Observing Gamma-Ray Bursts with

Nobuyuki Kawai
(Tokyo Tech)

ASTRO-H Team
2. ASTRO-H X-ray Astronomy Satellite

- Launch in 2014
- Launch site: Tanegashima Space Center, Japan
- Launch vehicle: JAXA H-IIA rocket
- Orbit Altitude: 550km
- Orbit Type: Approximate circular orbit
- Orbit Inclination: ~31 degrees
- Orbit Period: 96 minutes

- Total Length: 14m
- Mass: <2.6 metric ton
- Power: <3500 W
- Telemetry Rate: > 8 Mbps (X-band)
- Recording Capacity: > 12 Gbits
- Mission life: > 3 years

ASTRO-H

Suzaku (6m, 1.7t)
2. ASTRO-H Instruments

Hard X-ray Telescopes (HXT)
Focal Length = 12 m

Hard X-ray Imagers (HXI) 5-80 keV

Soft X-ray Telescopes (SXT-S, SXT-I)
Focal Length = 5.6 m

Fixed Optical Bench

Solar power

Microcalorimater (SXS) 0.3-12 keV

X-ray CCD (SXI) 0.4-12 keV

Deployable Optical Bench

Soft γ-ray detectors (SGD) 10-600 keV

Sunshades
## 2. ASTRO-H Instruments

<table>
<thead>
<tr>
<th>Instrument Type</th>
<th>Energy Range</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hard X-ray Imaging System (HXT+HXI)</strong></td>
<td>5-80 keV</td>
<td>Effective area: 300 cm² (@30 keV)</td>
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<td></td>
<td></td>
<td>Spatial resolution: 1.7 arcmin (HPD)</td>
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<td></td>
<td></td>
<td>Energy resolution: 2 keV</td>
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<td></td>
<td></td>
<td>Field of view: 9 arcmin² @30 keV</td>
</tr>
<tr>
<td><strong>Soft X-ray Spectrometer System (SXT-S+SXS)</strong></td>
<td>0.3-10 keV</td>
<td>Energy resolution: 7 eV</td>
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<td></td>
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<td>Spatial resolution: 1.7 arcmin (HPD)</td>
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<tr>
<td></td>
<td></td>
<td>Effective area: 210 cm² (@6 keV)</td>
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<tr>
<td></td>
<td></td>
<td>Field of view: 3 arcmin² @6 keV</td>
</tr>
<tr>
<td><strong>Soft X-ray Imaging System (SXT-I+SXI)</strong></td>
<td>0.5-12 keV</td>
<td>Spatial resolution: 1.7 arcmin (HPD)</td>
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<tr>
<td></td>
<td></td>
<td>Effective area: 360 cm² @6 keV</td>
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<tr>
<td></td>
<td></td>
<td>Energy resolution: 150 eV</td>
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<td></td>
<td></td>
<td>Field of view: 38 arcmin² @6 keV</td>
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<tr>
<td><strong>Soft γ-ray detector (SGD)</strong></td>
<td>10-600 keV</td>
<td>Effective area: 100 cm² @100 keV</td>
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<td></td>
<td></td>
<td>Energy resolution: 2 keV @40 keV</td>
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<tr>
<td></td>
<td></td>
<td>Astrometric accuracy: &lt;0.6 arcdeg (E&lt;150 keV)</td>
</tr>
</tbody>
</table>
X. Soft X-ray Spectrometer (SXS/XCS)

- High Resolution Spectroscopy by a micro calorimeter array

<table>
<thead>
<tr>
<th>Requirements (Goal)</th>
<th>Requirements (/Goal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy resolution</td>
<td>7 eV (FWHM)</td>
</tr>
<tr>
<td></td>
<td>(4 eV (FWHM) Goal)</td>
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<tr>
<td>Energy range</td>
<td>0.3 - 12 keV</td>
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<tr>
<td>Field of view</td>
<td>2.9 x 2.9 arcmin</td>
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<tr>
<td>Detector array</td>
<td>6 x 6</td>
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<tr>
<td>Absorber size</td>
<td>800 µm</td>
</tr>
<tr>
<td>Effective area</td>
<td>160 / 210 cm^2</td>
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<tr>
<td></td>
<td>(at 1 / 6 keV)</td>
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</tbody>
</table>

