Gamma-ray Observation in Space
Synergy between X-ray and Gamma-ray Observation present and future

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Gamma-ray Mission in 21st Century

INTEGRAL 2002

GLAST 2006

Swift 2003

Compton-GRO Satellite

AGILE 2003
X-ray/Gamm-ray Observation is crucial to access Black Hole

- Hot plasma
  - High Temperature
  - electron/ion

Non-Thermal Emission from accelerated Particle

Toward the event horizon

Non-Thermal Emission from the extremely high density/temperature plasma

To Probe Obscured Black Hole

NGC4945

Done et al. 1996
Gamma-ray Black Hole (Blazars)

- Synchrotron, peak at IR-X ray energies
- Inverse Compton, peak at GeV-TeV energies from the same electron distribution

The relativistic jet points close to the observer. The non-thermal emission is Doppler boosted and greatly enhanced.
Blazar Variability & Internal Shocks

Mrk421

\[ R_{\text{fo}} = 0.7, \ T_{\text{chr}} = 40 \ \text{ks} \Rightarrow D_0 = 1 \times 10^{13} \ \text{cm} \]

\[ s_G = 0.015, \ G = 15 \ \text{(assumed)} \]

\[ \left( \frac{\Gamma}{\sigma_\Gamma} \right) = 1,000 \]

\[ L_{\text{kin}} \sim 1,000 \ L_{\text{jet}} \]

Tanihata, Takahashi, Kataoka et al. 2002,
Iwamoto, Takahara et al. 2003

Particle Accelerator in SNRs (I)

The remnant of SN 1006

Discovery of synchrotron X-ray emission by ASCA (Koyama et al. 1995)

CANGAROO
TeV Gamma-ray
(Tanimori et al. 1998)

Power-law type spectrum
= synchrotron radiation

\[ h\nu_{\text{synch}} = 5.3 \ E_{\text{100 TeV}}^2 \ (\text{keV}) \]

Direct evidence of > 10 TeV particles

X-ray observation \Rightarrow \text{highest energy electrons}

(from presentation by Uchiyama 2003)
**Particle Accelerator in SNRs**

(2)

Accelerator \(\rightarrow\) Target

Emission due to electron/proton interaction in the dense molecular cloud

**Annihilation Fountain in the Center of Milky Way**

Caption: Map of the distribution of positions towards the center of the Milky Way Galaxy, including the newly discovered antihydrogen "cloud." The brightened feature corresponds to the nucleus of the Galaxy. The horizontal structure lies along the plane of the Galaxy. The antihydrogen "cloud" is located above the Galactic center.

Courtesy of B. D. Elm (University of California, Riverside) and Y. E. Purcell (Northwestern University)
Deep Sky:

Black holes are ubiquitous in the Universe

Gamma-ray Burst

Optical discoveries of host galaxies and measurements of spectroscopic redshift distances

Gamma Ray bursts are occurring in distant (z = 1-3) galaxies

Most powerful and relativistic phenomena known (10^{52}-10^{54} ergs)
Present and Future X-ray/Gamma-ray Missions

Electro-Magnetic Radiation and Electron Energy

Electron Energy

keV  MeV  GeV  TeV

Radio Synchrotron

GLAST(Bremsstrahlung)

GLAST(Inverse Compton)

X-ray Brems.

X-ray Inv. Compton

X-ray Synch.
**Integral Mission (2002-)**

**Big Gamma-ray Mission After CGRO**
(15 keV 10 MeV)
Imaging (Coded Mask)
High Energy Resolution
X-ray Detector (JEM-X)

*from Integral Homepage*

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**High resolution Gamma-ray detector (SPI)**

19 Cooled Ge detector (each 6x7 cm)
FWHM : 2keV @ 1.3 MeV

*from Integral Homepage*
Solar Flare Spectrum by SPI

SPI / INTEGRAL detection of gamma-ray line emission correlated with a proton flare

IBIS (CdTe + CsI(Tl))
7 keV @ 100 keV

16384 CdTe detectors
total area 2620 cm²
with 4x4 mm² x2mm³ detector

from Integral Homepage
Galactic Plane Scan
Cen region with ISGR (CdTe Imager)
Swift Mission (2003- )

- **Multi-wavelength observatory**
  - Burst Alert Telescope (BAT): 10-150 keV
    - detect ~ 300 gamma ray bursts per year
    - onboard computation of positions
    - arc-minute positional accuracy
  - Dedicated telescopes for X-rays, UV, and optical afterglow follow up:
    - 0.3-10 keV X-ray Telescope (XRT)
    - 170-650 nm UV/Optical Telescope (UVOT)
    - 0.3-2.5 arc-second locations
    - existing hardware from JET-X and XMM
    - determine redshifts from X-ray absorption, lines, and Lyman-\(\alpha\) cutoff

# Rapid response satellite

! 20 - 70 sec to slew within FOV of BAT

- autonomous operations
- factor 100 improved response time
- continue monitoring of fading afterglow

**BAT Imager on Swift**

- **32768 CdZnTe detectors**
  - (4x4 mm\(^2\) x2mm\(^3\) detector)
Multiwavelength Cascade of Images

- Gamma Ray (arc-minute)
- Background-subtracted images
- X-ray (2.5 arc-second)
- UVOT (0.3 arc-second)

HST, Keck, etc.

