HXMT: the Hard X-ray Modulation Telescope mission
POLAR: the GRB polarimeter onboard China’s Tiang-Gong 2 Spacelab

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Hard X-ray Modulation Telescope (HXMT) satellite

- China’s 1st X-ray astronomy satellite
- Selected in 2011
- Total weight ~2500 kg
- Cir. Orbit 550 km, incl. 43°
- Pointed, scanning and GRB modes
- Designed lifetime 4 yrs
- Launch in June 2017
HXMT core sciences

1. Galactic plan scan and monitor survey: finding more weak short transients at hard X-rays
2. Pointed observations: high statistics observations of bright sources and high cadence XRB outbursts
3. GRB observations: up to 3 MeV with large area
4. Multi-wavelength observations
HXMT Payloads

High Energy (HE):
- Normal Mode
  - NaI, 20-250 keV, ~5000 cm²
  - CsI, 50-700 keV, ~5000 cm²

High Energy (HE):
- GRB Mode
  - NaI, 100-300 keV, 5000 cm²
  - CsI, 250-3000 keV, 5000 cm²

Medium (ME):
- Si-PIN, 5-30 keV, 952 cm²

Low Energy (LE):
- SCD, 1-15 keV, 384 cm²

Main characteristics of the HXMT Mission

<table>
<thead>
<tr>
<th>Detectors</th>
<th>LE: SCD, 384 cm²; ME: Si-PIN, 952 cm²; HE: NaI/CsI, 5000 cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Resolution</td>
<td>HE: 25μs; ME: 20μs; LE: 1ms</td>
</tr>
<tr>
<td>Energy Resolution</td>
<td>LE: 2.5% @ 6 keV; ME: 8% @ 17.8 keV; HE: 19% @ 60 keV</td>
</tr>
<tr>
<td>Field of View of one module</td>
<td>LE: 6° × 1.5°; 6° × 4°; 60° × 3°; blind; ME: 4° × 1°; 4° × 4°; blind; HE: 5.7° × 1.1°; 5.7° × 5.7°; blind</td>
</tr>
<tr>
<td>Source Location</td>
<td>&lt;1' (20σ source)</td>
</tr>
</tbody>
</table>
HXMT Sensitivity: pointed observation

\[ t = 10^6 \text{ sec}, \ 3\sigma \]

\[ \Delta E/E = 1/2 \]
Two modes of HXMT/HE

<table>
<thead>
<tr>
<th>Mode</th>
<th>NaI Energy Range (keV)</th>
<th>CsI Energy Range (keV)</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal mode</td>
<td>20 – 250</td>
<td>40 – 600</td>
<td>Normal HV</td>
</tr>
<tr>
<td>GRB mode</td>
<td>100 – 1250</td>
<td>200 – 3000</td>
<td>Lower HV to reduce gain by 5X. And turn-off AGC system</td>
</tr>
</tbody>
</table>


(Gruber+, ApJS, 2014)
Effective area

Front incident  Back incident

HXMT’s GRB capability comparison

Quite sensitive in soft gamma-rays (MeV), 10X larger than GBM on-board Fermi satellite.

### Expected HXMT GRB detection rates

<table>
<thead>
<tr>
<th>Significance (sigma)</th>
<th>GRB mode (GRBs/year)</th>
<th>Normal mode (GRBs/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Front</td>
<td>Back</td>
</tr>
<tr>
<td>5</td>
<td>70</td>
<td>130</td>
</tr>
<tr>
<td>10</td>
<td>40</td>
<td>110</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
<td>80</td>
</tr>
</tbody>
</table>

About 200 GRBs per year > 5 sigma

1st yr observation program: July, 2017

From HXMT AO-1: Regular; ToO; scanning
The Milky Way is highly variable in X-ray eyes!

HXMT scan mode

The Center of the Milky Way viewed by NASA RXTE satellite

May 10 1999

HXMT scanning survey of the Milky Way

Repeatedly scanning the whole Milky Way, to discover new variable black holes and neutron stars, and monitor activities of the known X-ray sources.

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Shuang-Nan Zhang, Institute of High Energy, Chinese Academy of Sciences
Collaborations of POLAR

- PIs:
  - Shuang-Nan Zhang
  - Martin Pohl

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GRB Models and Polarization

The leading models that describe the prompt emission are based on synchrotron emission from relativistic electrons in GRB jets.