MnKα, profile
FWHM = 3.8 eV
50 mK heat sink
X. Soft X-ray Spectrometer (Dewar)

Operating Temperature 50 mK

\[ A_{\text{eff}}(E) = A_{\text{XRT}}(E) \times t(E) \times \text{psf} \times f_{\text{array}} \times a(E) \]
3. ASTRO-H Mission Instruments

X. Soft X-ray Spectrometer (SXT_S)

Soft X-ray Telescope (SXT) will be an upgraded version of the Suzaku X-ray telescope (XRT). The diameter and focal length is larger, thus number of the nesting shells are increased.

(1) thicker aluminum substrate for the larger radii,
(2) more forming mandrels for better substrate shaping
(3) precise alignment bars
(4) glue to fix reflectors on the alignment bars
(5) stronger housing.
5. ASTRO-H Science

Cluster of Galaxies

- Dynamics
  - (Turbulence, Collisions)
- Non-thermal Emission
- Cluster Outskirt
  - (Site of Structure Formation)
- Temperature Map
- Heavy Metal Distribution

Simulation of Centaurus Cluster

To the virial radius, and beyond

M.R. George et al. 2009

Credit: NASA/STScI/Fabian, et al.

Astro-H will detect bulk velocity flow as small as 300 km/s in the brightest 30 clusters with \( T > 60 \times 10^{6} \) K (\( kT > 5 \) keV.)
7. ASTRO-H Schedule

calendar year

<table>
<thead>
<tr>
<th></th>
<th>2008</th>
<th>2010</th>
<th>2011</th>
<th>2014</th>
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<tbody>
<tr>
<td>Japanese FY</td>
<td>2007</td>
<td>2008</td>
<td>2009</td>
<td>2010</td>
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<tr>
<td>Milestones</td>
<td></td>
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</tr>
<tr>
<td>Phase</td>
<td>Research</td>
<td>Development</td>
<td>Development</td>
<td></td>
</tr>
<tr>
<td>Design phase</td>
<td>System Design</td>
<td>Primary Design</td>
<td>Detailed Design</td>
<td>Fabrication</td>
</tr>
<tr>
<td>Spacecraft system</td>
<td>Primary Design</td>
<td>Detailed Design</td>
<td>Assembly (TA)</td>
<td>FM fabrication / component test</td>
</tr>
<tr>
<td>Mission components</td>
<td>SXS</td>
<td>EM</td>
<td>PFM, test</td>
<td>PF, PFM, test</td>
</tr>
<tr>
<td>(XRT)</td>
<td>FM fabrication / calibration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground system / Operation</td>
<td>Ground / Operation Software design</td>
<td>I/F test</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nominal operation (PV)</td>
<td>Nominal operation (AO1)</td>
<td>(AO2)</td>
<td></td>
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</table>

Launch

2010/04/15 SRON
ASTRO-H will be the only “General Observatory in X-ray” in 2010’s. There is a world-wide devoid of future X-ray missions around 2013. An X-ray mission is indispensable to maximize the scientific yields expected by large radio, infrared, and optical missions.

ASTRO-H

HESS/MAGIC/VERITAS/Cangaroo3

CTA/AGIS

Fermi

AGILE

INTEGRAL

Chandra, XMM-Newton

Suzaku

MAXI

Herschel

JWST

ALMA

NuSTAR/eROSITA/GEMS

High-resolution interferometer in the millimeter band.

