40 years of X-ray bursts: Extreme explosions in dense environments

X-ray Burst Science with ASTRO-H

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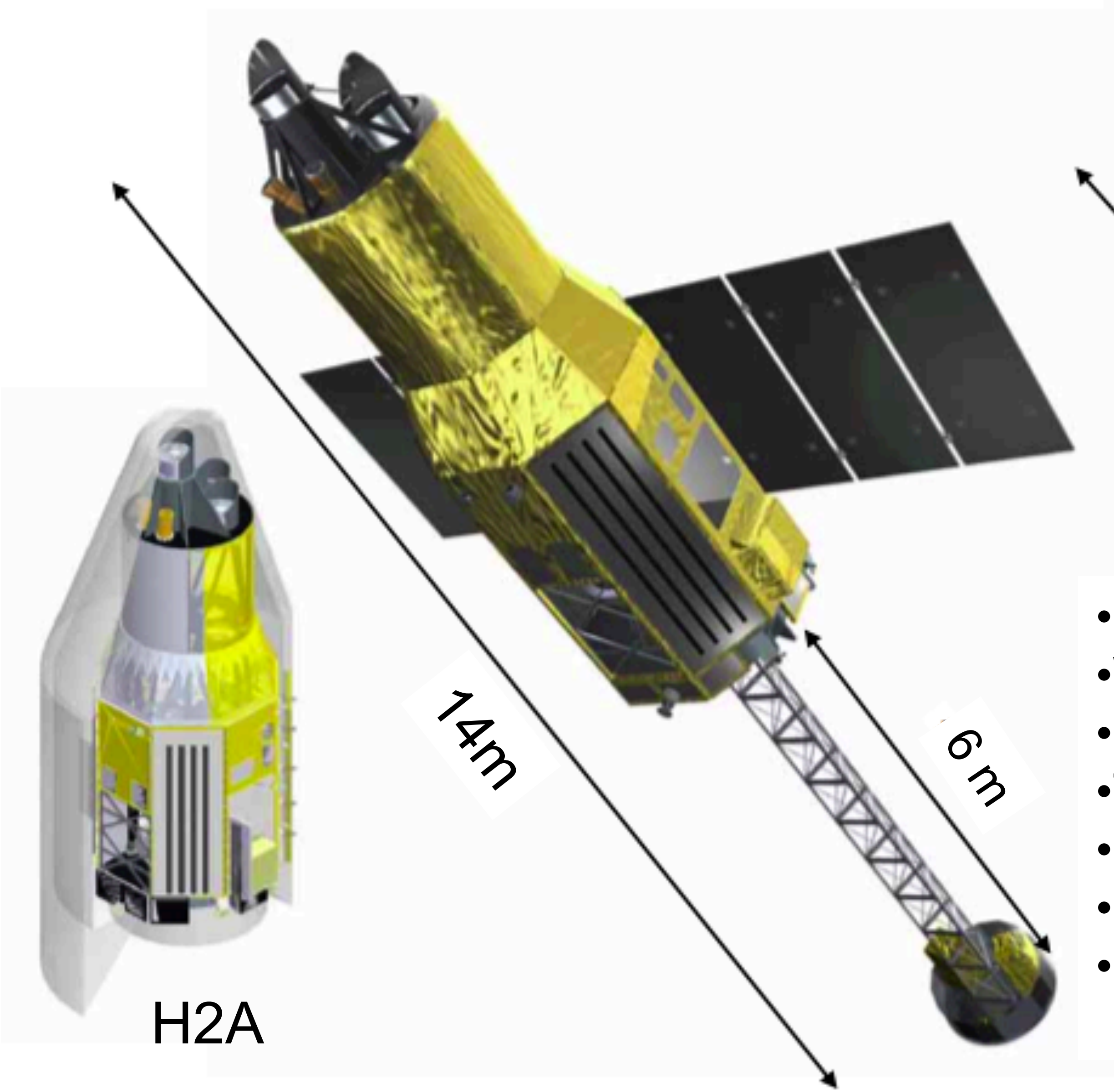
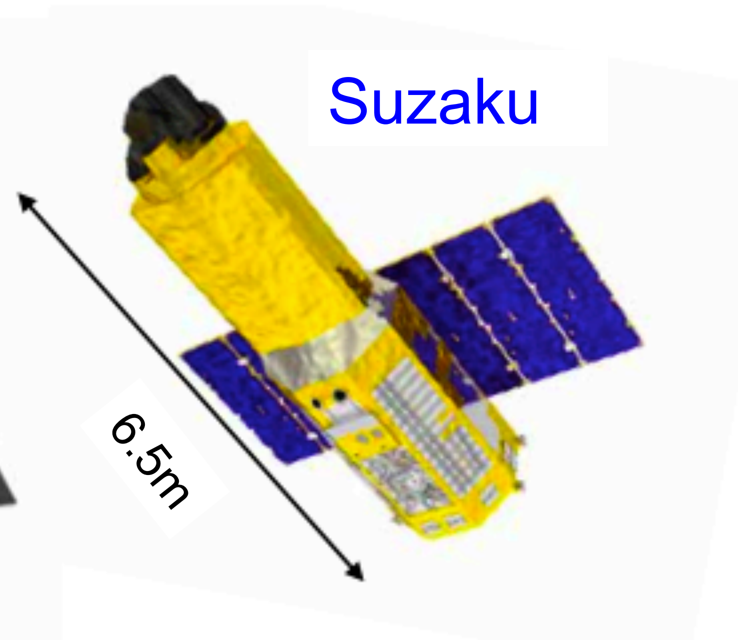
on behalf of the ASTRO-H team

Outline of the talk

- ASTRO-H and the mission instruments
  - Soft X-ray spectrometer (SXS)
  - Soft X-ray imager (SXI)
  - Hard X-ray imagers (HXI)
  - Soft gamma-ray detectors (SGD)
- X-ray burst science with ASTRO-H
  - Measurement of the gravitational redshift
  - Probing the burst products

ASTRO-H



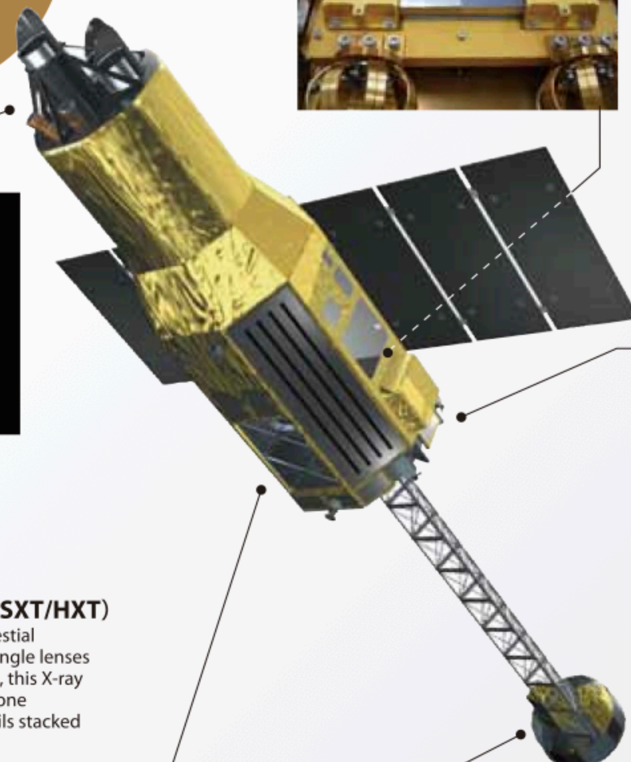


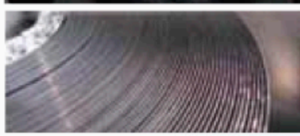
- Length :14 m
- Weight : 2750 kg
- Power : 3500 W
- Telemetry : 8Mbps (X-band)
- Data Recorder : 12 Gbits
- Launch : 2015
- Life : 3 year (requirement)
  5 year (goal)

Cutting-edge Instruments

Soft X-ray Imager (SXI)

This is a wide field-of-view X-ray camera using an array of four large-format X-ray CCD chips. It provide simultaneous imaging and spectroscopic data in the energy range of 0.5 keV to 12 keV. The detector will be placed in the main body of the satellite.





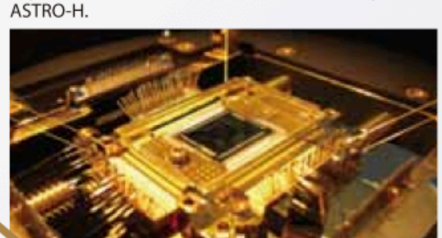
Close-up view of the aperture.

Reflecting X-ray Telescopes (SXT/HXT)

This instrument focuses X-rays from celestial objects onto the detectors. Unlike the single lenses and mirrors usually used for visible light, this X-ray reflecting telescope is made up of over one thousand reflector-coated aluminum foils stacked into concentric circles.

Soft X-ray Spectrometer (SXS)

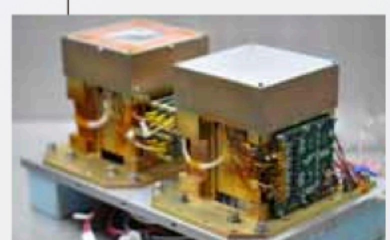
Specialized detector elements are cooled down to near absolute zero (-273 degrees Celsius) using a series of refrigeration units. When an X-ray hits a detector element, its temperature slightly rises. This increase in "heat" is measured, and from this the energy of the incident X-ray can be estimated to a higher degree of accuracy than any achieved to date. Researchers from around the world have great expectations for this instrument, the centerpiece of ASTRO-H.



