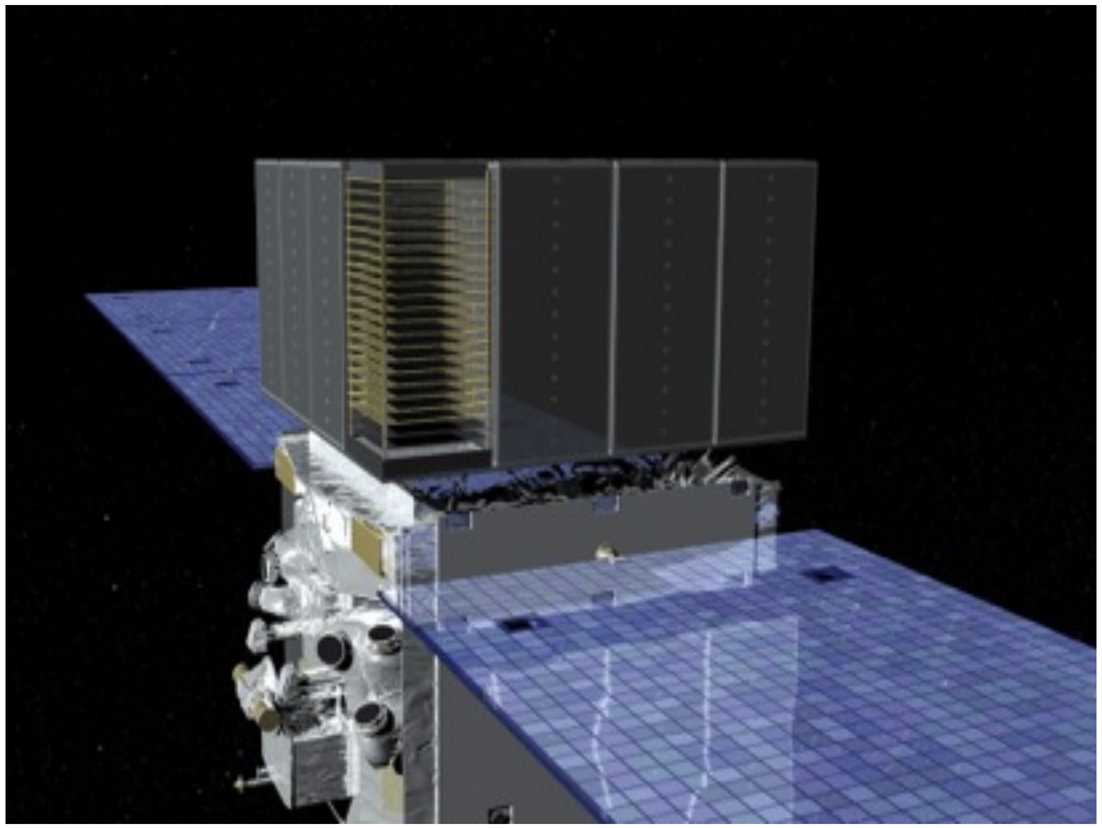
The ASTRO-H X-ray Astronomy Satellite and Fermi

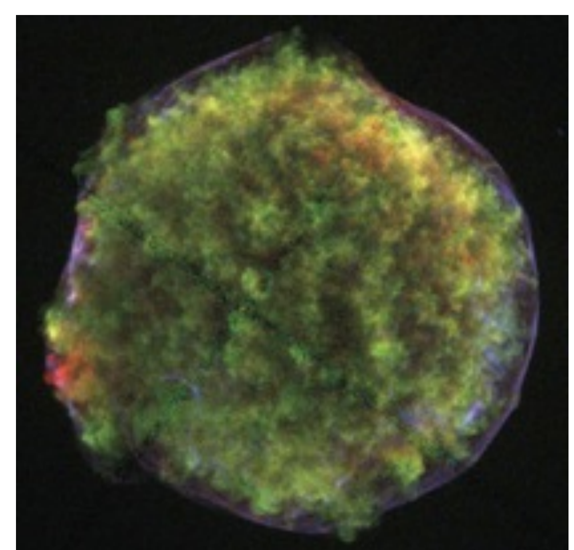
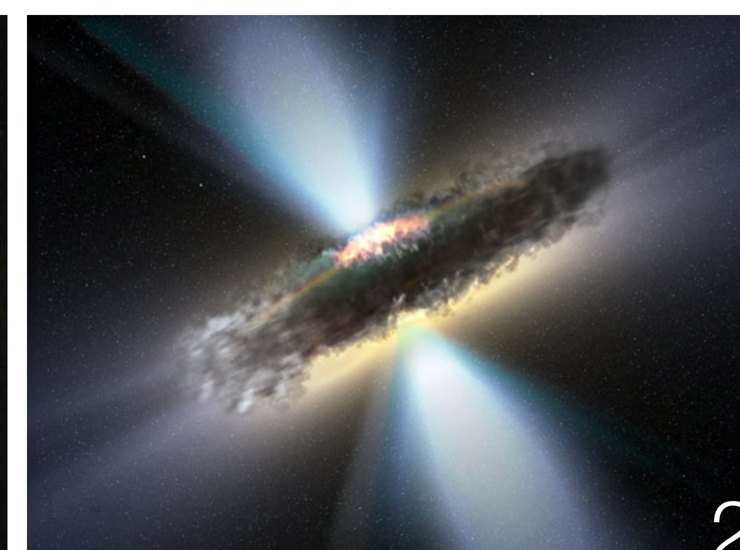
Tadayuki Takahashi
ISAS/JAXA

ASTRO-H (launch in 2015 JFY) will push on X-ray astronomy to a new exciting phase



There are many important topics, which ASTRO-H and Fermi should work together to understand the high energy universe.

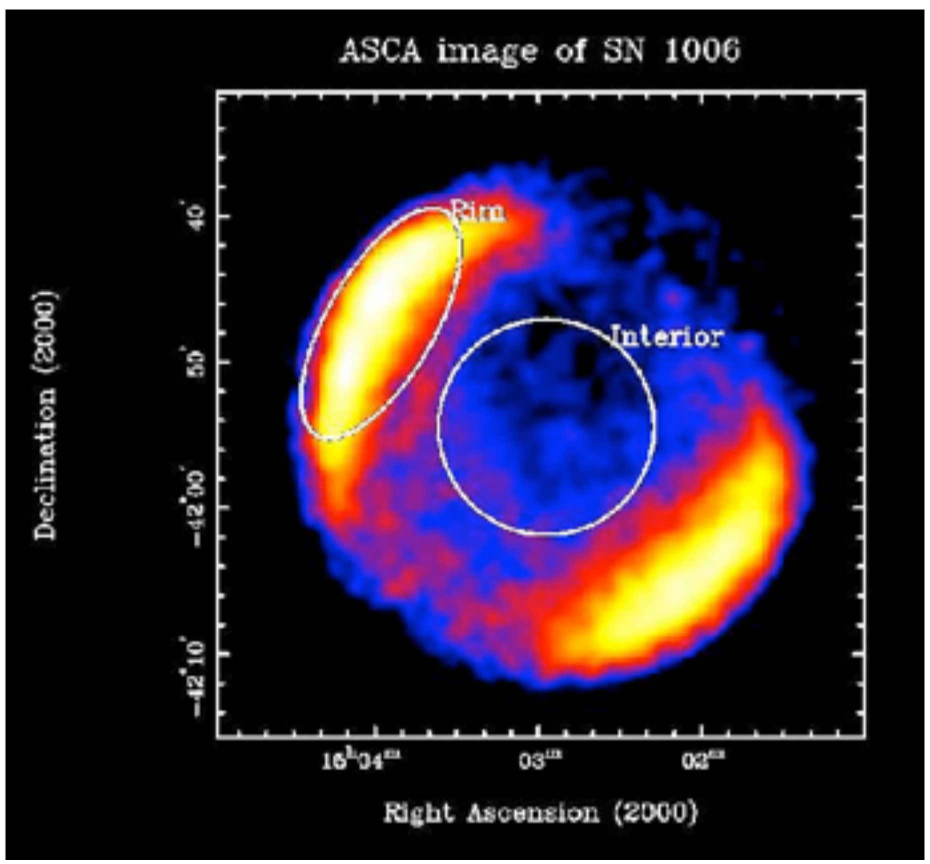


1. Synergy between X-ray and Gamma-ray

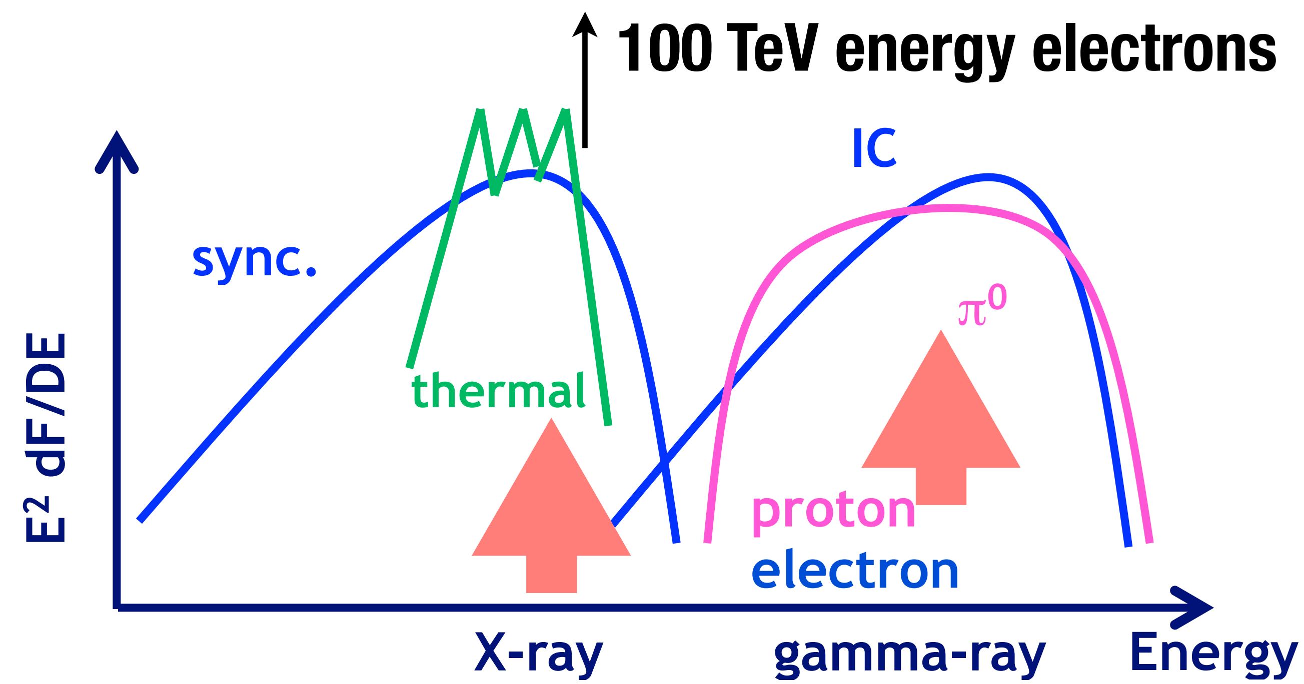
X-ray observation is very sensitive to the existence of the distribution of high energy electrons (particle accelerators)

ASCA (Koyama et al. 1995)



X-ray Synchrotron

$$h\nu_{synch} = 5.3\, E^2_{100\,\mathrm{TeV}} B_{10\,\mu\mathrm{G}} \quad [\mathrm{keV}]$$

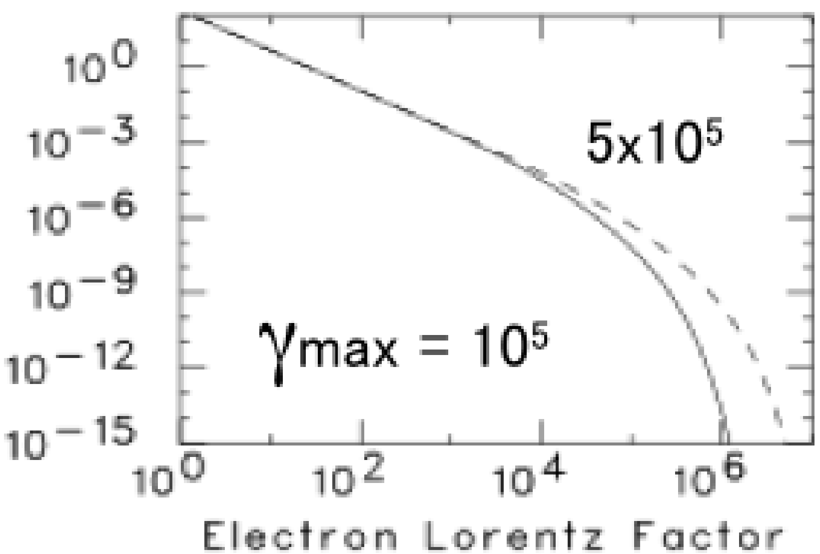


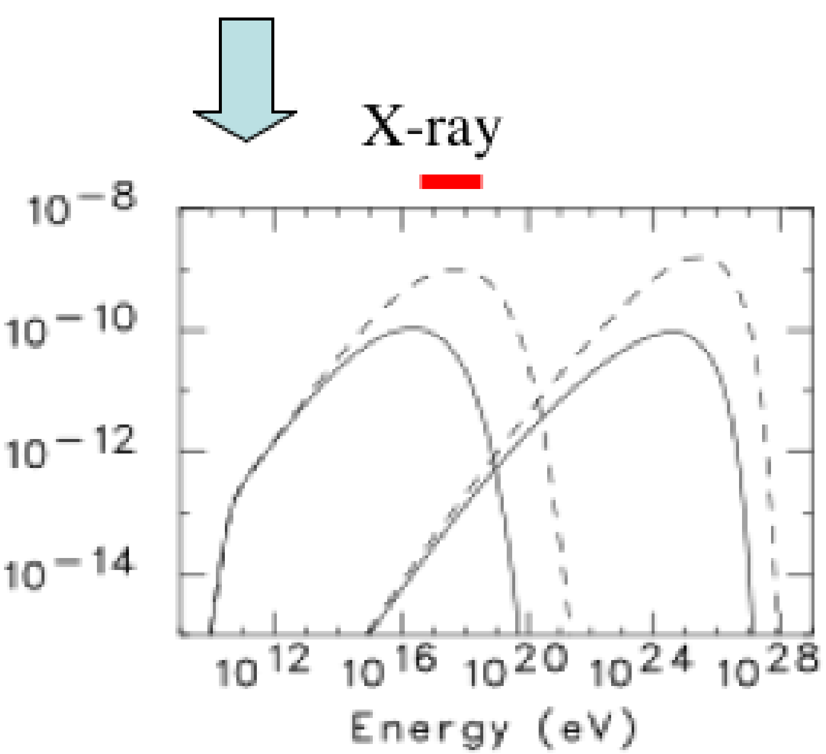
Cooling time of X-ray emitting electrons is much shorter than radio ones

$$t_{sync} = E/(dE/dt) = 1.25 \times 10^3 \left(\frac{E_e}{100TeV}\right)^{-1} \left(\frac{B}{10\mu G}\right)^{-2} year$$

1. Synergy between X-ray and Gamma-ray

Blazar spectra from accelerated particles





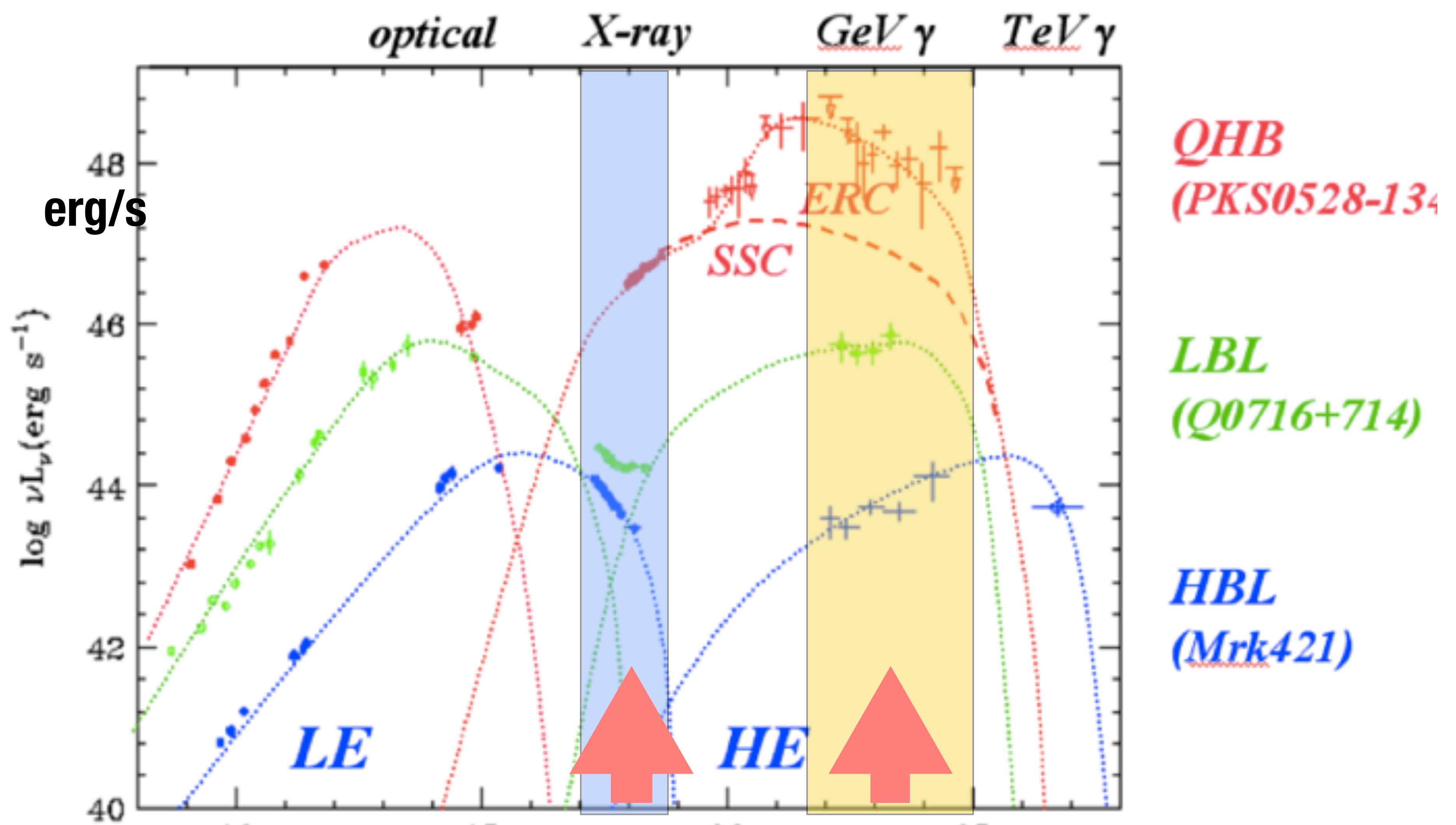


Fig. by Kataoka

Simultaneous flare in light curves are often observed in X-ray/TeV gamma-ray (Due to the change of acceleration efficiency in the jet or condition of accretion disk)

2. ASTRO-H Mission

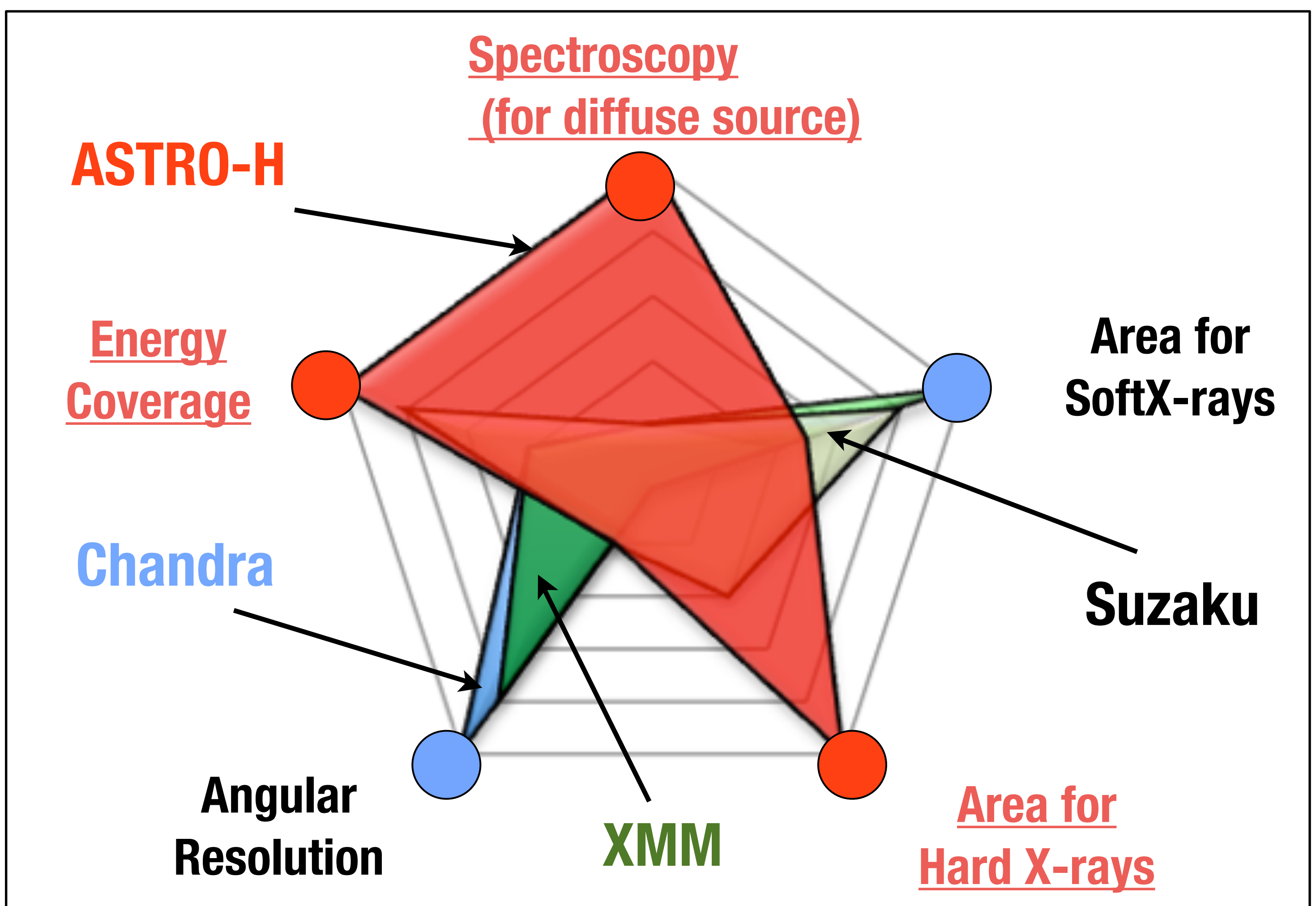
ASTRO-H, which is the 6th in the series of the X-ray observatories from Japan, is designed to have

