Galactic cosmic-ray hydrogen spectra in the 40-300 MeV range measured by the High-Energy Particle Detector (HEPD) on board the CSES-01 satellite during the current solar minimum

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China Seismo-Electromagnetic Satellite

电磁监测试验卫星

37^{th} International Cosmic Ray Conference - Berlin (DE), July 12-23, 2021

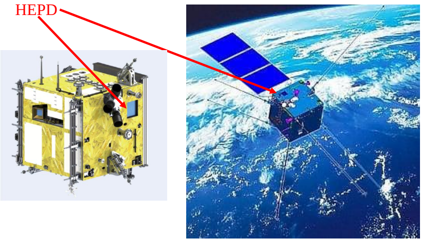
Mission objectives

- Monitoring electromagnetic near-Earth space environment
- Measuring iono-magnetospheric perturbations possibly due to seismo-electromagnetic phenomena
- Monitoring EM man-made effects at LEO altitude
- Studying spectra of charged particles precipitating from Van Allen radiation belts
- Observing changes in solar activity

The CSES-01 satellite

Platform	Mass	$\simeq$ 700 kg
Orbit	Type	Sun-Synchronous
	Altitude	507 km
	Inclination	97°
	Period	94 min
	Local time descending node	14:00
	Revisit period	5 days
Mission	Life Span	$\geq$ 5 years

CSES-01 Launched by CZ-2D Vehicle on Feb 2. (15:51)
@Jiuquan Sat. Launching Center

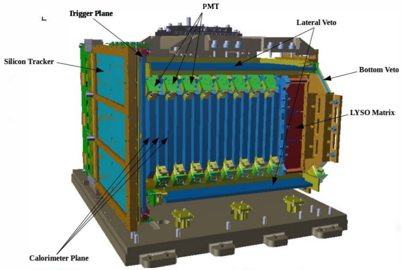


CSES-Limadou Collaboration

Limadou refers to the Italian contribution to the CSES-01 mission
Several Italian institutes and universities involved:

- Italian Space Agency (ASI)
- INFN - Roma Tor Vergata, Bologna, Perugia, LNF, Naples, TIFPA
- University of Rome Tor Vergata
- University of Trento
- National Institute for Astrophysics - Institute for Space Astrophysics and Planetology (INAF-IAPS)
- Uninettuno University
- National Institute of Geophysics and Volcanology (INGV)

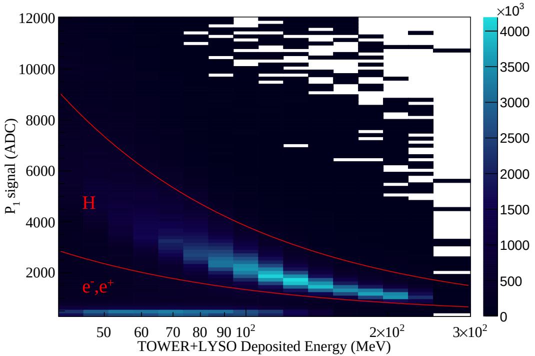
High-Energy Particle Detector (HEPD)



- 2 planes of double-sided Si microstrip sensors (TRACKER) → track-related information
- 1 layer of plastic scintillator (TRIGGER) → start acquisition
- range calorimeter comprising:
  - 16 layers of $15\times15\times1$ cm^3 plastic scintillators (TOWER), read out by 2 PMTs each→ energy deposit
  - 3×3 matrix of inorganic crystals (LYSO), read out by 1 PMT each → increase range
- 5 5 mm-thick plastic scintillator planes (VETO) → reject up-going or not fully-contained particles[1]

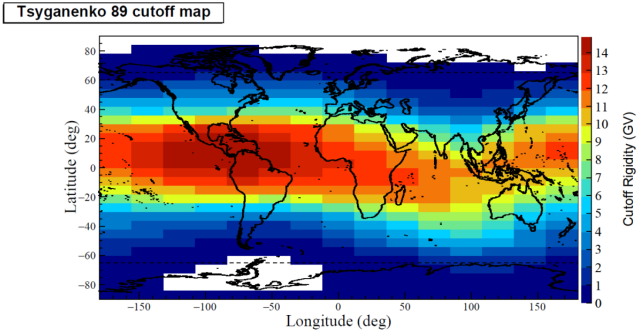
En. range (e^-)	3 MeV-100 MeV
En. range (p)	30 MeV-200 MeV
Angular resol.	$< 8^\circ$ @ 5 MeV
Energy resol.	$<$ 10% @ 5 MeV
Acceptance	$\sim$400 cm^{2}sr
Mass (+ el.)	$\sim$44 kg

