Soft Gamma-ray Polarimetry with ASTRO-H SGD

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T. Mizuno (Hiroshima Univ.) on behalf of the SGD team and Polarization team
Objectives of ASTRO-H (#3)

- The most sensitive wideband observation over an energy range from 0.3 to 600 keV

Soft Gamma-ray Detector (SGD)

- Highly-sensitive observation in 60-600 keV
  - narrow-FOV Compton Camera
  - extremely-low background

Takahashi+12, Proc. SPIE
SGD Concept

- **Si-CdTe** Compton Camera + BGO shield/Fine Collimator
- Constrain incident angle using Compton kinematics
  - efficient background suppression
  - extra success: soft gamma-ray polarimetry (e.g., Astrophysical jets)

**Background Level**

\[
\cos \theta = 1 + \frac{m_e c^2}{E_1 + E_2} - \frac{m_e c^2}{E_2}
\]

Suzaku HXD-GSO

0.1 Crab

Astro-H SGD

\( BG \leq 100 \text{ mCrab} \)

Tajima+ 10, Proc. SPIE
Watanabe+12, Proc. SPIE
Science Case: Cyg X-1 (~1 Crab)

- A very famous Black-hole binary with a radio jet
- \(\gamma\)-ray pol. vector (\(\perp\) to B-field) by INTEGRAL not parallel nor perpendicular to the radio jet
- With SGD, we are able to detect (or constrain) polarization down to 60 keV for the first time

soft component (Comptonization by disk corona, no pol.)

Pol. Fraction & MDP for 100 ks obs.

\(\gamma\)-ray pol. (\(\geq 230\) keV)
Laurent+11, Jourdain+12
PA~42 deg.
Science Case: Cyg X-1 (~1 Crab)

- We can confirm INTEGRAL results in high-E and perform a precise polarization measurement in low-E (alignment and direction of B-field)

100 ks, 60-100 keV

\[ m_{\text{obs}} = 10.58 \pm 0.60\% \]
\[ \Delta \phi = 1.6 \text{ deg} \]

100 ks, 330-600 keV

\[ m_{\text{obs}} = 14.4 \pm 4.0\% \]
\[ \Delta \phi = 8.2 \text{ deg} \]

SGD is also able to detect polarization from 100 mCrab objects (less-bright \( \mu \)-QSOs, AGN flare, etc.)
Hardware Development: Full EM Compton Camera Electric Test

- Configuration of full EM Compton Camera
  - sensor module is the same as FM in terms of design and material
  - FPGA, some PCBs and passive parts are not space qualified
- Fully functional except for one out of 8 side-CdTe modules
  - fraction of bad channels (noisy, disconnected)
    - Si: ~0.03%, CdTe: ~2%
  - no degradation of energy resolution
- Verification of imaging capability with Compton kinematics (proof of BG rejection)

(Ichinohe, Takeda, Watanabe, Togonakamura, Furui)

T. Mizuno et al. Ichinohe’s master thesis
Hardware Development: Environmental Tests of SGD-S EM

(Ohta, Watanabe, Nakazawa, Noda, Ichinohe, MHI)

• Vibration test
  – issue found in radiator support in 2012
  – improvement of the structure verified by an analysis and test on 2013 Mar.
• Thermal-balance test: confirmation of thermal design
• Acoustic test: no apparent damage. effects on FC evaluated
Hardware Development: SGD-S FM
1st Integration Test (2014 Mar. to May)

- 2 FM Compton Camera + 1 EM Compton Camera
- 25 BGO + 11 APD
- End-to-end test using FM and pre-FM electronics (CSA, HV, AE, DPU, DE)

All BGO+APD (11 of 25) are working well

(Murakami, Kawano, Ohno)

-- 2014/May/23 Func-D @EIC
-- 2014/May/14 SGD test @ EIC
-- 2014/Mar/27 SGD subsystem test
Summary

• SGD is a very sensitive spectrometer and polarimeter

• SGD is able to detect (or constrain) polarization for 100 mCrab source + Energy overlap with INTEGRAL for 1Crab source

• Most of designs have been established through EM tests (2012-2013)

• FM production and tests started in 2013 and have been continuing toward delivery in 2014.

Thank you for your Attention
Reference

- Lei et al. 1997, Space Sci. Rev. 82, 309
- Laurent et al. 2011, Science 332, 438
- Tajima et al. 2010, proc. SPIE 7732, 773216
- Takeda et al. 2010, NIMA 622, 619
- Takahashi et al. 2012, proc. SPIE 8443, 84431Z
- Watanabe et al. 2012, proc. SPIE 8443, 844326
- Fukazawa et al. 2014, proc. SPIE
- Mizuno et al. 2014, proc. SPIE
- Noda et al. 2014, proc. SPIE
- Ohno et al. 2014, proc. SPIE
Backup Slides
SGD as a **Polarimeter**

- **Si-CdTe Compton Camera + BGO shiled**
- **Constrain incident angle using Compton kinematics**
  - Efficient background suppression (θ-cut)
  - Polarization measurement (φ-measurement)

\[
\cos \theta = 1 + \frac{m_e c^2}{E_1 + E_2} - \frac{m_e c^2}{E_2}
\]

Lei+97 (Concept of Compton polarimeter)
Performance Verification (1)

- SGD prototype was tested at Spring-8
- Use 90-degree scattered photons to reduce the beam intensity (~170 keV, 92.5% polarized)
- Detectors were rotated to study systematic effects

Takeda+ 10, NIMA

250 keV (>99.9%)
170 keV (92.5%)
Performance Verification (2)

• Beam test at Spring-8

\[ m_{\text{obs}} = 0.82 \] agrees with the expectation (0.855) within 3% => verifying the detector concept and simulation
Science Case 2: GRS 1915+105 (~100 mCrab)

- A very famous Galactic microquasar
- Possible correlation between radio and hard X-rays (Rodriguez+08), implying a jet emission in X-ray/$\gamma$-ray band
- Polarization measurement is crucial to establish (or constrain) the jet emission in $\gamma$-rays

![Graph showing soft and hard components with polarization fraction and MDP for 100 ks observation.](image-url)
Science Case 2: GRS 1915+105 (~100 mCrab)

- SGD can detect (or constrain) polarization for 100 mCrab source

100 ks, 60-100 keV
\[ m_{\text{obs}} = 13.6 \pm 1.5\% \]
\[ \Delta \phi = 3.0 \text{ deg} \]

100 ks, 180-330 keV
\[ m_{\text{obs}} = 12.5 \pm 4.0\% \]
\[ \Delta \phi = 8.7 \text{ deg} \]
Science Case 3: AGN flare (~100 mCrab)

- Blazars are source of strong polarization (~70%)
- Correlation btw. flux and polarization in radio and optical
- SGD is able to detect polarization if they flare up to ~100 mCrab

(Odaka, Stawarz)
Calibration of Energy Scale

- Calibrations of photo absorptions are not useful for high energy photons (due to low absorption probability in Si) and low energy photons (due to attenuation before reaching bottom sensors)
- Use Compton scattering events of gamma-ray lines
  - Calibrate CdTe layers at high energies
  - Calibrate CdTe and Si low energy region using single Compton events \( E_{\text{LE}} = E_{\text{line}} - E_{\text{HE}} \) (Ichinohe)