Swift Performance

- Location in host galaxies
- Probe the surrounding environment
- Use gamma-ray bursts as cosmological probes

GRB FIREBALL MODEL

- $E \sim 10^{51} - 10^{54}$ ergs
- $T = 0.9$ s
- $R = 10^{6}$ cm
- Pre-Burst
- Burst
- Afterglow
- Formation
- Spacial

Sensitivity

- GRB980228
- $N_{\text{per sample}}$ vs. $T_{\text{orig}}$
- BATSE
- Swift BAT
- Swift XRT & UVOT
- SAX+ HETE

$N_{\text{per sample}}$ vs. $T_{\text{orig}}$

$N_{\text{per sample}}$ vs. $T_{\text{orig}}$

$N_{\text{per sample}}$ vs. $T_{\text{orig}}$
**AstroE2 Multi-band Mission**

- Recovery Mission of Astro-E
- Launch in 2005
- Design almost identical to Astro-E

Five thin-foil mirrors
Four X-ray CCD cameras (XIS)
Microcalorimeter array (XRS)

Non-imaging Hard X-ray detector

<table>
<thead>
<tr>
<th></th>
<th>S(cm$^2$)</th>
<th>$\Delta E$ (eV)</th>
<th>$\Delta \theta$ (arcsec)</th>
<th>$E_{\text{det}}$ (keV)</th>
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</thead>
<tbody>
<tr>
<td>Chandra</td>
<td>800</td>
<td>120</td>
<td>0.5</td>
<td>0.3~10</td>
</tr>
<tr>
<td>Newton</td>
<td>10,000</td>
<td>120</td>
<td>10</td>
<td>0.3~12</td>
</tr>
<tr>
<td>Astro-E</td>
<td>5,000</td>
<td>10</td>
<td>100</td>
<td>0.5~600</td>
</tr>
</tbody>
</table>

**Hard X-ray Detector (HXD)**

- Narrow FOV
  - by well type (phoswitch) active shield
  - & passive fine collimator (<100keV)
- Wide energy band (10 – 600 keV)
  - w/ 64 Si-PIN (2mm thick) diodes
- Background rejection
  - w/ LSI pulse shape discrimination
  - anti-coincidence with 36 detector units
  - & onboard CPU software
  - Low Background & High sensitivity are expected

ISAS, U.Tokyo, Hiroshima, Saitama, Kanazawa, SLAC
Astro-E2 HXD & Integral

Continuum Spectrum

Simultaneous observation with highly sensitive X-ray instruments gives us very unique opportunities to study gamma-ray sources.

High Resolution Detector (XRS) on AstroE2

- Bulk motions of ICM in cluster mergers will be detected for the first time

Detection of a thermal Doppler width of an iron K-line:

for \( kT = 10 \text{ keV}, E_{\text{line}} = 6.7 \text{ keV} \) \( \sigma_L = 2.9 \text{ eV} \)

and the intrinsic line width is 6.9 eV:

if we have 6 eV resolution…

Direct measure of gas temperature

(FWHM: 5.93 ± 0.16 eV)

(Inoue, 2002)
**Glast Mission**

- International Mission
- Japanese Contribution (Hiroshima, ISAS, RIKEN, Titech)
- Wide FOV, Survey Operation
- 20MeV - 300 GeV
- Large Area Silicon Strips.

**Tracker Module Mechanical Design**

- 4x4 array of Si-strip sensors (X)
- 16 Towers
- 15cm

**Utilize Pair-production**
New approach GLAST will bring forth
- EGRET's 3rd Catalog in 2 days -

All 3EG sources + ~ 80 new in 2 days

Time Variability Monitoring: Flares (Blazars, AGNs, Coronas), Precessions and Glitches (Pulsars), Lensing (AGNs)

- GRB940217 (100sec)
- PKS 1622-287 flare
- 3C279 flare
- Vela Pulsar
- Crab Pulsar
- 3EG 2020+40 (SNR g Cygni?)
- 3EG 1835+59
- 3C279 lowest 5s detection
- 3EG 1911-2000 (AGN)
- Mrk 421
- Weakest 5s EGRET source

*zenith-pointed, "rocking" all-sky scan

Sensitivity of GLAST


GLAST

NASA
Unidentified Source

172 of the 271 sources in the EGRET 3rd catalog are “unidentified”

EGRET source position error circles are ~0.5°, resulting in counterpart confusion.

GLAST will provide much more accurate positions, with ~30 arcsec - ~5 arcmin localizations, depending on brightness.

Future Perspectives

From presentation by S. Ritz, 2001
Future Mission
-- Focusing Hard X-ray Experiments --

Key technology: Super Mirror & γ-ray Imager

Focusing Telescope is not only for the equipment to take pictures but also for the key to achieve high sensitivity. Because, a mirror concentrates the incoming flux onto a small spot of the detector, greatly reduce background.

NeXT Mission
Beyond COMPTEL

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

Compton-Dominant Region

COMPTEL (1989-2000)

MegA Mission (proposed by COMPTEL Team)

\[ \text{Total weight 1000 kg} \]

\[ \text{Weight 650kg} \]

Next generation Compton Telescope in Japan

- Semiconductor Multi Compton Telescope (SMCT) (ISAS)

  with high Z semiconductor (CdTe)

  Compact BUT Detection Efficiency at 1 MeV becomes 10 times higher than COMPTEL (weight 1 ton) on CGRO

- Compton telescope based on Micro Gas Pixel Chamber (Kyoto Univ.)

ISAS/SLAC/Osaka U., Hiroshima U./ U.Tokyo
**Polarization**

- Polarization in X-ray/Gamma-ray is the only remaining parameter to be measured.
- Expected from Jet Sources/Pulsars/Accretion Disk/GRB
- Development of New and Sensitive Instruments are crucial

**Gamma-ray**

- by Newly Designed Gamma-ray Polarimeter (Kamae et al. 2003)
- by Compton Telescope (INTEGRAL, SMCT, MEGA...)

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**Summary**

- X-ray and Gamma-ray energy band in space are very important window to study high energy particles (cosmic rays) in the universe
- By combining information from X-ray and Gamma-ray observations, we can deepen our understandings of “Accelerator” in the universe