1) Higher Energy Resolution

and

2) Wider energy coverage with higher sensitivities

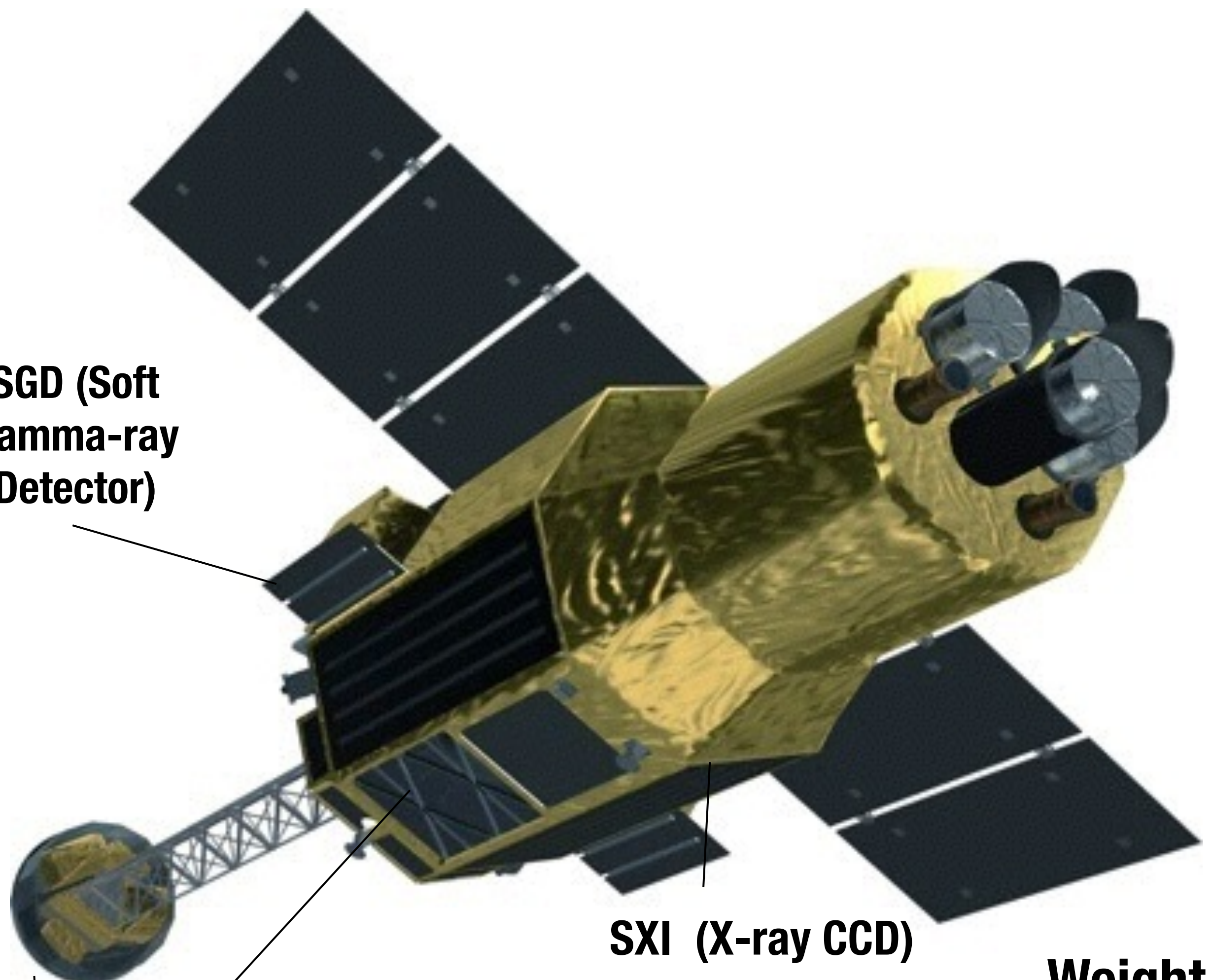
than existing X-ray missions.



ASTRO-H is an international X-ray observatory. More than 200 scientists from Japan/US/Europe/Canada are involved in.

2008: The ASTRO-H project has officially started.
2010: PDR completed
2012: CDR completed

2. ASTRO-H Mission



Weight 2.7 t

Height 14 m

- Orbit Altitude: 550km
- Orbit Inclination: ~31 degrees
- Launch : 2015 (JFY)

International Contribution

NASA Micro Calorimeter Array/ADR Two soft X-ray Telescopes Eight Science Advisors Pipeline Analysis
SRON & U. of Geneva Filter Wheel/MXS for SXS **CEA/DSM/IRFU** Contribution to BGO Shield/ASIC test **ESA** Three Science Advisors Contribution to mission instruments User support in Europe
CSA Metrology System

1) Science operations will be similar to those of Suzaku, with pointed observation of each target until the integrated observing time is accumulated, and then slewing to the next target.
2) The area of the sky accessible at a time is a belt within which the Sun angle is between 60° and 120°.
3) It is expected to take ~72 min for the 180° maneuver.

2. ASTRO-H Team

The ASTRO-H X-ray Astronomy Satellite

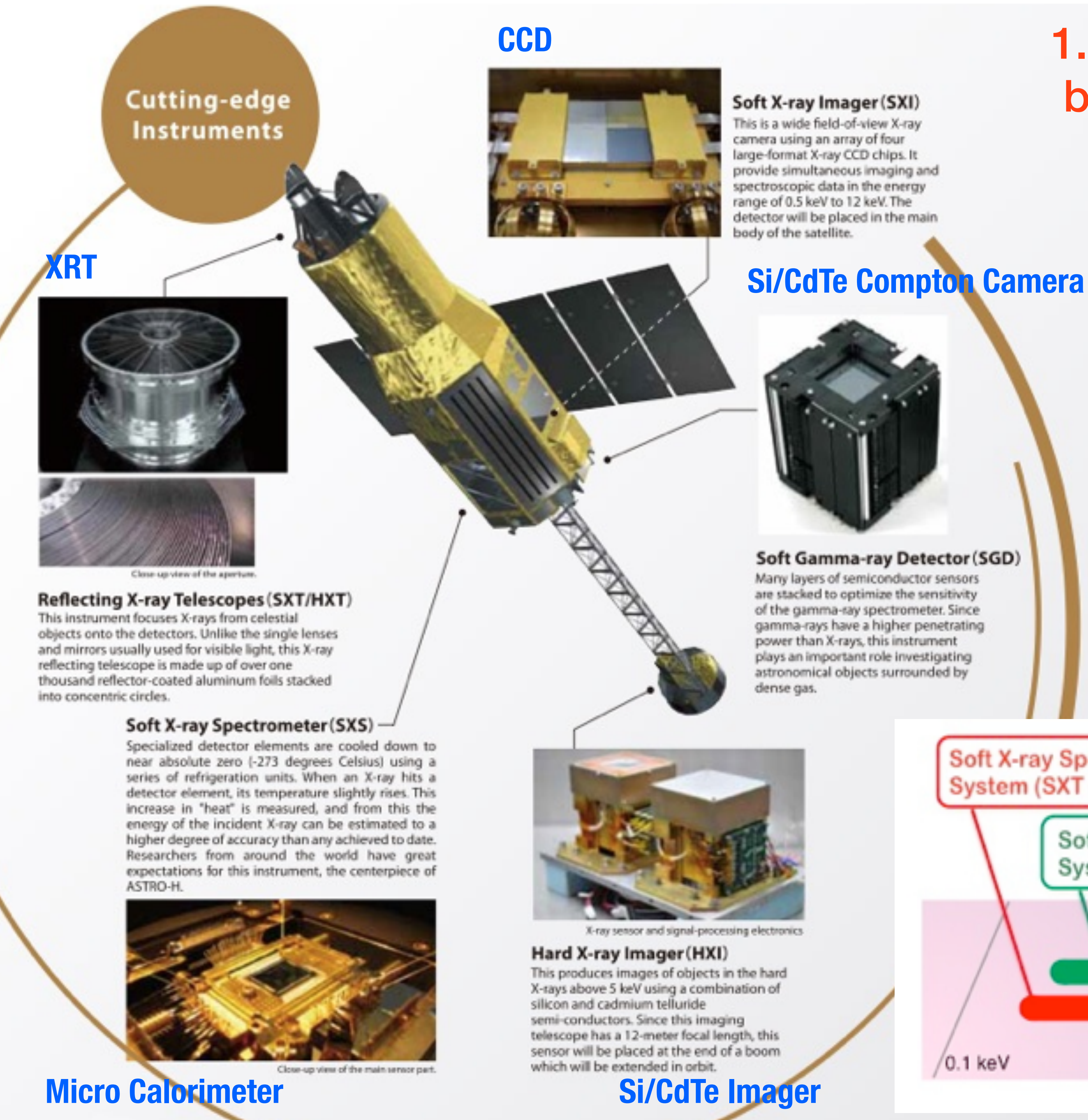
Tadayuki Takahashi[a], Kazuhisa Mitsuda[a], Richard Kelley[b], Felix Aharonian[c], Hiroki Akamatsu[d], Fumie Akimoto[e], Steve Allen[f], Naohisa Anabuki[g], Lorella Angelini[b], Keith Arnaud[h], Makoto Asai[f], Marc Audard[i], Hisamitsu Awaki[j], Philipp Azzarello[i], Chris Baluta[a], Aya Bamba[k], Nobutaka Bando[a], Mark Bautz[l], Thomas Bialas[b], Roger Blandford[f], Kevin Boyce[b], Laura Brenneman[b], Greg Brown[m], Edward Cackett[n], Edgar Canavan[b], Maria Chernyakova[c], Meng Chiao[b], Paolo Coppi[o], Elisa Costantini[d], Jelle de Plaa[d], Jan-Willem den Herder[d], Michael DiPirro[b], Chris Done[p], Tadayasu Dotani[a], John Doty[q], Ken Ebisawa[a], Megan Eckart[b], Teruaki Enoto[r], Yuichiro Ezoe[s], Andrew Fabian[n], Carlo Ferrigno[i], Adam Foster[t], Ryuichi Fujimoto[u], Yasushi Fukazawa[v], Stefan Funk[f], Akihiro Furuzawa[e], Massimiliano Galeazzi[w], Luigi Gallo[x], Poshak Gandhi[p], Kirk Gilmore[f], Matteo Guainazzi[y], Daniel Haas[d], Yoshito Haba[z], Kenji Hamaguchi[h], Atsushi Harayama[a], Isamu Hatsukade[aa], Katsuhiro Hayashi[a], Takayuki Hayashi[a], Kiyoshi Hayashida[g], Junko Hiraga[ab], Kazuyuki Hirose[a], Ann Hornschemeier[b], Akio Hoshino[ac], John Hughes[ad], Una Hwang[ae], Ryo Iizuka[a], Yoshiyuki Inoue[a], Kazunori Ishibashi[e], Manabu Ishida[a], Kumi Ishikawa[r], Kosei Ishimura[a], Yoshitaka Ishisaki[s], Masayuki Ito[af], Naoko Iwata[a], Naoko Iyomoto[ag], Chris Jewell[y], Jelle Kaastra[d], Timothy Kallman[b], Tuneyoshi Kamae[f], Jun Kataoka[ah], Satoru Katsuda[a], Junichiro Katsuta[v], Madoka Kawaharada[a], Nobuyuki Kawai[ai], Taro Kawano[a], Shigeo Kawasaki[a], Dmitry Khangaluyan[a], Caroline Kilbourne[b], Mark Kimball[b], Masashi Kimura[aj], Shunji Kitamoto[ac], Tetsu Kitayama[ak], Takayoshi Kohmura[al], Motohide Kokubun[a], Saori Konami[s], Tatsuro Kosaka[am], Alexander Koujelev[an], Katsuji Koyama[ao], Hans Krimm[b], Aya Kubota[ap], Hideyo Kunieda[e], Stephanie LaMassa[o], Casey Lambert[x], Philippe Laurent[aq], François Lebrun[aq], Maurice Leutenegger[b], Olivier Limousin[aq], Michael Loewenstein[b], Knox Long[ar], David Lumb[y], Grzegorz Madejski[f], Yoshitomo Maeda[a], Kazuo Makishima[ab], Maxim Markevitch[b], Candace Masters[b], Hironori Matsumoto[e], Kyoko Matsushita[al], Dan McCammon[as], Daniel McGuinness[b], Brian McNamara[at], Joseph Miko[b], Jon Miller[au], Eric Miller[av], Shin Mineshige[aw], Kenji Minesugi[a], Ikuyuki Mitsuishi[e], Takuya Miyazawa[e], Tsunefumi Mizuno[v], Koji Mori[aa], Hideyuki Mori[e], Franco Moroso[an], Theodore Muench[b], Koji Mukai[b], Hiroshi Murakami[ax], Toshio Murakami[u], Richard Mushotzky[ay], Housei Nagano[e], Ryo Nagino[g], Takao Nakagawa[a], Hiroshi Nakajima[g], Takeshi Nakamori[az], Shinya Nakashima[a], Kazuhiro Nakazawa[ba], Yoshiharu Namba[bb], Chikara Natsukari[a], Yusuke Nishioka[aa], Masayoshi Nobukawa[ao], Hirofumi Noda[r], Masaharu Nomachi[bc], Steve O' Dell[bd], Hirokazu Odaka[a], Hiroyuki Ogawa[a], Mina Ogawa[a], Keiji Ogi[j], Takaya Ohashi[s], Masanori Ohno[v], Masayuki Ohta[a], Takashi Okajima[b], Atsushi Okamoto[aj], Tsuyoshi Okazaki[a], Naomi Ota[be], Masanobu Ozaki[a], Frits Paerels[bf], Stèphane Paltani[i], Arvind Parmar[bg], Robert Petre[b], Ciro Pinto[n], Martin Pohl[i], James Pontius[b], F. Scott Porter[b], Katja Pottschmidt[b], Brian Ramsey[bd], Rubens Reis[au], Christopher Reynolds[ay], Claudio Ricci[aw], Helen Russell[n], Samar Safi-Harb[bh], Shinya Saito[a], Shin-ichiro Sakai[a], Hiroaki Sameshima[a], Kosuke Sato[al], Rie Sato[a], Goro Sato[ah], Yoichi Sato[aj], Makoto Sawada[k], Peter Serlemitsos[b], Hiromi Seta[bi], Yasuko Shibano[a], Maki Shida[a], Takanobu Shimada[a], Keisuke Shinozaki[aj], Peter Shirron[b], Aurora Simionescu[a], Cynthia Simmons[b], Randall Smith[t], Gary Sneiderman[b], Yang Soong[b], Lukasz Stawarz[a], Yasuharu Sugawara[bj], Satoshi Sugita[j], Hiroyuki Sugita[aj], Andrew Szymkowiak[o], Hiroyasu Tajima[e], Hiroaki Takahashi[g], Hiromitsu Takahashi[v], Shin-ichiro Takeda[a], Yoh Takei[a], Toru Tamagawa[r], Keisuke Tamura[e], Takayuki Tamura[a], Takaaki Tanaka[ao], Yasuyuki Tanaka[v], Yasuo Tanaka[a], Makoto Tashiro[bi], Yuzuru Tawara[e], Yukikatsu Terada[bi], Yuichi Terashima[j], Francesco Tombesi[b], Hiroshi Tomida[aj], Yoko Tsuboi[bj], Masahiro Tsujimoto[a], Hiroshi Tsunemi[g], Takeshi Tsuru[ao], Hiroyuki Uchida[ao], Hideki Uchiyama[bk], Yasunobu Uchiyama[ac], Yoshihiro Ueda[aw], Shutaro Ueda[g], Shiro Ueno[aj], Shinichiro Uno[bl], Meg Urry[o], Eugenio Ursino[w], Cor de Vries[d], Atsushi Wada[a], Shin Watanabe[a], Tomomi Watanabe[b], Norbert Werner[f], Nicholas White[b], Dan Wilkins[x], Shinya Yamada[s], Takahiro Yamada[a], Hiroya Yamaguchi[b], Kazutaka Yamaoka[e], Noriko Yamasaki[a], Makoto Yamauchi[aa], Shigeo Yamauchi[be], Tahir Yaqoob[b], Yoichi Yatsu[ai], Daisuke Yonetoku[u], Atsumasa Yoshida[k], Takayuki Yuasa[r], Irina Zhuravleva[f], Abdu Zoghbi[ay], John ZuHone[b],

SPIE paper 2014

Authors: 254
(Scientists 201)
Institutions: 64

Note:
Fermi LAT paper
(Atwood et al. 2009)
Authors: 240

3. ASTRO-H Mission Overview

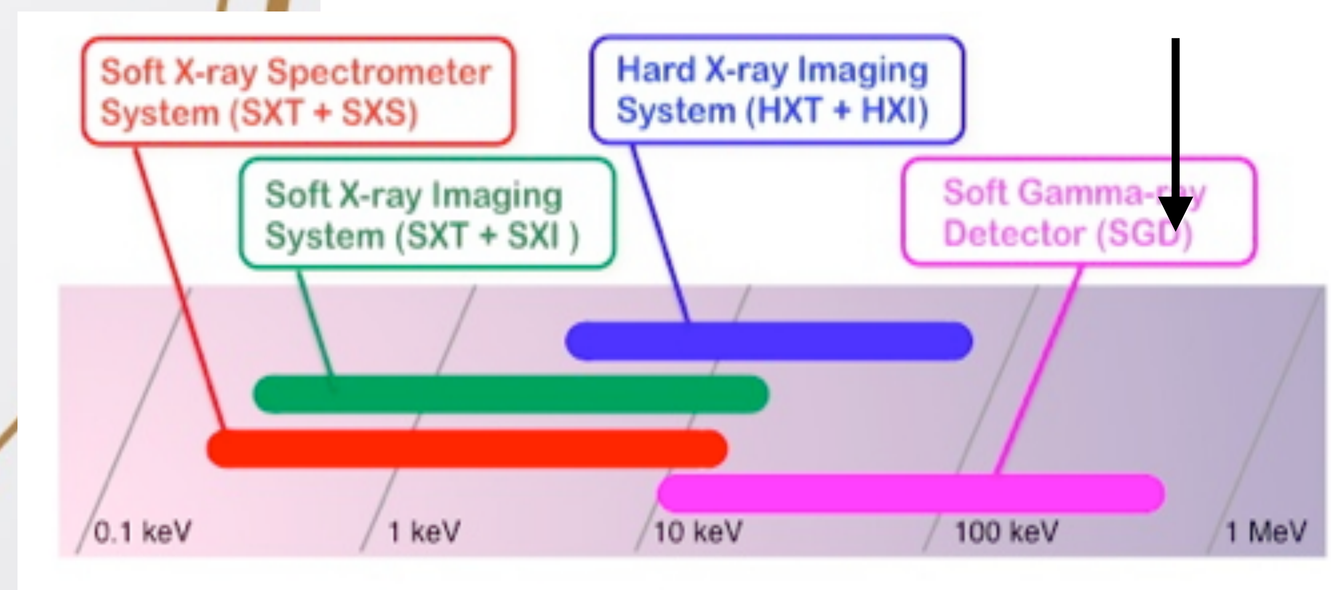


1. High Resolution Spectroscopy by a micro-calorimeter array

ASTRO-H is the first mission to carry out high resolution spectroscopy of extended objects at Fe-K

