X線観測とCTA

Multiwavelength Astronomy and CTA: X-rays

高橋忠幸

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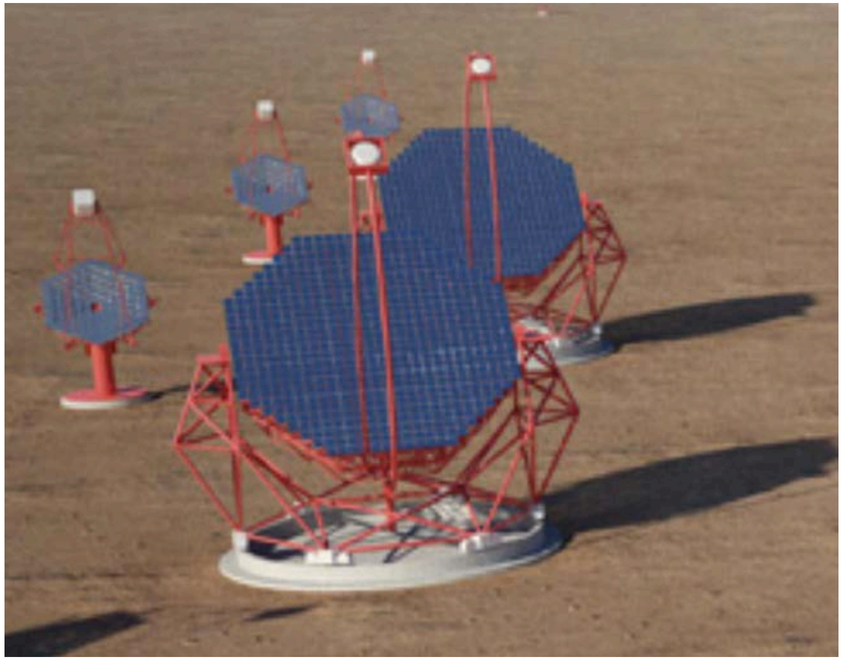
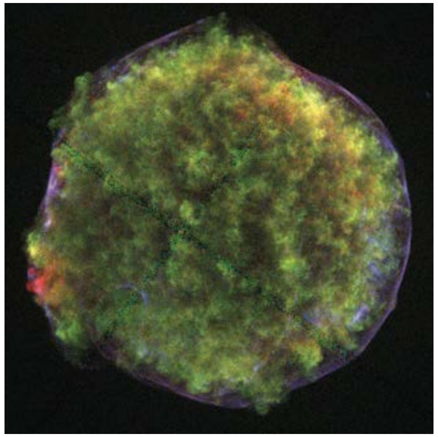
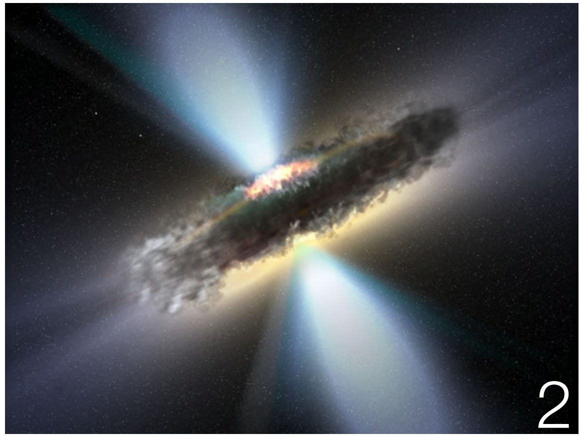
ASTRO-H White Paper
“Shock and Acceleration” Aharonian, Uchiyama et al. (2014, astro-ph)
“Broad-band Spectroscopy and Polarimetry”, Paolo, Stawarz et al. (2014, astro-ph)
“Multiwavelenth Astronomy and CTA: X-rays”,Takahashi, Uchiyama, Stawarz (2013)

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



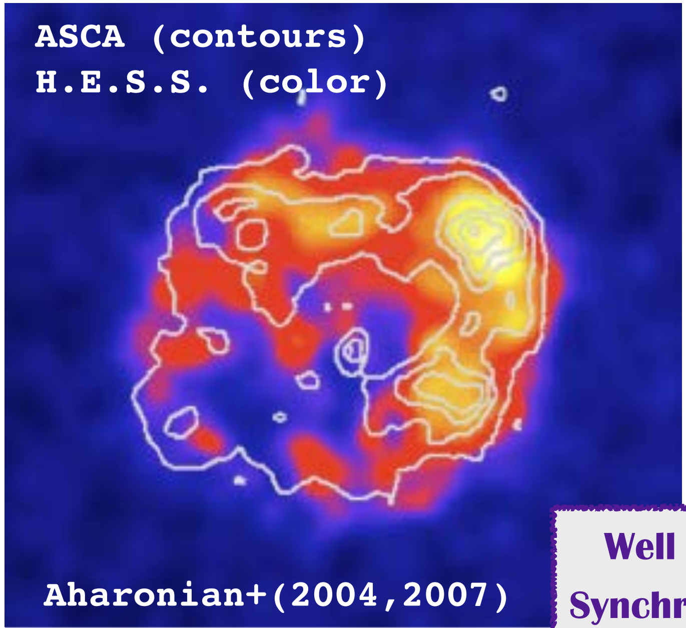
There are many important topics, which ASTRO-H and TeV telescopes should work together to understand the non-thermal universe.





