The HERD space mission

Dr. Felicia Barbato – On behalf of HERD collaboration
GSSI and INFN
Still open question about cosmic rays…

- where are they produced?
- how are they accelerated to such high energies?
- how do they propagate in the Galaxy and the Universe?

Necessity to study the sub-PeV region to understand the (dominant) origin of the knee

Is it due to the maximum energy achievable at the source or to diffusion processes in the Galaxy?
Current data suggest a hardening of the spectra above about 0.2 TeV/nucleon

- $\gamma_{(E>0.2\text{TeV/nucleon})} \approx -2.6$ for all considered elements
- $\gamma_{(E>0.2\text{TeV/nucleon})} \approx -2.7$ for protons

The hardening @ $\approx 200$-400 GeV is well established since first observation by Pamela -> Implication on the acceleration mechanism

The softening @ $\approx 10$ TeV is observed by different experiment with the 1st strong evidence in DAMPE data
Scientific objectives

HERD primary scientific goals include:

- Precise measurements of the energy spectra of CR individual species up to few PeV
- Study electrons and photon of spectra from GeV up to tens of TeV
- Indirect dark matter search
- Contributing to multi-messenger observations together with other satellites and ground-based experiments
The HERD collaboration

The High Energy cosmic-Radiation Detection (HERD) facility is an international space mission that will start operation around 2027 to make cosmic ray direct measurements at the highest possible energies with current technologies.
**Mission Profile**

**HERD** expected to be installed around 2027

**CSS** expected to be completed in 2022

<table>
<thead>
<tr>
<th>Life time</th>
<th>&gt; 10y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbit</td>
<td>Circular LEO</td>
</tr>
<tr>
<td>Altitude</td>
<td>340-450 km</td>
</tr>
<tr>
<td>Inclination</td>
<td>42°</td>
</tr>
</tbody>
</table>

**MG**

<table>
<thead>
<tr>
<th>Life time</th>
<th>&gt; 10y</th>
</tr>
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<tbody>
<tr>
<td>FOV</td>
<td>+/- 70°</td>
</tr>
<tr>
<td>Power</td>
<td>&lt; 1.5 kW</td>
</tr>
<tr>
<td>Mass</td>
<td>&lt; 4 t</td>
</tr>
</tbody>
</table>
# The payload

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>SCD</strong></td>
<td>Charge Reconstruction</td>
<td></td>
</tr>
<tr>
<td><strong>PSD</strong></td>
<td>Charge Reconstruction</td>
<td>γ Identification</td>
</tr>
<tr>
<td><strong>FIT</strong></td>
<td>Trajectory Reconstruction</td>
<td>Charge Identification</td>
</tr>
<tr>
<td><strong>CALO</strong></td>
<td>Energy Reconstruction</td>
<td>e/p Discrimination</td>
</tr>
<tr>
<td><strong>TRD</strong></td>
<td>Calibration of CALO response for TeV protons</td>
<td></td>
</tr>
</tbody>
</table>

## Main requirements

<table>
<thead>
<tr>
<th></th>
<th>γ</th>
<th>e</th>
<th>p, nuclei</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy Range</strong></td>
<td>&gt;100MeV</td>
<td>10 GeV</td>
<td>30 GeV</td>
</tr>
<tr>
<td></td>
<td>100 TeV</td>
<td></td>
<td>3 PeV</td>
</tr>
<tr>
<td><strong>Energy resolution</strong></td>
<td>1% @ 200 GeV</td>
<td>1% @ 200 GeV</td>
<td>20% @ 100 GeV -1 PeV</td>
</tr>
<tr>
<td><strong>Effective Geometric Factor</strong></td>
<td>&gt;0.2 m²sr @ 200 GeV</td>
<td>&gt;2 m²sr @ 200 GeV</td>
<td>&gt;1 m²sr @ 100 TeV</td>
</tr>
</tbody>
</table>
SCD is made by silicon micro-strip detectors that will measure with precision the impinging particle charge $|Z|$.