2. Wide Band /High Sensitivity Observation

0.3 keV - 600 keV : Four Instruments including Hard X-ray Focusing optics



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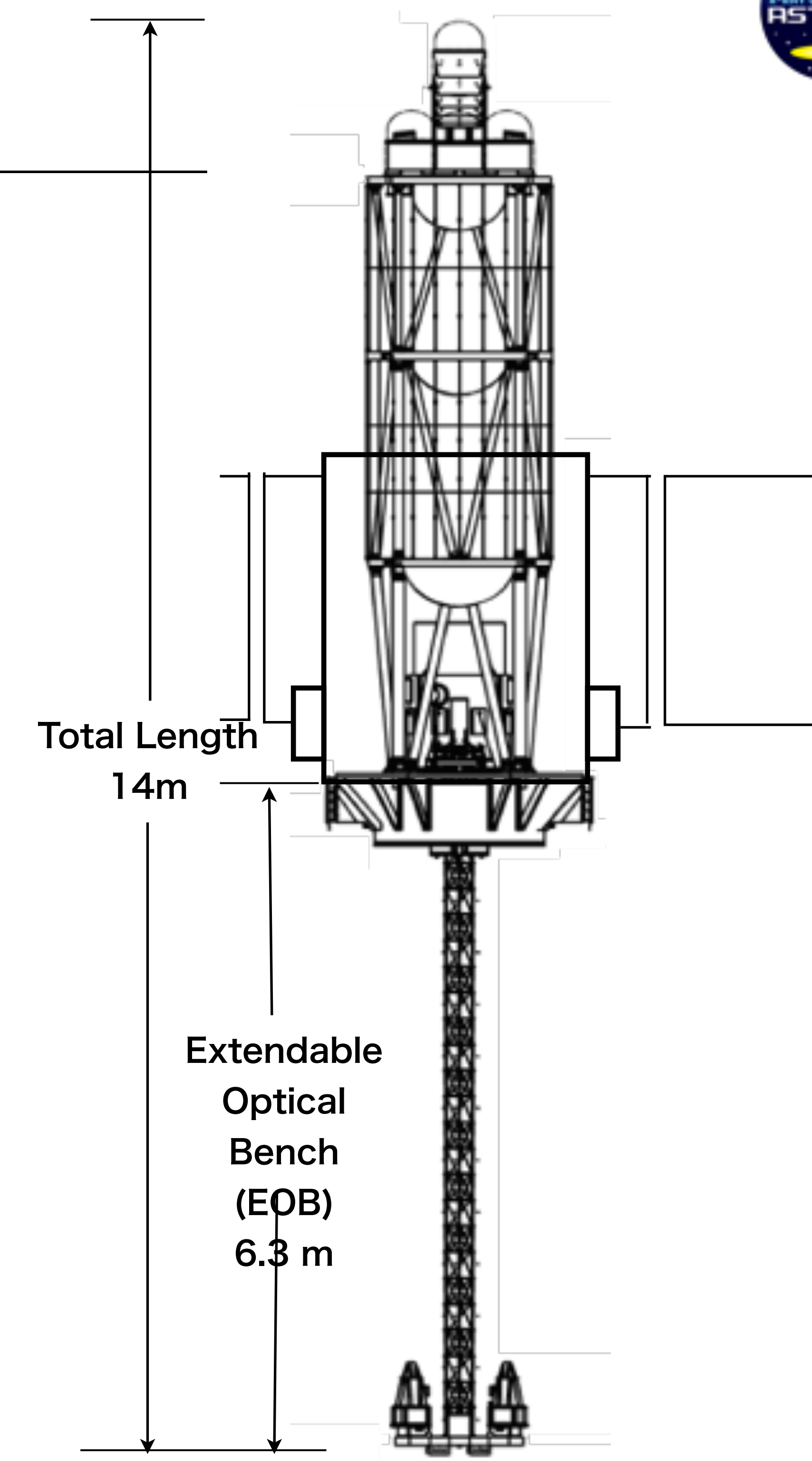
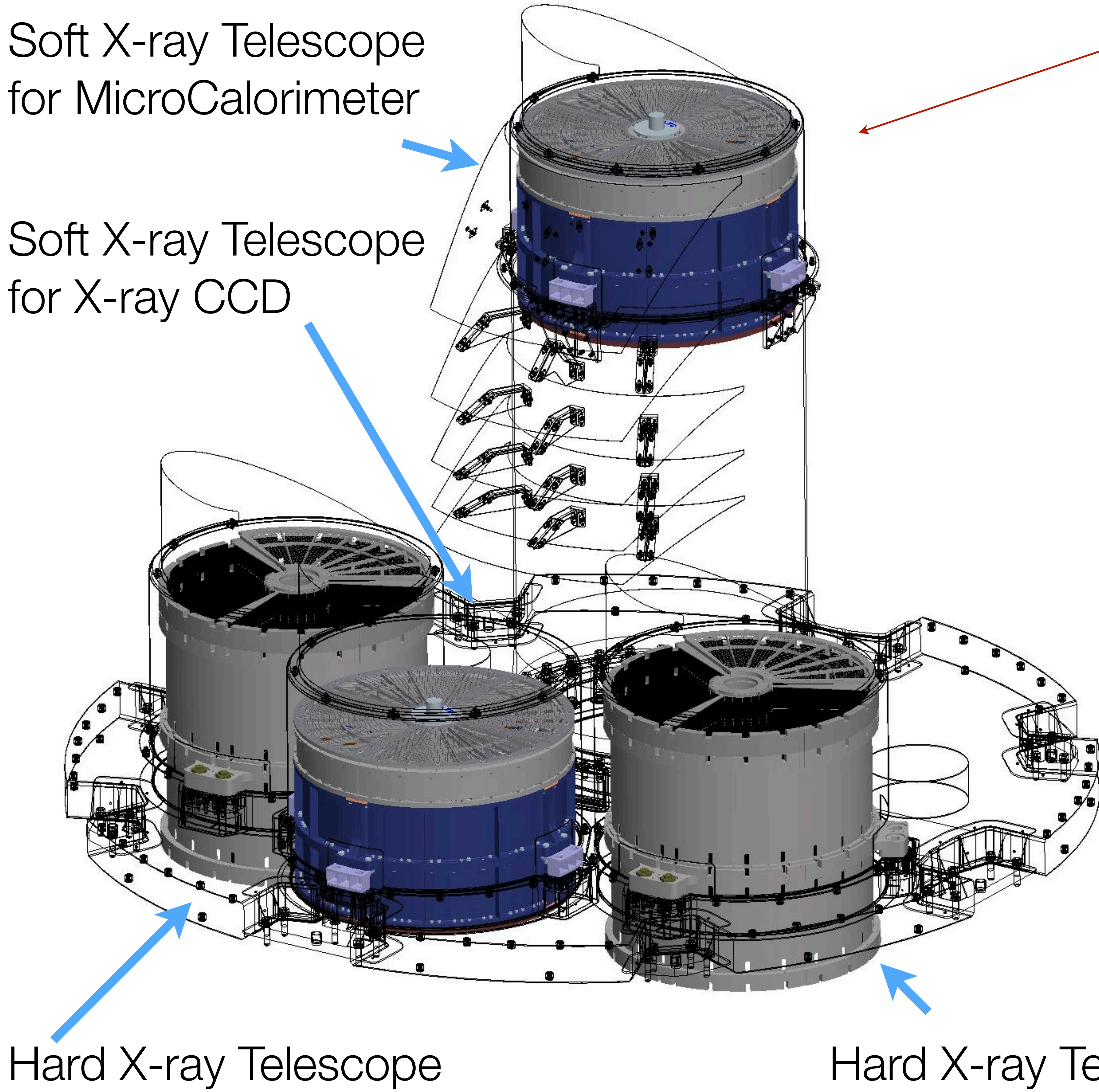
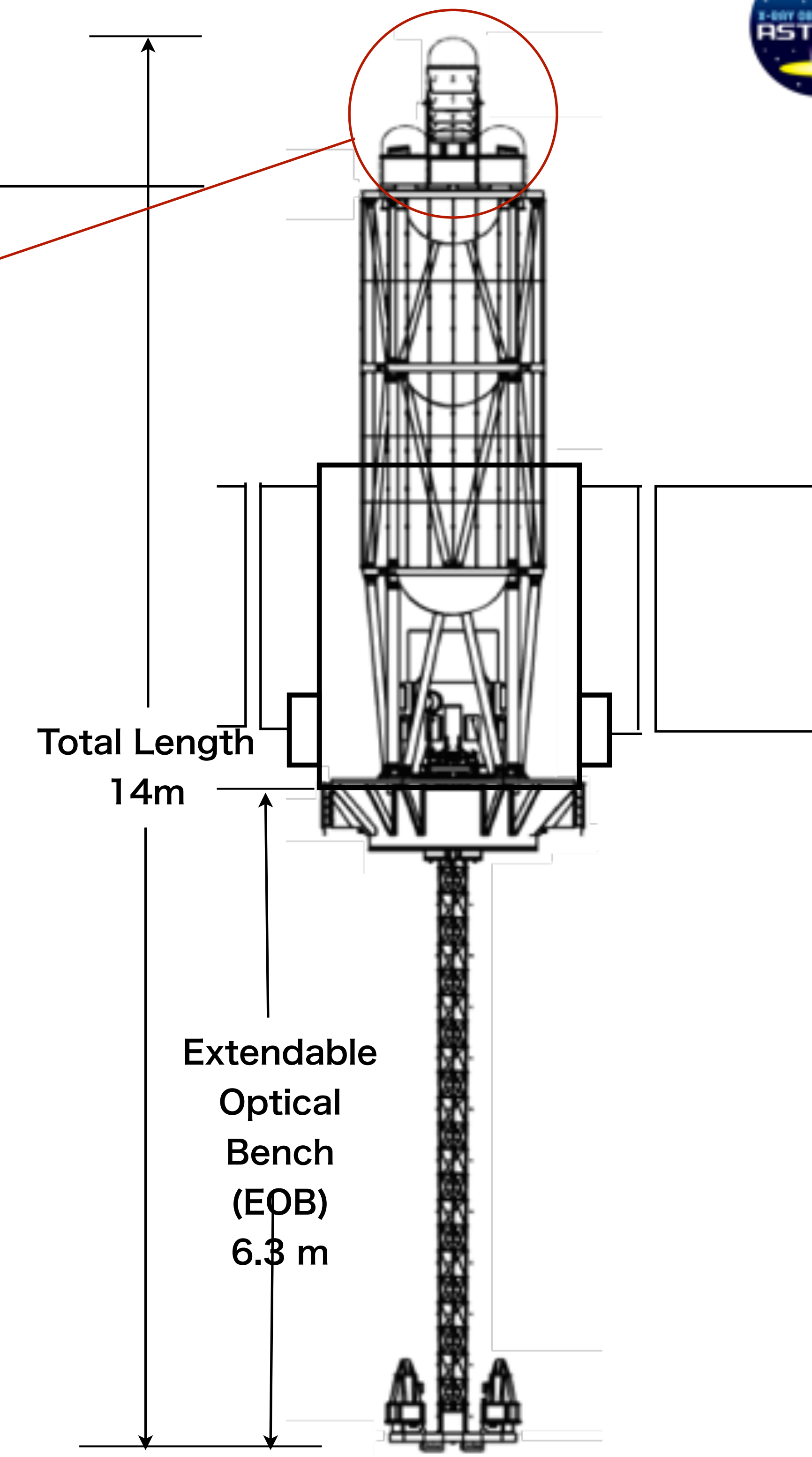


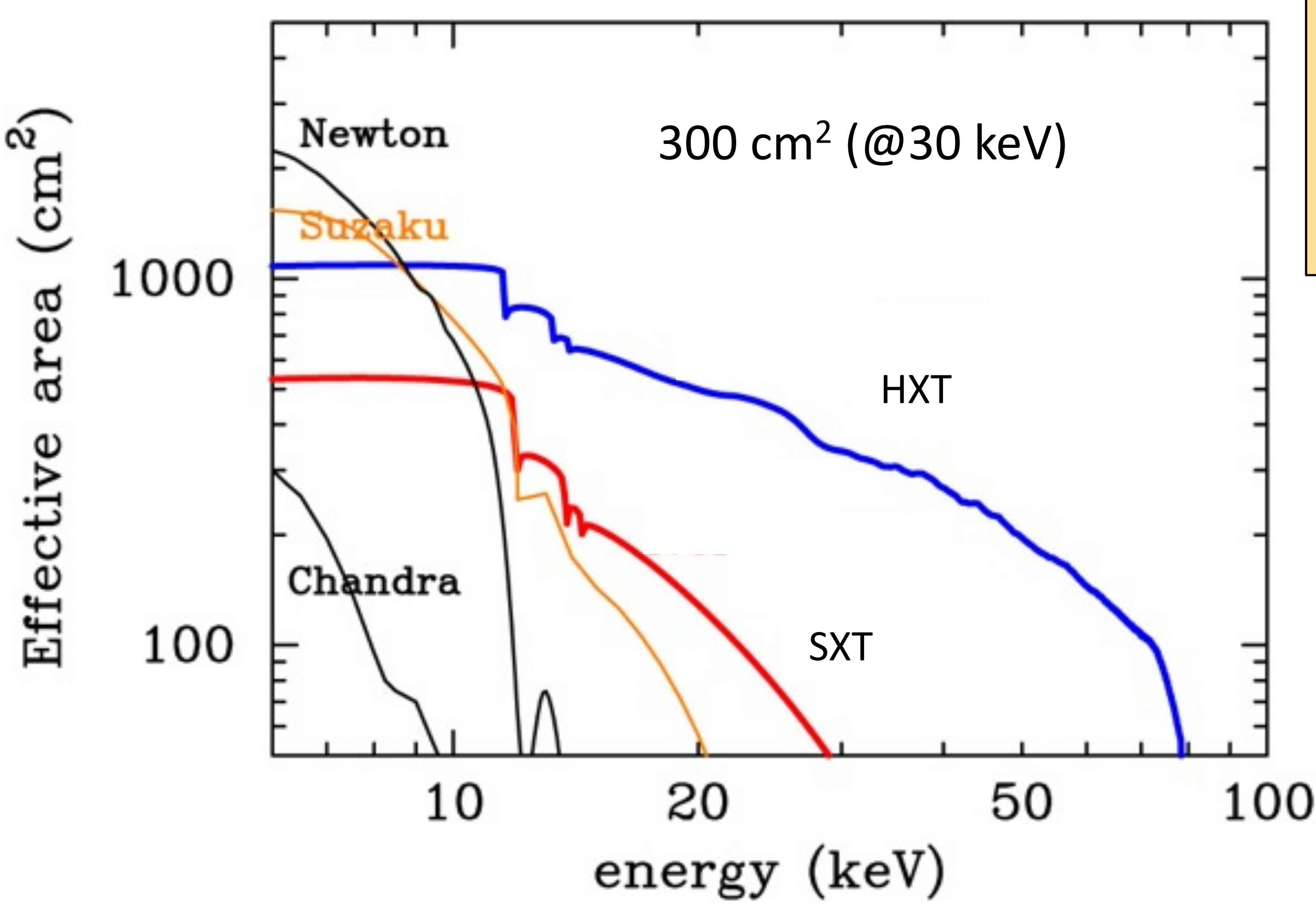
Telescopes (2 HXT + 2 SXT)

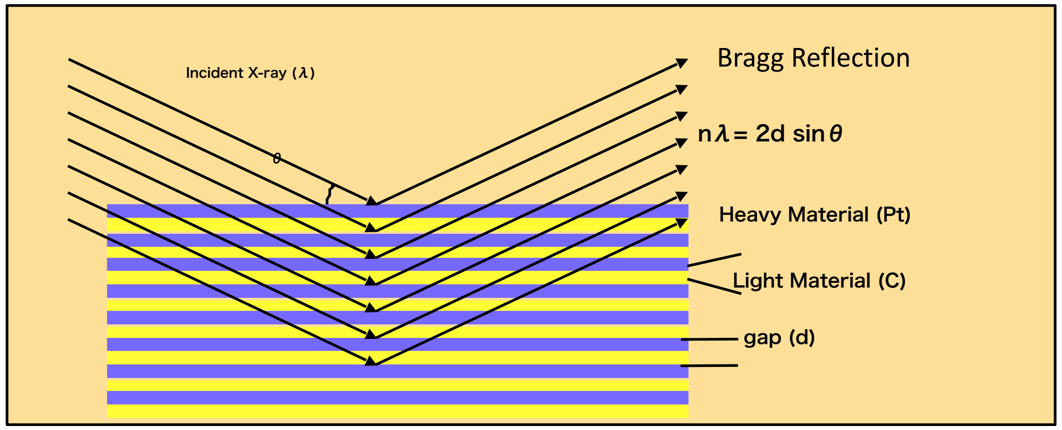


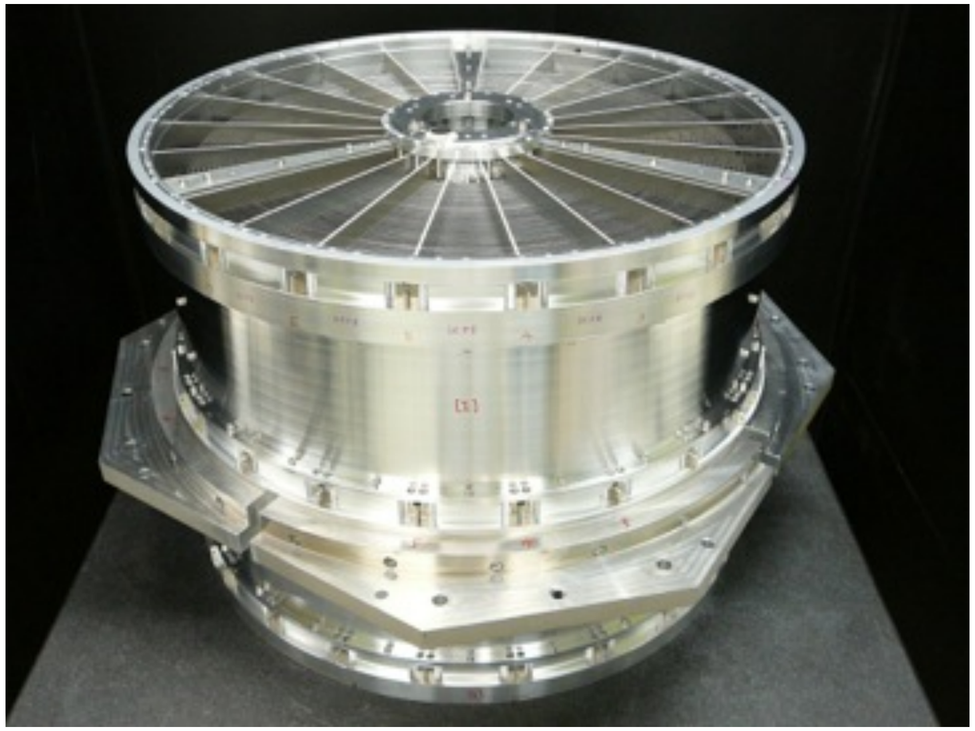


Hard X-ray Telescope

- Pt/C depth-graded multilayer X-ray telescope
- Large photon collecting area above 10 keV.
- Careful calibration using SPring-8 Hard X-ray Beam line was performed





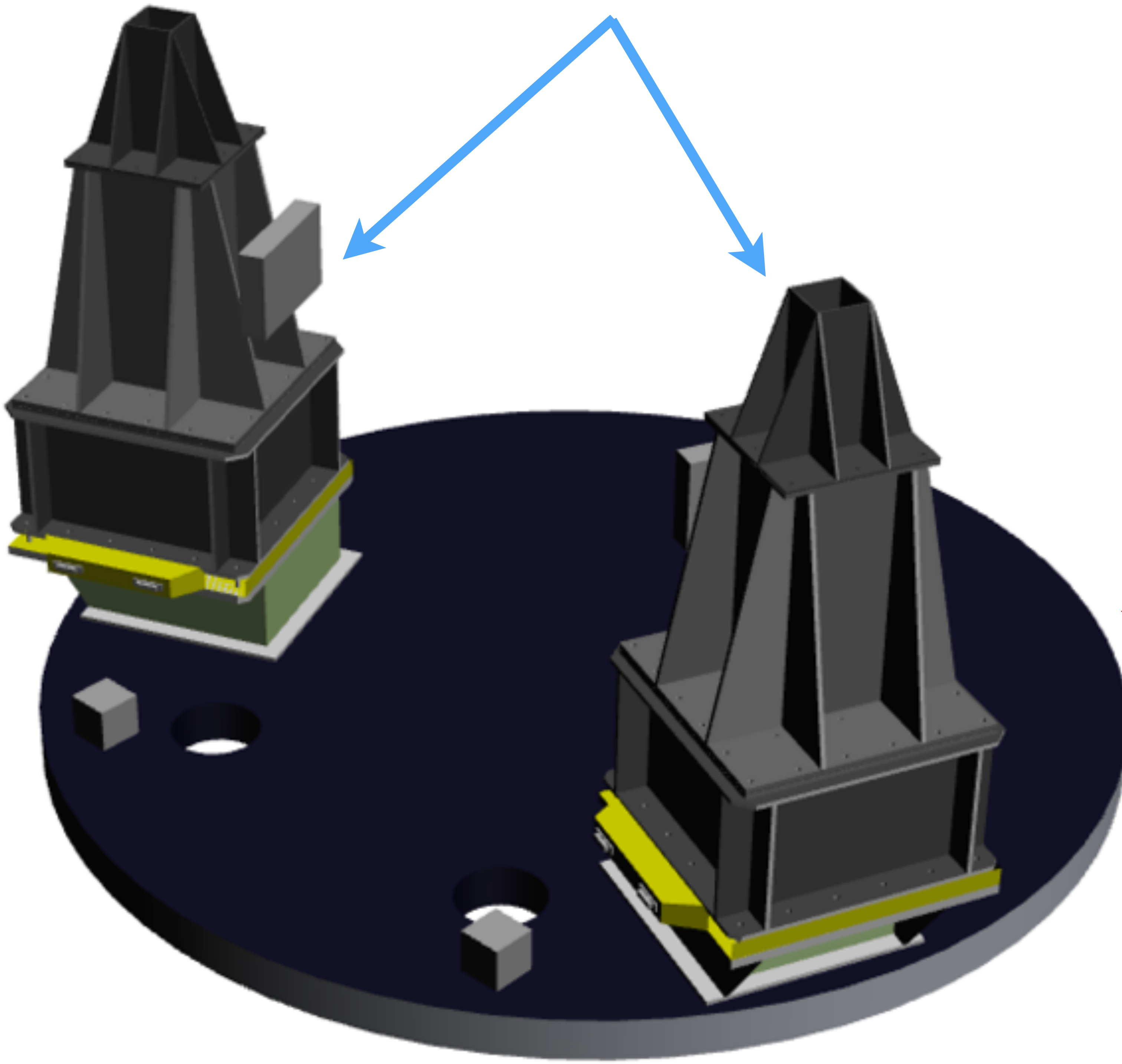


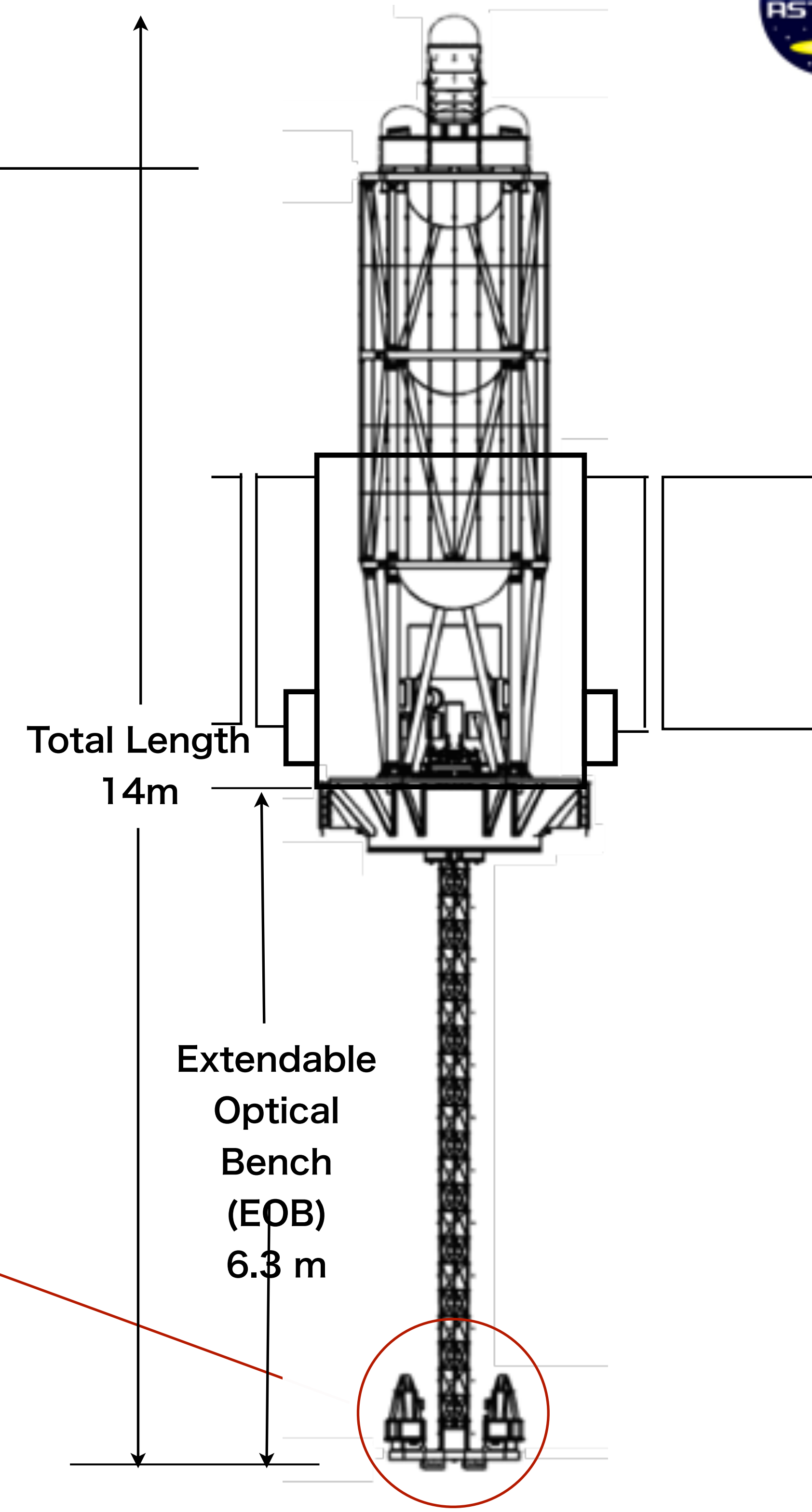
HPD < 1.7 arcmin

- Nagoya U., Ehime U., ISAS, Chubu U.