1. keV-TeV Connection: SNRs

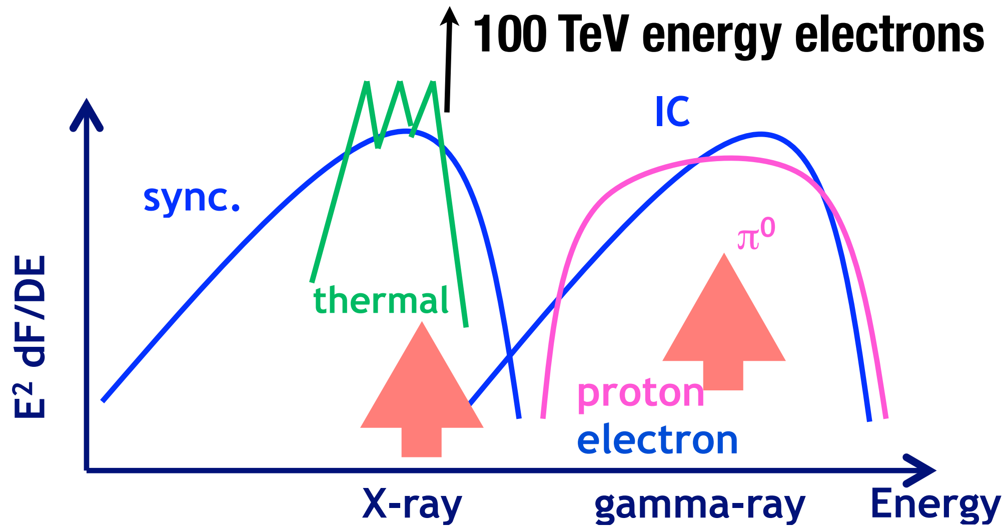
X-ray observation is very sensitive to the existence of the distribution of high energy electrons (particle accelerators)



Well correlated Synchrotron X-rays and TeV gamma-rays

X-ray Synchrotron

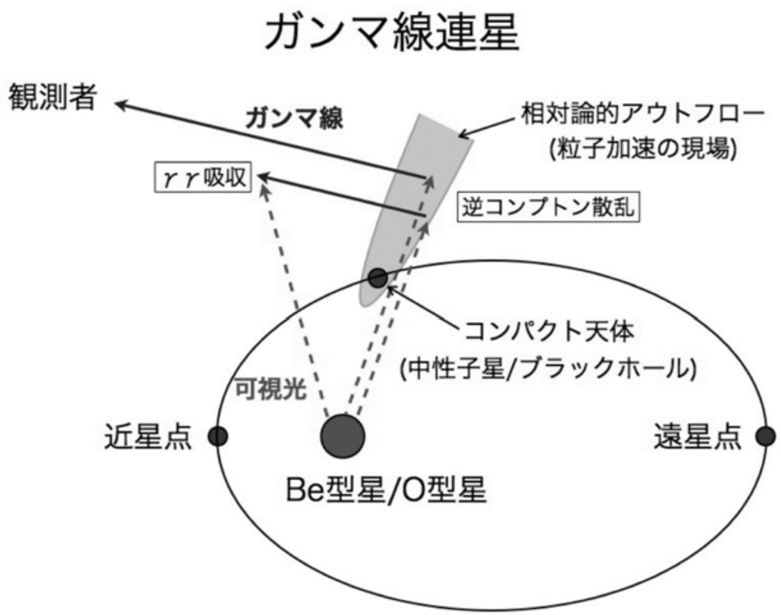
$$h\nu_{\rm synch} = 5.3\ E^2_{100\,{\rm TeV}} B_{10\,\mu{\rm G}}\quad [{\rm keV}]$$



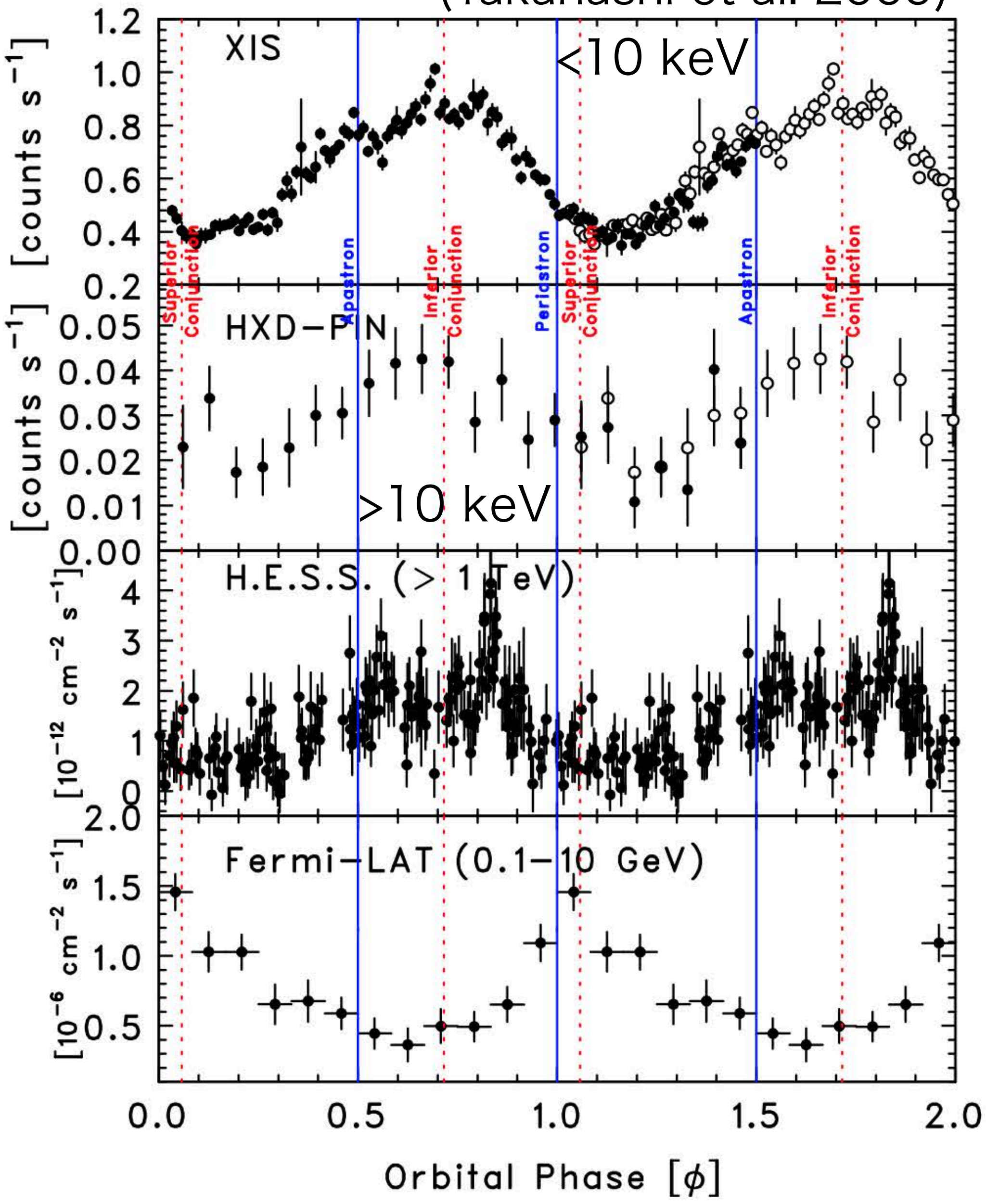
Cooling time of X-ray emitting electrons is much shorter than radio ones

