 GV) or L_{AACGM}-shell above a given threshold ($L_{thresh} > 7$)

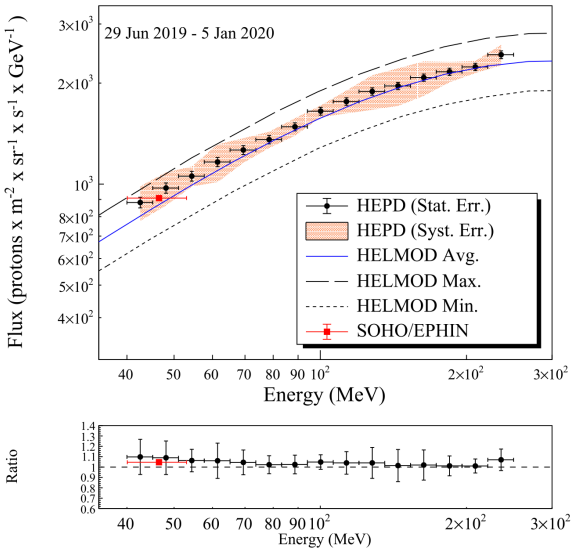
GCRs analysis - Results

The goal of the APJ paper (*) is to demonstrate the **capabilities of HEPD-01 to measure protons** and the possibility to study the solar modulation:

- Bayesian **unfolding** is used to take into account passive structures of HEPD
- **Contamination** due to high-energy electrons is **below 10%**







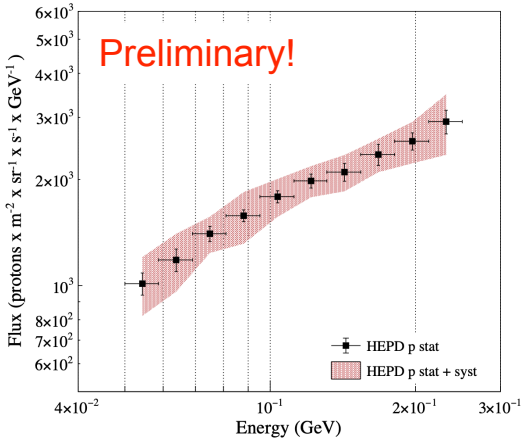
(*) S. Bartocci et al 2020 ApJ 901 8

Solar modulation and solar activity

GCRs - Solar modulation

Flux spectrum and spectral index calculated for each Carrington Rotation (CR) for 50-250 MeV protons.

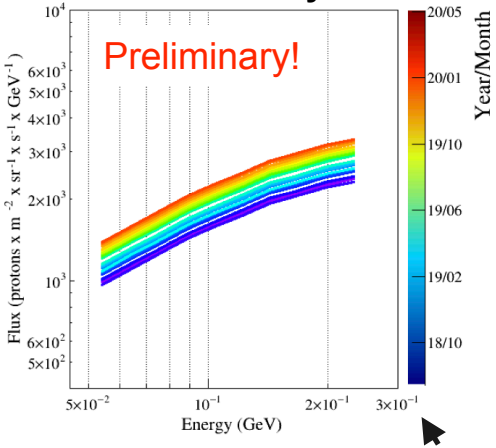
Example of flux during CR (51 analyzed)



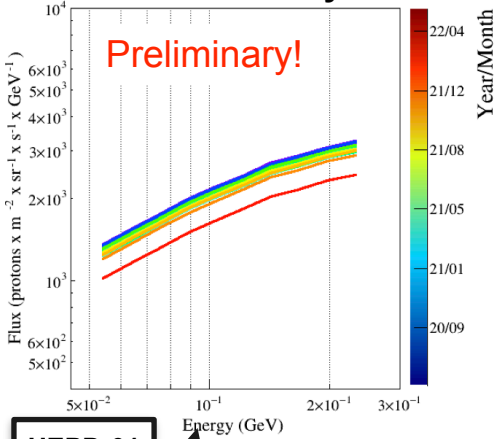
Measuring precisely solar modulation helps constraining model such HelMod (*)