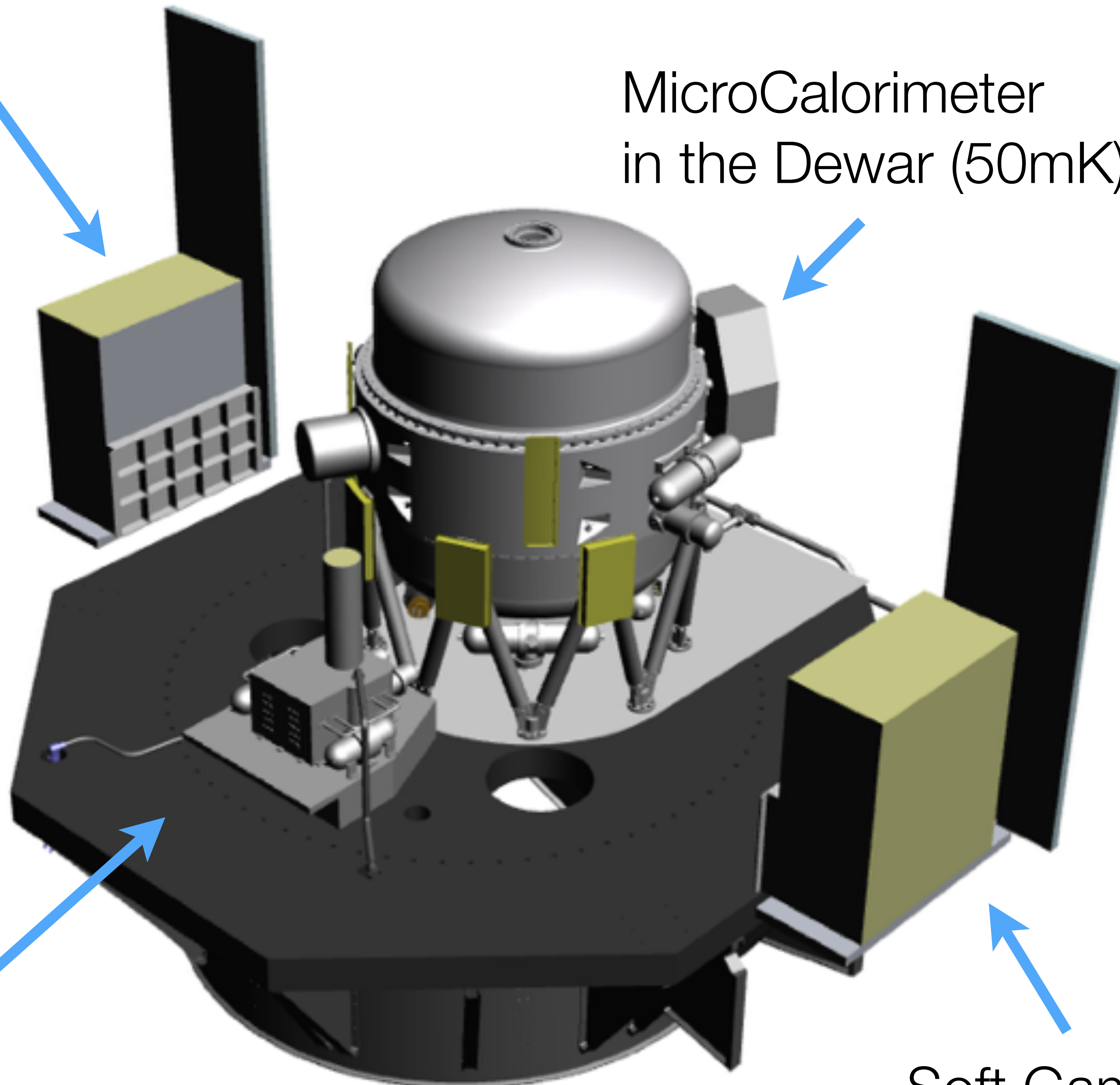
Instruments on the HXI plate

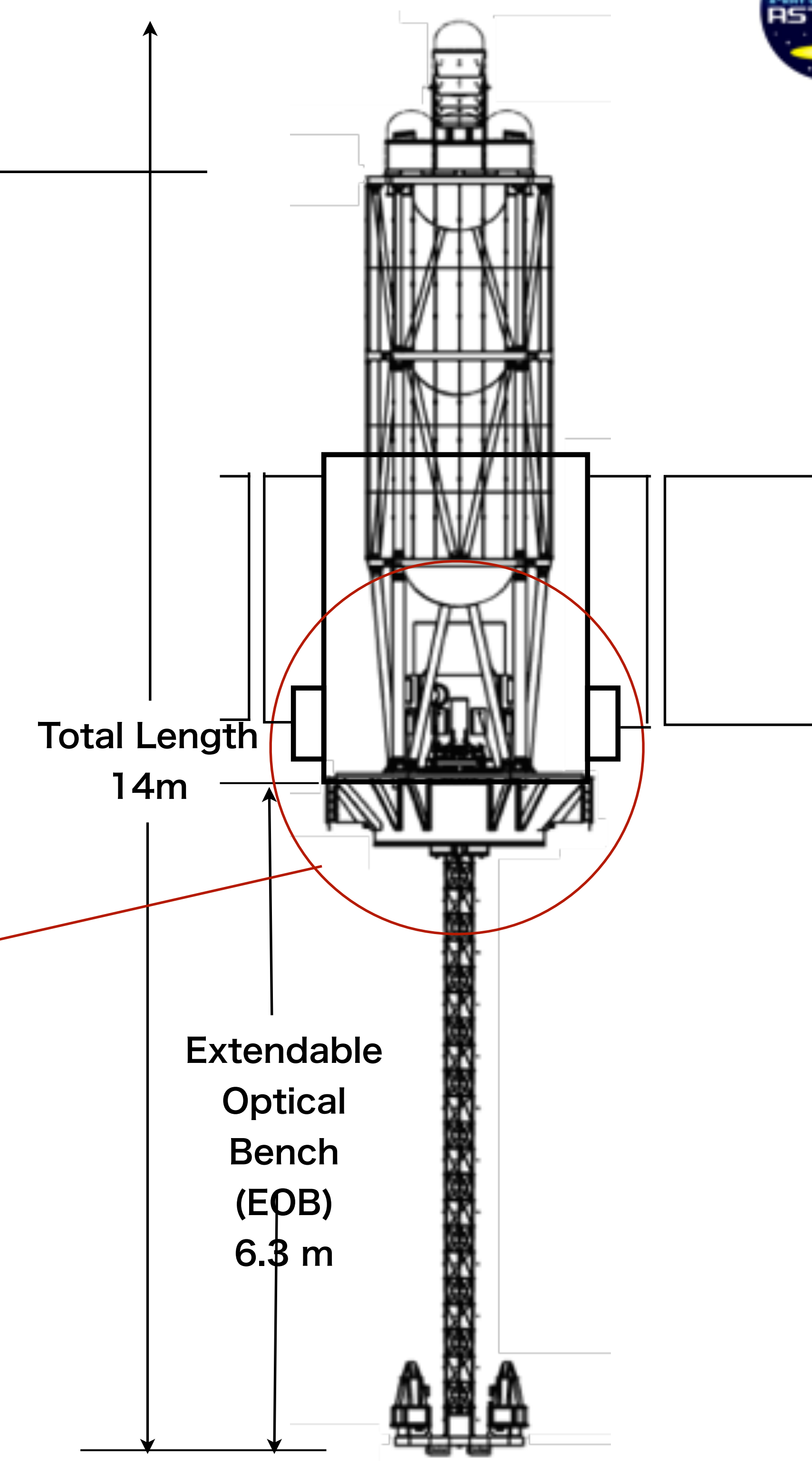
Si+CdTe Hybrid
Hard X-ray Imager





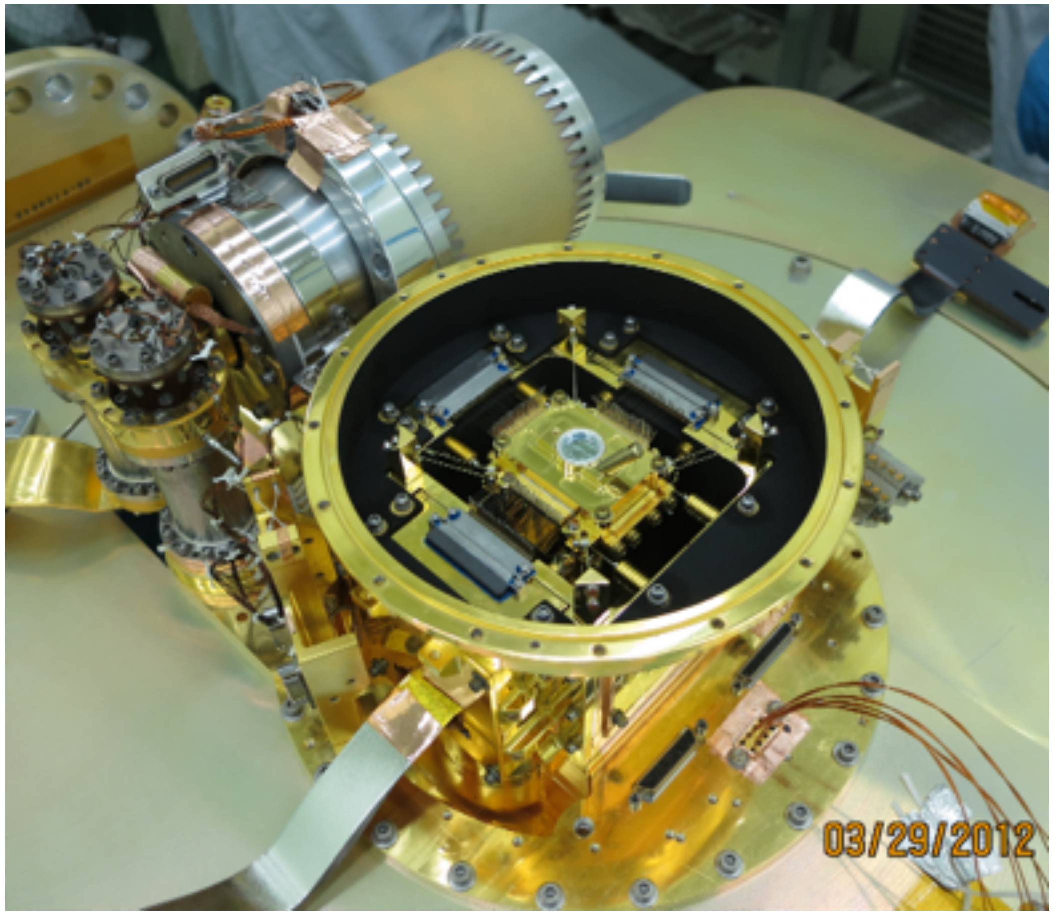
Instruments on the baseplate





Micro-calorimeter and Dewar

- X-ray micro-calorimeter spectrometer with energy resolution better than 7 eV (FWHM)
- 6 × 6 array with 3’ × 3’ field of view
- Operated at 50 mK
  - Nominal expected liquid He lifetime 3.3 years

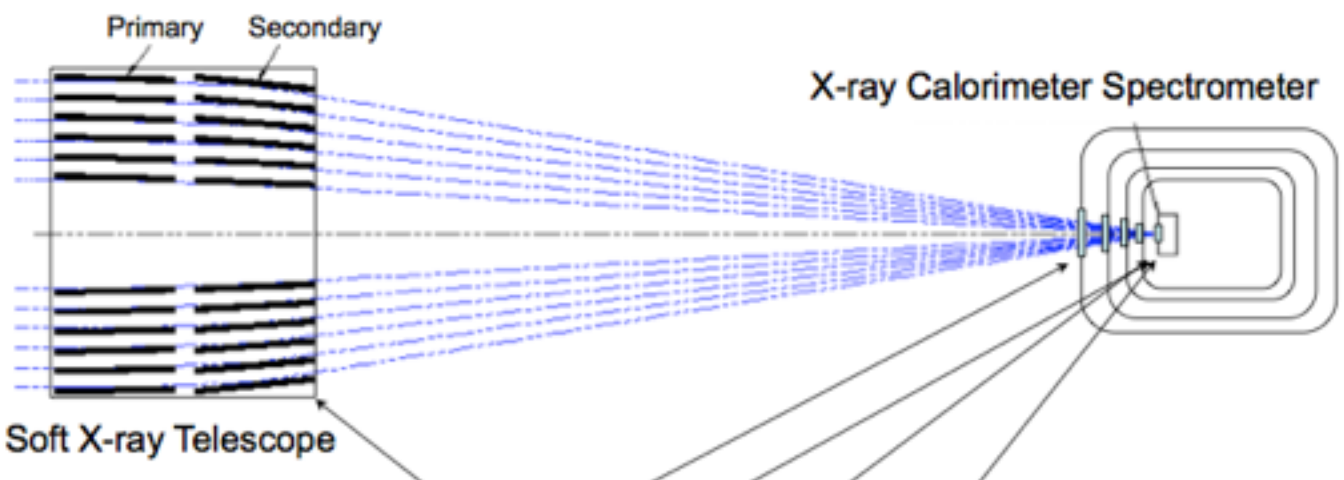


SXS detector assembly

SXS dewar

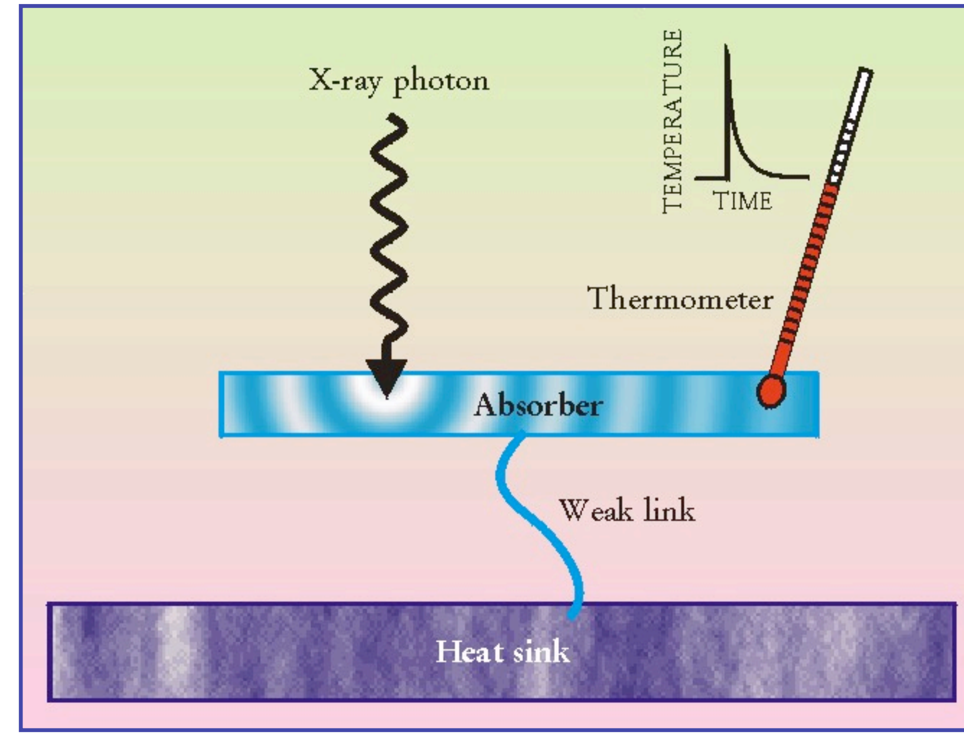
Sumitomo Heavy Industries, Ltd.

Micro-calorimeter and Dewar

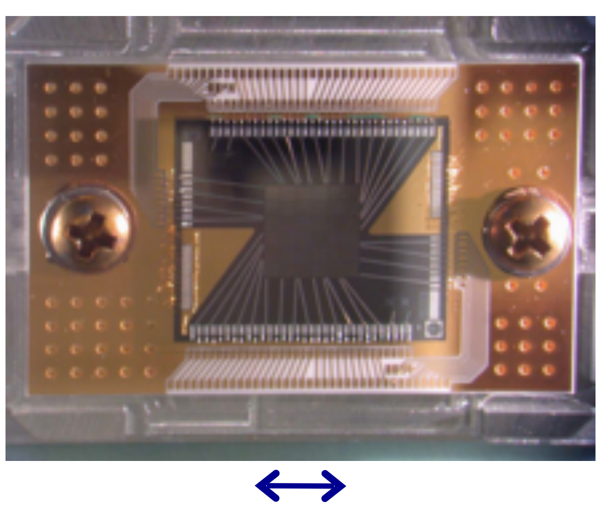


$$A_{eff}(E) = A_{XRT}(E) * t(E) * psf * f_{array} * a(E)$$

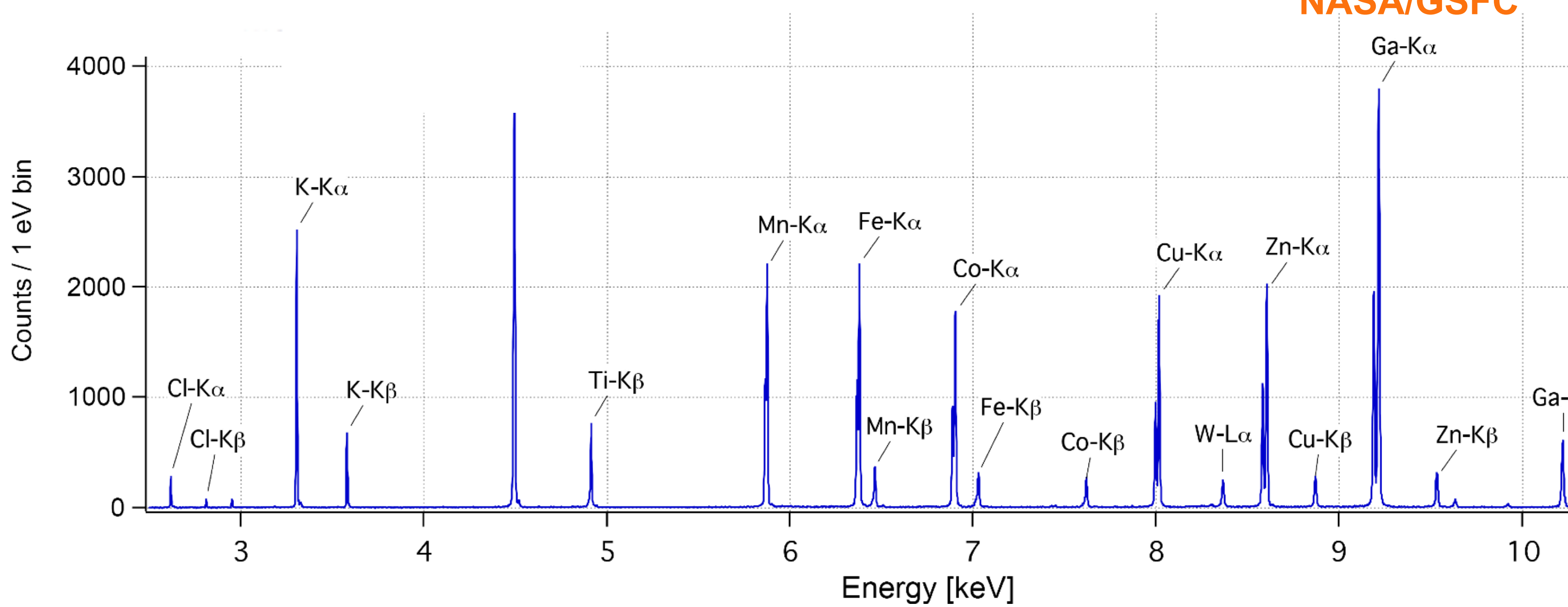
t = transmission of blocking filters
psf = x-ray image point spread function
f_{array} = geometric filling factor of array
a = absorption efficiency of detector



NASA/GSFC



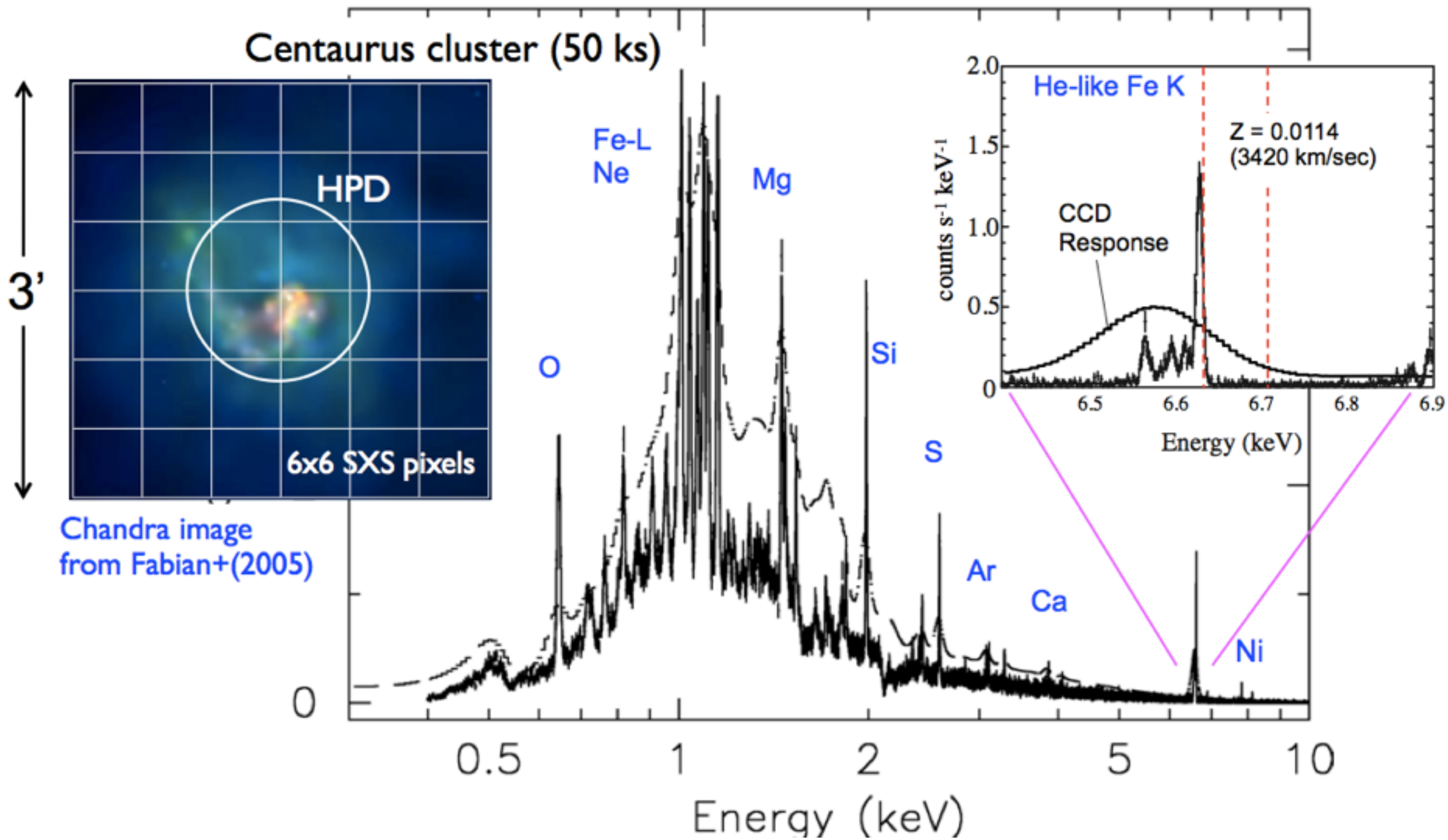
5 mm



(Takahashi et al., 2012, SPIE, 8443, 1)