Particle Identification with HEPD



- Calorimeter (TOWER+LYSO) measures the energy loss per unit length→ good separation of various species (>90%)
- Check with MC simulations for selection efficiency estimation
- Dedicated configuration for light-nuclei ID (not shown in the figure)

Cutoff Map

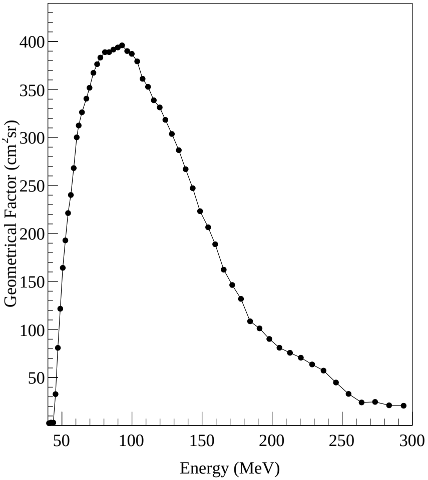


- Static map (IGRF-12 [2] + Tsyganenko-89 [3]) is used to select galactic particles
- Even if HEPD is switched off at $\pm 65^{\circ}$, its high field-of-view allows to collect GCRs for a fair amount of time per day
- Live Time is accumulated only in these regions

Analysis and Flux Evaluation

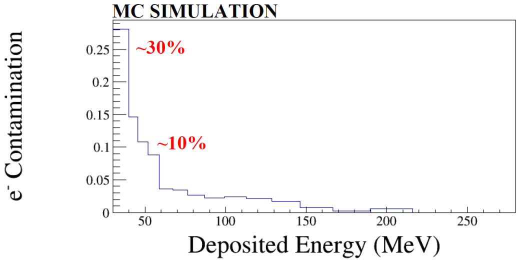
- Only fully-contained protons are included in the flux sample to better estimate the initial energy of the proton
- Multi-particle events are rejected requiring no hit on the VETO system and only a single trigger pad hit in the final sample
- Only a single crystal of LYSO hit is required to reject possible electromagnetic showers due to mis-identified high-energy electrons
- Up-going protons are rejected requiring no hit in the bottom layer of the VETO system
- Selection efficiency are checked with MC
- Bayesian approach is used to take into account passive structures of HEPD and unfold the final spectrum

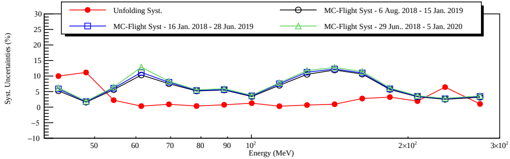
HEPD Geometrical Factor



- Total geometrical acceptance of HEPD for Z=1 particles as a function of the energy.
- It is evaluated using a MC simulation of isotropically generated ($0^\circ < \theta < 90^\circ$ and $0^\circ < \phi < 180^\circ$) protons with primary energy ranging from 1 MeV to 10 GeV
- It shows a maximum value of $\sim$400 cm^{2}sr at $\sim$90 MeV,
- It steeply decreases at lower energies, because of the energy lost in hadronic interactions
- It decreases also at higher energies, because of the narrower geometrical aperture.