Close-up view of the main sensor part.

Soft Gamma-ray Detector (SGD)

Many layers of semiconductor sensors are stacked to optimize the sensitivity of the gamma-ray spectrometer. Since gamma-rays have a higher penetrating power than X-rays, this instrument plays an important role investigating astronomical objects surrounded by dense gas.

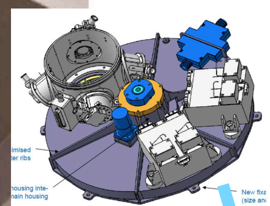


X-ray sensor and signal-processing electronics

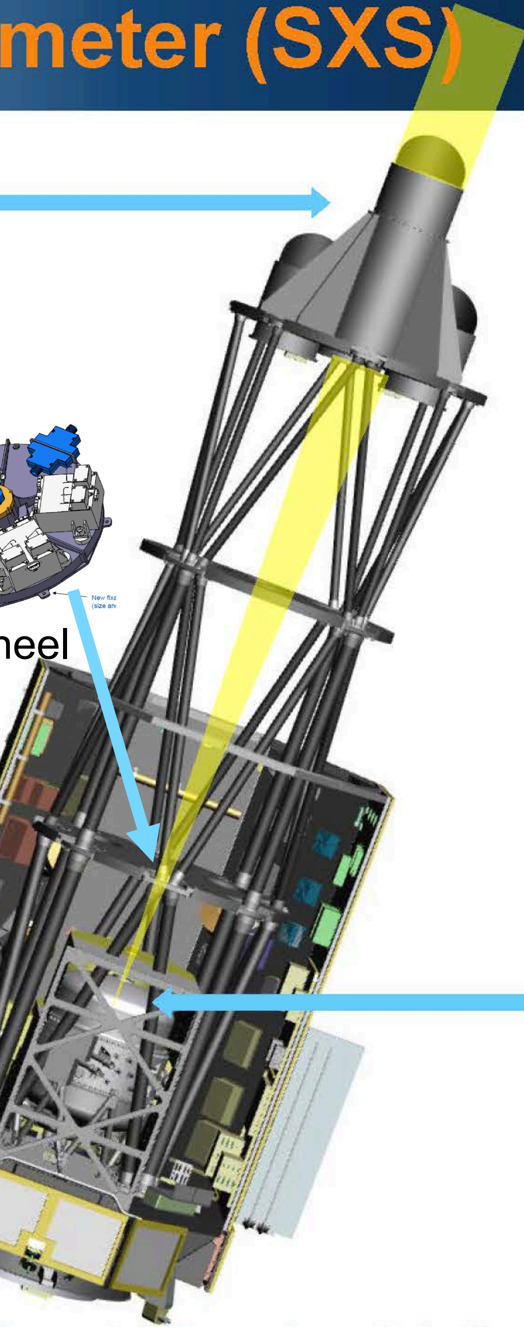
Hard X-ray Imager (HXI)

This produces images of objects in the hard X-rays above 5 keV using a combination of silicon and cadmium telluride semi-conductors. Since this imaging telescope has a 12-meter focal length, this sensor will be placed at the end of a boom which will be extended in orbit.

Soft X-Ray Spectrometer (SXS)



Filter wheel



Soft X-Ray Telescope

5.6 m focal length – *fixed optical bench*

203 concentric shells (1624 individual reflectors)

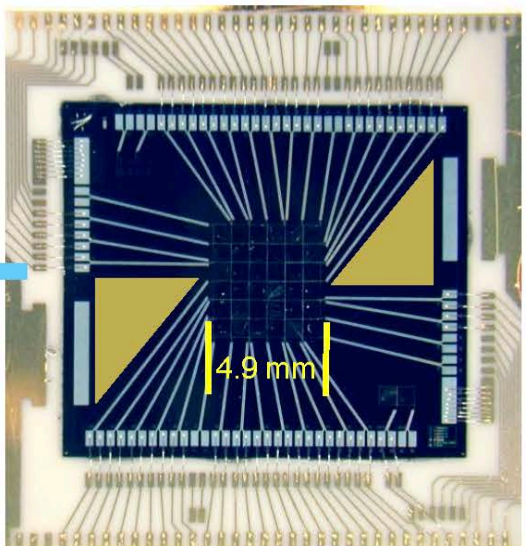
Outer Diameter: 45 cm
Mass: CBE = 46 kg

Half-Power Diameter of better than 1.7 arcmin

X-ray Calorimeter Spectrometer

SXS – energy resolution better than 7 eV at system level

6 x 6 array of 30” x 30” pixels (3 arcmin field of view)



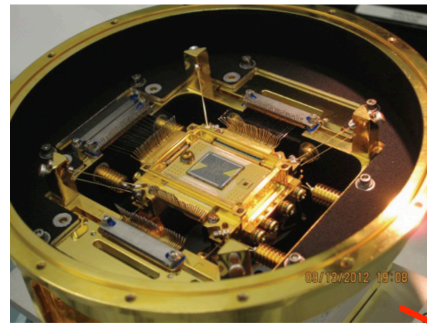
SXS: cooling chain

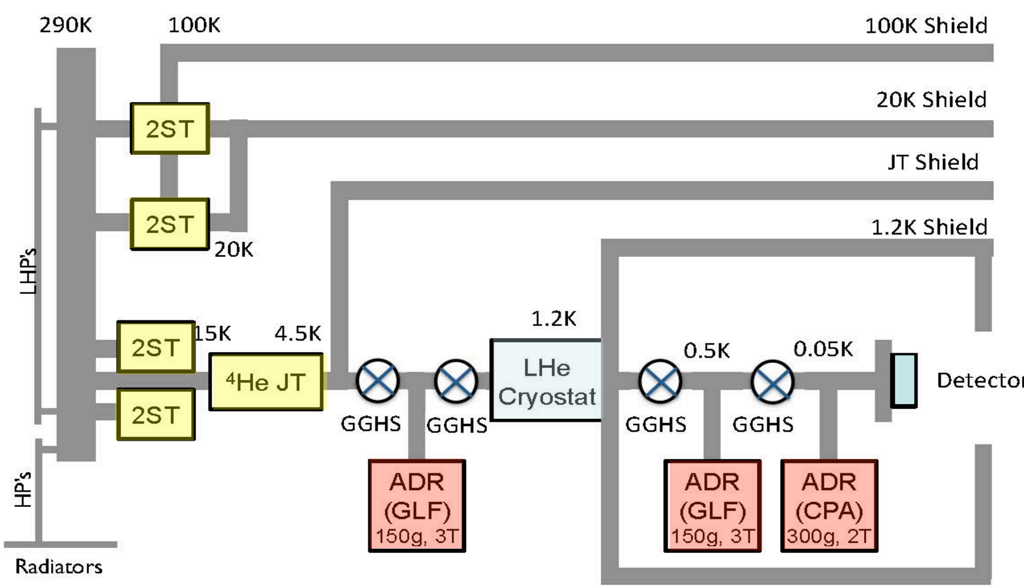
Cooling system

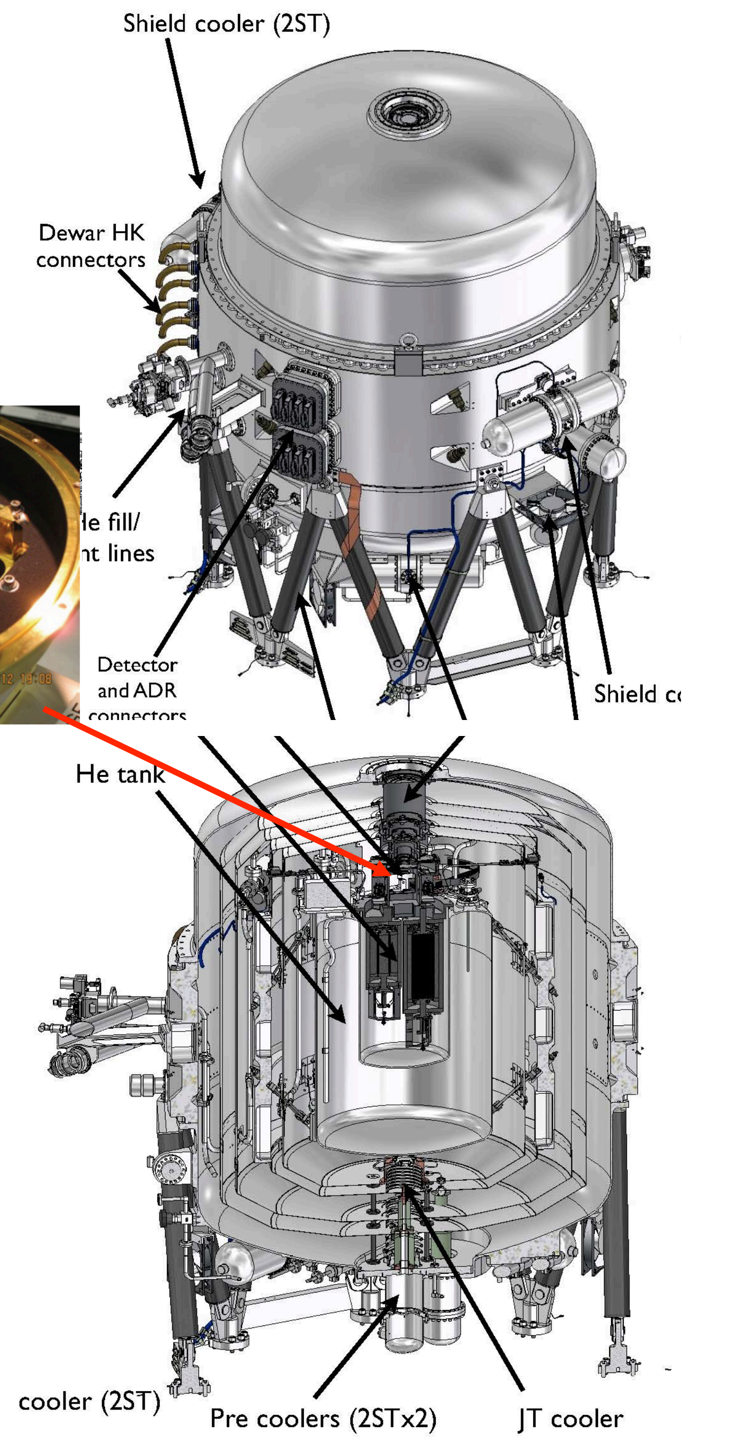
- Detector temp : 50 mK
- 2 ADR + LHe/ADR + JT + ST