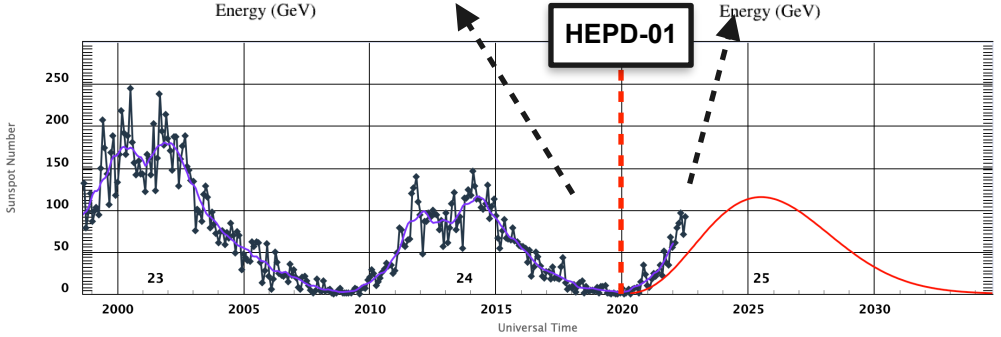
(*) M.J. Boschini et al., Advances in Space Research 62.10 (2018)

24th solar cycle

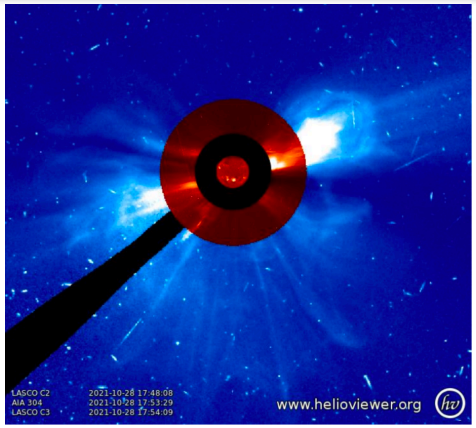


25th solar cycle





First SEP observation - October 28, 2021

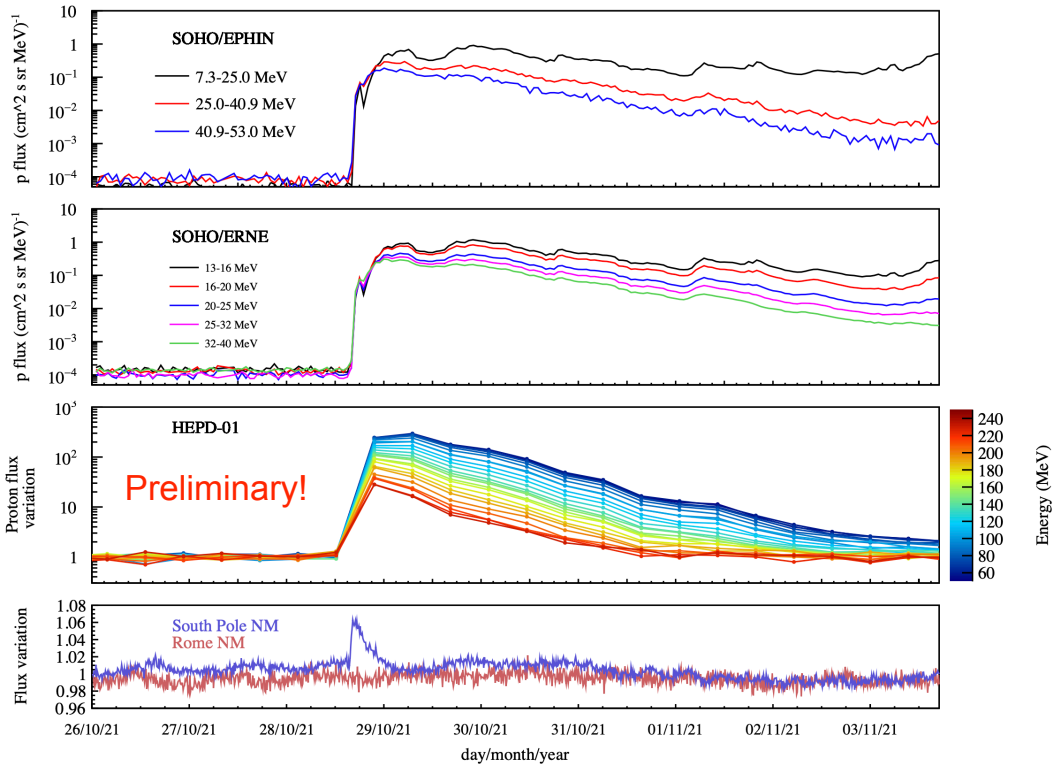