Contamination of the flux sample due to high-energy electrons is below 10% above ∼50 MeV

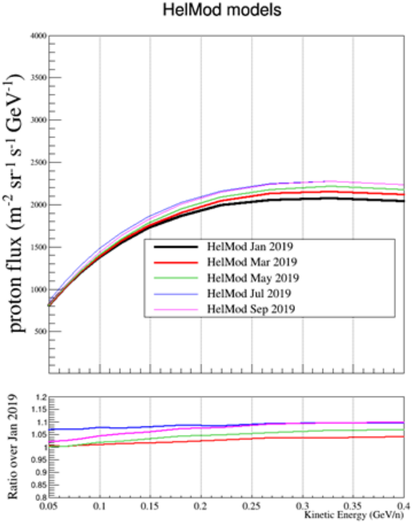




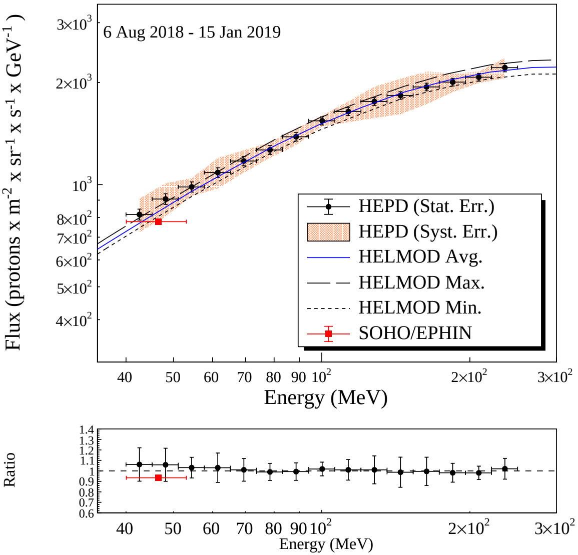
Unfolding-related unc. evaluated once over the 2018-2019 period, while MC-flight unc. evaluated over 3 6-month periods

Helmod Model

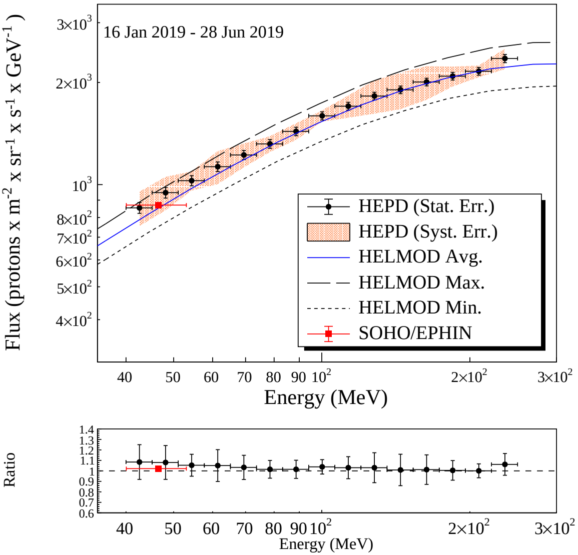
- The heliospheric modulation model (HelMod) [4] is a 2D Monte Carlo model to simulate the solar modulation of galactic cosmic rays (GCRs)
- It is employed to solve the transport-equation down to Earth
- It is capable of providing modulated spectra which agree within the experimental errors with those measured by AMS-01, BESS, PAMELA and AMS-02 during the solar cycles 23 and 24



