Hard X-ray Polarimeter PoGO and GLAST mission

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Outline:
• Introduction
• PoGO mission
• Hardware Developments
• Scientific Targets
In X-ray Astrophysics, the imaging capability, spectral resolving power and point source sensitivity have improved by orders of magnitude. However, …
(Little) Progress of Polarization Measurement

Crab Nebula Polarization measurement with OSO-8 (1976)

- Two carbon Bragg diffraction polarimeters @2.6 keV and 5.2 keV
- 19.2+-1.0 % polarization from Crab Nebula (Weisskopf et al. 1976)
- Signal/BG ratio was ~9(2.6 keV)/2(5.2 keV)
- No significant (3σ) pol. detection from Crab pulsar

Results have not been surpassed for ~30 years, but PoGO (Polarized Gamma-ray Observer) can do!
What can polarization tell us about HE objects?

--- Processes known to polarize hard X-rays ---

• **Synchrotron emission**: pol. vector is perpendicular to magnetic field and can tell us the direction of the field.
  • SNRs, Pulsars, AGN jets, micro-quasars and GRBs
• **Compton Scattering**: pol. vector is perpendicular to the plane of scattering and can tell us the geometry of the photon source and the scatterer (e.g., accretion disk)
  • BH binaries, Seyfert AGNs
• **Propagation of photons in strong magnetic field**: photons with pol. vector perpendicular to magnetic field are highly absorbed. Good for the test of quantum electrodynamics and reconstruction of the direction of the magnetic field.
  • Isolated pulsars, NS binaries with a strong cyclotron line.

• Polarization is a powerful tool for the direct measurement of source geometry.
Concept of the Compton Polarimeter

Utilize azimuthal angle asymmetry of Compton Scattering to measure hard X-ray polarization

Klein-Nishina cross section

\[
\frac{d\sigma}{d\Omega} = \frac{r_0^2}{2} \frac{k^2}{k_0^2} \left( \frac{k}{k_0} + \frac{k}{k_0} - 2 \sin^2 \theta \cos^2 \phi \right)
\]

Azimuthal angle distribution

90 degree scattering is the best for the polarization measurement

Modulation Factor is defined as

\[
\frac{N_\perp - N_{ll}}{N_\perp + N_{ll}}
\]
**Polarized Gamma-ray Observer (PoGO)**

- Utilize well-type phoswich counter design: plastic scintillators (main detector) shielded by slow scintillators (active collimator) and side/bottom BGO. Similar to Suzaku HXD-II.
- Energy band is 30-100 keV: Non-thermal process is dominant and photons are expected to be polarized in many objects.
- Low background (~10 mCrab) and large effective area (240 cm²): very high sensitivity for polarization.
Uniqueness of PoGO

- Ultra-low BG: only 10-20 mCrab
- Large Effective Area: 230 cm² @40 keV
- Narrow FOV: 1.25 msr

Extremely high sensitivity

- minimum detectable pol. degree is ~3 % for 100 mCrab (1σ) by a single, 6 hours balloon flight

Expected source and BG spectra

Balloon-borne mission:
- very low cost
- possible observation of flaring events (alerted by, e.g., GLAST)
Collaboration/Schedule of the Mission

• United States: NASA/GSFC, SLAC and Princeton Univ.
  Balloon Flight, DAQ, Beam Test and plastic scintillators
• Japan: Tokyo Institute of Technology, Hiroshima Univ., Yamagata Univ. and JAXA/ISAS
  • PMTs, Beam Test and MC Simulation
• Sweden and France: Royal Institute of Technology, Stockholm Univ. and Ecole Polytechnique
  PMTs, BGO scintillators and Reflectors

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<td>2003</td>
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<td>2004</td>
<td>Spring8/Argonne Beam Test</td>
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<td>2005</td>
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<td>2006</td>
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<td>2008</td>
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1st prototype (fast scinti. 7 units) 2nd prototype (fast/slow 19 units+anti)

Flight Instrument Integration and Test

GLAST Launch & Obs.
Argonne Beam Test (2003)

- 60, 73 and 83 keV synchrotron beam
- Tested prototype detector (7 units fast scintillators) as well as Geant4 simulation

Modulation Curve for 73 keV beam

- Modulation Factor: 42\pm 1\% (data) vs. \sim 47\% (simulation)

Validated prototype on 10\% level.
- Bugs in Geant4 (pol. processes in Rayleigh scattering and Compton Scattering) were found and reported. (more than a year ago….)
- Details are in Mizuno et al. (NIMA, 2005).
KEK Beam Test (2004)

- 30, 50 and 70 keV synchrotron beam
- Tested prototype detector with flight-design PMTs

- Flight configuration scintillators and PMTs were tested.
- Lowest energy X-rays for PoGO were tested and validated.
- Details are in Kataoka et al. (SPIE, 2005).
Laboratory Test of prototype (2005)

- **2nd prototype** with a long hexagonal slow tube and BGO is now being tested.
- Used a strong Am source and Compton Scattering technique to generate polarized X-rays in laboratory: very low cost and high flexibility.
- M. Ueno (Titech), K. Yamamoto (Hiroshima Univ), T.P. Ylinen and B.G. Kiss (KTH)

This new prototype will be tested at KEK next month.
Possible Targets for PoGO(1)

Crab Pulsar obs. by PoGO can distinguish among pulsar emission models


GeV gamma-ray spectrum from Vela pulsar

GLAST + PoGO will provide a very strong restriction on the pulsar emission mechanism.
Possible Target for PoGO (2)

Geometry of Astrophysical Jets

- High Frequency-Peaked BL Lac Objects (HBL)
  - observe in flaring state notified by, e.g., GLAST.
  - Multi-wavelength spectrum by GLAST and PoGO can also constrain the jet mechanism
- Galactic microquasars
  - GRS 1915+105/GRO J1655-40

Other Possible Targets

- Galactic BHBs in hard state: accretion disk geometry
  - Cyg X-1, GX339-4, etc.
- Binary pulsars with cyclotron line: propagation of photons in magnetic field
  - Her X-1, Cen X-3, Vela X-1, etc.

~10 Galactic/extragalactic high energy object could be observed by PoGO
Summary

• PoGO is a balloon-borne instrument scheduled to be launched in 2008 and will open a new window in high energy astrophysics, i.e., polarization.
• It is based on a well-type phoswich counter design and has a very high sensitivity down to 10% polarization from 100 mCrab source. ~10 Galactic/extragalactic objects could be observed.
• Test of the 2nd prototype started.
• Collaboration of GLAST and PoGO will provide a strong constrain on the emission mechanism of pulsars, AGN/micro-quasar jets, etc.
Backup Slides for discussion
Galactic Black Hole Binaries

- Crab total
- Signus X-1 Soft State
- Cygnus X-1 Hard State
- GLAST-LAT

3 sigma detection for 10% polarization

Cygnus X-1 Longterm

Detection limit (3 sigma) for 10% polarization