To discriminate between models: $\Pi \sim 10\%$

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## Summary of the current GBR polarization measurements

<table>
<thead>
<tr>
<th>GRB</th>
<th>Instru/Satellites</th>
<th>Pol degree(%)</th>
<th>Energy range(keV)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>110721A</td>
<td>GAP/IKAROS</td>
<td>$84^{+16}_{-28}$</td>
<td>70–300</td>
<td>@3.3σ, with constant pol direction</td>
</tr>
<tr>
<td>110301A</td>
<td>GAP/IKAROS</td>
<td>70 ± 22</td>
<td>70–300</td>
<td>@3.7σ, with constant pol direction</td>
</tr>
<tr>
<td>100826A</td>
<td>GAP/IKAROS</td>
<td>27 ± 11</td>
<td>70–300</td>
<td>@2.9σ, with inconstant pol direction</td>
</tr>
<tr>
<td>021206</td>
<td>RHESSI</td>
<td>80 ± 20; 41^{+57}_{-44}</td>
<td>150–2000</td>
<td>With large systematic error</td>
</tr>
<tr>
<td>140206A</td>
<td>IBIS/INTEGRAL</td>
<td>&gt;48</td>
<td>200–400</td>
<td>Unable to restrict GRB model</td>
</tr>
<tr>
<td>061122</td>
<td>IBIS/INTEGRAL</td>
<td>&gt;60; &gt;65; &gt;52</td>
<td>250–800; 250–350; 350–800</td>
<td>Unable to restrict GRB model</td>
</tr>
<tr>
<td>041219A</td>
<td>IBIS/INTEGRAL</td>
<td>&lt;4; 43 ± 25; 98 ± 33</td>
<td>200–800; 200–800; 100–350</td>
<td>With variable pol direction</td>
</tr>
<tr>
<td>041219A</td>
<td>IBIS/INTEGRAL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>041219A</td>
<td>SPI/INTEGRAL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>960924</td>
<td>BATSE/CGRO</td>
<td>&gt;50</td>
<td>20–1000</td>
<td>Unable to restrict GRB model</td>
</tr>
<tr>
<td>930131</td>
<td>BATSE/CGRO</td>
<td>&gt;35</td>
<td>20–1000</td>
<td>Unable to restrict GRB model</td>
</tr>
</tbody>
</table>

Design of POLAR detector

- Main scientific goals
  - Measure the polarization of the GRB prompt emissions as well as Solar flare emissions, to confirm or restrict the radiation models
  - In 2 years of flight lifetime, be able to measure ~ 100 GRBs, contributing to the largest GRB prompt emission polarization observation database
  - For the GRBs with fluence higher than $10^{-5}$ erg cm$^{-2}$, the Minimum Detectable Polarization (MDP) of POLAR can reach down to < 10%

Detection principle of POLAR

Klein-Nishina equation:
\[
\frac{d\sigma_p}{d\Omega} = \frac{1}{2} r_0^2 \varepsilon^2 (\varepsilon + \varepsilon^{-1} - 2\sin^2 \theta \cos^2 \eta)
\]

Detection principle of POLAR

Compton Scattering with polarization

Distribution function
\[
C(\xi) = A\cos(2(\xi - \varphi + \frac{\pi}{2})) + B
\]

Modulation factor\[
\mu = \frac{C_{\text{max}} - C_{\text{min}}}{C_{\text{max}} + C_{\text{min}}}
\]

Polarization level\[
P = \frac{\mu}{\mu_{100}}
\]
Monte-Carlo Simulations – Minimum detectable polarization

\[ MDP = \frac{n_\sigma}{S_F \mu_{100} \varepsilon A} \sqrt{\frac{S_F \varepsilon A + B}{T}} \]

MDP varies with incident direction of the GRB photons. E. S. Garcia, 2010

MDP varies with total fluence given in the BATSE catalog for photons with energy above 20 keV. E. S. Garcia, 2010