Life

- 3 years with LHe
- 2 more years without LHe

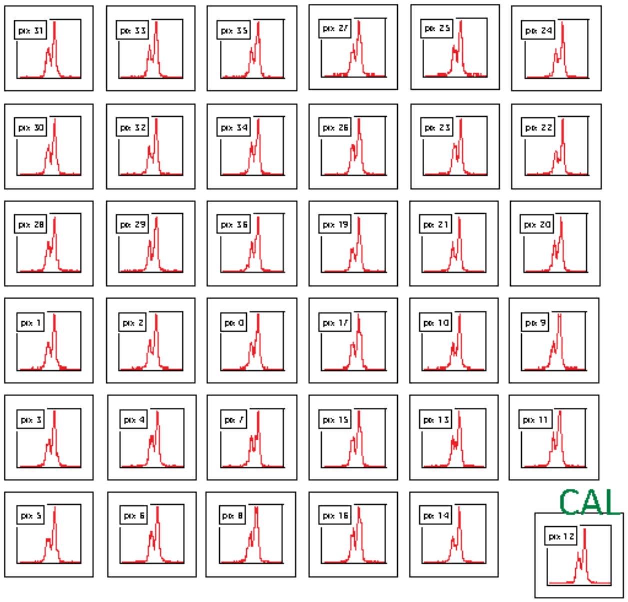






Performance of SXS

All 36 channels by location

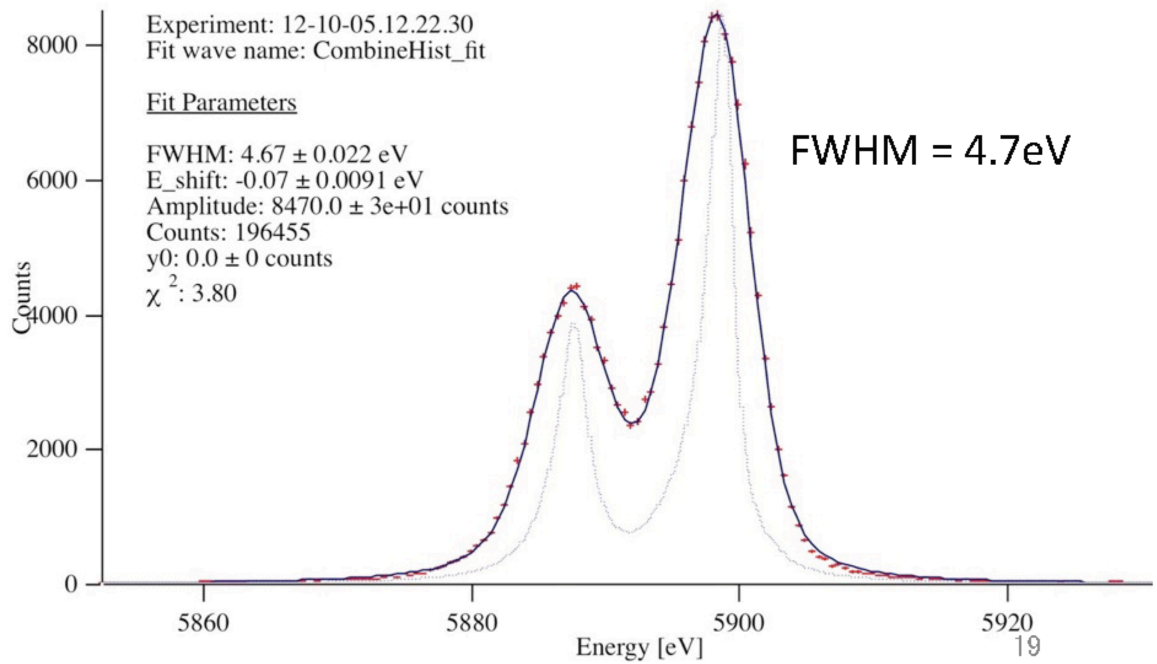


- FM detector system calibration campaign

Oct 2012 – Feb 2013, GSFC/NASA

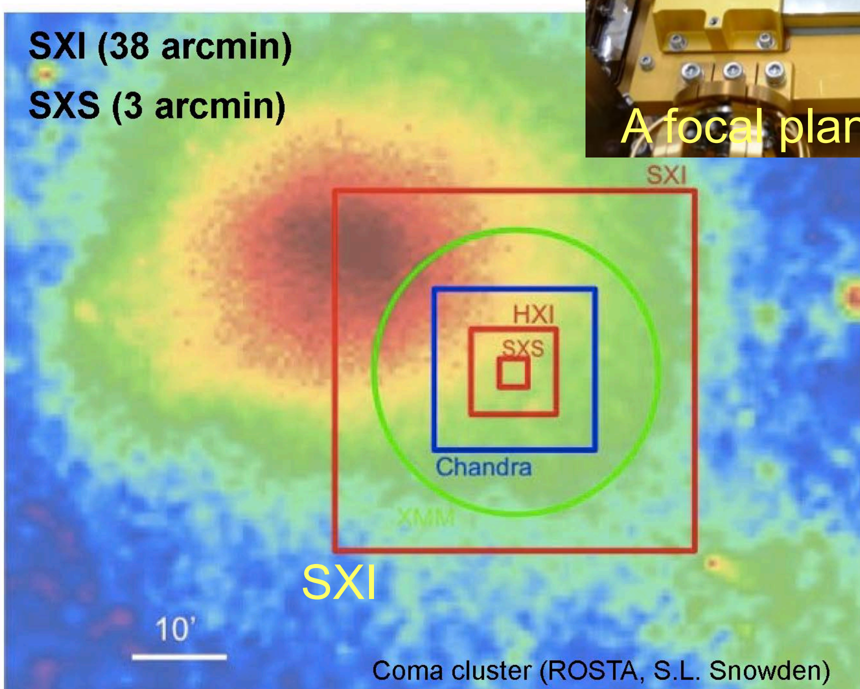
All pixels meet requirement < 7eV

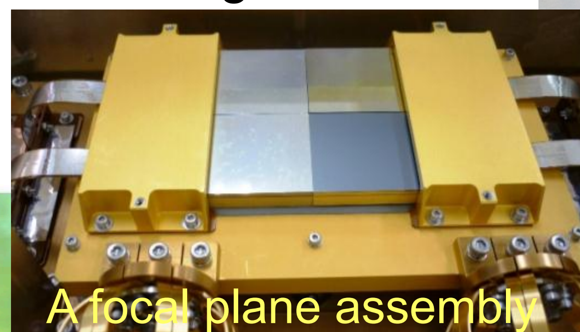
Composite fit to all 36 channels



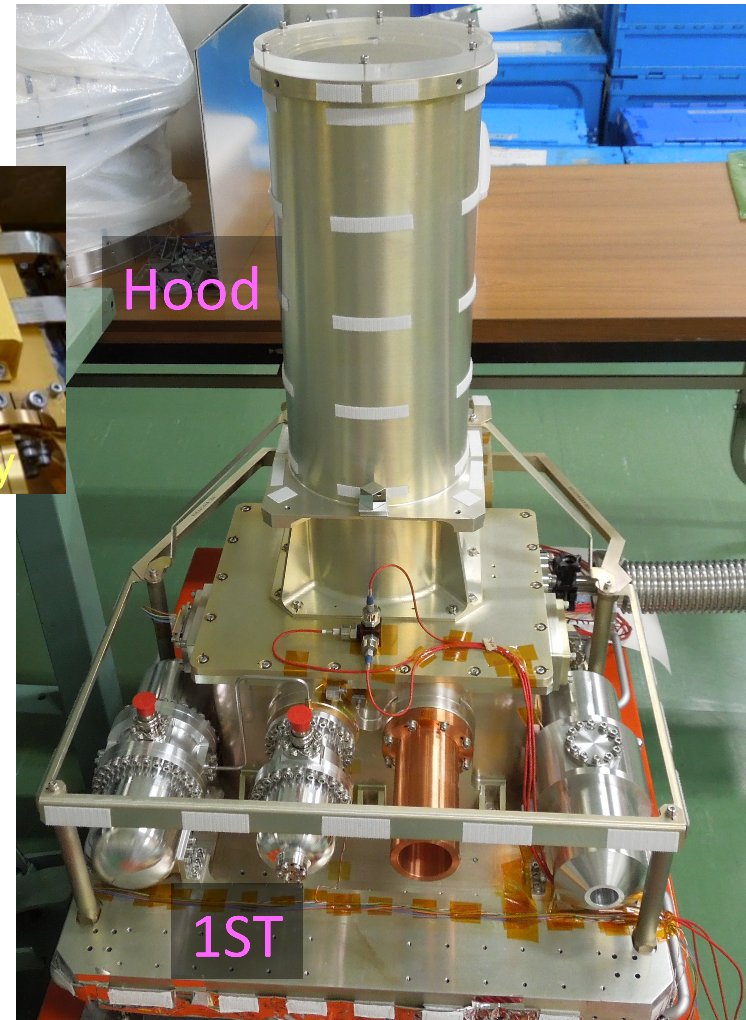
SXI: X-ray CCD camera