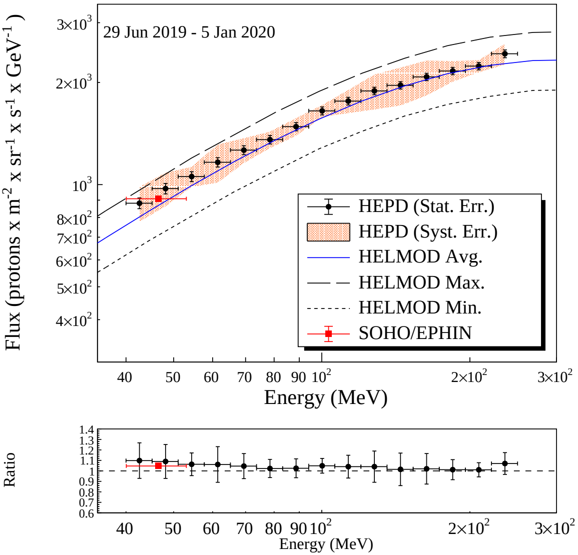
HEPD Results on GCRs 1/3



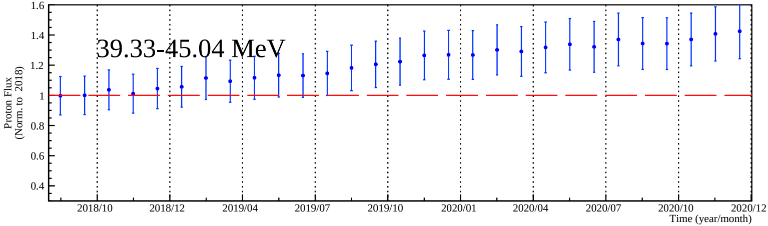
HEPD Results on GCRs 2/3

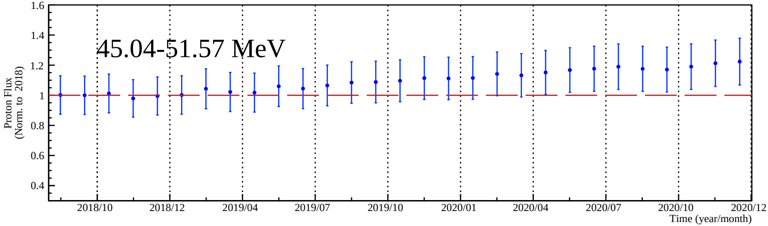


HEPD Results on GCRs 3/3



Preliminary





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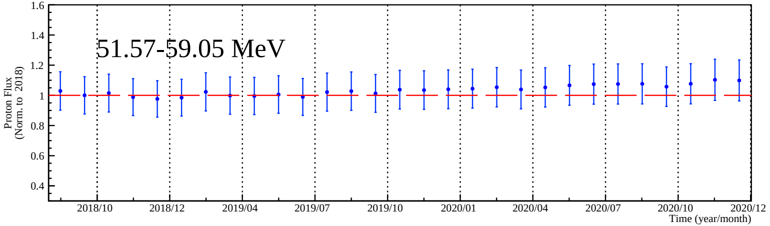

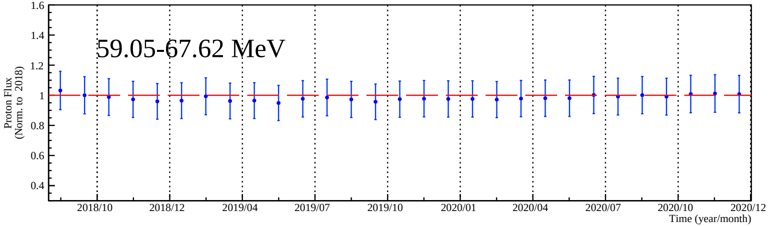

Conclusions

- New results on the galactic hydrogen energy spectrum between 40 and 300 MeV obtained by the HEPD experiment during the period from 2018 August 6 to 2020 January 5, almost at the end of the 24th solar cycle
- These have been the first results on galactic hydrogen obtained in such an energy range, at 1 au, since a series of balloon flights in 1960s/1970s
- the CSES-Limadou mission can be considered as an extension of PAMELA (2006–2016) in the study of low-energy cosmic rays
- Another mission (CSES-02) is in preparation, and it is expected to offer further insight into low-energy physics throughout the 25th solar cycle

References

[1] P. Picozza et al. "Scientific Goals and In-orbit Performance of the High-energy Particle Detector on Board the CSES". In: *The Astrophysical Journal Supplement Series* 243.1 (July 2019), p. 16. DOI: 10.3847/1538-4365/ab276c.

[2] Erwan Thébault et al. "Evaluation of candidate geomagnetic field models for IGRF-12". In: *Earth, Planets, and Space* 67, 112 (July 2015), p. 112. DOI: 10.1186/s40623-015-0273-4.

[3] N. A. Tsyganenko. "A magnetospheric magnetic field model with a warped tail current sheet". In: *Planet. Space Sci.* 37.1 (Jan. 1989), pp. 5–20. DOI: 10.1016/0032-0633(89)90066-4.

[4] M.J. Boschini et al. "Propagation of cosmic rays in heliosphere: The HelMod model". In: *Advances in Space Research* 62.10 (2018). Origins of Cosmic Rays, pp. 2859–2879. ISSN: 0273-1177. DOI: https://doi.org/10.1016/j.asr.2017.04.017.