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

1. keV-TeV Connection: Binaries



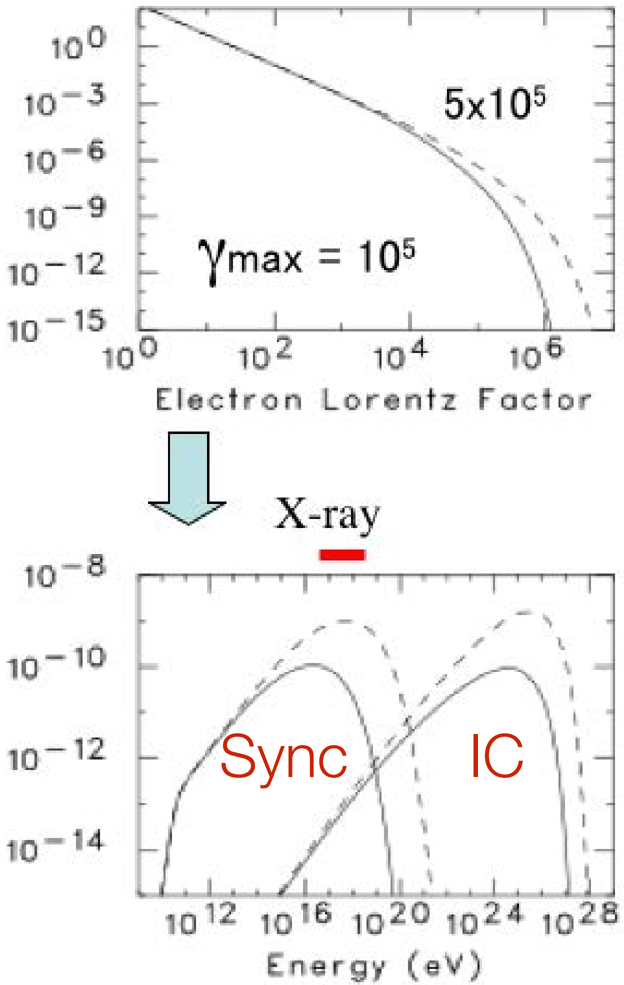
(Takahashi et al. 2009)



The X-ray/TeV data suggest the extremely efficient and rapid acceleration process. 10 TeV electron on a timescale of seconds.

1. keV-TeV Connection: Blazars

Blazar spectra from accelerated particles



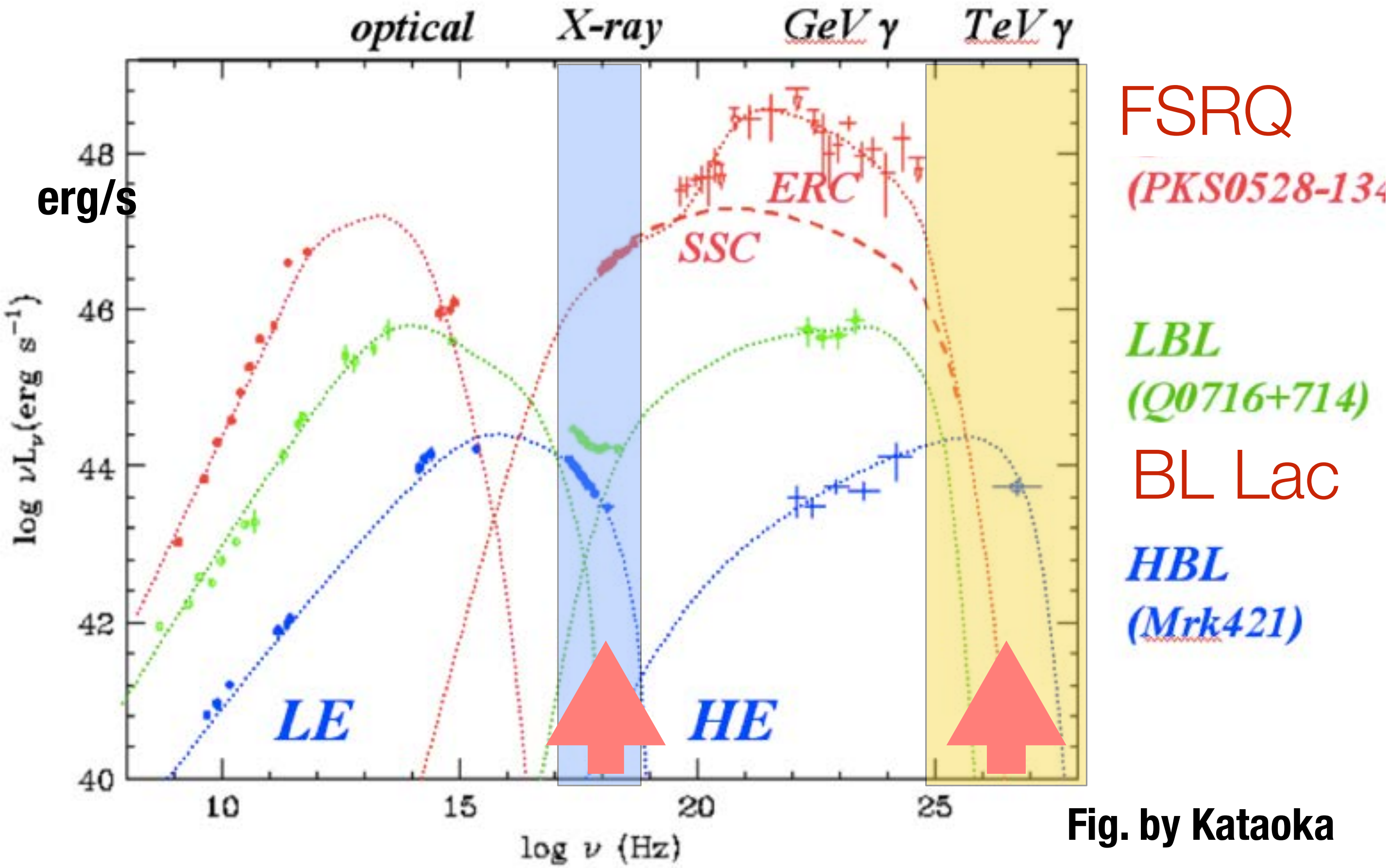


Fig. by Kataoka

X-ray spectra
can constrain the original electron spectrum
(Either high energy end or low energy end of electron distribution)