- 4 CCD chips with 31x31mm
- Depletion layer: 200μm
- Type: Back-illumination
- Operating temp.: -120 - -100 degC
- Exposure time: 4 sec
- FOV: 38x38 arcmin

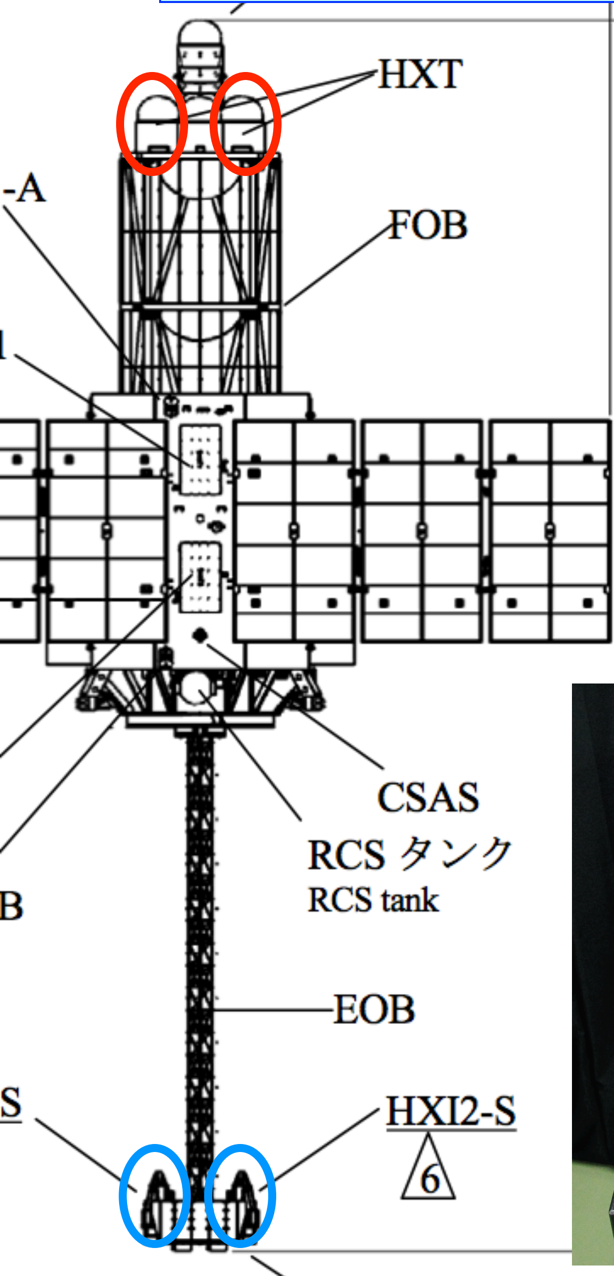




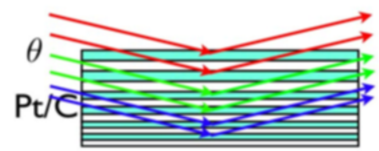
Engineering model



Hard X-ray telescopes & imagers



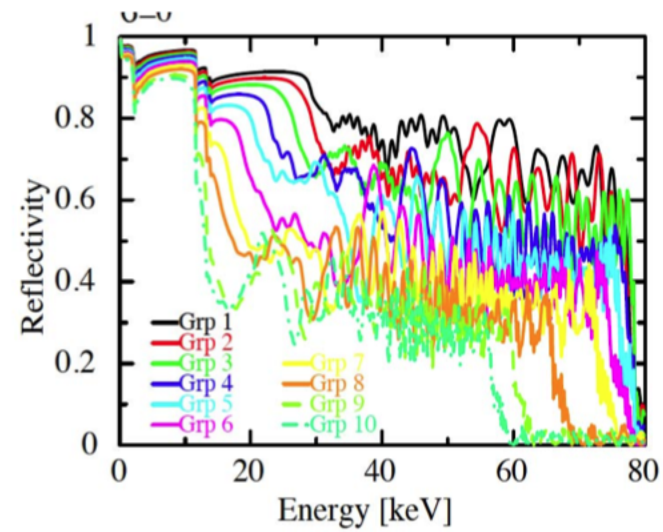
HXT principle

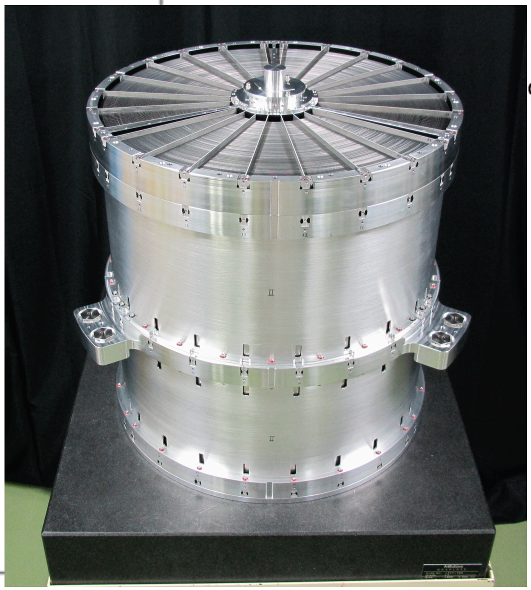


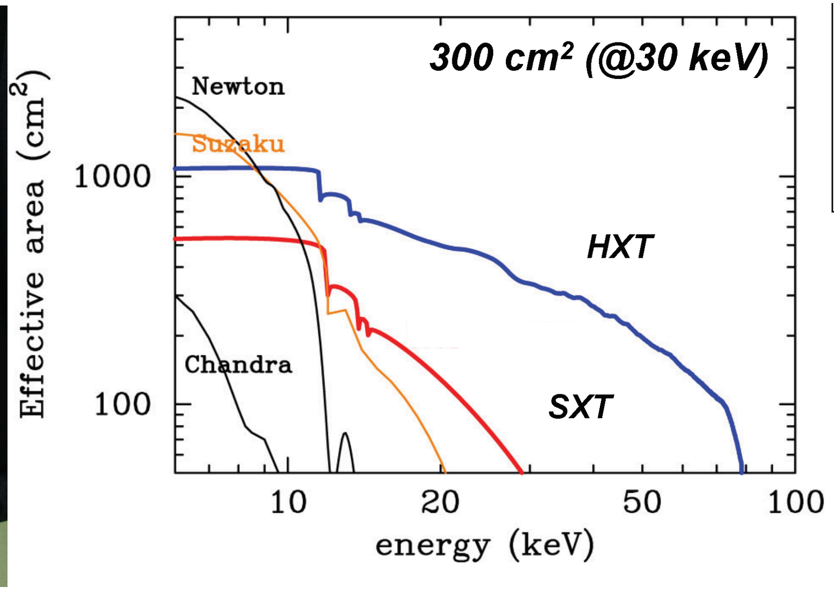
Depth-graded multilayer
Bragg reflection