Composite image of the Sun created by AIA 304, LASCO C2 and C3 approximately 2 hours after the start of the CME

Major, long-duration X1-class solar flare associated with a CME

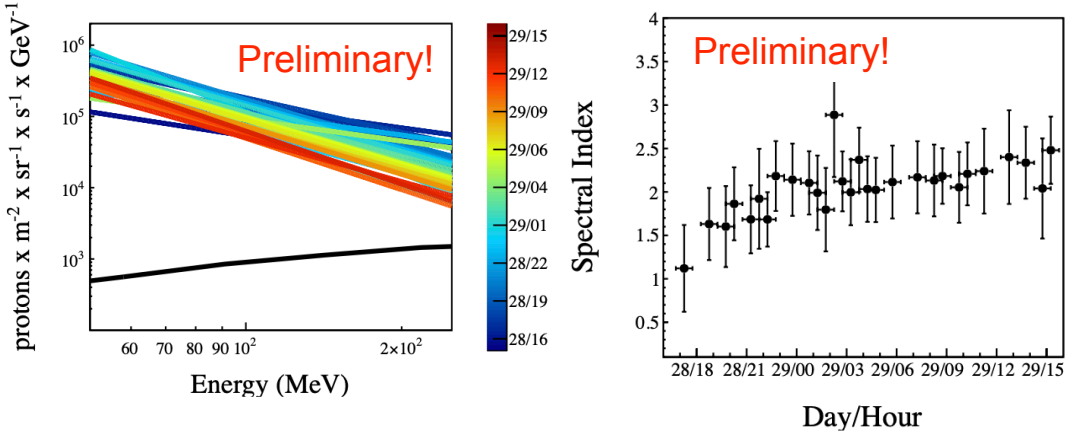
- **200x flux variation for ~50 MeV proton flux**

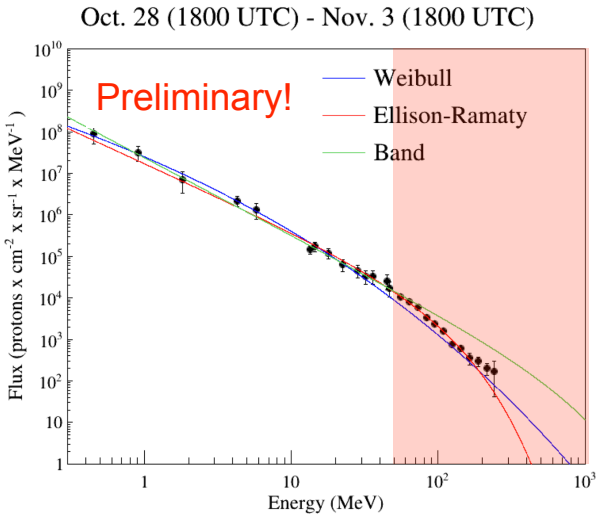
- **Rapid increase** for energies up to 250 MeV



