High-Energy Space Observatories in the New Era of Multi-Messenger Astrophysics

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i-Astro activities

Scientific
- All-Sky-ASTROGAM
- AMEGO
- CUBECOM
- IXPE

Spin-off
- TGF Flight Security
- Orbital Radiation Damage

Outreach & Dissemination
- Astronaut Summer School
- Space Summer School
- Balloon/CubeSat for student teams
ESAs FLEET ACROSS THE SPECTRUM

Thanks to cutting edge technology, astronomy is unveiling a new world around us. With ESAs fleet of spacecraft, we can explore the full spectrum of light and probe the fundamental physics that underlie our entire Universe. From cool and dusty star formation revealed only at infrared wavelengths, to hot and violent high-energy phenomena, ESA missions are charting our cosmos and even looking back to the dawn of time to discover more about our place in space.

- **planck**: Looking back at the dawn of time
- **herschel**: Unveiling the cool and dusty universe
- **jwst**: Observing the first light
- **cheops**: Stringing and first characterisation of exoplanets
- **euclid**: Exploring the dark Universe
- **gaia**: Surveying a billion stars
- **lisa pathfinder**: Testing the technology for gravitational wave detection
- **hst**: Expanding the frontiers of the visible Universe
- **xmm-newton**: Seeing deeply into the hot and violent Universe
- **integral**: Seeking out the extremes of the Universe

www.esa.int
Space Missions are essential to observe the whole electromagnetic spectrum.

**Altitude for 90% detection:**
- < 1 keV - 200 km
- 3 keV - 80 km
- 30 keV - 35 km

**50% absorption limit**
High energy astrophysics (0.1 – 100 MeV)

Polarimetry
- 2 extra parameters (angle and degree);
- emission production mechanism and object geometry.
High energy astrophysics (0.1 – 100 MeV)

Multi-messenger astrophysics
Gravitational waves + Gamma-rays

LIGO-Virgo + INTEGRAL

• supernova explosions;
• stellar mergers.
High-energy astrophysics missions

Ongoing missions: INTEGRAL, SWIFT, Fermi

All-Sky-ASTROGAM
ESA F mission call
All-Sky-ASTROGAM

Sensitivity

$\text{MDP} \quad (< 20 \%)$

(Minimum Detectable Polarization)

100 mCrab, 0.3-2.0 MeV
1 year obs. Time
Compton Polarimetry

Unpolarized Beam

\[ \frac{d\sigma_{KN,U}}{d\Omega} = \frac{1}{2} r_0^2 \varepsilon^2 [\varepsilon + \varepsilon^{-1} - \sin^2 \theta] \]

Polarized Beam

\[ \frac{d\sigma_{KN,P}}{d\Omega} = \frac{1}{2} r_0^2 \varepsilon^2 [\varepsilon + \varepsilon^{-1} - 2 \sin^2 \theta \cos^2 \eta] \]
Pair Production Polarimetry

- e-/e+ pair is emitted in the plane of polarization of the photon;
- The pair distribution modulation amplitude and maxima phase depend on polarization degree and angle, respectively;

- Simulation code based on MEGAlib and BoGEMMS (Bologna Geant4 Multi-Mission Simulator) for pair production regime;
- Experimental: 1) MEGA prototype data; 2) NewSUBARU polarized beam (1 to 74 MeV); 3) Balloon prototype testing (HEMERA?).
Previous polarimetric studies

ESRF, Grenoble, France ~ 99% polarized radiation

Laue lens sample Cu crystals + CdTe detector →
Modulation Q and Polarization direction

Detectors: 2 x CdTe; 18x18 mm²; 2 mm thick 8x8 pixels; 2 mm pitch

<table>
<thead>
<tr>
<th>Distance between planes</th>
<th>Modulation factor</th>
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<tbody>
<tr>
<td>6 mm</td>
<td>0.287</td>
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<tr>
<td>10 mm</td>
<td>0.192</td>
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AMEGO NASA
All-sky Medium Energy Gamma-ray Observatory

- NASA Probe Class Call
- Energy Range: 0.2 MeV -> 10 GeV;
- Angular Resolution: 3° (1 MeV), 10° (10 MeV);
- Energy Resolution: <1% below 2 MeV; 1-5% at 2-100 MeV; ~10% at 1 GeV
- Sensitivity:
• XIPE: X-ray Imaging Polarimetry Explorer (PI: Enrico Costa, INAF/IAPS, Roma);

• LIP part of XIPE Instrument Team;

• Selection for M4 Call Phase A in 2015;

• Not selected for Phase B;

• Moved to NASA IXPE (Imaging X-ray Polarimeter Explorer) with INAF/IAPS Roma team.
Gas Pixelized Detector

Normalized electrons / bin
Azimuthal angle $\phi$ (°)

Ne

2 keV
4 keV
6 keV
8 keV

Polarized X-rays, 2.0 keV
Polarized X-rays, 5.0 keV

Ne gas
Polarimetry with Ne, Ar and Xe

Under development
- Experimental system for transverse measurement of electron clouds generated by X-rays;
- Electron distributions for several gas mixtures and for different absorption regions, electric fields and depths.
Cubesat Scientific Constellations

Use of Cubesat technology is a priority of H2020 EU recent calls for scientific applications.
COMCUBE Nanosat sub-WP

Development of a 3U Compton nanosat for the polarimetry of GRBs + qualification of the e-ASTROGAM technologies

- Cubesat: standard unit ⇒ 1U
- Size: 10 x 10 x 10 cm
- Weight: 1kg
- Power: ~ 1.3 W
NASA Ballon
Polarimetric Experiment
Orbital Proton
Radiation Damage and Activation

Acrorad and EURORAD CdTe detectors tested at ICNAS, Coimbra, cyclotron proton beamline.
Spin-off: Flight Security
Dissemination and Outreach

Portugal Space Summer School

Astronaut Summer School
Future Steps

- All-Sky-ASTROGAM selection for launch by 2026.
  - Mass model simulation;
  - Calorimeter development (PRODEX ?);
  - Experimental instrument characterization and radiation damage.

- AHEAD 2 activities: Development of CUBECOM demonstrator.

- AMEGO
  - Pair production polarization and scientific case;
  - Instruments’ characterization and eventually more (PRODEX ?);

- IXPE mission:
  - Study mixtures of noble and quenching additive gases (DME or isobutane);
  - Development of gas testing system to measure the transverse spreading of the electron clouds produced by X-rays;