2. ASTRO-H Mission

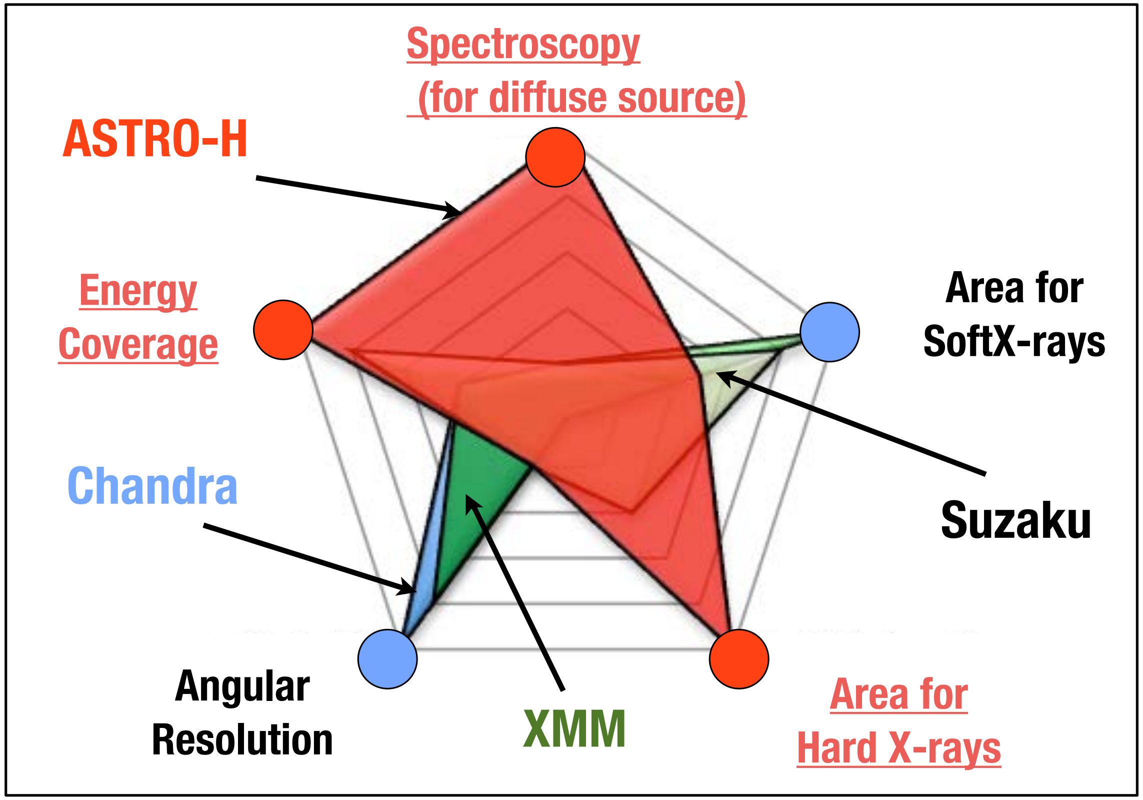
ASTRO-H, which is the 6th in the series of the X-ray observatories from Japan, is designed to have

1) Higher Energy Resolution

and

2) Wider energy coverage with higher sensitivities

than existing X-ray missions.

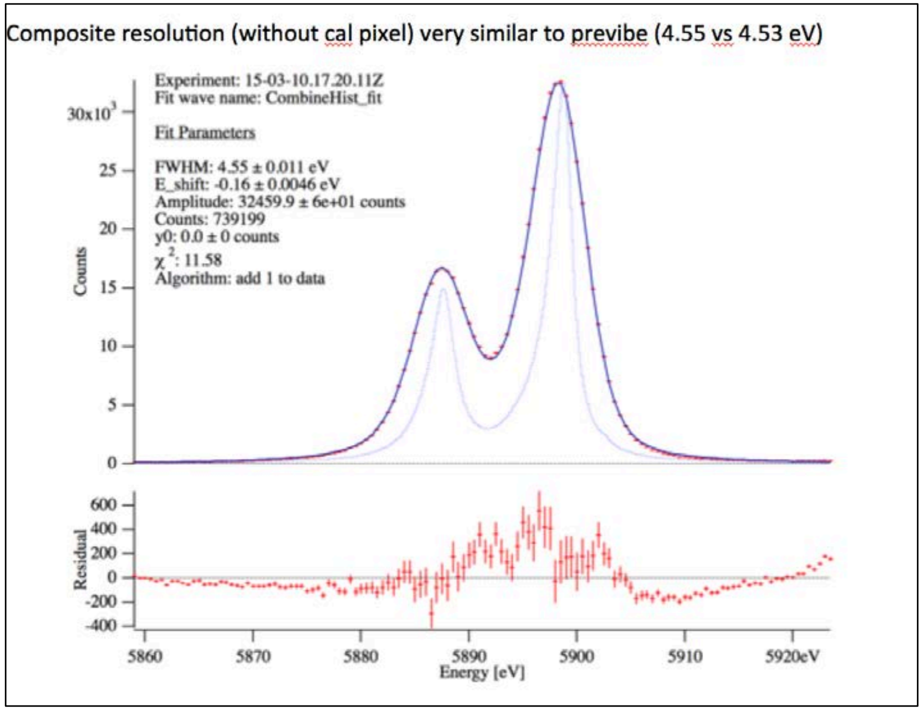


ASTRO-H is an international X-ray observatory. More than 200 scientists from Japan/US/Europe/Canada are involved in.