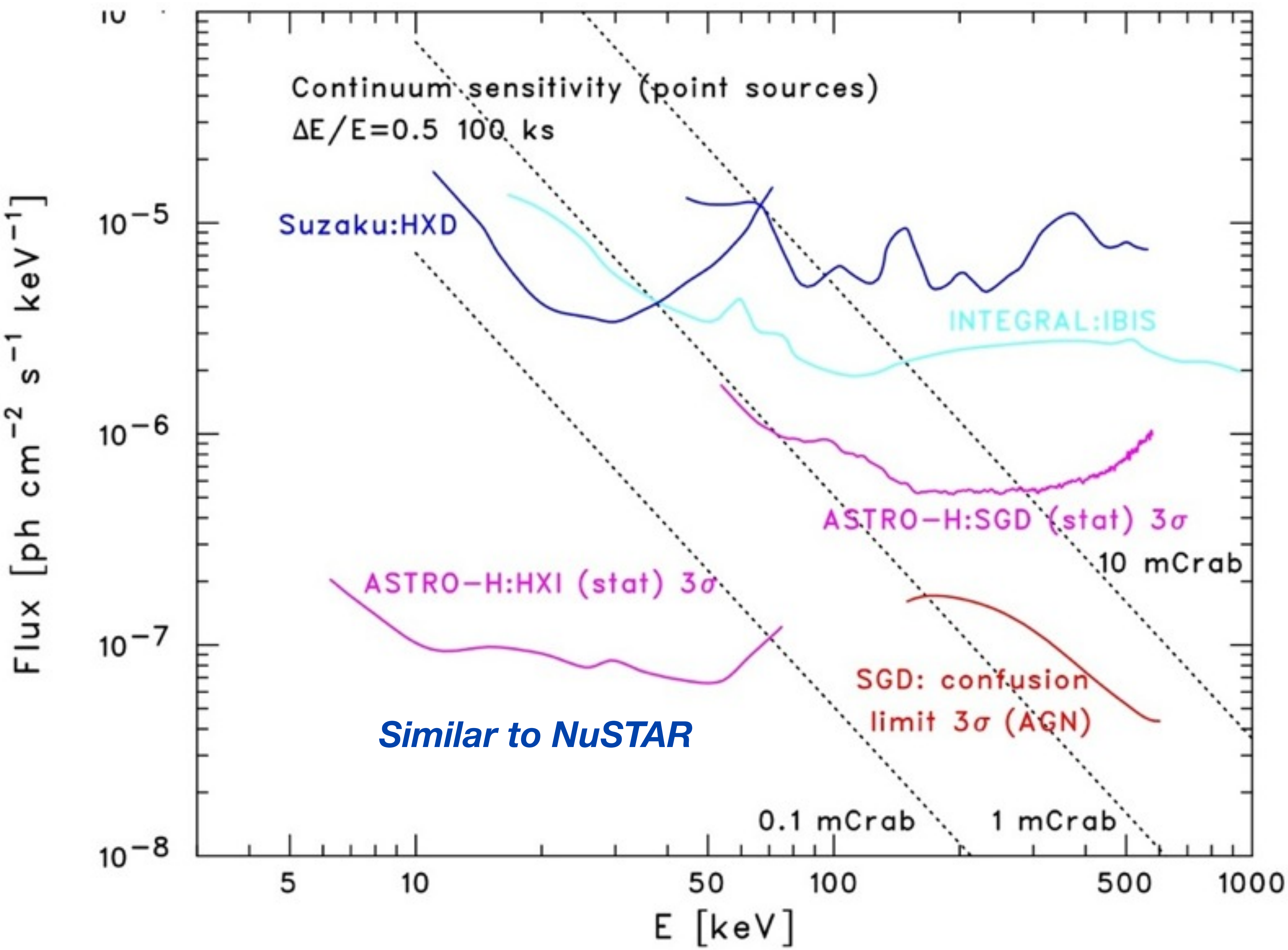
Micro-calorimeter and Dewar

Energy resolution: ΔE ~7eV

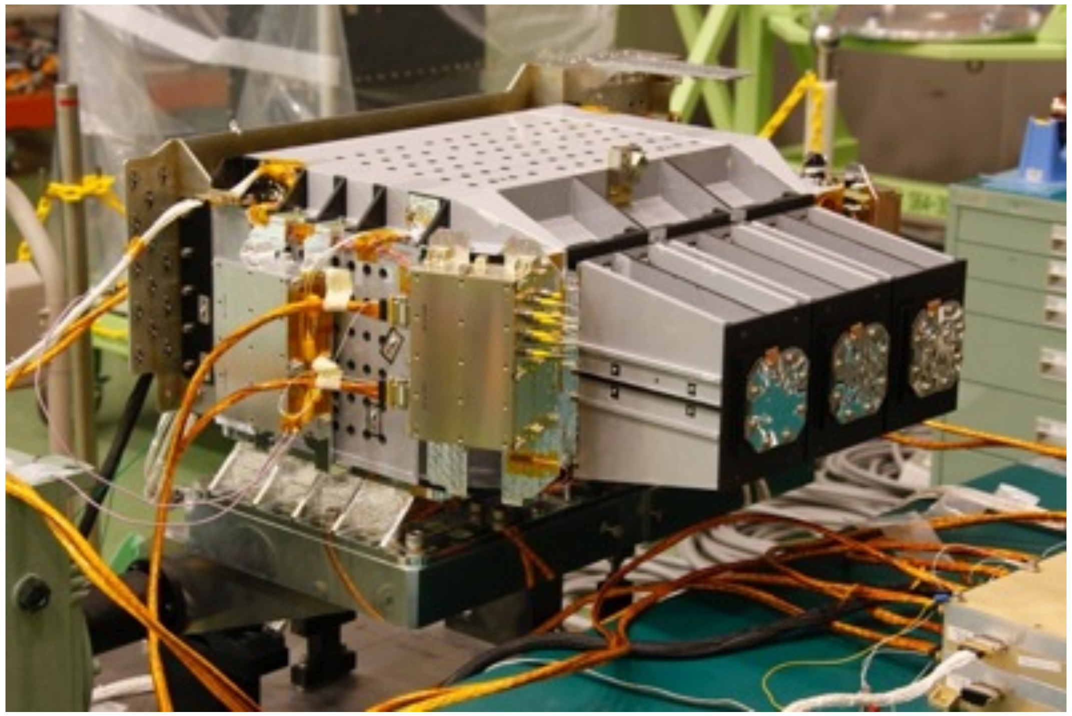


5. Broadband Coverage by ASTRO-H

Vast improvements in Hard X-ray/Soft Gamma-ray



Gamma-ray Detector onboard ASTRO-H

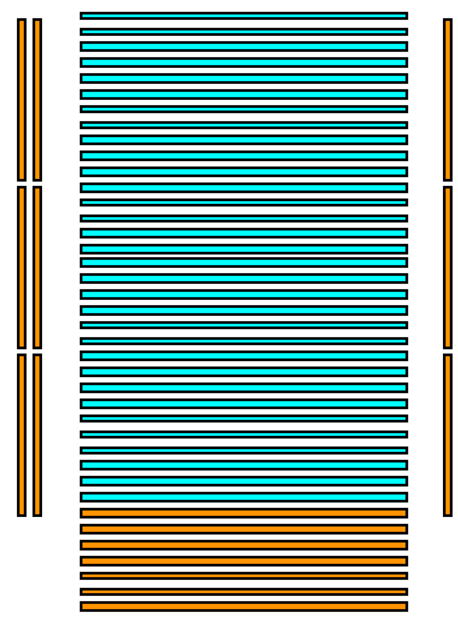


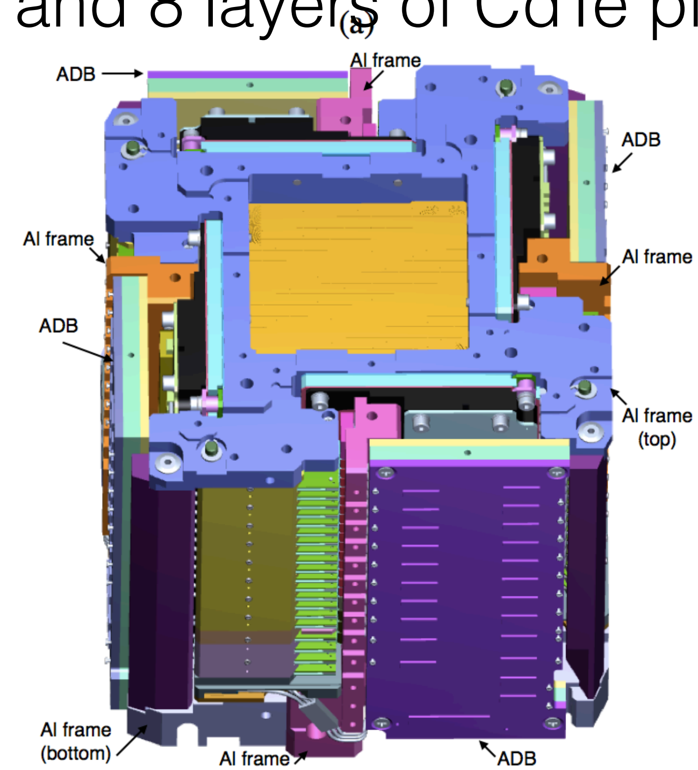
Si/CdTe Compton Camera
installed in Narrow FOV (BGO) Active Shield
Takahashi+(2004), Tajima+(2010),
Watanabe+(2012), Fukazawa+(2014)

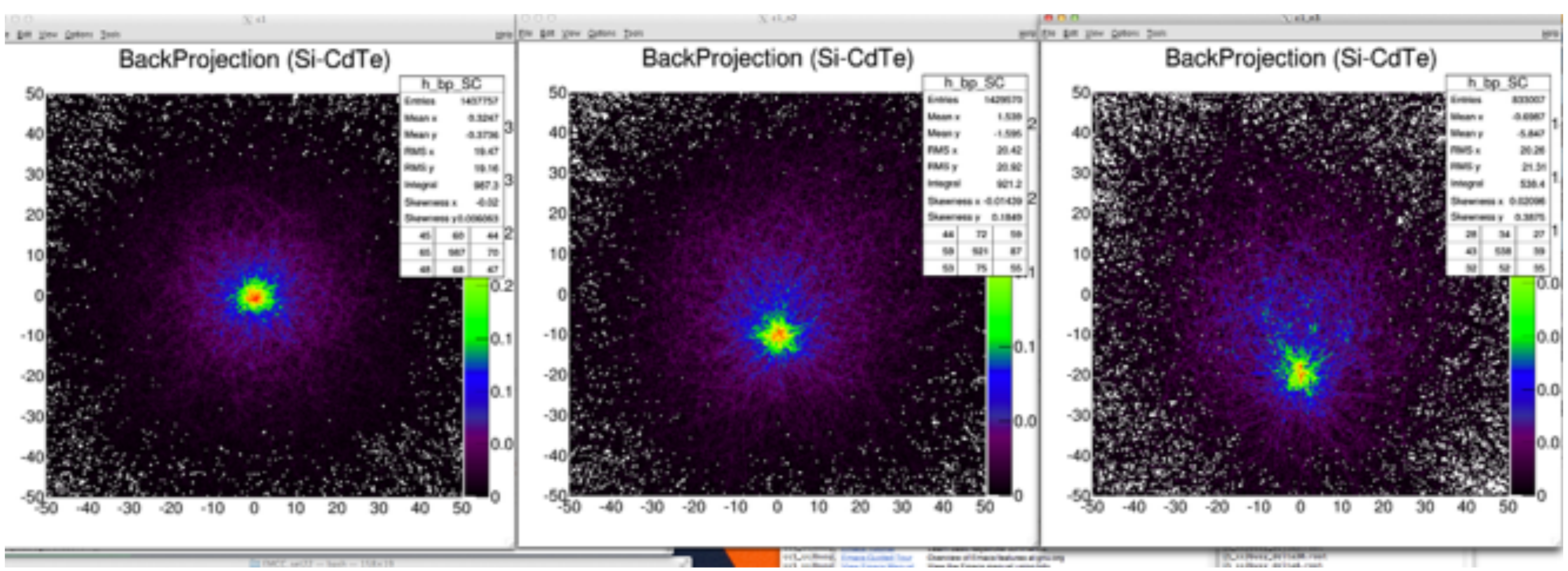
Soft Gamma-ray Detector (4-600 keV)

Si/CdTe Compton Camera

32 layers of Si pixel and 8 layers of CdTe pixel







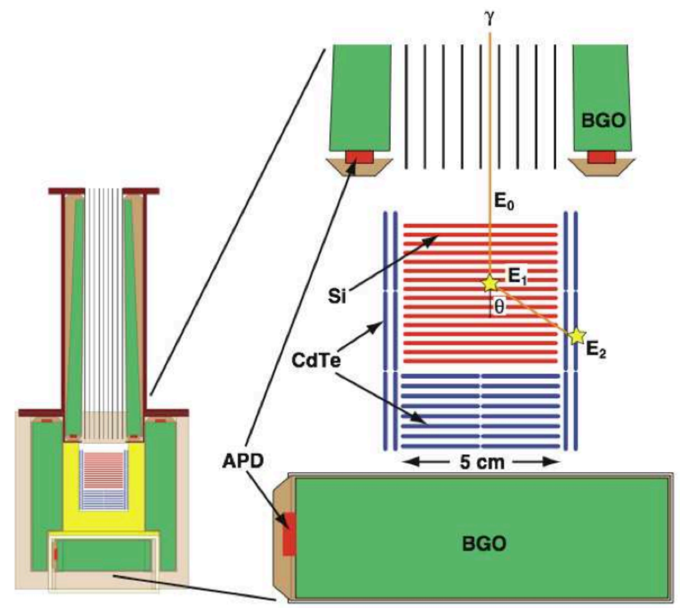
13312 pixels in total are
processed independently
by 208 readout ASICs
for one camera

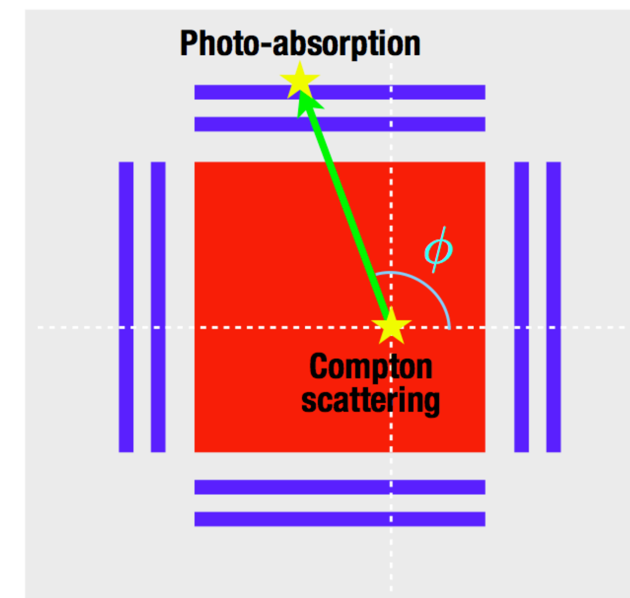
6 Compton Camera
for SGD1 and SGD2

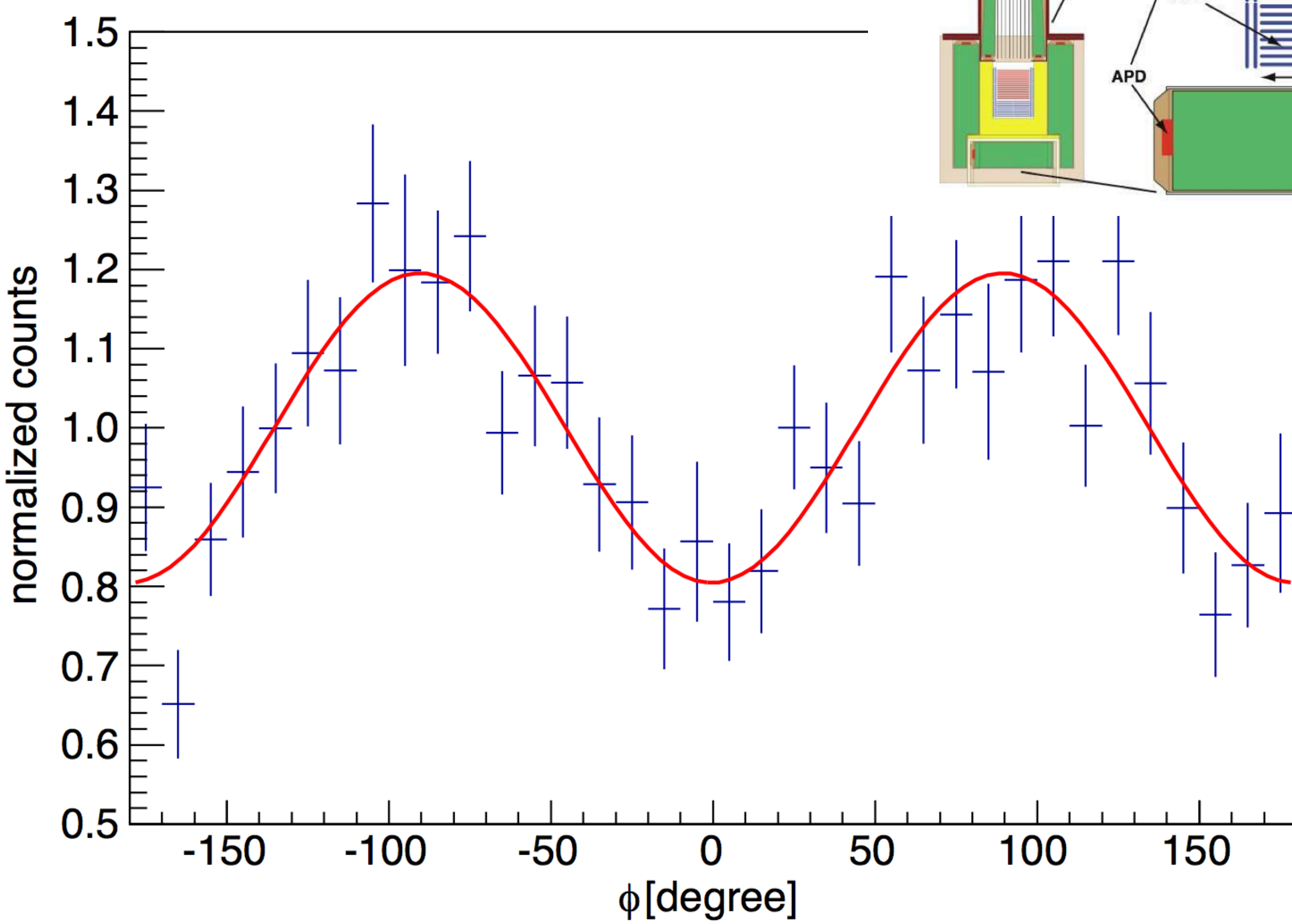
Gamma-ray Detector onboard ASTRO-H

Energy dependent polarization measurement from

Crab Pulsar/Nebula
Microquasars
Blazars







Mrk 501 (Outburst)

60-100 keV energy band

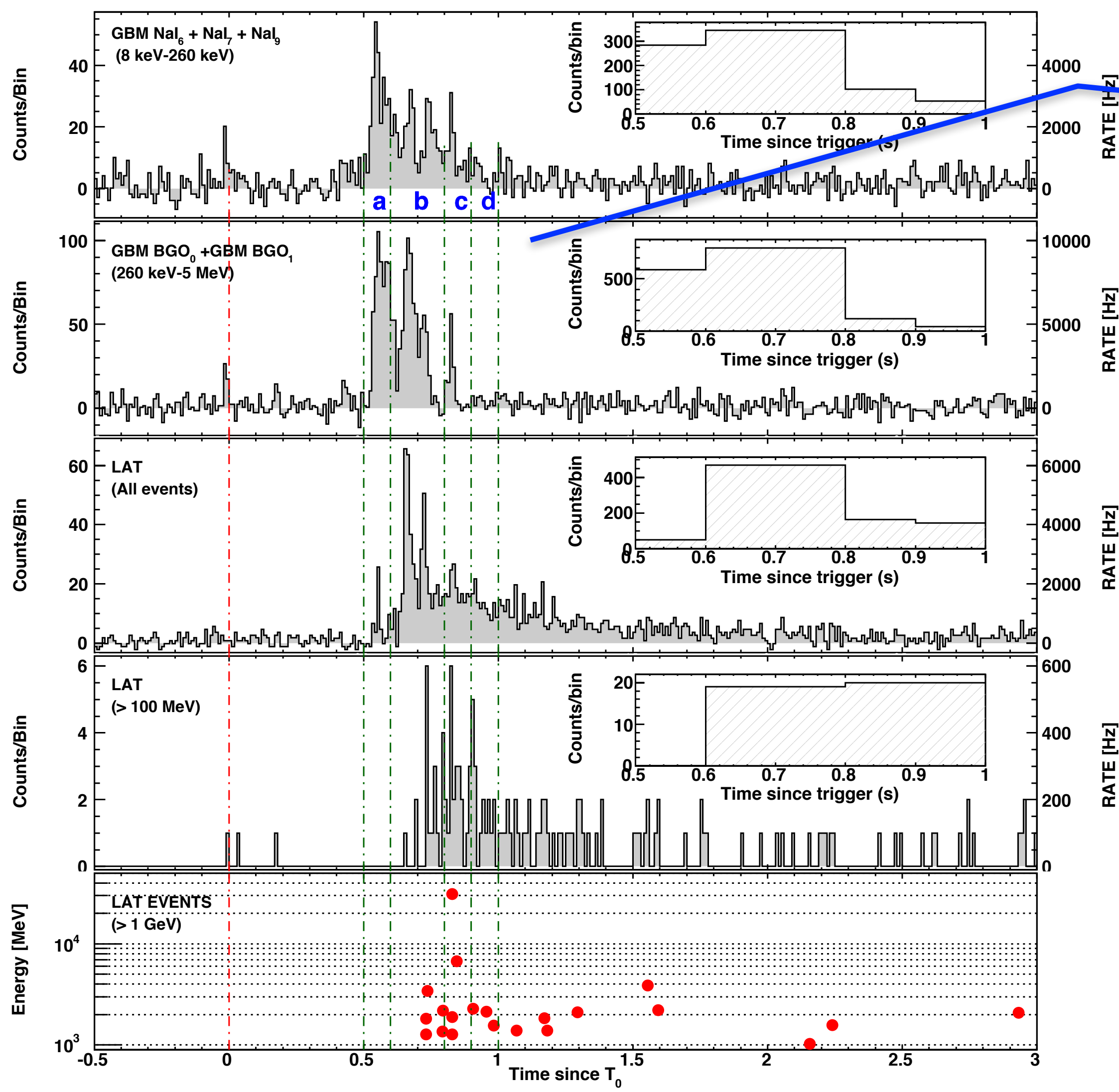
$F_{13\text{-}200keV} = 16 \times 10^{-10}$ erg/s/cm^2

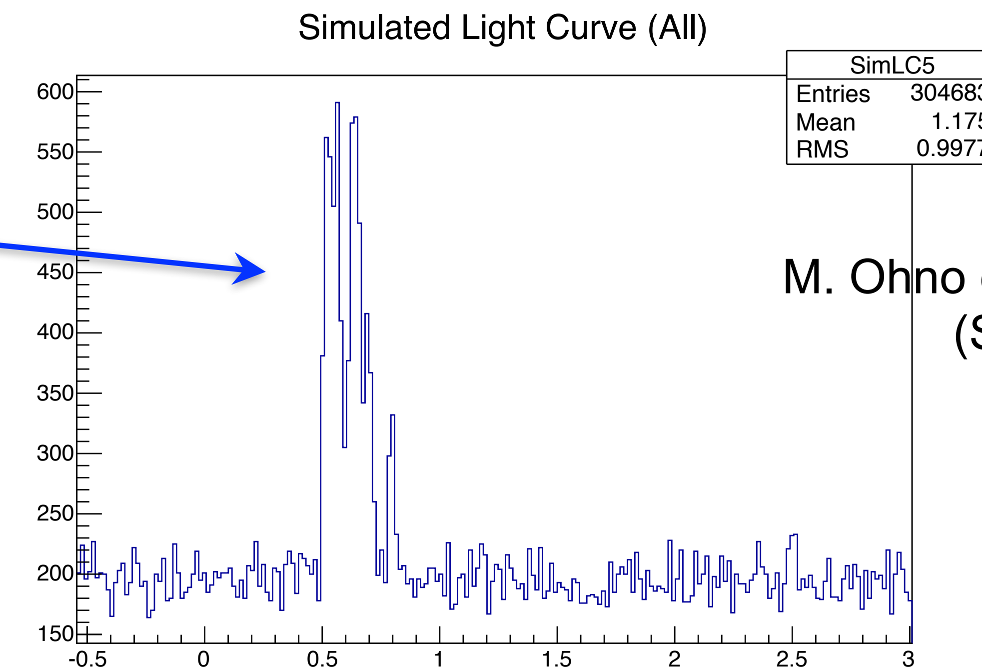
Degree of polarization 30 %

From ASTRO-H White Paper (Broad band Spectroscopy and Polarimetry) L. Stawarz et al.