- It is the outermost detector to avoid early charge-change interactions in the PSD.
- It is highly segmented to minimize the backscattered secondary particles coming from the CALO.
Plastic Scintillator Detector (PSD)

Requirements:

• high efficiency in charged particles detection (>99.98%)
• high dynamic range to identify nuclei at least up to iron
• segmented to reduce the Back-scattering particles from the calo

Light attenuation length

Birks saturation tested at CNAO

F. Barbato
Fiber Tracker (FIT)

- 4 identical side sectors + 1 top sector
- 7 x-y planes in each side sector
- 5 x-y planes in the top sector
- 6 x modules (106 cm fiber length) in each x plane
- 10 y modules (77 cm fiber length) in each y plane
- 1 fiber mat + 3 silicon photomultiplier (SiPM) arrays

\[ \sigma_{\text{FIT}} = (45.0 \pm 0.1) \, \mu\text{m} \]
Calorimeter (CALO)

- **7500 LYSO cubes** with edge length of 3 cm
- It accepts particles coming from each surface

<table>
<thead>
<tr>
<th>Particle</th>
<th>Energy</th>
<th>Effective acceptance</th>
<th>Energy resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protons</td>
<td>≤ 1 PeV</td>
<td>&gt; 1 m²sr</td>
<td>~ 30%</td>
</tr>
<tr>
<td>Electrons</td>
<td>≤ 10 TeV</td>
<td>~ 2 m²sr</td>
<td>~ 2%</td>
</tr>
</tbody>
</table>

**First readout system**
- WaveLength Shifting fibers (WLS)
- Image Intensified scientific CMOS
- Frame rate: > 800 frames/sec
- Low read-out noise (< 1.5e)

The double read-out scheme will strongly improve both the calibration and trigger capabilities

**Second readout system**
- Photo-diodes with different active areas connected to HIDRA chips
- The S/N ratio for MIP is ≥ 4
- Expected saturation level ~ 250 TeV
Transition Radiator Detector (TRD)

The TRD, installed on a lateral face of the detector, is needed to calibrate the response of the calorimeter to high energy hadronic showers.

**Linearity for $10^3 < \gamma < 10^4$**
- Electron $0.5 \text{ GeV} < E < 5 \text{ GeV}$
- Proton $1 \text{ TeV} < E < 10 \text{ TeV}$

**Calibration procedure**
- Calibrate TRD response using $[0.5 \text{ GeV}, 5 \text{ GeV}]$ electrons in space (and beam test)
- Calibrate CALO response using $[1 \text{ TeV}, 10 \text{ TeV}]$ protons from TRD
1. The HERD data can clearly reveal the knees of both protons and Helium nuclei and can critically address the Z-dependence, A-dependence, or constant knee of different compositions, which are very important to understand the physical nature of the knee of CRs.

2. B/C is important to probe the propagation of CRs. The HERD measurements will extend the precise B/C ratio to a few TeV/nucleon, and thus can precisely determine the propagation behaviour of CRs.

3. The Iron nuclei are the end products of stellar nucleosynthesis. The heavy nuclei in CRs are thus very good tracer of the acceleration sites of CRs. HERD is expected to strongly improve such measurements.
Electrons and positrons

"The different behavior of the cosmic-ray electrons and positrons measured by AMS is clear evidence that most high energy electrons originate from different sources than high energy positrons."

PRL 122 041102 (2019)

HERD will measure the all electron flux up to several tens of TeV in order to detect:
- spectral cutoff at high energy
- local SNR sources of very high energy e⁻ ...

... and additional information from anisotropy measurement!
Thanks to its large acceptance and sensitivity, HERD will be able to perform a full gamma-ray sky survey in the energy range >100MeV

- extend Fermi-LAT catalog to higher energy (>300GeV)
- increase the chances to detect rare $\gamma$ events

**Targets of Gamma-Ray Sky Survey:**

- search for dark matter signatures
- study of galactic and extragalactic $\gamma$ sources
- study of galactic and extragalactic $\gamma$ diffuse emission
- detection of high energy GRBs
The High Energy cosmic-Radiation Detection (HERD) space mission is now being designed, as a result of an international collaboration among several Chinese and European institutions, to make cosmic ray (CR) direct measurements at the highest possible energies with current technologies.

HERD primary scientific goals include:

- extend the measurement of p and He flux up to a few PeV testing the theory of the knee structure as due to acceleration limit

- extend the measurement of e^+e^- flux up to several tens of TeV testing the hypothesis of the expected cutoff at high energy distinguishing between DM or astrophysical origin of positron excess

- large acceptance, high sensitivity to γ up to several hundreds of GeV searching for γ line associated to DM annihilation accomplishing a γ sky survey up to very high energy
Energy resolution for electrons

σ/E (%) vs Energy deposition in CALO (GeV)

Protons
Helium
Carbons

σ/E (%) vs Beam energy (GeV)

- Large PDs
- Small PDs
- Combined PDs

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MG-16 - Online