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

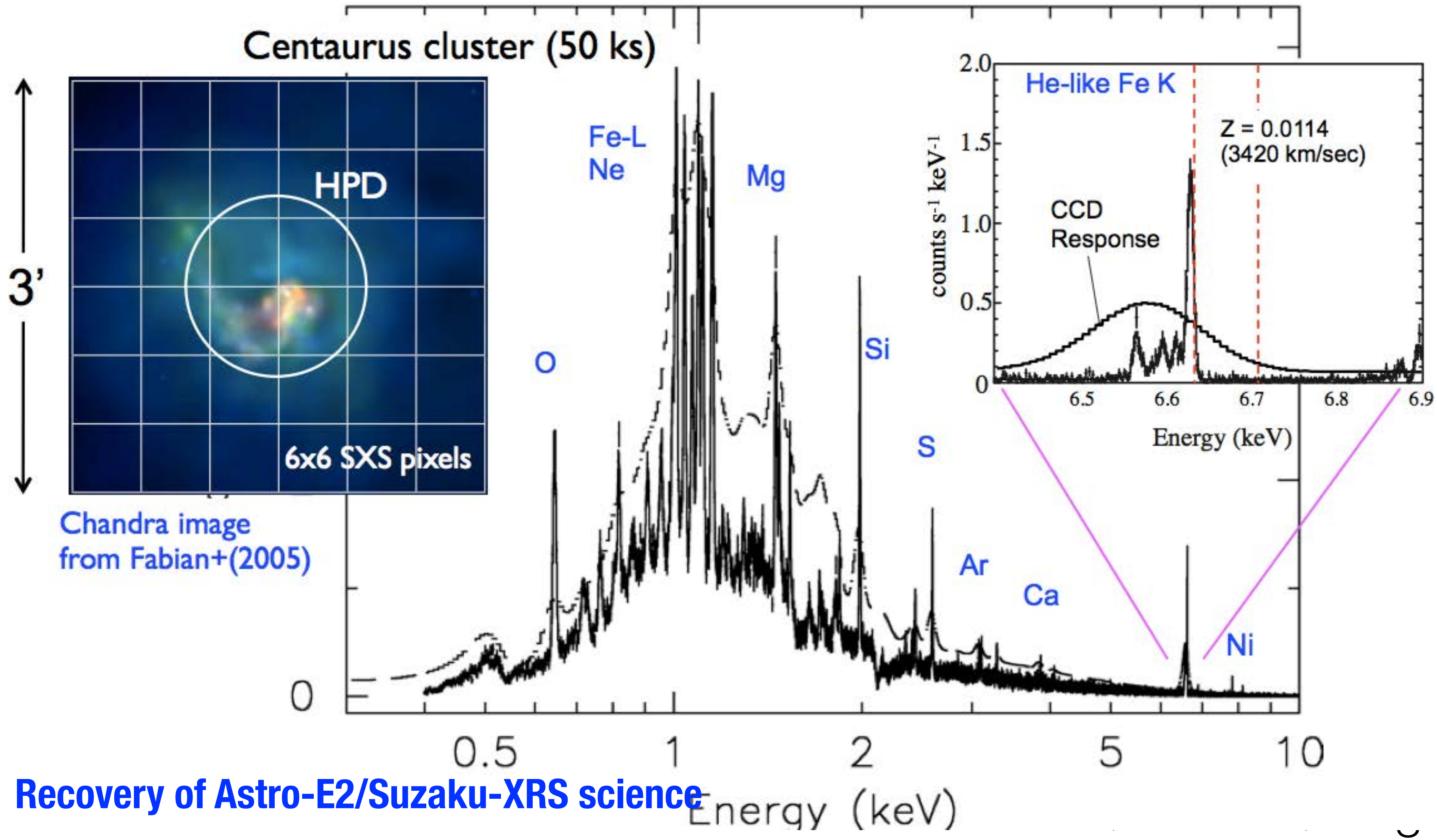
ASTRO-H Micro-calorimeter

- X-ray micro-calorimeter spectrometer with energy resolution better than 7 eV (FWHM) (0.3 keV to 12 keV)
- 6 × 6 array with 3’ × 3’ field of view
- Operated at 50 mK
  - Nominal expected liquid He lifetime 3.3 years (can be operated even w/o He)



