The CSES mission

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Outline of the talk:
The China Seismo Electromagnetic Satellite mission
The High Energy Particle Detector
Pre-launch activities
Launch and preliminary results

ECRS 2018 - Barnaul - Russia
China Seismo-Electromagnetic Satellite

monitoring of earthquake-related electromagnetic field and particles in the ionosphere

This space mission will study seismo-ionospheric perturbations of electromagnetic field, plasma and particles and their correlation with geophysical activity.
China **Seismo-Electromagnetic Satellite**

monitoring of earthquake-related electromagnetic field and particles in the ionosphere

This space mission will study seismo-ionospheric perturbations of electromagnetic field, plasma and particles and their correlation with geophysical activity.

Space is a privileged place for the statistical study of pre-seismic effects: **covering large areas simultaneously**.

The satellite was launched on 2\textsuperscript{nd} February 2018, with an expected lifetime of 5 years. It has a 98° Sun-synchronous circular orbit at 507 km of altitude

Two different orbital working zones:
- *payload operating zone*: instruments will collect measurements (latitude range of ± 65°)
- *platform adjustment zone*: all detectors switched off, satellite attitude and orbit control system activities will be performed

3-axis attitude stabilized satellite based on CAST2000 platform

Mass = 730 kg
Peak power consumption = 900 W
Project objectives of CSES

• to study the *ionospheric perturbations* possibly associated with earthquakes
• to explore new approaches for short-term prediction and theoretic studies on the mechanism of earthquake preparation processes
• to measure *Cosmic Ray* in an energy range below the one which has been studied so far by current CR space missions (PAMELA, AMS-02)
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• to check the **reliability of the EM satellite earthquake monitoring system** by using new techniques and equipments
• to obtain world-wide data of the EM field, plasma and energetic particles in space environment
• to provide a good basis for a space-ground system in earthquake monitoring in the near future in China

• to extract EM information associated possibly with the earthquakes of $M_s \geq 6$ in Chinese territory and that of $M_s \geq 7$ in the global scale
• to analyze seismo-ionospheric perturbations in order to test the possibility for **short-term earthquake forecasting** with satellite observation
<table>
<thead>
<tr>
<th>Measurements</th>
<th>Instruments</th>
</tr>
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</table>
| Electrical and magnetic fields and their perturbations in ionosphere | Search-Coil magnetometer (SCM)  
Fluxgate magnetometer  
Electrical field detector (EFD) |
| Disturbance of plasma in ionosphere | Plasma analizer (PAP)  
Langmuir probe (LAP) |
| Flux and energy spectrum of the particles in the radiation belts | High Energy Particle Package (HEPP)  
High Energy Particle Detector (HEPD) |
| Profile of electronic content | GPS occultation receiver (GNSS-RO)  
Tri-frequency transmitter (TBB) |
CSES-Limadou Collaboration

- Collaboration:
  - China National Space Administration (CNSA)
  - Italian Space Agency (ASI)
- Developed by:
  - China Earthquake Administration (CEA)
  - Italian National Institute for Nuclear Physics (INFN)
  - Chinese and Italian Universities

The Italian Collaboration named the project LIMADOU after the Chinese name of the missionary Matteo Ricci who explored China in the 16th century
The HEPD detector

**Silicon tracker:** two planes of double-side *silicon micro-strip detectors* placed on the top of the HEPD in order to provide the direction of the incident particle (213mm × 213mm × 0.3mm)
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**Trigger:** a layer of **thin plastic scintillator** divided into six segments (200mm × 30mm × 5mm each)
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**Calorimeter:** a tower of 16 layers of 1 cm thick plastic scintillator planes followed by a 3x3 matrix of inorganic scintillator (LYSO)
The calorimeter volume is surrounded by 5mm thick plastic scintillator planes: VETO

All the scintillator detectors (trigger, calorimeter and VETO) are read out by photomultiplier tubes (PMT R9880-210 from Hamamatsu)

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To reconstruct particle trajectories in Van Allen belts requires **good energy and angular resolution**

- separate electrons and protons identifying electrons within a proton background (10^{-5} ÷ 10^{-3})
- identify light nuclei

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Range</td>
<td>e: 3 ÷ 100 MeV</td>
</tr>
<tr>
<td></td>
<td>p: 30 ÷ 200 MeV</td>
</tr>
<tr>
<td>Angular resolution</td>
<td>&lt; 8° @ 5 MeV</td>
</tr>
<tr>
<td>Energy resolution</td>
<td>&lt; 10% @ 5 MeV</td>
</tr>
<tr>
<td>Particle identification</td>
<td>&gt; 90%</td>
</tr>
<tr>
<td>Operation mode</td>
<td>Event by event</td>
</tr>
<tr>
<td>Scientific Data Bus</td>
<td>RS-422</td>
</tr>
<tr>
<td>Operative temperature</td>
<td>-10 ÷ +35°C</td>
</tr>
<tr>
<td>Mass</td>
<td>&lt; 44 kg</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>&lt; 27 W</td>
</tr>
<tr>
<td>Mechanical dimensions</td>
<td>53×38×40 cm³</td>
</tr>
</tbody>
</table>
The HEPD models

4 HEPD versions produced:
- Electrical Model, EM (2014)
- Structural and Thermal Model, STM (2015)
- Qualification Model, QM (2016)
- Flight Model, FM (2016)
Pre-launch activities
A full GEANT4 simulation of the apparatus was performed, accounting for detector response to all particles and reproducing readout electronics and trigger conditions.