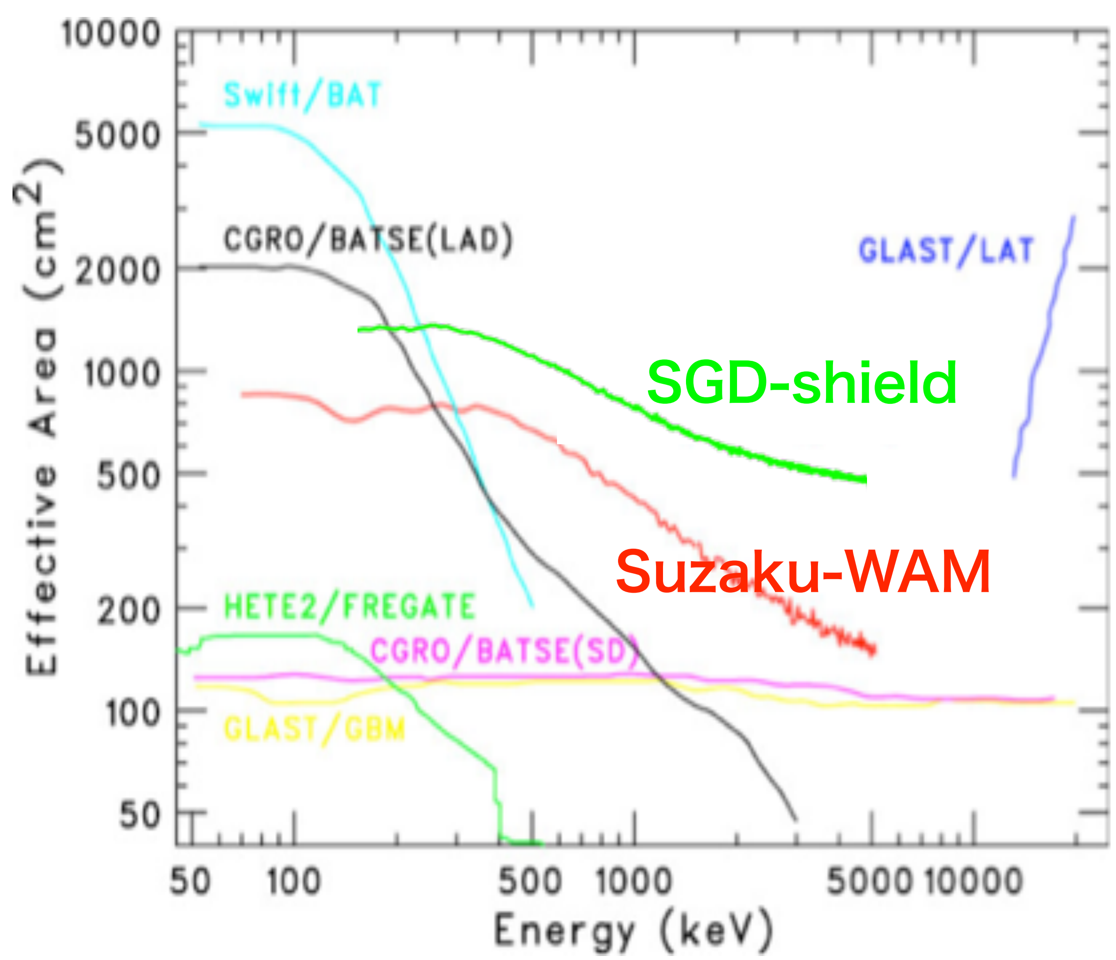
Gamma-ray Detector onboard ASTRO-H

Gamma-ray Burst Detection





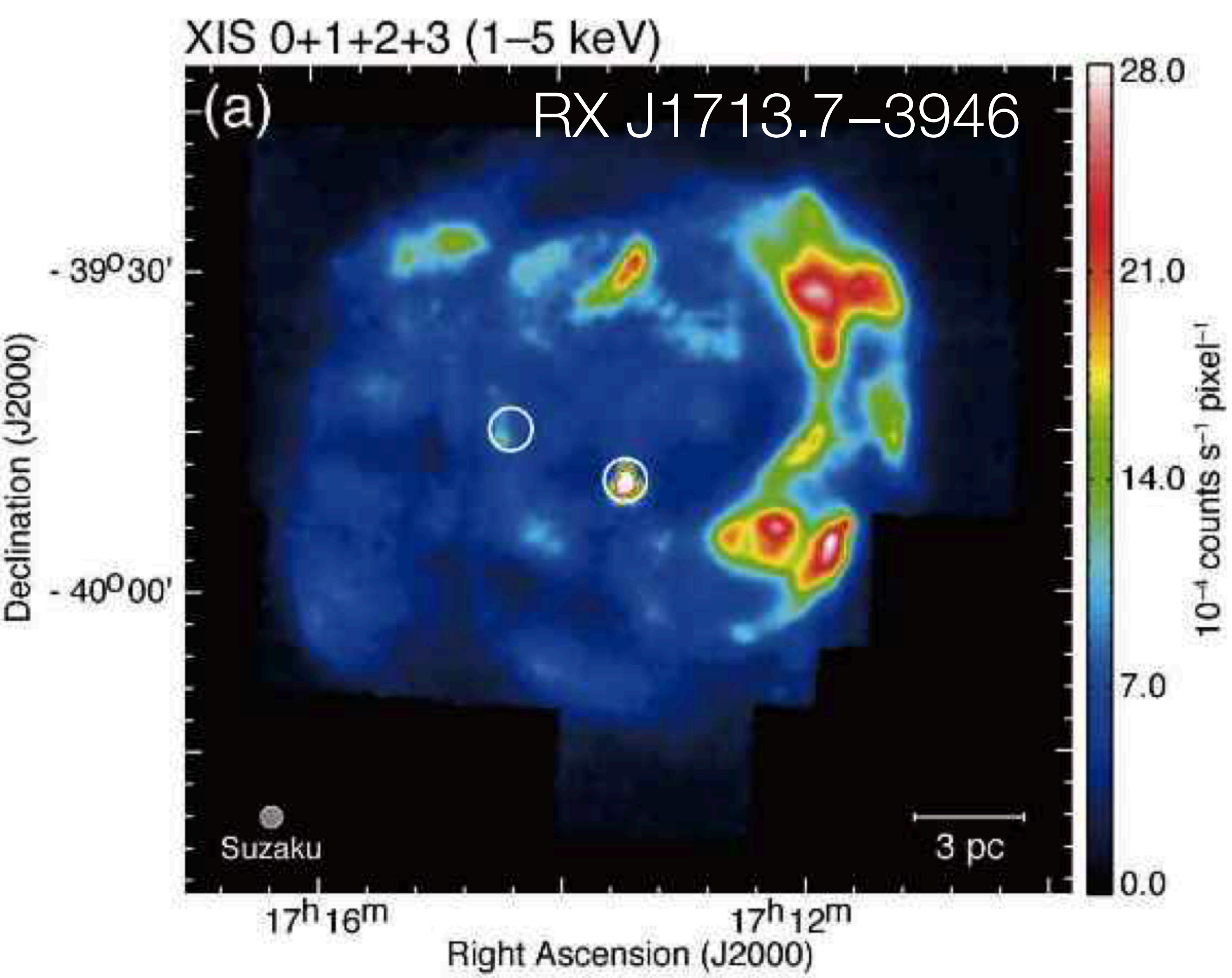
M. Ohno et al.(2014)
(See Poster)



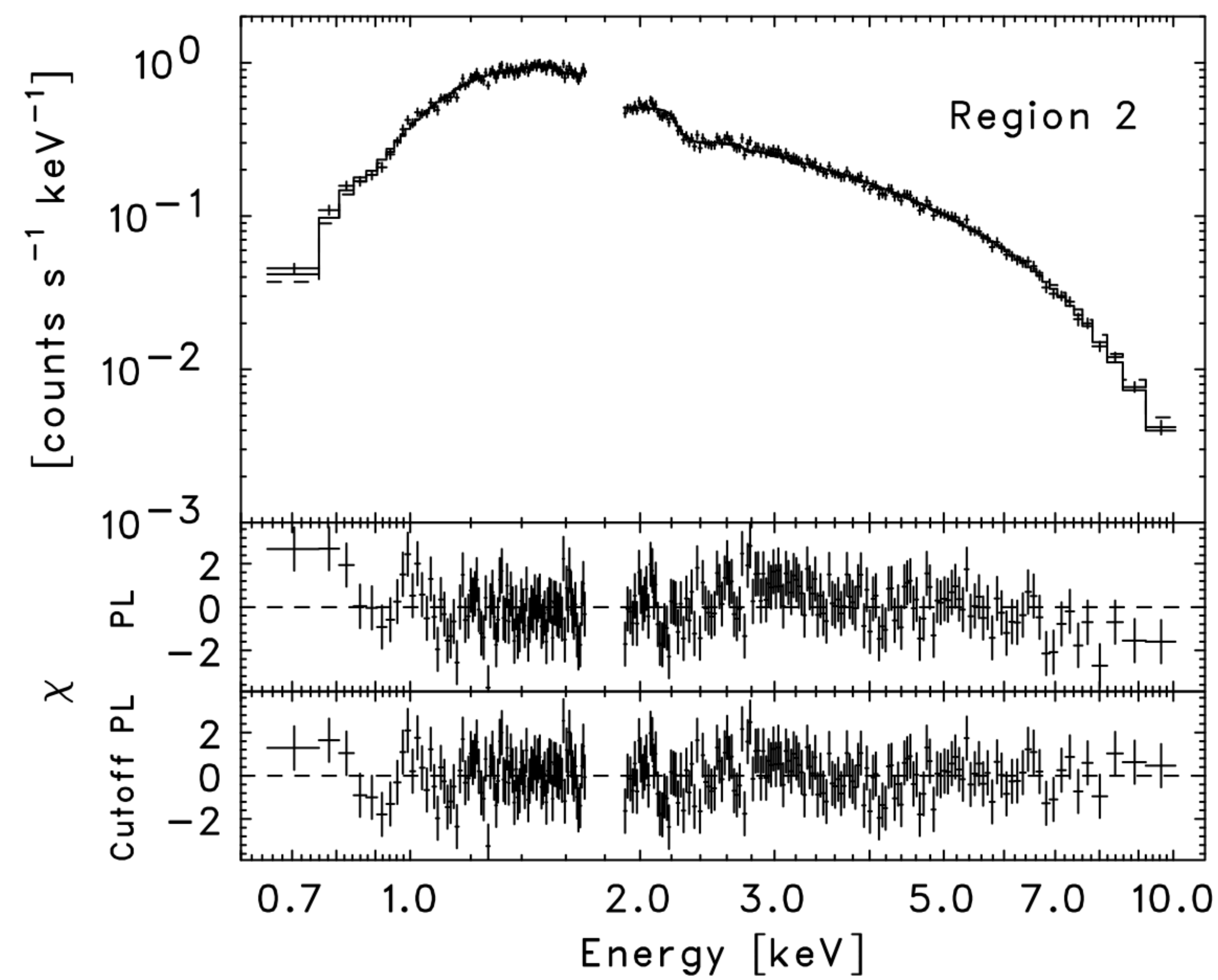
- ➢ASTRO-H SGD-shield could provide complementary dataset to Fermi-GBM
- ➢5~60 % of GRBs can be detected by Fermi and SGD-shield simultaneously (based on Suzaku-Fermi detection rate)

Thermal Emission from Non-thermal SNR

- X-ray thermal emission can be used to estimate the gas density and the fraction of shock energy consumed for heating (important information to study the origin of the Gamma-ray emission)
- Synchrotron X-ray spectrum beyond the cutoff measured with HXI is also important to study maximum energy attainable in the SNR.



Suzaku (Sano+, 2013)



Suzaku (Takahashi+, 2008, Tanaka+, 2008)

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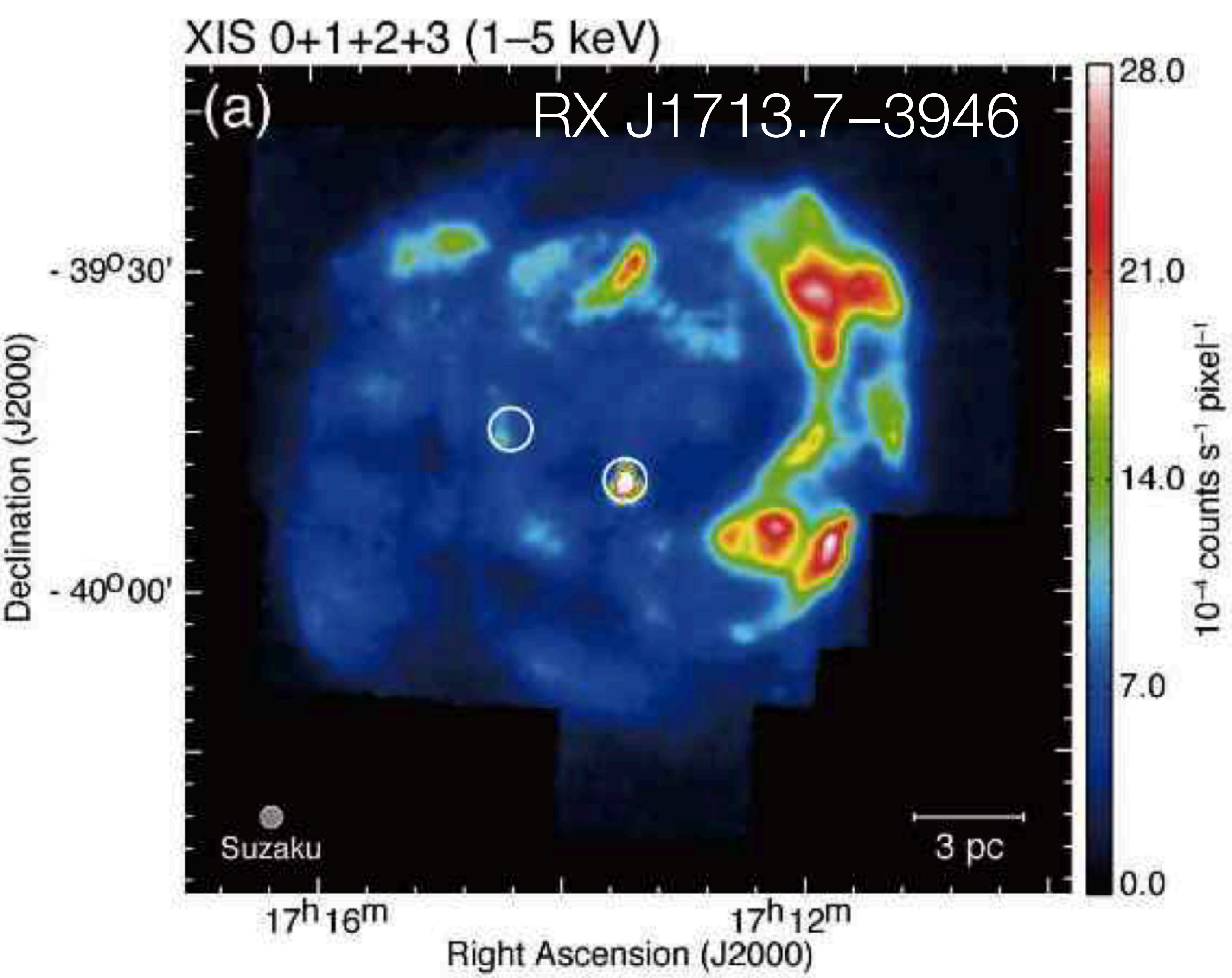
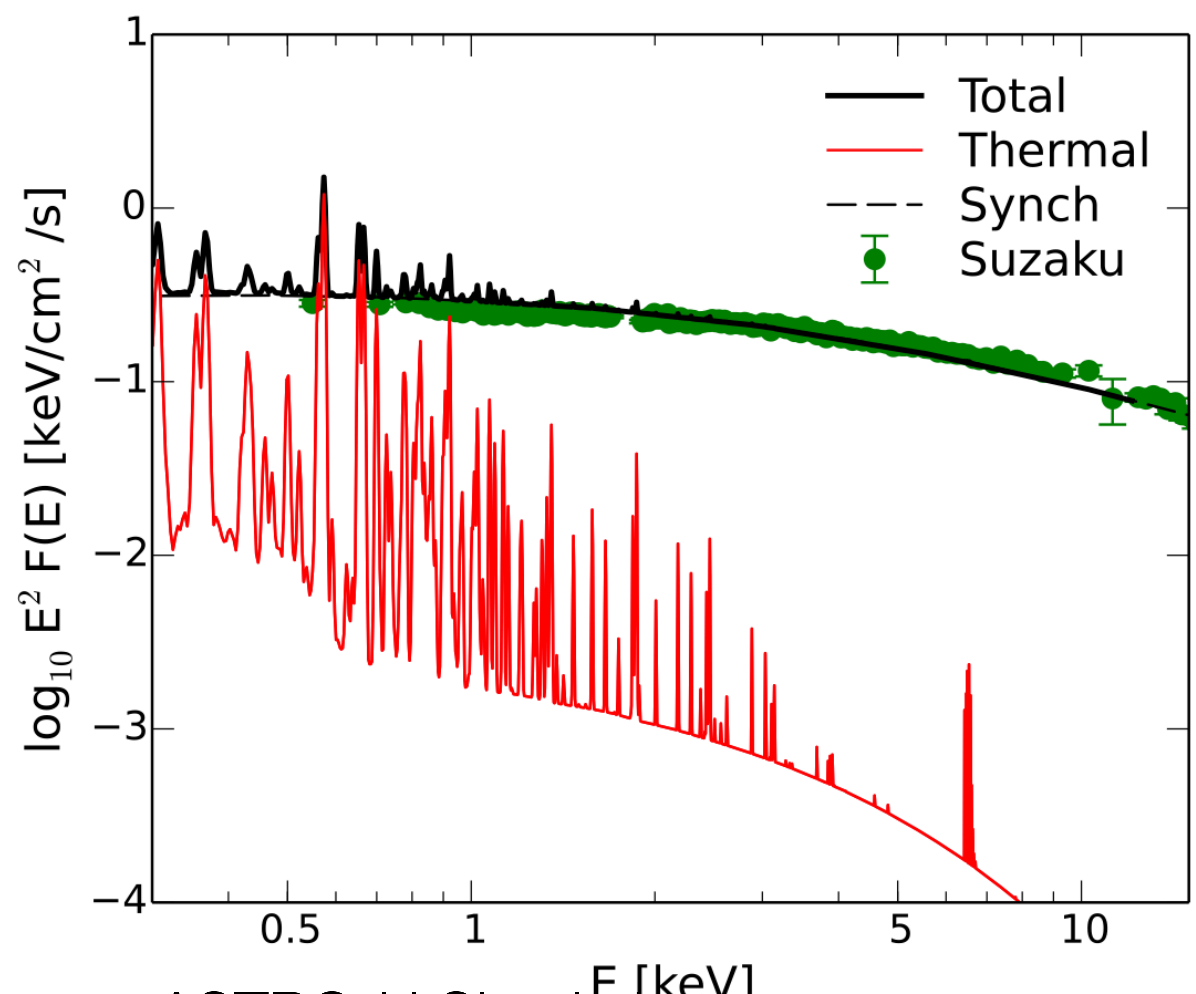
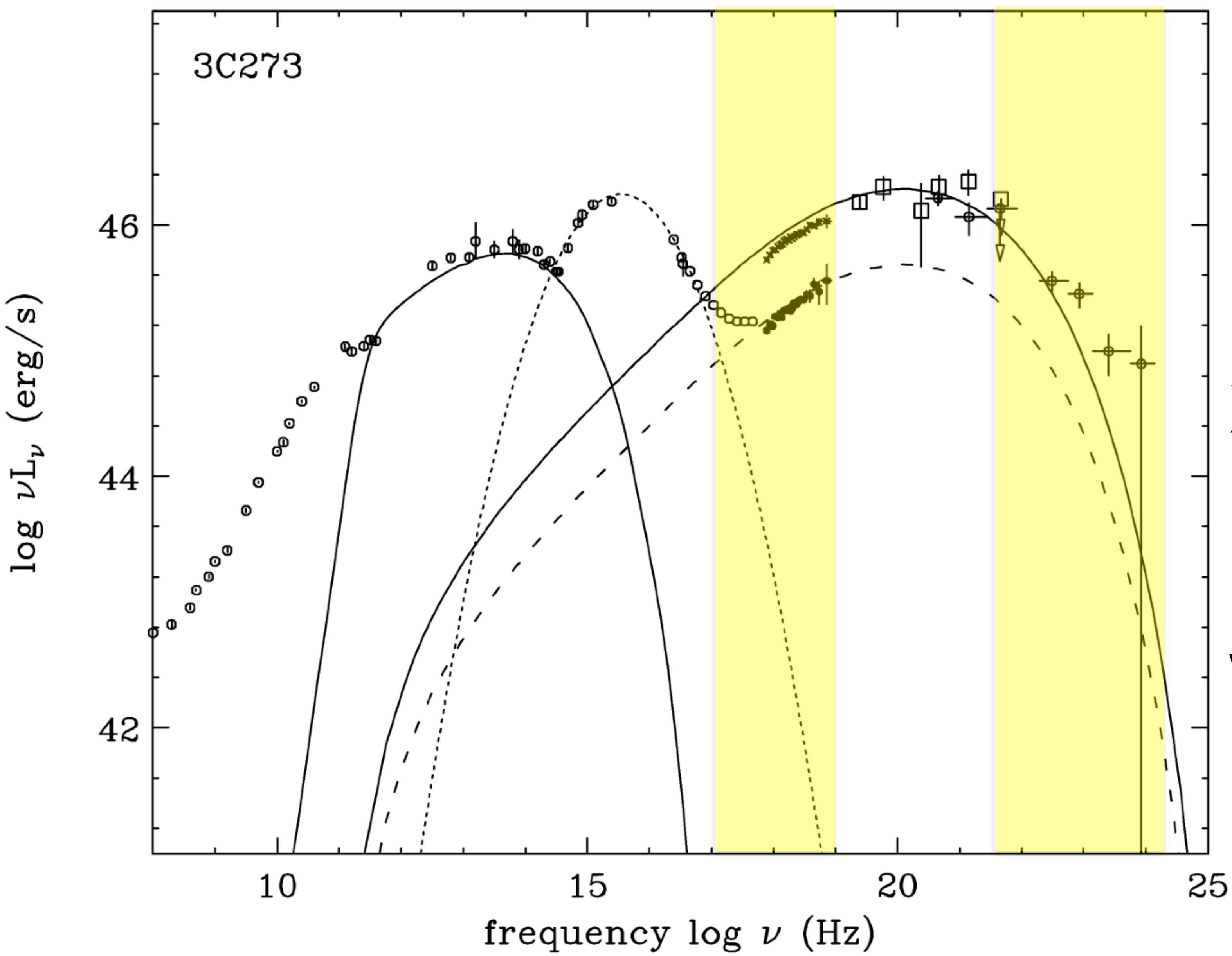