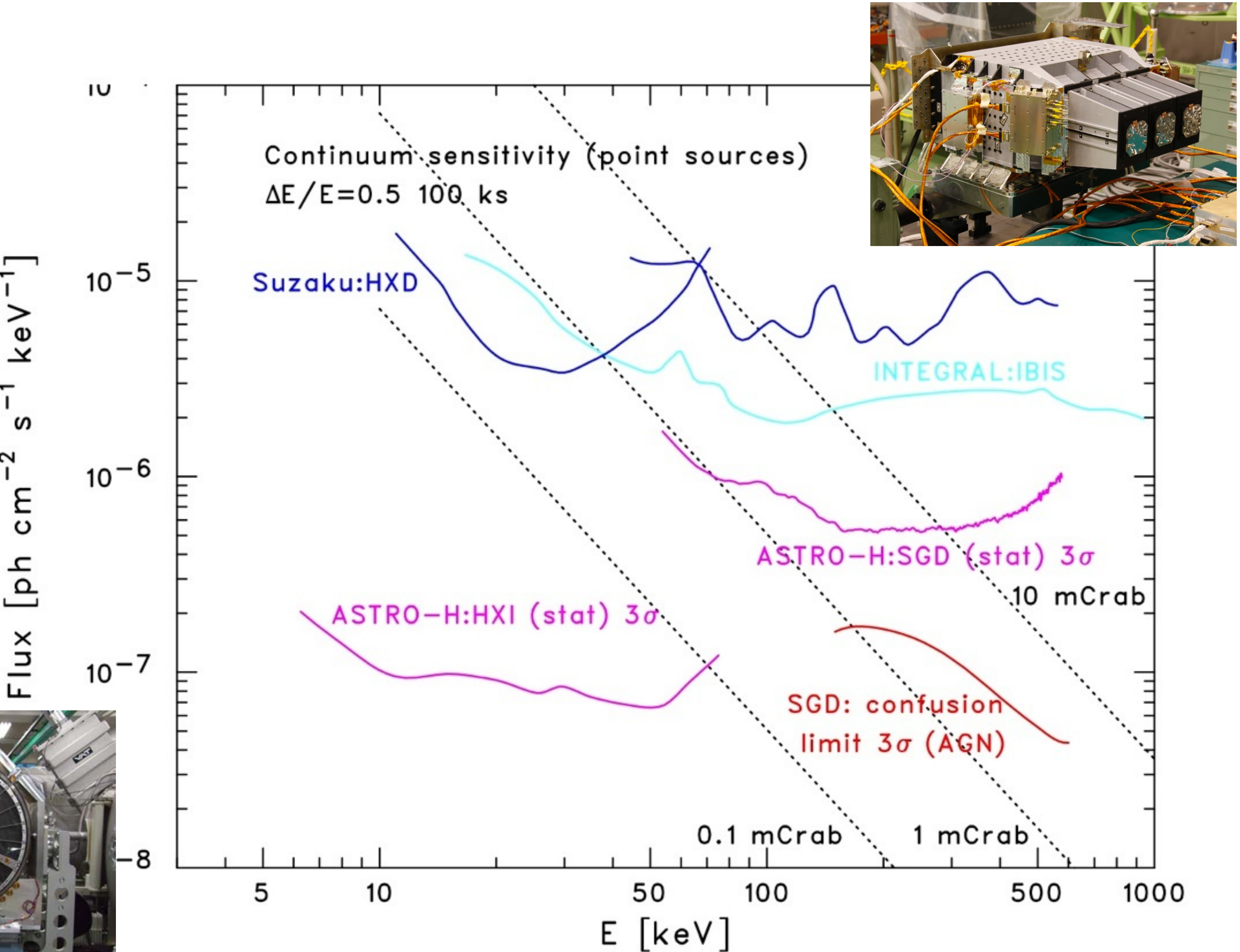
Imaging

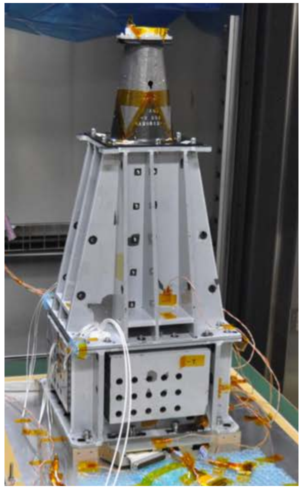
<7 eV (FWHM) @ 6 keV

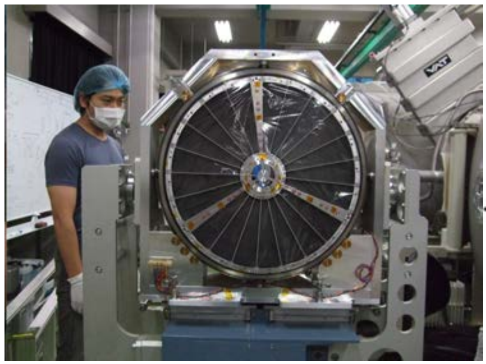


Recovery of Astro-E2/Suzaku-XRS science

3. Broadband Coverage by ASTRO-H

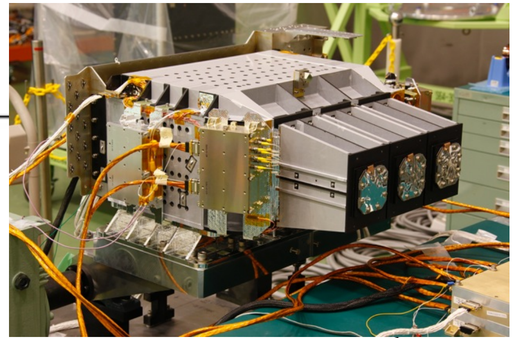


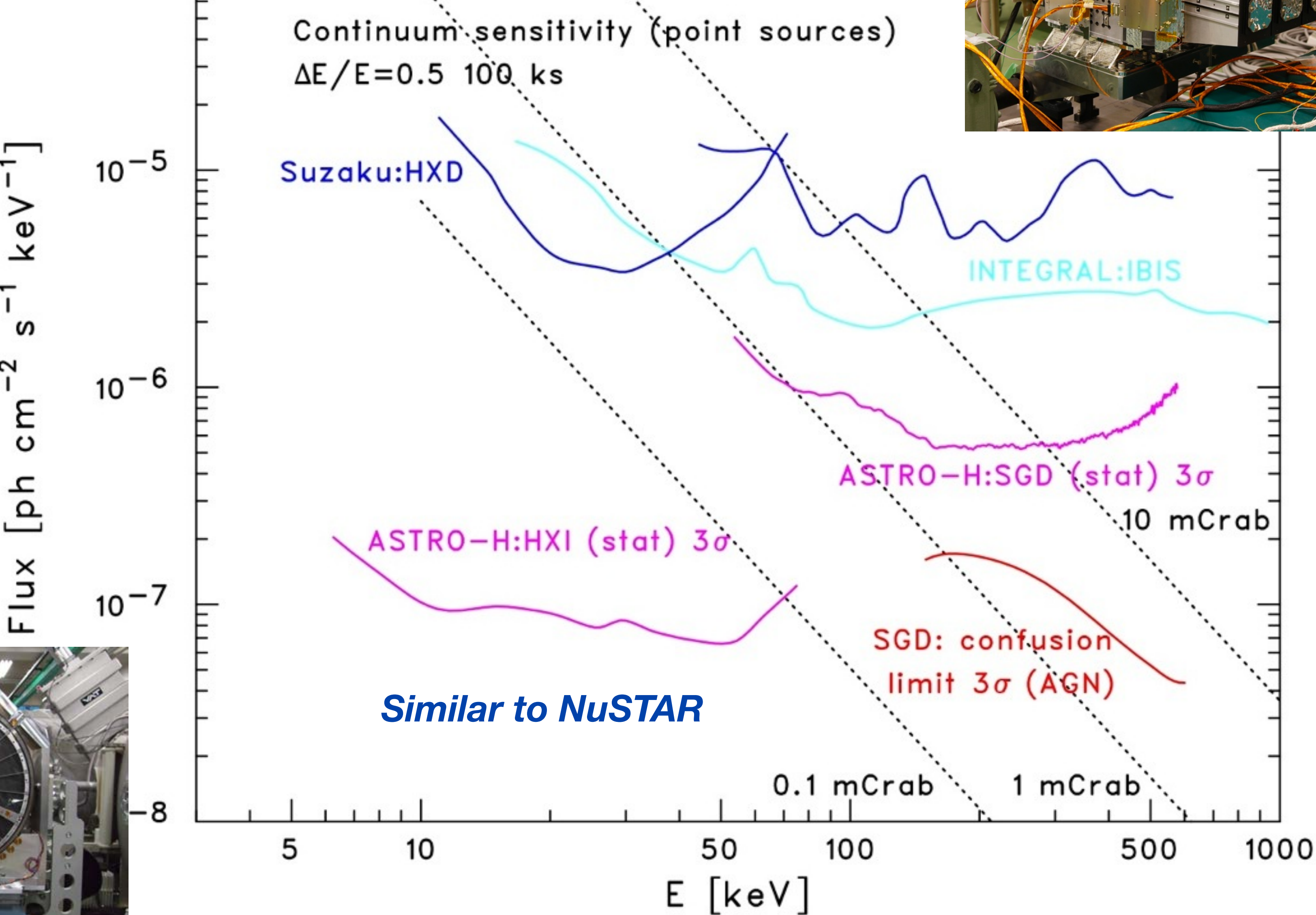


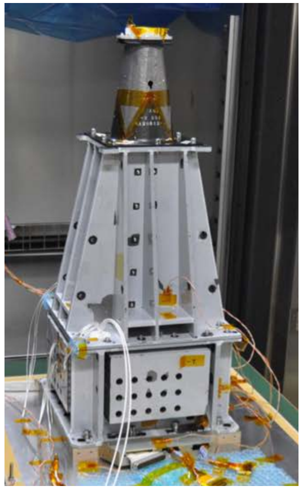