$$2d[\text{Å}]\sin\theta = m\frac{12.39}{E[\text{keV}]}$$

Super mirror



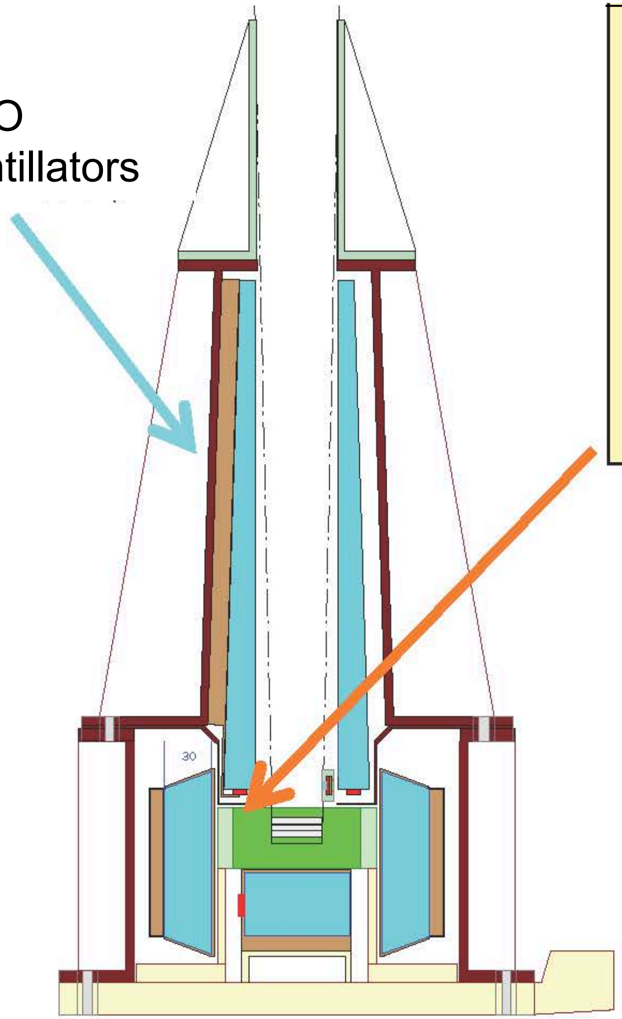


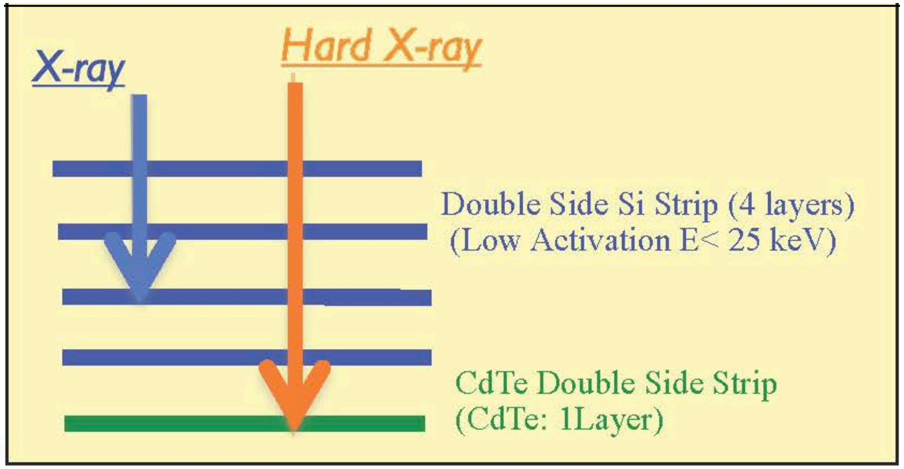


HXI: hard X-ray imagers

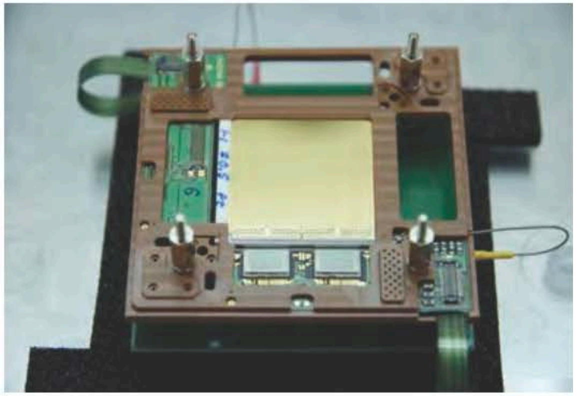
Si + CdTe hybrid imager sensitive in 5−80 keV