Suzaku (Sano+, 2013)



ASTRO-H Simulation
(WP18, Aharonian, Uchiyama+ (2014))

Jet-Disk Coupling in Active Galaxies



RXTE + EGRET (Kataoka, TT+, 2002)

3C273

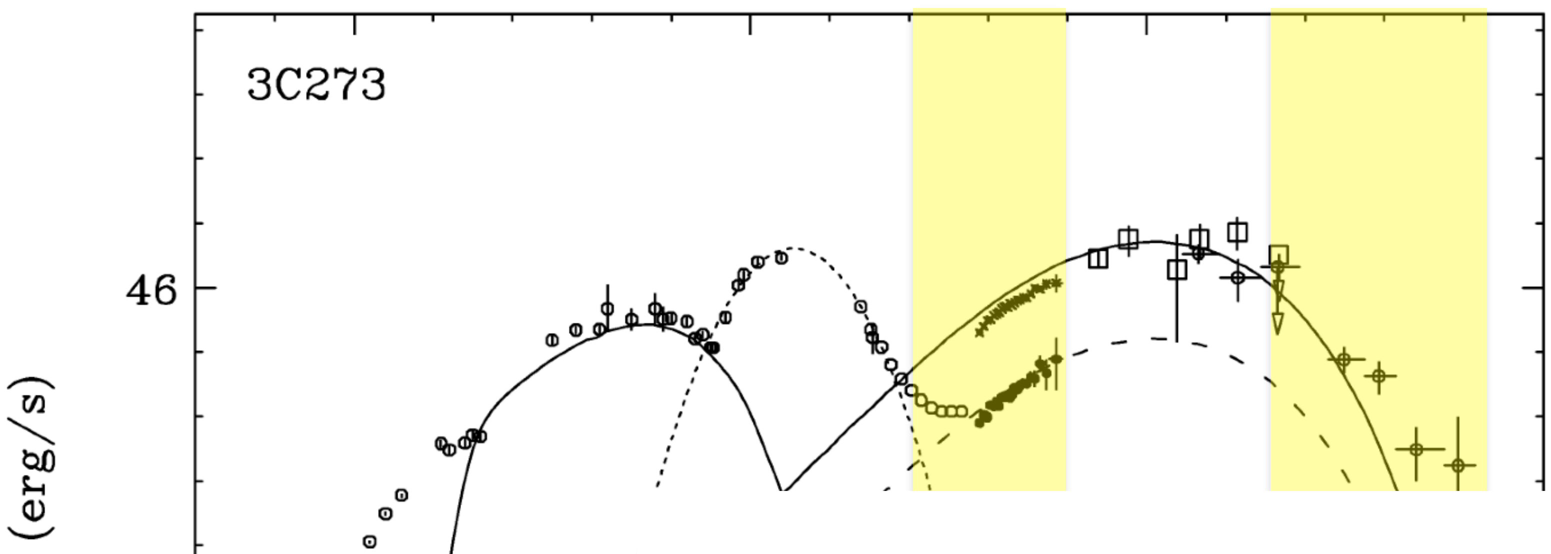
a slightly misaligned FSRQs, observed at intermediate angles of about ~ 10 deg.

X-ray:
Continuum from disk/corona and jets)

Weak fluorescent Fe line (detectable with micro-calormeter)

Jet/Outflow
Launching
Feedback

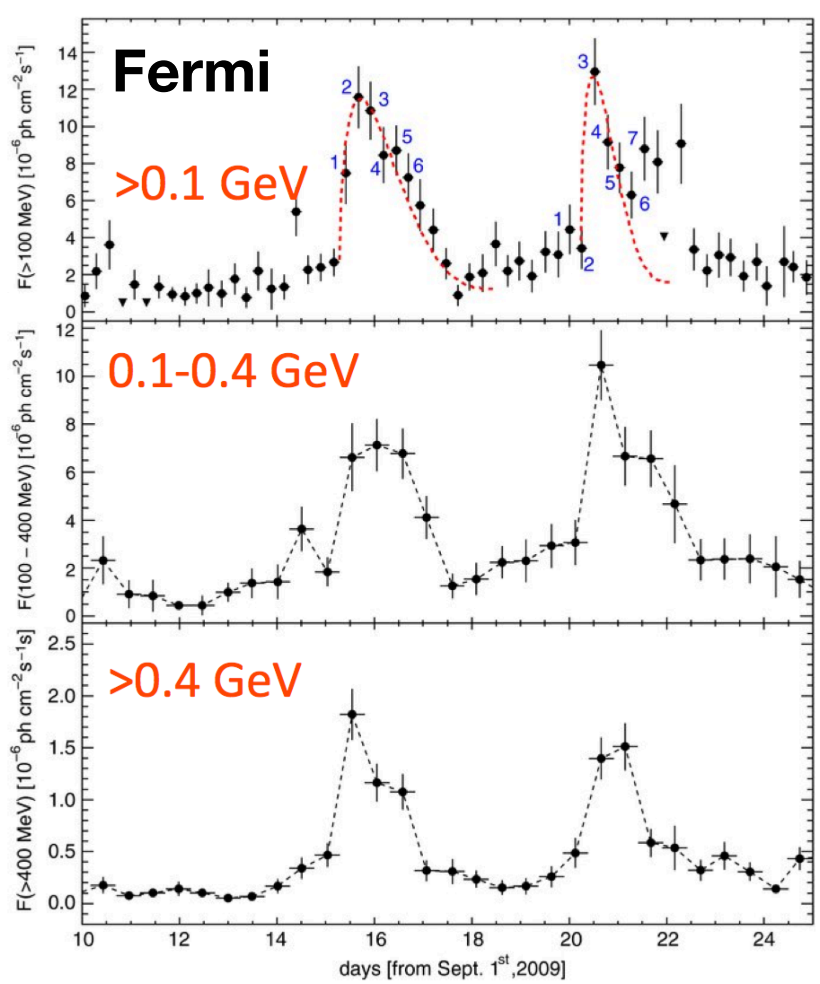
Jet-Disk Coupling in Active Galaxies

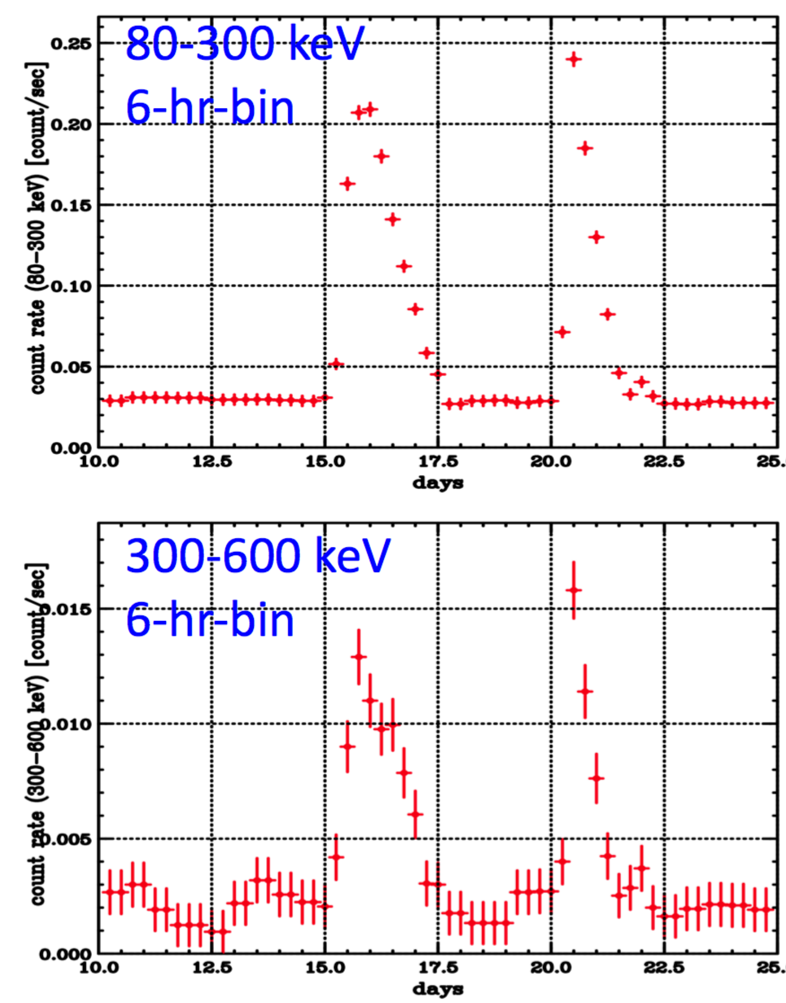


3C273

a slightly misaligned FSRQs, observed at intermediate angles of about ~ 10 deg.

ASTRO-H WP19
(Lukasz, Paolo et al.)



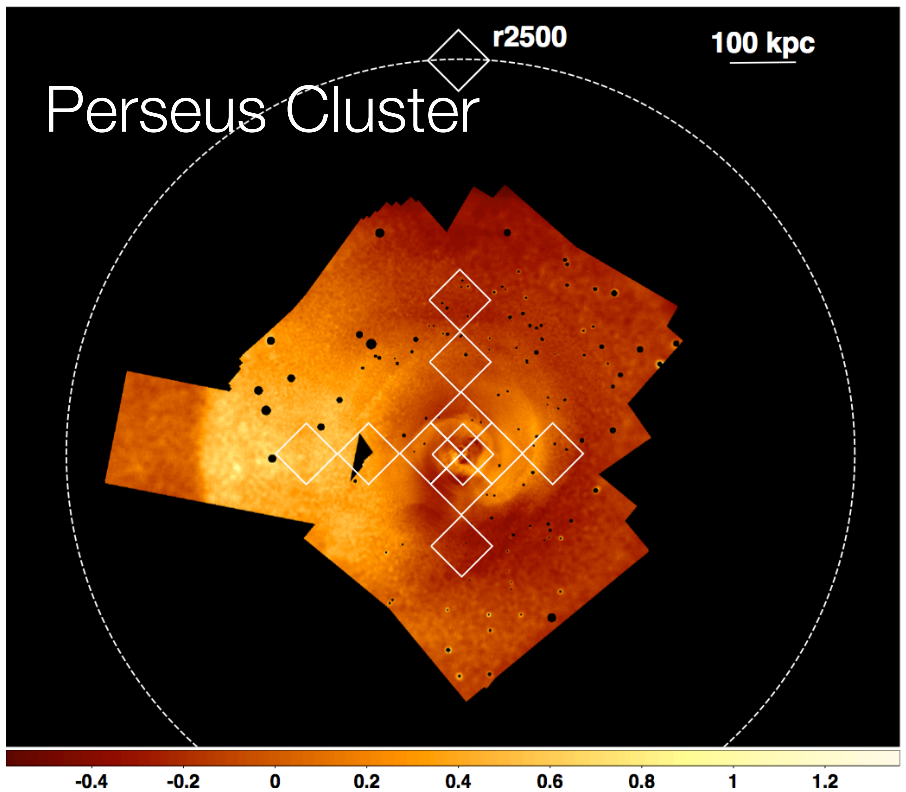


SGD simulation

Abdo et al. 2010

Jet/Outflow
Launching
Feedback

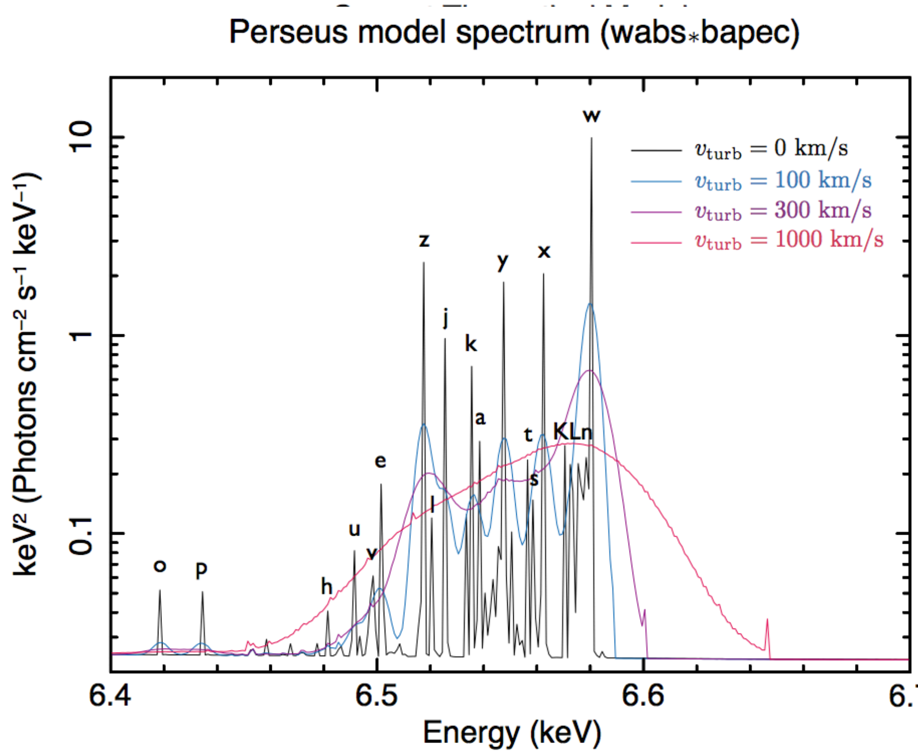
Turbulent and bulk motions in Cluster of Galaxies

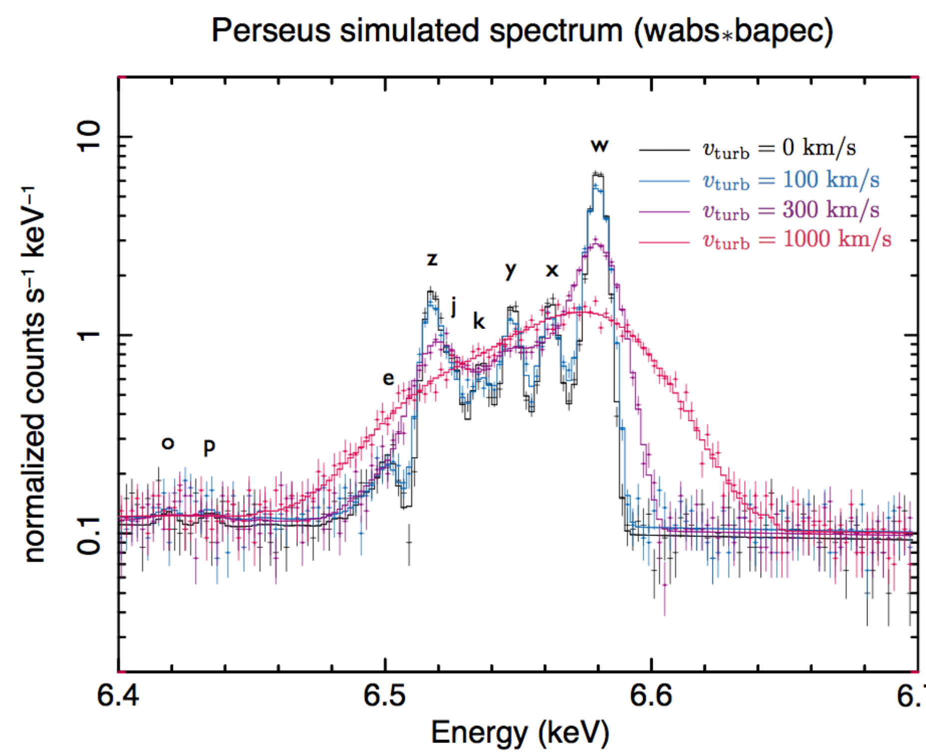


From Merging Clusters, ASTRO-H can obtain dynamical information about the ICM from line shifts, widths

First ever probe of:

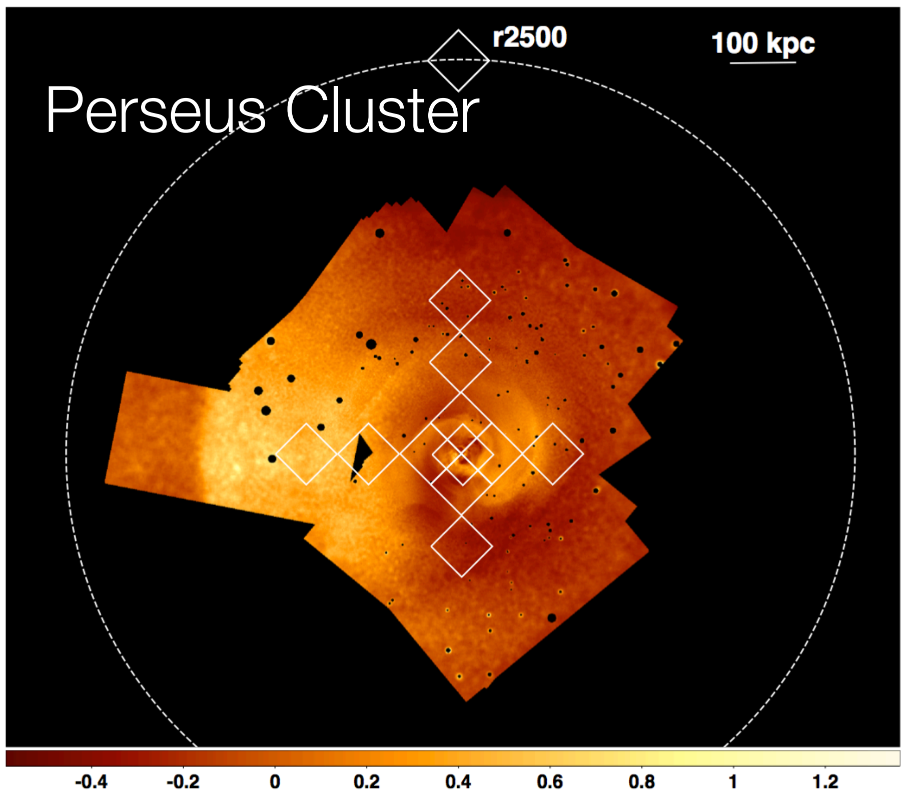
- plasma viscosity
- turbulent pressure support
- merger dynamics
- motions induced by AGN feedback