Monte Carlo output and real data have the same format and the same software is used to reconstruct the event in both cases, allowing a fair comparison of reconstructed parameters and Monte Carlo truth.
Spring 2016: start of test and qualification campaign with the HEPD Qualification Model

**Vibration test** at SERMS laboratory in Terni (PG) simulating launch and flight

**Thermal and vacuum test** at SERMS laboratory simulating space environment

January 2017: the HEPD Flight Model was installed on the CSES satellites.
Vibration, thermal-vacuum, magnetic cleanliness and aging tests were accomplished (Feb-May 2017)
Calibration with electrons

Beam Test @ Frascati BTF
Electrons and positrons from 30 to 150 MeV

The HEPD FM during the beam test at the BTF

Energy loss in the Calo

Energy loss in the LYSO
Calibration with protons

Beam test @ Proton Cyclotron of Trento
Protons from 51 to 300 MeV

Number of hit Calo planes

Energy loss in the Calo

100 MeV
Sigma/peak 0.08

Very good energy resolution

The HEPD FM during the beam test at Trento
Launch and preliminary results
On February 2\textsuperscript{nd} 2018 at 3:15 pm (Beijing time, GMT+8) the CSES Satellite was successfully launched from Chinese base “Jiuquan Satellite Launch Center”, located in the Gobi desert in Inner Mongolia.
On February 6th, the HEPD health check procedure was successfully run. Since February 12th, HEPD has been tested in different configurations in order to:

- study the trigger rates along the orbit in different trigger configurations;
- study to define the optimal trigger thresholds in flight;
- perform an in-flight calibration to be compared with beam test results;

CSES commissioning activities will last until the end of July 2018

- Since the beginning of May an encrypted data transfer from CEA-ICS to ASI-SSDC has been working
- Till now HEPD has produced ~350 GB of data
- Construction of a dedicated pipeline for the HEPD data processing and storage is in progress (pipeline: satellite → raw file → L0 → L1 → L2)
A comparison with atmospheric muon data confirms that pedestals, as well as the MIP peak, are in the same position, confirming the same behavior of the detector after the launch.

The highest **electron peak** at 600 counts and the **proton peak** at 2800 counts are visible.

HEPD preliminary results

HEPD status monitoring in quasi-real time by quicklook software (executed from L0 format) to get immediate information about strips and PMTs ADC counts and trigger rate in different orbital zones.
During the commissioning we performed a trigger threshold scan to optimize the detector acceptance.

Raw trigger rate map compared with IGRF-computed field in CSES positions calculated from telemetry data.
Particle identification analysis is still ongoing. Background contribution has to be accounted to obtain a proper separation between particle species.

Preliminary results show that particle identification is compatible with expectations from simulation (where no satellite background is accounted for).
Preliminary work on electron rate reconstruction

Preliminary reconstructed electron rate as a function of latitude and longitude (30th March – 30th April)

Electron flux (SPENVIS AE-8 MAX integral flux)
• The Limadou collaboration conceived, designed, constructed, qualified and is currently operating the High Energy Particle Detector.
• Huge testing work on HEPD preceded the launch, including beam tests and comparison with a Monte Carlo simulation developed on purpose.
• As the other CSES payloads, HEPD is still under commissioning but it is in good shape, providing good quality data and confirming expectations.
Outlook

- CSES satellite is the first of a constellation of “CSES-like” satellites expected to be launched in the coming years.
- The launch of CSES-2 is planned for the 2021
- The role of the Italian collaboration in CSES-2 could be bigger than in CSES-1
  - Improved version of HEPD (Lyso or BGO crystals used to measure gamma rays burst)
  - Electric Field Detector
- CSES follow up activity in Italy:
  Zirè experiment proposed as payload on NUSES mission
  “Zirè will perform characterization the coupling among Lithosphere-atmosphere-ionosphere-magnetosphere through the study of cosmic rays in the energy interval $1 \text{ MeV} < E < 100 \text{ MeV}$”.
- NUSES is a mission proposed by (GSSI-INFN-FBK, industrial partner TAS-I) and approved by the Italian government as a flagship initiative to relaunch the economy of the L’Aquila area
- Time to fly 3-4 years since the final decision on funding will be taken (end of July)
Thank you!