# Technical properties summary of POLAR

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Detector material</td>
<td>Plastic scintillator (EJ-248M)</td>
</tr>
<tr>
<td>2</td>
<td>Yearly detectable GRBs</td>
<td>~50</td>
</tr>
<tr>
<td>3</td>
<td>GRB localization accuracy</td>
<td>≤5° (Fluence≥10^{-5} erg cm^{-2})</td>
</tr>
<tr>
<td>4</td>
<td>Detection energy range</td>
<td>~50–500 keV</td>
</tr>
<tr>
<td>5</td>
<td>Field of view</td>
<td>±90° × ±90°</td>
</tr>
<tr>
<td>6</td>
<td>Modulation factor</td>
<td>40%@200 keV</td>
</tr>
<tr>
<td>7</td>
<td>MDP</td>
<td>~10% (Fluence_{total} ≥ 3×10^{-5} erg cm^{-2})</td>
</tr>
<tr>
<td>8</td>
<td>Detector geometry area</td>
<td>~550 cm^{2} (on-axis view)</td>
</tr>
<tr>
<td>9</td>
<td>Mass</td>
<td>OBOX: 27.6 kg, IBOX: 3.52 kg</td>
</tr>
<tr>
<td>10</td>
<td>Size</td>
<td>OBOX: 462×462×268.5 mm^{3} IBOX: 247×160×85 mm^{3}</td>
</tr>
<tr>
<td>11</td>
<td>Maximum power consumption</td>
<td>≤80 W</td>
</tr>
<tr>
<td>12</td>
<td>Time accuracy (UTC)</td>
<td>±1 ms</td>
</tr>
<tr>
<td>13</td>
<td>Reliability</td>
<td>0.90 (in 2 years lifetime)</td>
</tr>
</tbody>
</table>

Calibration with radioactive source

Calibration with low energy X-ray fluorescence

\[ \chi^2 / \text{ndf} = 1.435 \times 10^5 / 2 \]
\[ p0 = 31.84 \pm 406.8 \]
\[ p1 = 92.74 \pm 8.151 \]

\[ \chi^2 / \text{ndf} = 2.878 \times 10^6 / 4 \]
\[ p0 = -851.6 \pm 482.1 \]
\[ p1 = 109.5 \pm 2.081 \]

**ESRF beam test in 2015 - introduction**

- **Facility introduction**
  - **Beamline:** ID11
  - **Polarization:** 100%
  - **Pol direction:** horizontal
  - **Energy range:** 35 ~ 140 keV
  - **Beam size:** minimum (H×V) 0.2×0.07 μm², maximum (H×V) 1200×1000 μm²
  - **Initial intensity:** ~10⁷ phs/s

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Detector positions for different off-axis

ESRF modulation curve

Modulation curve, 140 keV

- 140 keV, on-axis measurement
- Modulation factor
  - 0° polarization: 39.31%
  - 90° polarization: 40.23%
  - Simulated result: ~40%

In-orbit calibration scheme

Top view of POLAR: locations of 4 $^{22}$Na sources and 25 modules

Triggering pattern of the 1600 channels

In-orbit calibration scheme

Result with event selection criteria

Triggering pattern of the 1600 channels

Current status

- successfully launched on 15th/September
- successfully powered-on on 22nd/September
- powered-off on 14th/October for docking of TG-2 and Shenzhou-11 spaceship
- powered on again on 18th/November...
Preliminary results: Crab pulsar

Preliminary results: solar flare

Oct. 12, 2016: consistent with RHESSI results

Preliminary results: GRB 20160928A

>90 degree off-axis, not good for polarization

Preliminary results: GRB 20161129A

GRB 20161129A detected on the tail of a big Solar Flare

~45 deg off-axis, possible for polarization measurement

GRB 20161129A – background subtracted
Consistent with SWIFT and GRB

~ 80 – 500 keV

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Preliminary results: GRB161218B

Raw lightcurve:

GRB time: GPS 1928:30778.0-1928:30806.8
Observation Hit maps

Background off GRB

Total during GRB

Efficiency statistics

Efficiency of 1600 channels

Efficiency distribution

<table>
<thead>
<tr>
<th>eff_PDF</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Entries</td>
<td>1600</td>
</tr>
<tr>
<td>Mean</td>
<td>1.035</td>
</tr>
<tr>
<td>RMS</td>
<td>0.6106</td>
</tr>
</tbody>
</table>
Summary and outlook

- HXMT is China’s 1st X-ray astronomy satellite: 2017-06.
- HXMT AO-1 1st yr observation program available.
  - 1/3 total time in Galactic plane scan and monitoring
  - GRB mode when in Earth shadow or HE not used (~1/2)
  - Will invite ESA, ASI, MPE, etc., for joint studies.
- POLAR, launched on 2016-09-14, is working as expected.
- POLAR has detected the Crab pulsar, solar flares and GRBs.
- In-orbit calibration is on-going: polarization for solar flares and GRBs are expected for bright events.

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