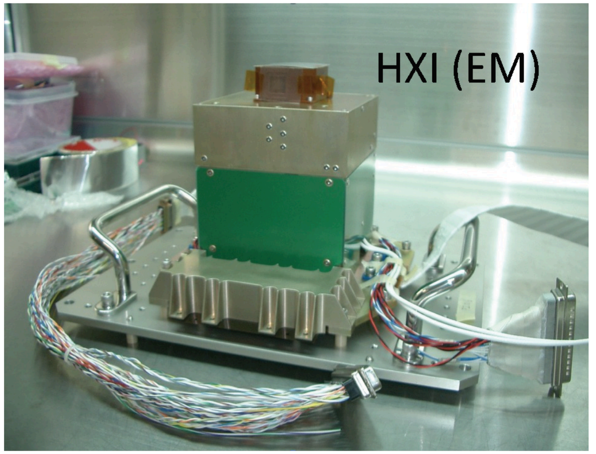
BGO scintillators





Engineering model



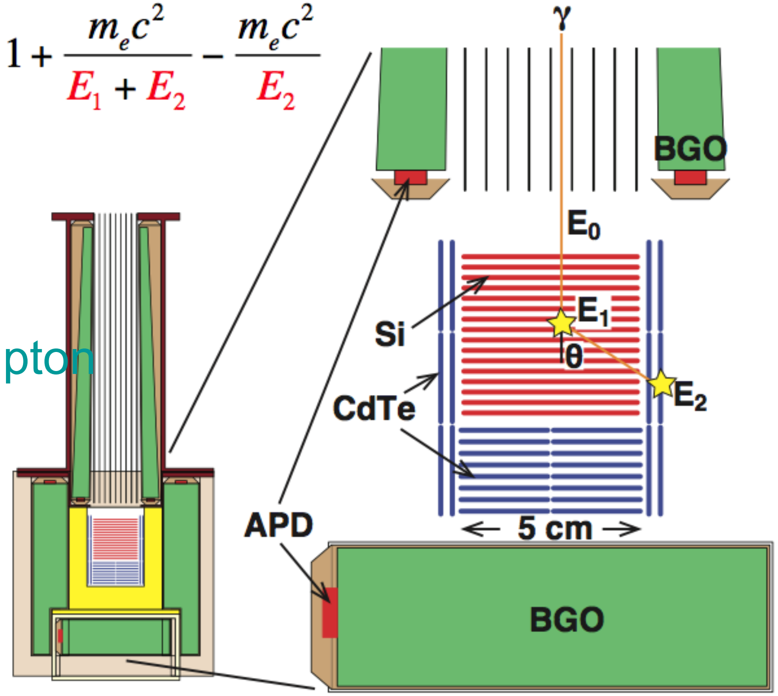


SGD

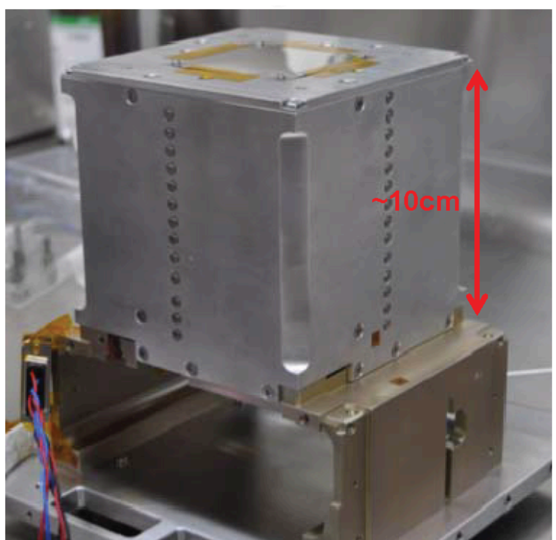
Principle

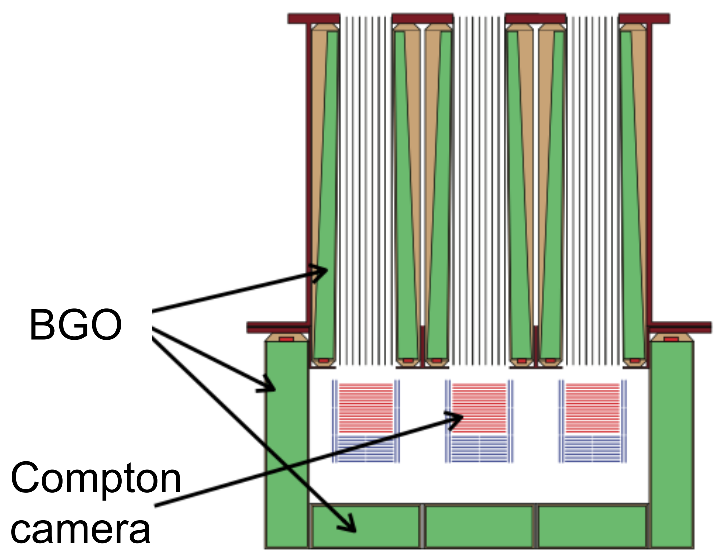
Narrow field Compton camera

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



Engineering model



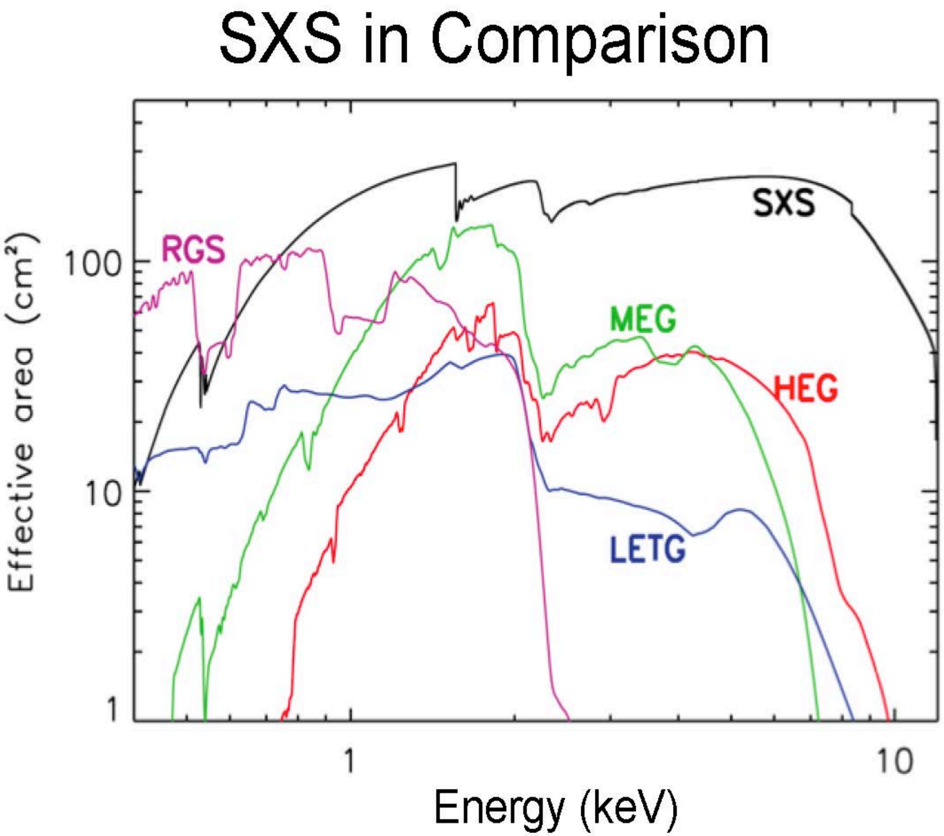


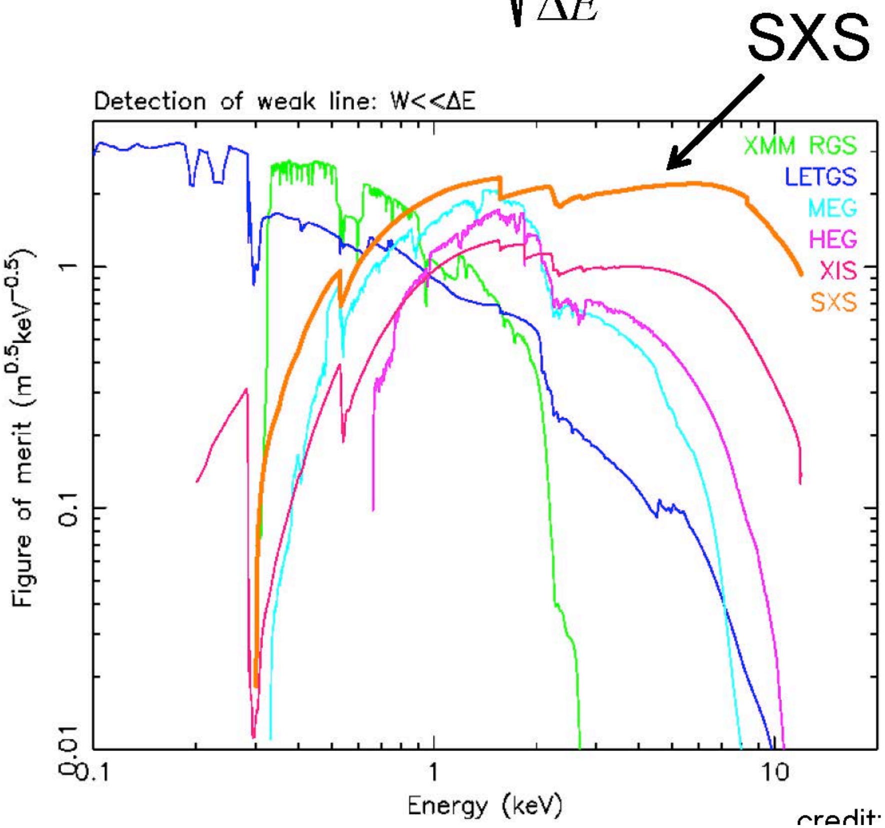
SXS performance compared with existing observatories

Figure of merit

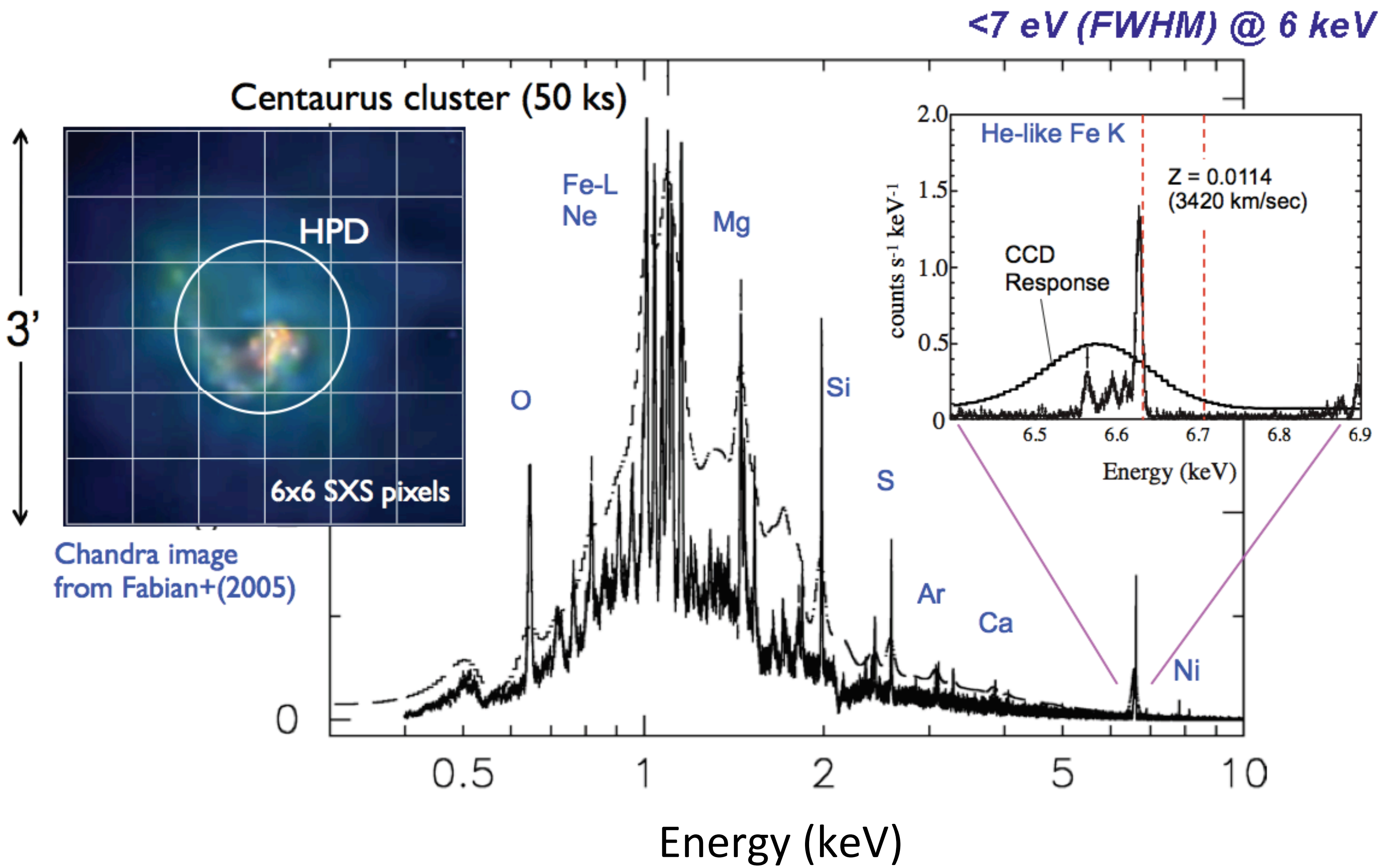
$$FOM \sim \sqrt{\frac{A}{\Delta E}}$$

Effective area





Example of the SXS spectrum : cluster of galaxies



ASTRO-H in the JAXA's clean room

Schedule

- Thermal vacuum test in June and July.
- Mechanical environment tests in Aug. and Sept.
- Launch in early 2016.

1. Surface gravitational redshift of a NS

Absorption lines in the burst spectra

Identification of the lines

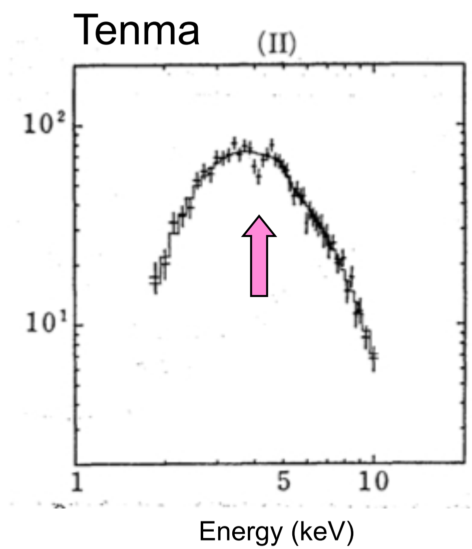
Gravitational redshift

Target selection is crucial.