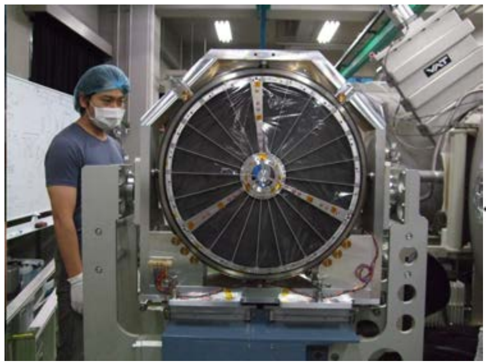
3. Broadband Coverage by ASTRO-H

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



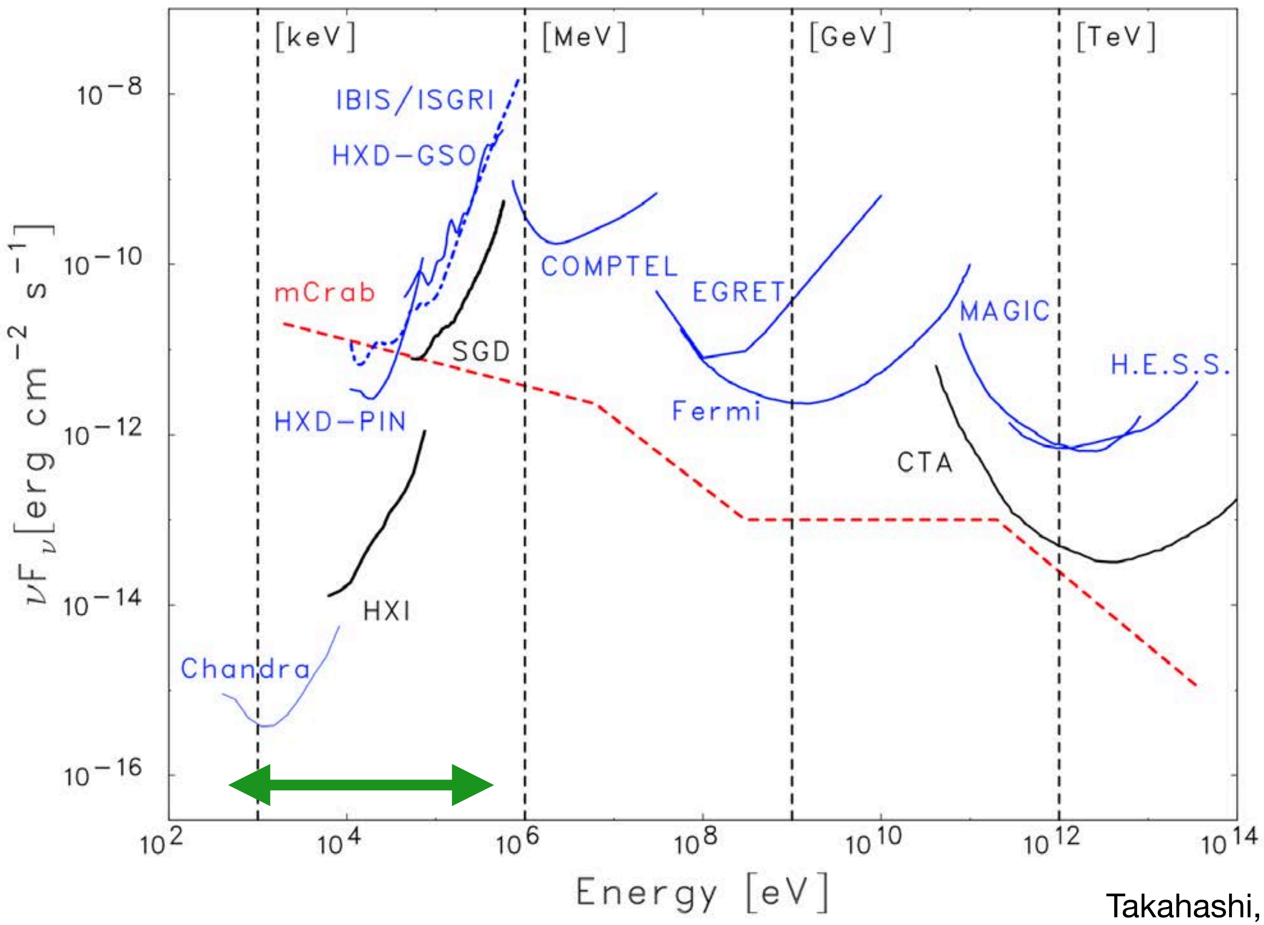






3. Broadband Coverage by ASTRO-H

1) To trace particle acceleration structures in clusters of galaxies and SNRs;
2) To investigate the detailed physics of astrophysical jets.

