High Sensitivity Balloon-Borne Hard X-Ray/Soft Gamma-Ray Polarimeter PoGOLite

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Contents:
• Polarization in soft $\gamma$-rays
• PoGOLite mission overview/performance
• Laboratory test and beam test
• Expected sciences
Polarization in Soft $\gamma$-rays ($E \geq 10\text{keV}$)

A powerful tool to investigate source geometry and emission mechanism

- **Synchrotron emission**: direction of B-field.
  - Pulsar wind nebular
  - Binary pulsar and rotation-powered pulsar
  - Jets in AGN and $\mu$-QSO
- **Compton Scattering**: orientation of the scatterer
  - Black-hole binaries (accretion disk geometry)
- **Propagation in strong magnetic field**: test of quantum electrodynamics, direction of B-field
  - Highly magnetized neutron star

rot. powered pulsar
Harding 2004

BHB, $\mu$-QSO
Mirabel 2006

Crab nebula & pulsar by CXO
Only Crab nebula was observed in X-rays (Weisskopf et al. 1978). All the others (incl. Crab nebula) await to be observed above 10 keV.

<table>
<thead>
<tr>
<th>Source name</th>
<th>Category</th>
<th>flux@40 keV</th>
<th>non-thermal process dominated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crab nebula and pulsar</td>
<td>nebula/pulsar</td>
<td>1Crab/0.1Crab</td>
<td></td>
</tr>
<tr>
<td>Vela X-1</td>
<td>pulsar</td>
<td>0.6Crab</td>
<td></td>
</tr>
<tr>
<td>Her X-1</td>
<td></td>
<td>0.12Crab</td>
<td></td>
</tr>
<tr>
<td>Cyg X-1</td>
<td>BHB</td>
<td>0.6Crab</td>
<td></td>
</tr>
<tr>
<td>GX 339-4</td>
<td></td>
<td>0.3Crab</td>
<td></td>
</tr>
<tr>
<td>IE1740.7-292</td>
<td></td>
<td>0.23Crab</td>
<td></td>
</tr>
<tr>
<td>GS2000+25</td>
<td></td>
<td>0.3Crab</td>
<td></td>
</tr>
<tr>
<td>GRS 1915+105 (flare)</td>
<td>µ-QSO</td>
<td>0.24Crab</td>
<td></td>
</tr>
<tr>
<td>GRO J1655-40 (flare)</td>
<td></td>
<td>1.0Crab</td>
<td></td>
</tr>
<tr>
<td>Mkn501 (flare)</td>
<td>AGN</td>
<td>0.23Crab</td>
<td></td>
</tr>
<tr>
<td>CenA</td>
<td></td>
<td>0.06Crab</td>
<td>(Candidates for pol. measurements, Kataoka et al. 2005)</td>
</tr>
</tbody>
</table>

Large Effective Area, High Modulation Factor and Low Background are required.
PoGOLite Mission Overview

Highly-sensitive polarization measurement in 25-80 keV

- International collab. among Japan, US, Sweden and France
  - Engineering flight (61 units) in 2009
  - Science flight (217 units) in 2010

- Well-type phoswich detector
  - Slow Plastic:
    - narrow FOV (5 deg²)
  - Fast Plastic:
    - Large Aeff (>=200 cm²) and high MF (>=25%)
  - BGO/Polyethylene Shield:
    - low BG (~0.1 Crab)

- Slow Plastic Scint. Collimator
- Fast Plastic Scint. (Pol. measurement)
- Bottom BGO
- PMT assembly (low noise and high QE)

SAS (Side Anticoincidence Shield)

PoGOLite
The Polarized Gamma-ray Observer

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Mission Concept (1)

Well-type phowich Detector: Very Low Background

- Yellow: Polyethylene neutron shield
- Orange: Side and bottom BGO (217+54 units)
- Pink: Phoswich Detector Cell (217 units)

Expected Crab spectrum and residual BG by a detailed MC simulation

BG~0.1Crab (typically >=1Crab in competing missions)
Mission Concept (2)

Tightly-packed 217 hexagonal arrays

- Each unit works as scatterer and absorber
  - Large effective area
- Rotationally symmetrical through every 60 degree
  - High modulation factor

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Effective Area (cm²)

- Aeff >= 200 cm²
  - ~20% of geometrical area

Modulation Factor (%)