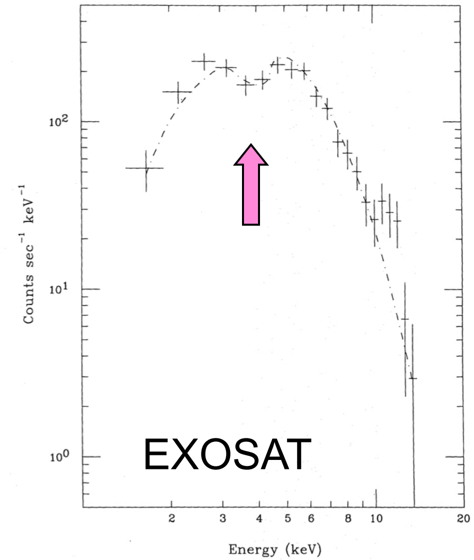
Magnetic field
NS spin

Spectral features may be smeared out.

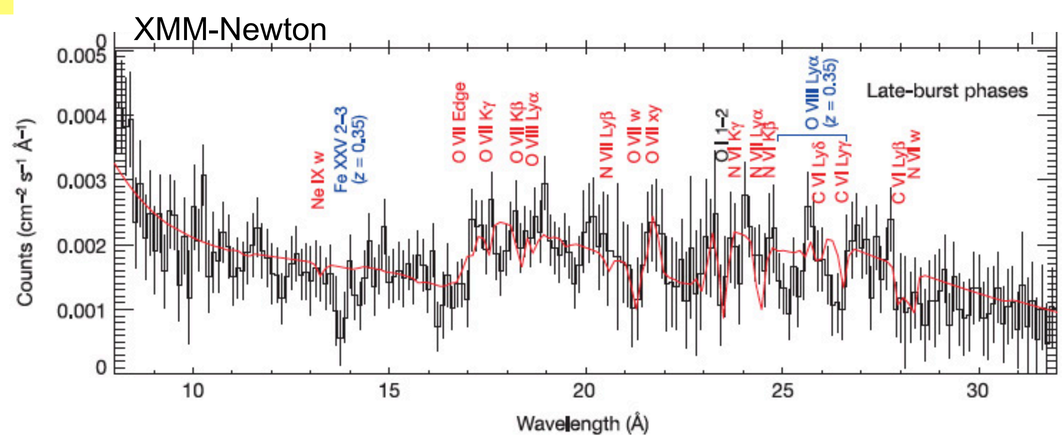
Past observations



Waki et al. 1984, PASJ, 36, 819



Magnier et al. 1989, MNRAS, 237, 729



Cottam et al. 2002, Nature, 420, 51

Magnetic field and spin of NSs

(1) Rotational broadening

$$\Delta E = 1600\left(\frac{\nu_{\rm spin}}{600{\rm Hz}}\right)\left(\frac{R}{10{\rm km}}\right){\rm eV}$$

(2) Zeeman splitting

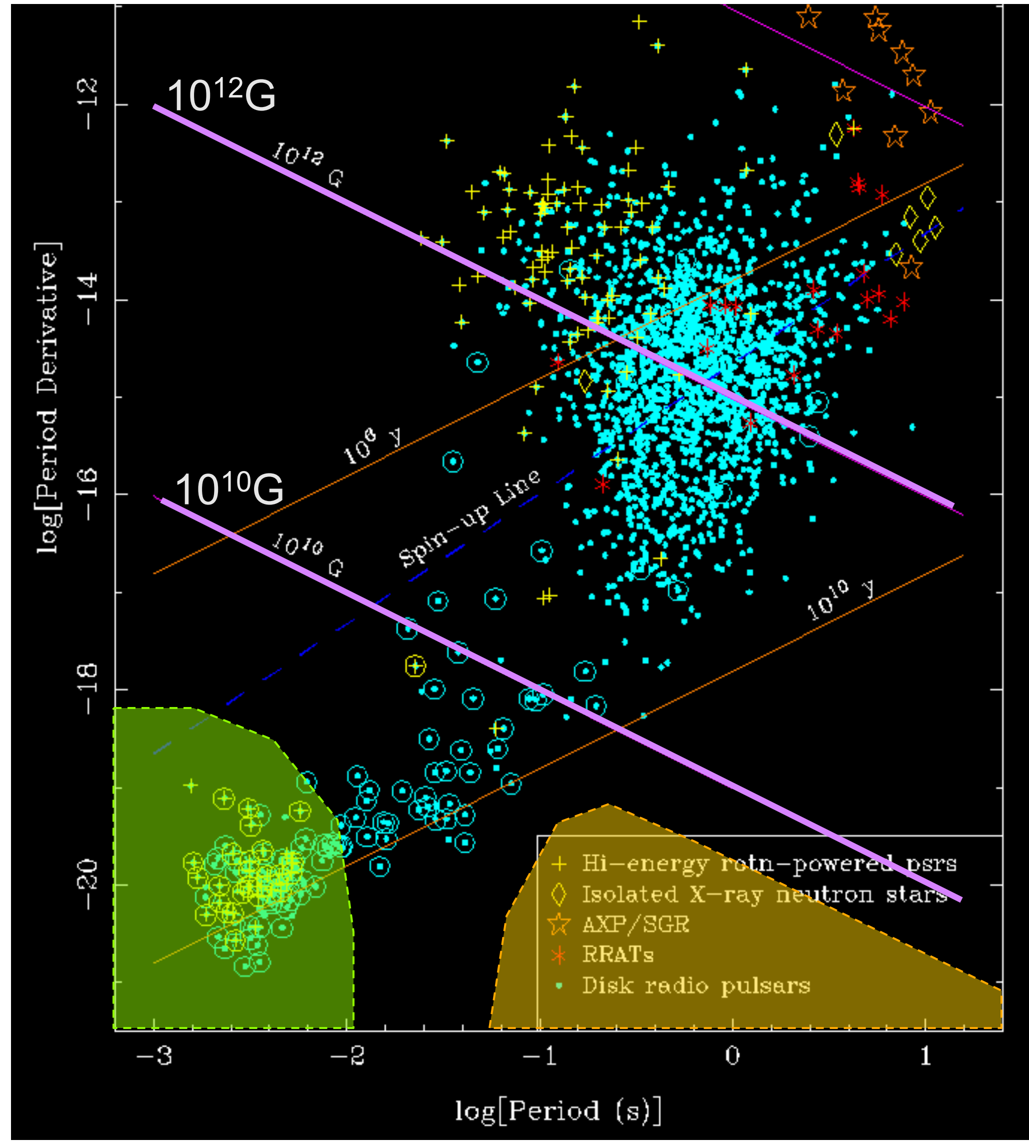
$$\Delta E \approx 12\left(\frac{B}{10^9{\rm G}}\right){\rm eV}$$

Burst oscillation

Recycle scenario of MSPs

Most of the bursting sources are rapidly spinning: ~200-600 Hz

We must carefully select a slow-spin source.

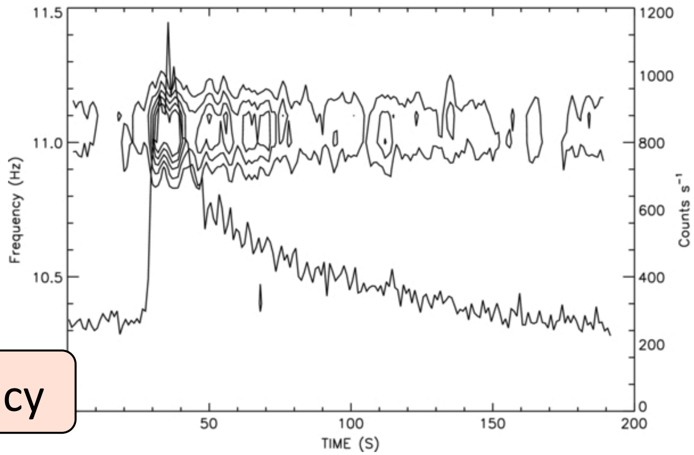


http://www.atnf.csiro.au/research/pulsar/index.html?n=Main.Images

A unique burst source : Terzan 5 X2

- A transient source in the globular cluster Terzan 5.
- Spin frequency : 11 Hz
- Magnetic field : 10^9-10^{10} G

Cavecchi et al. 2011, ApJ, 740, L8



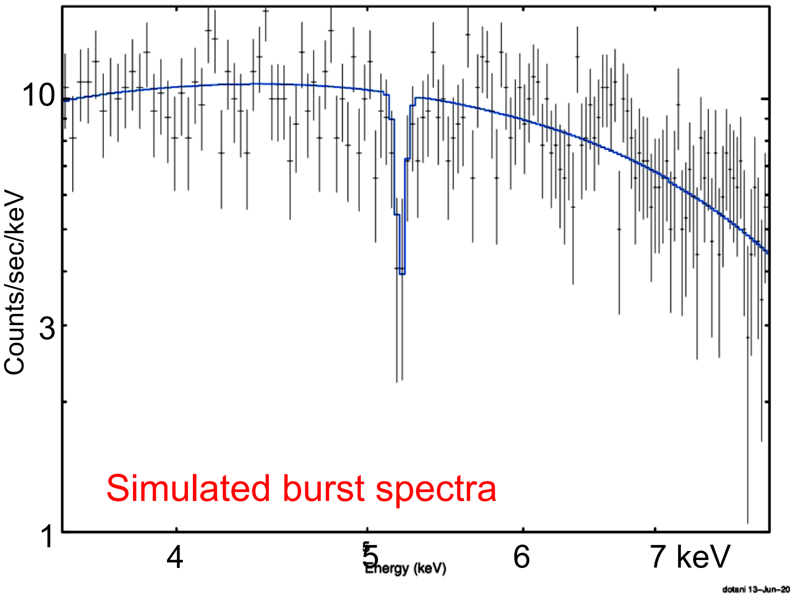
Narrow lines may be expected from the bursting atmosphere.