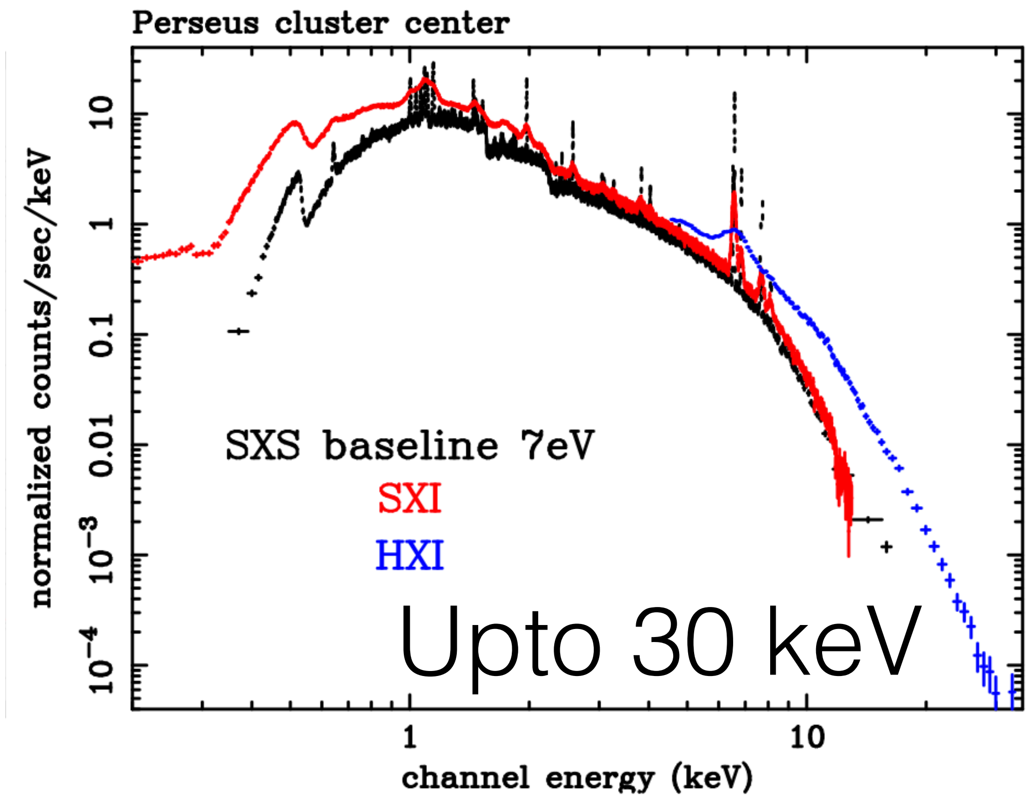


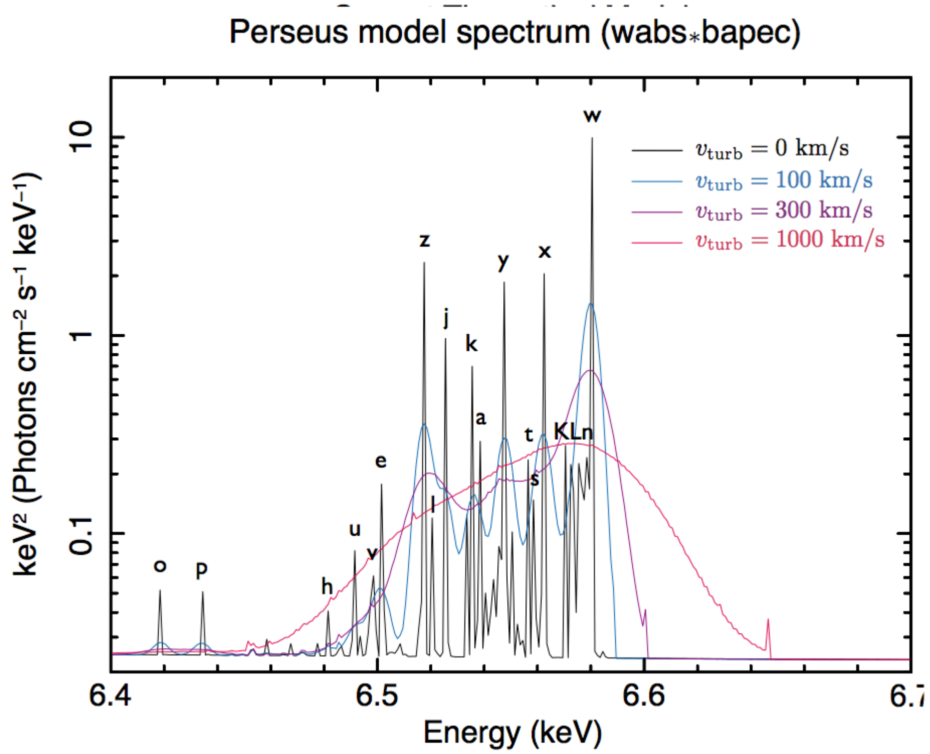


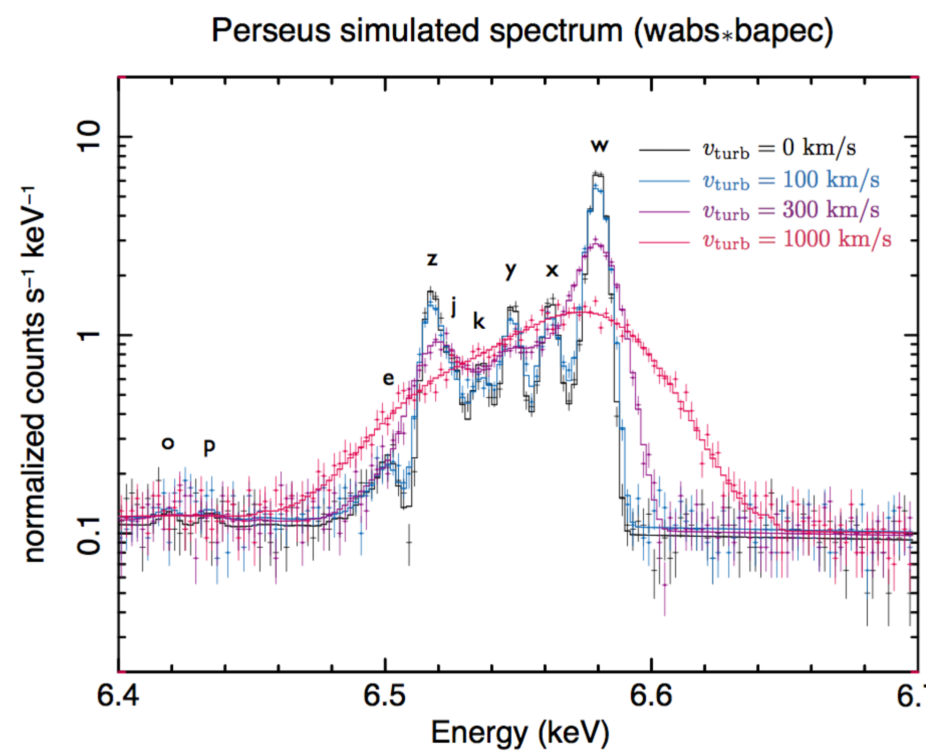
From ASTRO-H White Paper (Cluster related science) S. Allen, T. Kitayama, M. Markevitch et al.

Turbulent and bulk motions in Cluster of Galaxies









From ASTRO-H White Paper (Cluster related science) S. Allen, T. Kitayama, M. Markevitch et al.

Dark Matter Search (Sterile neutrino?)

DIRECT DETECTION OF WARM DARK MATTER IN THE X-RAY

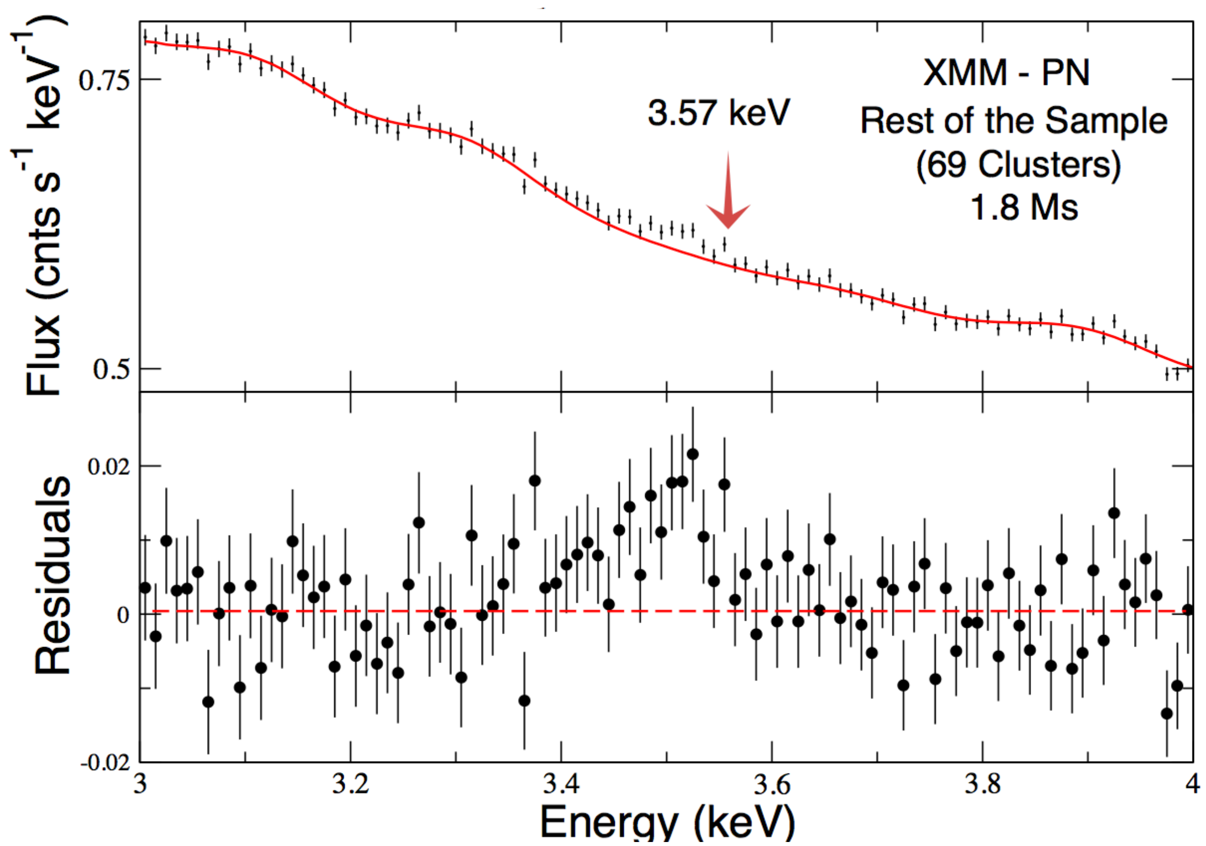
Kevork Abazajian,[1] George M. Fuller,[1] and Wallace H. Tucker[1,2]

Received 2001 May 31; accepted 2001 July 31

?

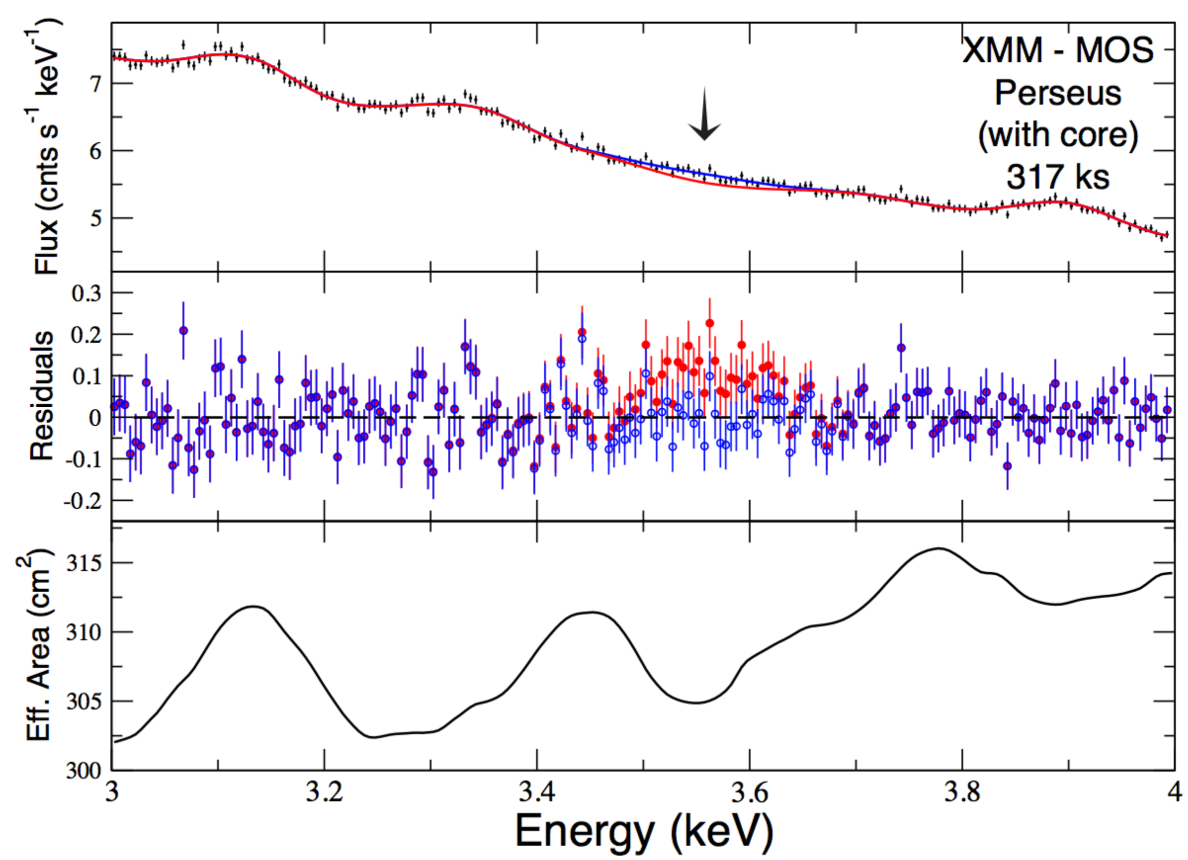
DETECTION OF AN UNIDENTIFIED EMISSION LINE IN THE STACKED X-RAY SPECTRUM OF GALAXY CLUSTERS

Esra Bulbul[1,2], Maxim Markevitch[2], Adam Foster[1], Randall K. Smith[1] Michael Loewenstein[2], and Scott W. Randall[1]



68 Cluster of Galaxies

(stacked analysis)



Perseus Cluster

Dark Matter Search

ASTRO-H Simulation (Perseus Cluster) 1Msec

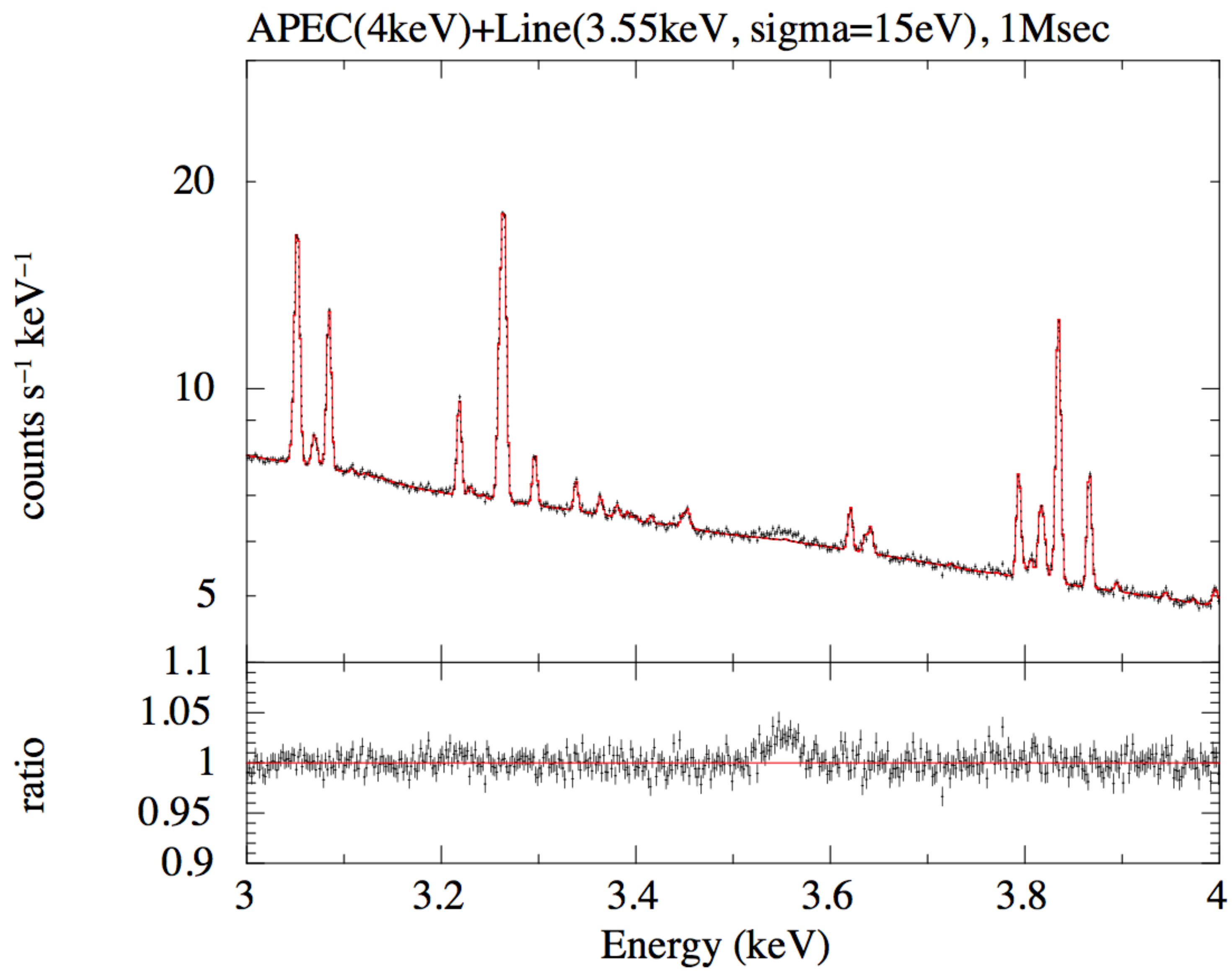


Figure 48: Simulated spectra of the Perseus core at $z = 0.0178$ with (black) and without (red) a dark matter line at 3.55 keV after an exposure of 1 Msec by SXS. For the dark matter line, we adopt the flux 3×10^{-5} ph s^{-1} cm^{-2} within the field-of-view of SXS from Table 5 of Bulbul et al. (2014) and $W_{dm} = 35$ eV corresponding to the velocity dispersion $\sigma_{dm} = 1300$ km s^{-1}. For the ICM thermal emission, we assume $kT = 4$ keV and $Z = 0.7$ solar with no turbulent broadening.

ASTRO-H WP11, Kitayama, Tamura, Allen+

2012 Aug (TTM)

2013 May (Acoustic Test)


2014 April (EIC/MIC)


2014 June (EIC/MIC)


11. Summary

1) ASTRO-H is scheduled to fly in 2015_{JFY}. Wide-band and high-resolution observations will provide exciting data sets for many science fields

2) ASTRO-H will enable direct observations of the dynamical evolution of stars, galaxies and clusters; powered by micro-calorimeters.

3) Synergy with other new X-ray (NuSTAR, eROSITA, Astrosat etc.) missions and other wavelength (CTA, Fermi, LOFAR, ALMA, JWST, GW ...) observatories should be important

2014 Nov - 2015 Oct : Final Integration and Testing
ASTRO-H Science Cases (White Papers) will be available soon from astro-ph.

ASTRO-H International Team

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NASA
esa
KIPAC
CSA ASC
SRON
Netherlands Institute for Space Research
RIKEN
東京大学
THE UNIVERSITY OF TOKYO
京都大学
KYOTO UNIVERSITY
CfA
Irfu
cea
Yale
THE UNIVERSITY of WISCONSIN MADISON
JOHNS HOPKINS UNIVERSITY
名古屋大学
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立教大学
首都大学東京
日本大学
芝浦工業大学
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東京工業大学
Tokyo Institute of Technology
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SPACE TELESCOPE SCIENCE INSTITUTE
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KOBE UNIVERSITY
中央大学
OSAKA UNIVERSITY
大阪大学
金沢大学
KANAZAWA
工学院大学
KOGAKUIN UNIVERSITY
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MIT
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NIMS
UNIVERSITY OF WATERLOO
Lawrence Livermore National Laboratory
三菱重工
NEC
NIPPI
住友重機械
OHB
Noqsi Aerospace, ltd

ASTRO-H International Team

Science Task Force

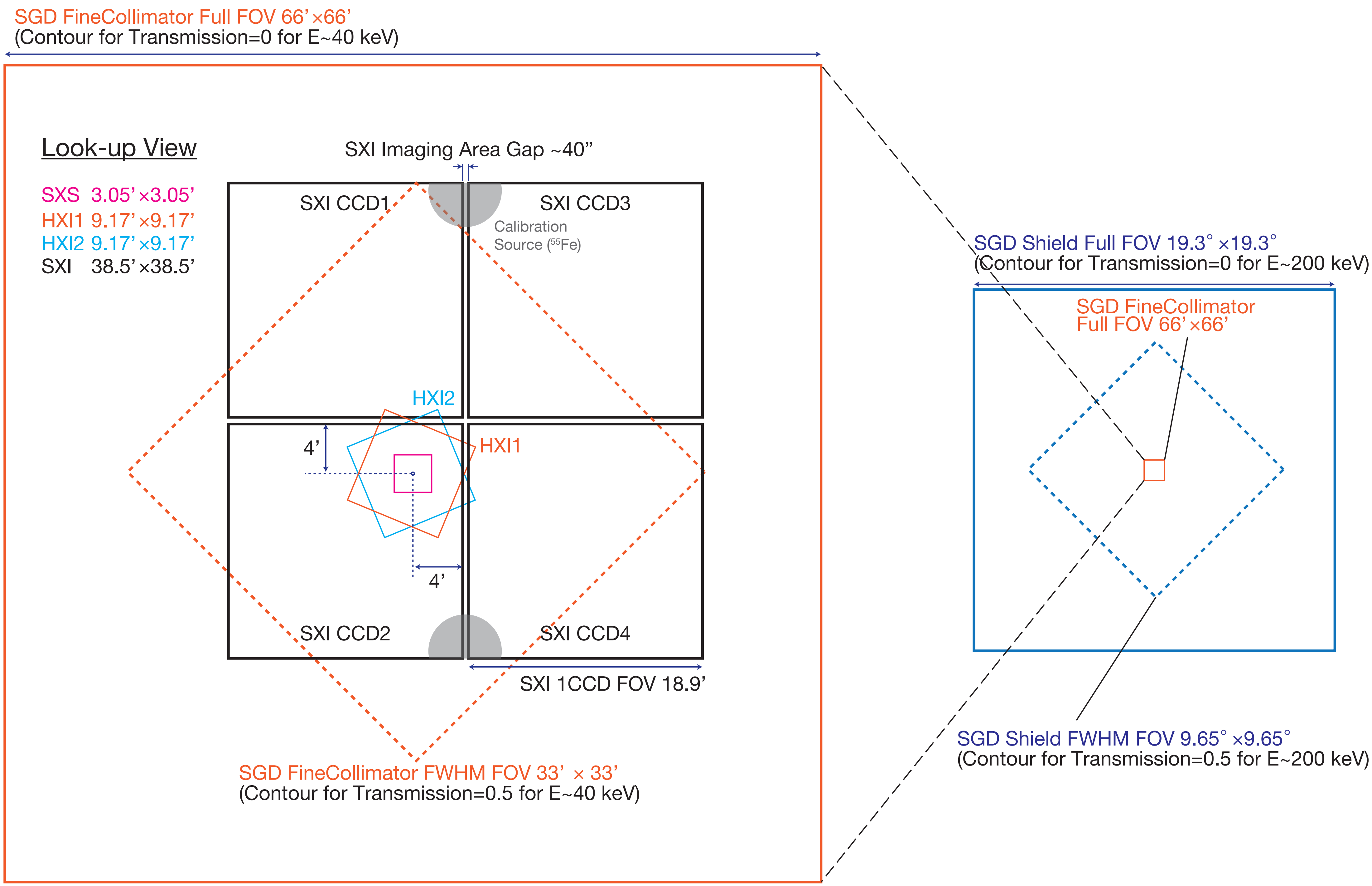
Stars
White dwarfs
Low-mass binaries
High-mass binaries and magnetars
Black hole spin and accretion
Young SNRs
Old SNRs and PWN
Galactic center
ISM and galaxies
Cluster-related sciences
AGN reflection
AGN winds
New spectral features
Shocks and acceleration
Broad-band and polarization
High-z chemical evolution

A. Appendix

Table 2. Key parameters of the ASTRO-H payload

Parameter	Hard X-ray Imager (HXI)	Soft X-ray Spectrometer (SXS)	Soft X-ray Imager (SXI)	Soft γ-ray Detector (SGD)
Detector technology	Si/CdTe cross-strips	micro calorimeter	X-ray CCD	Si/CdTe Compton Camera
Focal length	12 m	5.6 m	5.6 m	–
Effective area	300 cm^2@30 keV	210 cm^2@6 keV 160 cm^2 @ 1 keV	360 cm^2@6 keV	>20 cm^2@100 keV Compton Mode
Energy range	5 –80 keV	0.3 – 12 keV	0.4 – 12 keV	40 – 600 keV
Energy resolution (FWHM)	2 keV (@60 keV)	$<$ 7 eV (@6 keV)	$<$ 200 eV (@6 keV)	$<$ 4 keV (@60 keV)
Angular resolution	<1.7 arcmin	<1.3 arcmin	<1.3 arcmin	–
Effective Field of View	$\sim 9 \times 9$ arcmin^2	$\sim 3 \times 3$ arcmin^2	$\sim 38 \times 38$ arcmin^2	0.6×0.6 deg^2 ($<$ 150 keV)
Time resolution	25.6 μs	5 μs	4 sec/0.1 sec	25.6 μs
Operating temperature	−20°C	50 mK	−120°C	−20°C

A. Appendix



The center of the SGD FOV is designed to match the SXS FOV center.

File Revision: 20141010_0951SN

Resolving power

(Takahashi et al., 2012, SPIE, 8443, 1)