- MF >= 25%
  - In all energy band

Phoswich Detector Cell

pol. vector

Scattered photon
Proof of the Concept (1)

Test PDC with $\gamma$-rays

Accelerator test @KEK, 2007
(Ueno et al. 2007, in prep)

Lab. test with the flight-design DAQ

Phoswich Detector Cells

Clear separation of fast signals from BGO/slow signals down to 15keV (well below Eth of photo-absorption site)

Pol. measurement with flight-design sensors and DAQ

Compton scattering site

Pol. measurement with flight-design DAQ

Counting Rate (Relative)

Azimuth Angle [degree]

Integrated charge with slow-interval vs. fast branch

Slow/BGO branch: strong $\beta$-ray
($^{90}$Sr)

fast branch
weak 60 keV $\gamma$-ray
($^{241}$Am)

Pol. $\gamma$-ray beam

(see also poster by Tanaka, N15-97)
Proof of the Concept (2)

Test PDC and SAS with “Cosmic-Ray” BG

Soft $\gamma$-ray spectrum of $^{241}$Am/$^{137}$Cs measured while irradiated with accelerator protons

- No degradation of the PDC spectrum with protons at 3 kHz, where ~100 Hz expected
- No degradation of the SAS spectrum with protons at 6 kHz, where ~200 Hz expected

SAS PHA for BG monitor

- Cs only
- Cs + proton 930Hz
- Cs + proton 6.5 kHz
- Cs + proton ~60 kHz

662 keV

PDC irradiation

392MeV p

$^{241}$Am

(60keV)

SAS irradiation

392MeV p

$^{137}$Cs

(662keV)

Proton beam test at RCNP in Osaka Univ.

(see also poster by Tanaka, N15-97)
Expected Result (1)

Precise Measurement of Pol. Vector in Crab Nebula

- Soft $\gamma$-rays are thought to come from electrons trapped around the toroidal B-field (Pelling et al. 1987). Pol. angle is expected to be parallel to spin axis.
- Optical and X-ray pol. vector is $\sim$30 deg off.

20-80 keV, 6 hr obs. Simulation (19% polarization assumed)

- MF = $4.63 \pm 0.37\%$ (13 $\sigma$ detection).
- Pol. angle is determined by 2.3 degree resolution (1 $\sigma$).

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Precise measurement of B-field trapping high-energy electrons.
Expected Result (2)
Crab Pulsar Models

• Competing three pulsar models predict different polarization signatures in soft \( \gamma \)-rays.

  • Polar Cap:
    MF = 6.45\( \pm \)0.73\%, phase by 3.2 deg resol.

  • Outer Gap:
    MF = 5.00\( \pm \)0.73\%, phase by 4.2 deg resol.

  • Causitic:
    MF = 2.08\( \pm \)0.73\%, phase by 10 deg resol.

from a review by Harding 04

• Distinguish models w/o ambiguity
• Strong constraints on detailed emission mechanism
Expected Result (3)

Accretion Disk around Black Holes

- Compton reflection by accretion disk will produce polarized soft $\gamma$-rays

Cyg X-1 Hard state

Zdziarski et al. 2004

Cyg X-1 Soft state

PoGOLite energy band

Direct measurement of reflection component and disk orientation

- sig/BG $\geq$ 8
  - MF = 2.32 $\pm$ 0.23\% ($10\sigma$)
  - pol. angle resol. = 2.9 deg

- sig/BG $\approx$ 3
  - MF = 1.93 $\pm$ 0.36\% ($5\sigma$)
  - pol. angle resol. = 5.3 deg

PoGOLite: The Polarized Gamma-ray Observer
Summary

• Polarization in soft $\gamma$-rays
  • powerful probe to study source geometry and emission mechanism

• PoGOLite mission
  • pol. measurement in 25-80 keV
  • International collaboration among Japan, US, Sweden and France
  • A novel concept of well-type phoswich counter: low background (~100 mCrab) and high sensitivity (MF>=25%, Aeff>=200 cm$^2$)
  • Engineering flight in 2009, science flight in 2010
  • Concept has been proved through laboratory and accelerator tests

• Expected sciences by PoGOLite
  • Crab Nebula polarization vector in 2-3 degree resolution
  • Distinguish pulsar models w/o ambiguity
  • Disk reflection component of Cyg X-1

Open a new window in high energy astrophysics