SEP - Observation of the October 28, 2021

HEPD-01 solar proton evolution during the SEP (first 24h)





Spectral index analysis on the SEP:

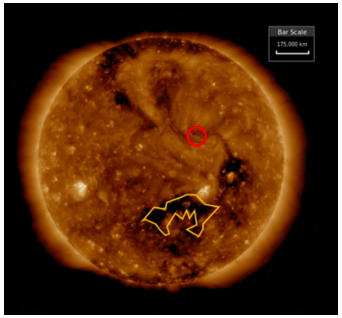
- softening of the spectrum in time
- magnitude of the **index is varying** from **1.12 to 2.47**

Data from HEPD01 + ULEIS, EPHIN and ERNE

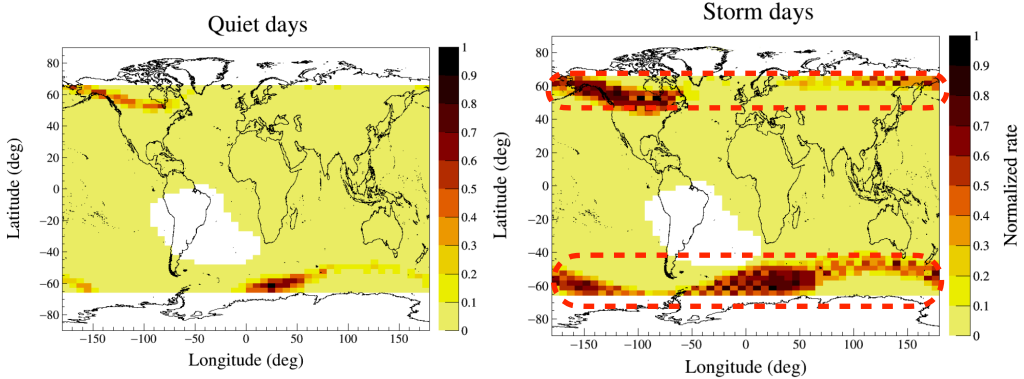
Weilbull provides the best fit: essential information about the SEP acceleration sources

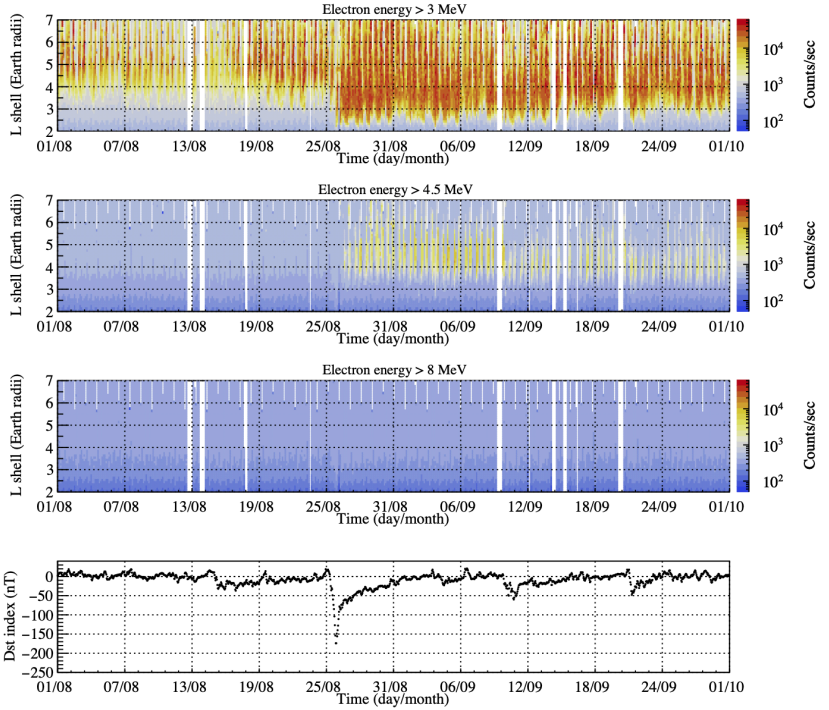
The geomagnetic storm of August 26, 2018

This storm was most probably caused by a filament eruption observed on the 20th of August 2018.