High accuracy

- Clean and clear results are expected:
  Independent of distance, radiation isotropy, details of the emission region, continuum models
- Caveat
  T5X2 is a transient source.

Assumed parameters:

Continuum : 2 keV bbody with Nh=1.2E22 cm-2
SXS count rate : 60 c/s
Absorption line : 5.2 keV, sigma = 30 eV.
Equivalent width : 50 eV
Exposure : 100 sec



Summing up a few bursts may enable us to detect an absorption line in the burst spectra.

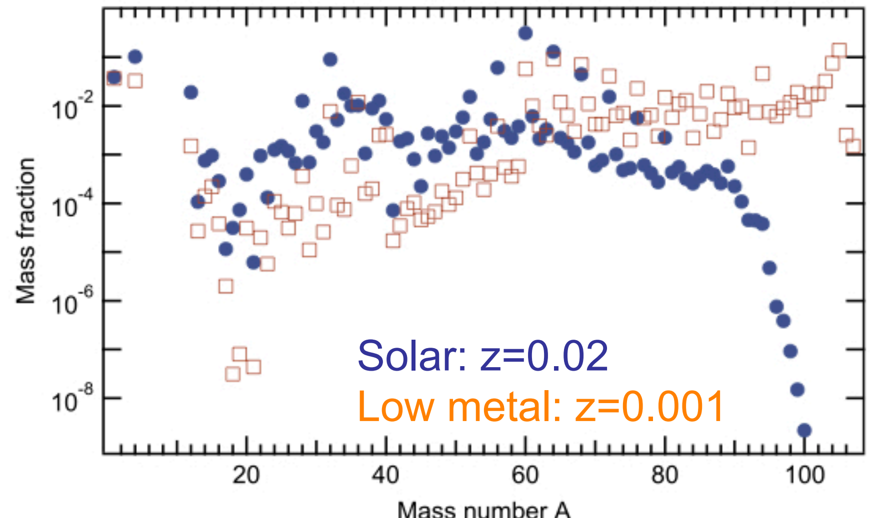
2. Burst wind : spectroscopy of the burst products

- •It is difficult to probe the burst products directory.
- •Burst products are only inferred from the characteristics of the light curves.

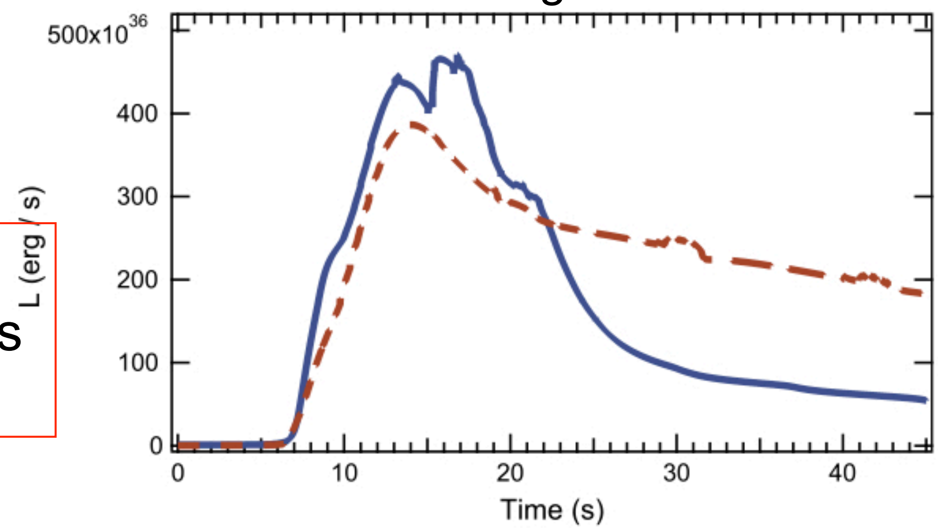
Some PRE bursts accompany strong winds, in which the burst products are contained.

We may be able to detect the spectral features due to the winds in the burst spectra.

Mean composition of the envelope

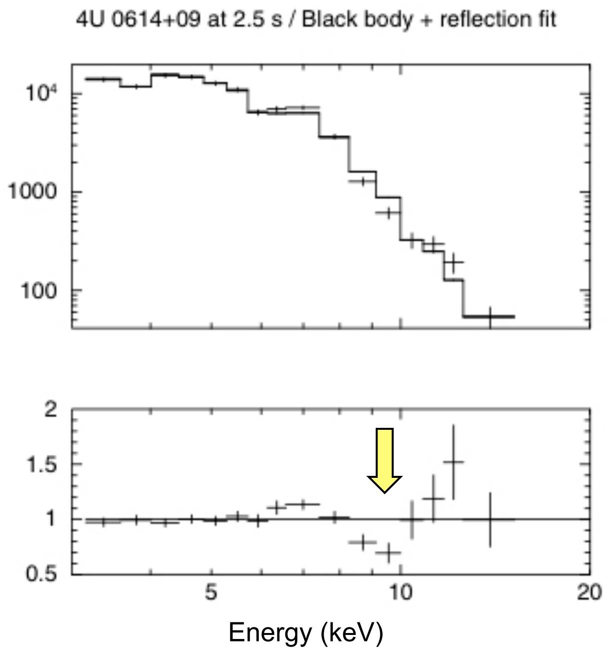


Burst light curve



Parikh et al. 2013, Prog. Part. Nucl. Phys. 69, 225

Spectral features in the burst winds



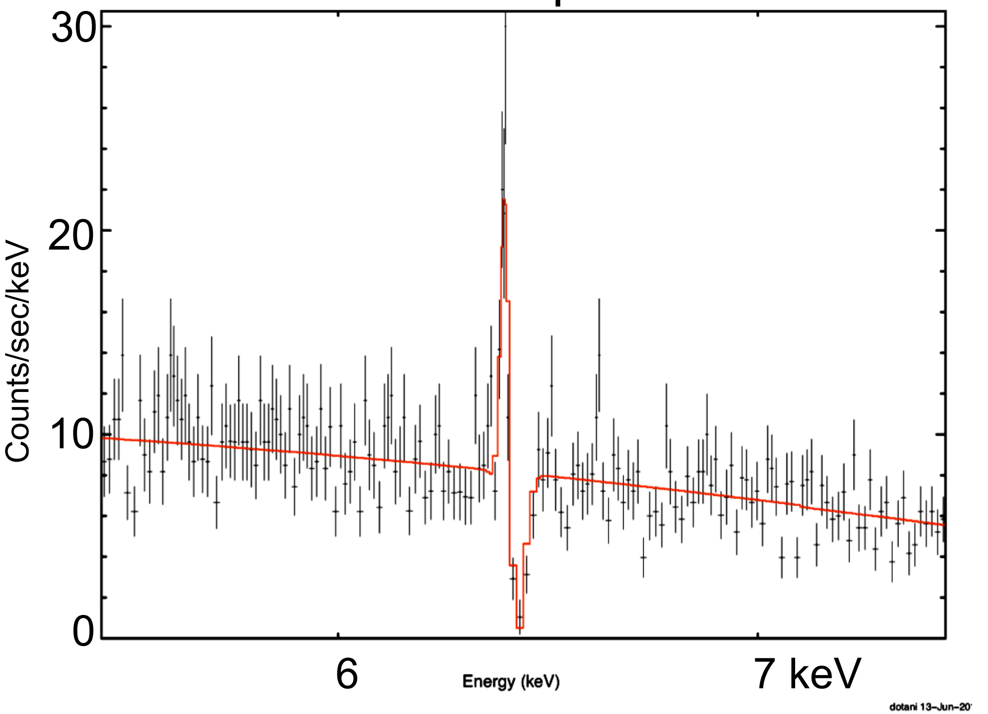
RXTE observations of 4U0614+09 showed absorption edge features during the super-expansion burst.

← Int Zand et al. 2010, A&A, 520, A81

Simulation parameters

- Continuum : 2 keV bbody with Nh=1.2E22 cm-2
- SXS count rate : 60 c/s
- Absorption line : 6.4 keV, sigma = 20 eV.
  - Equivalent width : 10 eV
- Emission line : 6.38 keV, sigma = 10 eV
  - Equivalent width : 10 eV
- Exposure : 300 sec

Simulated spectrum



Spectral features may be detected with super-expansion bursts or by overlaying several PRE bursts.

Summary

- ASTRO-H will be launched in early 2016. It is expected to open a new window of high resolution spectroscopy.
- Two topics are picked up as the expected science of X-ray bursts with ASTRO-H.
  - Absorption lines in the burst spectra may be used to determine the surface gravitational redshift of a neutron star. T5X2 is the only possible target at present and we need to catch its outburst.
  - Composition of the burst products may be probed with the spectral features in the burst winds.