2008 2010 2012 2014

(Energy)

TeV: $10^{12}$ eV

GeV: $10^9$ eV

(keV: $10^3$ eV)

Radio

Optical & infrared

X-ray

Gamma-ray

All-sky survey Gamma-ray satellite
Observing Gamma-Ray Bursts with ASTRO-H

Goal: high resolution spectroscopy of X-ray afterglow

- **Detect spectral features**
  - **Absorption edges (K edges of Fe, Si, S, …)**
    - Detectable if metal-rich
    - Gives redshifts for dusty dark GRBs
    - Gives metallicity * column density
  - Possible transient features
    - Detection reported with ASCA/BeppoSAX/Chandra/XMM
      » yet to be confirmed by Swift, Suzaku
    - Emission lines (Fe by ASCA, BeppoSAX, XMM)
    - Radiative recombination edge (ASCA, Chandra)
Observing Gamma-Ray Bursts with ASTRO-H

**Limitations:** ASTRO-H is not swift

- No BAT, no WFC, no autonomous slewing
  - Slew speed 180° /30 min
- Commandable only at 5 passes (10 min.) out of 15 orbits per day
  - commanding from stations outside Japan?
- Sun angle constraint: 60°–120°
  - only ½ sky accessible
  - does not go well with ground-based telescopes
    - override the constraint if thermal+power conditions allow?
- Needs flexible mission operation
  - well-trained ops team
  - capable mission planning tools
Observing Gamma-Ray Bursts with ASTRO-H

**Simulation:** GRB 050904 at $\sim 10^4$ s after onset

- $\Gamma$: $-1.7$
- Flux: $2^{-10}$ erg/cm$^2$/s

Cusumano et al. 2007
Observing Gamma-Ray Bursts with ASTRO-H

Simulation: GRB 050904 at \( \sim 10^4 \) s after onset

Flux: \( 2 \times 10^{-10} \) erg/cm\(^2\)/s
\( \Gamma: -1.7 \)

\( N_H = 2 \times 10^{22} \) cm\(^{-2}\)
\( N_H = 2 \times 10^{23} \) cm\(^{-2}\)

\( z = 2 \)
\( z = 4 \)
\( z = 6.3 \)

Fe K absorption edge
Observing Gamma-Ray Bursts with ASTRO-H

Simulation: GRB 050904 at ~$10^4$ s after onset

Flux: $2 \times 10^{-10}$ erg/cm$^2$/s
$\Gamma$: $-1.7$
$z=6.30$, $Z=1.0$
Exposure: 20 ks

$N_H = 2 \times 10^{23}$ cm$^{-2}$
$\rightarrow z=6.29\pm0.01$
$Z_{Fe}=0.94\pm0.06$

Simulations by Yonetoku, Fujimoto
Observing Gamma-Ray Bursts with ASTRO-H

Simulation: GRB 050904 at $\sim 10^4$ s after onset

Fe K absorption edge

Flux: $2 \times 10^{-10}$ erg/cm$^2$/s
$\Gamma$: $-1.7$
$z=6.30$, $Z=1.0$
Exposure: 20 ks

$N_H = 2 \times 10^{22}$ cm$^{-2}$
$\rightarrow z = 6.29 \pm 0.01$
$Z_{Fe} = 0.94 \pm 0.06$

$N_H = 2 \times 10^{23}$ cm$^{-2}$
$\rightarrow$ difficult to detect
Observing Gamma-Ray Bursts with ASTRO-H

**Simulation:** redshift = 2

Flux: $2^{-10}$ erg/cm$^2$/s  
$\Gamma$: $-1.7$  
z = 2.00, $Z=1.0$  
Exposure: 20 ks

Simulations by Yonetoku, Fujimoto

$N_H = 2 \times 10^{22}$ cm$^{-2}$  
Si K absorption edge

$z = 1.99 \pm 0.02$  
$Z_{Si} = 1.1 \pm 0.3$

$N_H = 2 \times 10^{23}$ cm$^{-2}$  
Fe K absorption edge

$Z = 2.000 \pm 0.006$  
$Z_{Fe} = 0.96 \pm 0.06$
Observing Gamma-Ray Bursts with ASTRO-H

**Conclusion**

- ASTRO-H SXS can detect and measure redshifts and column densities of heavy elements
  - if X-ray afterglow is bright (~GRB 050904)
  - if absorption column is large enough
    - $10^{22}$ for Si ($z<4$), $10^{23}$ for Fe
  - if observed early enough ($<10^4$ s, earlier better)
    - mission operation needs to be prepared for rapid TOO

- Your pressure/demand to ASTRO-H is welcome!

- ASTRO-H can be a pathfinder for future high-resolution X-ray mission: DIOS, Xenia, IXO,