- A **clear enhancement of HEPD-01 count rate for electrons** @ L >= 3
- Other geomagnetic storms under study





Appl. Sci. 2021, 11(12), 5680

Trapped protons in SAA

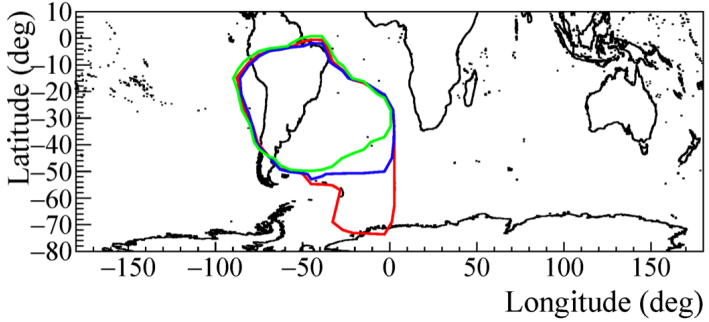
Trapped proton in SAA

Measurement of proton trapped in the South Atlantic Anomaly

- monitored since 1832 (F.C. Gauss), HEPD is one of the few instruments that can precisely measure particles inside SAA
- A correct modelisation (AP9) of the SAA is of capital importance (human and instruments)

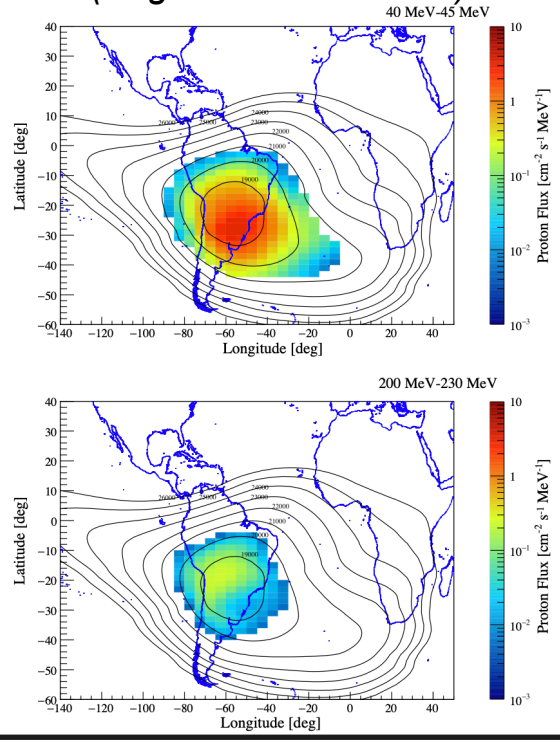
Appl. Sci. 2021, 11(8), 3465

SAA with AP9 model



Phys. Rev. D 105, 062001

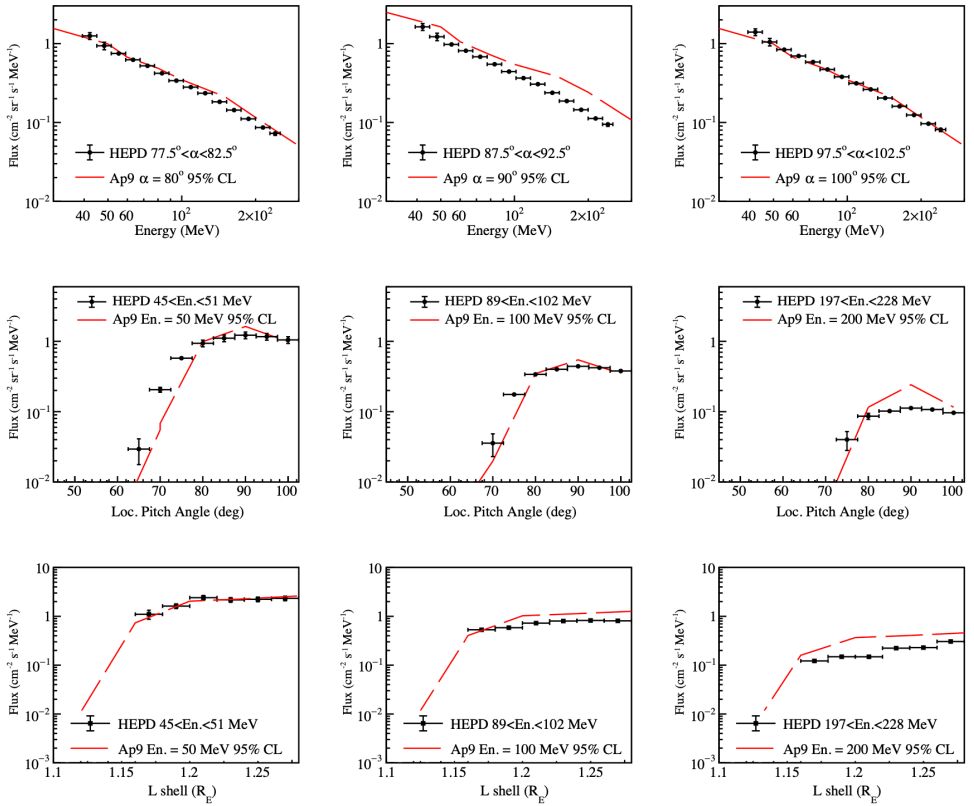
SAA with HEPD-01 data
(Aug 2018 - Dec 2020)



Trapped proton in SAA

HEPD-01 provides differential fluxes from protons trapped in SAA

- Fluxes calculated as a function of:
  - Energy (top)
  - local pitch-angle (middle)
  - L-shell (bottom)
- HEPD-01 directly compared with prediction coming from AP9
- First results at Low-Earth Orbit during the solar minimum between the 24th and 25th cycle in this energy range (lower then 250 MeV)
- No time variation has been observed



Phys. Rev. D 105, 062001

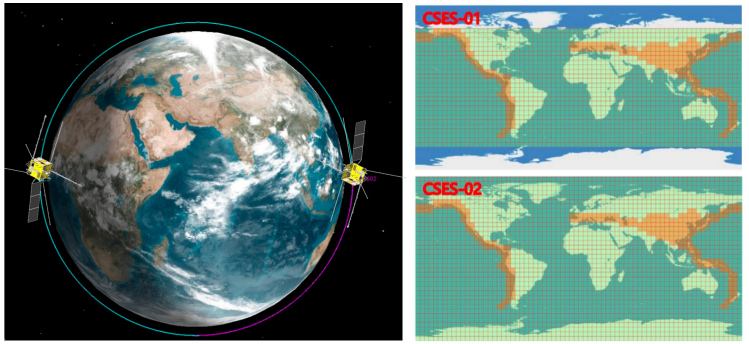
Summary and perspectives

In this talk we reviewed the **latest results and measurements** concerning the wide scientific program **of HEPD-01** on board of the CSES-01 satellite:

- The galactic **hydrogen energy spectrum** between 40 and 250 MeV;
- **Preliminary results on solar modulation** of galactic cosmic rays opens for a study of solar activity and of acceleration mechanism;
- **Measurement of proton fluxes in the SAA**;
- HEPD-01 proved to be a precious instrument for the study of solar activity and SEP events;

The new phase of the CSES mission will start with launch of the second satellite, during 2023. An exciting phase will start!

Multi-point observatory with CSES-02



The new HEPD-02

Main changes:

- Doubled trigger plane;
- 3 layer of **pixel tracker;**
- **Extended** LYSO **calo;**
- **Full latitude** span [-90,90];