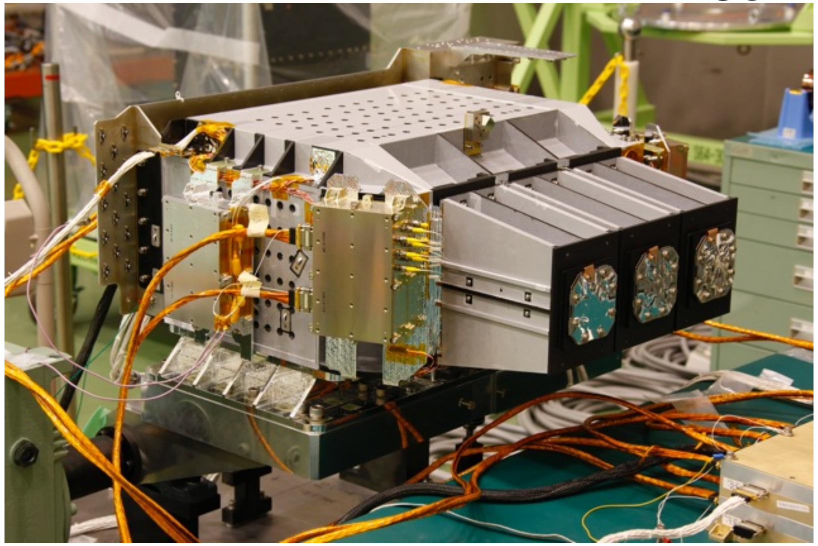


Takahashi, Uchiyama and Stawarz (2013)

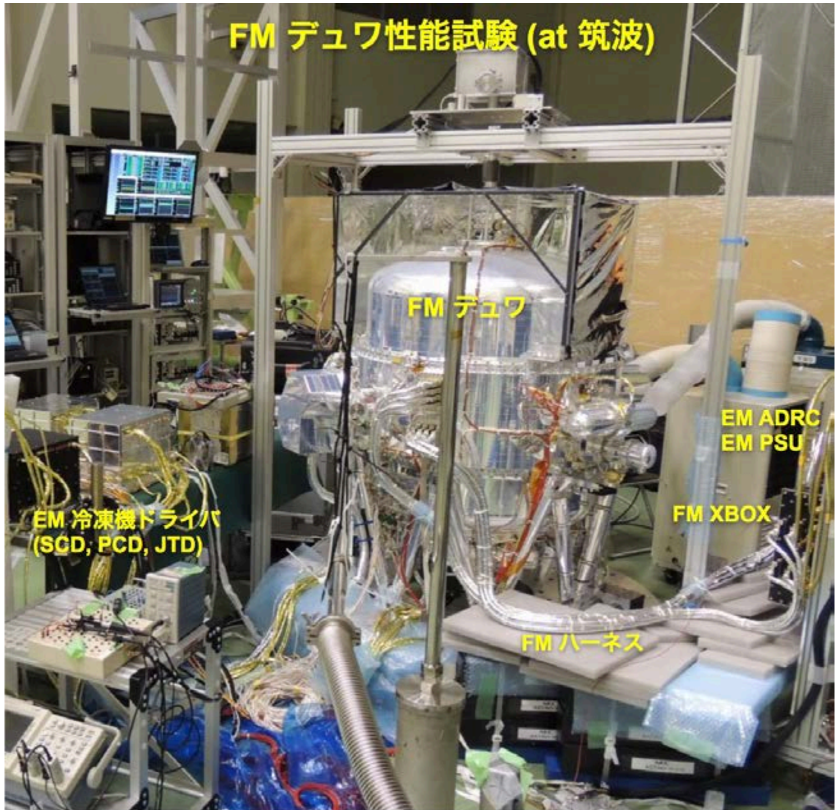
FM XRTs and Instruments are being delivered

XRT

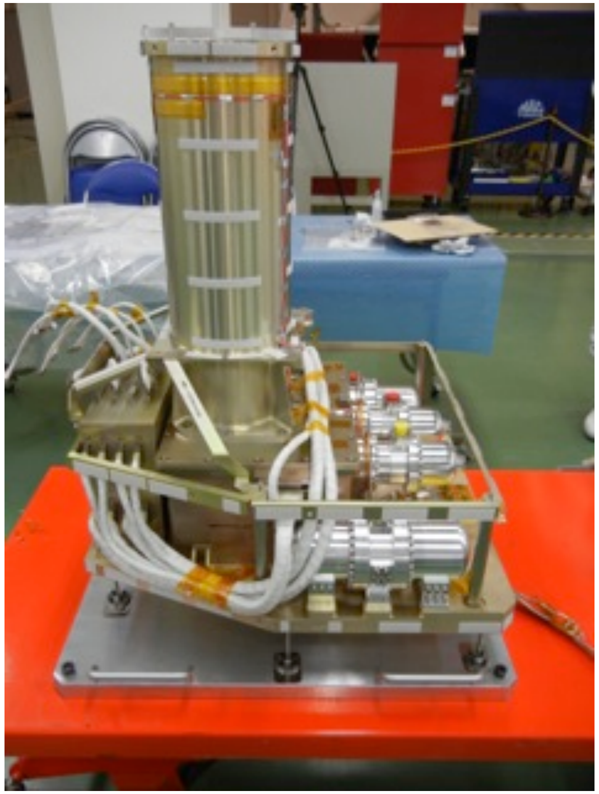
SGD



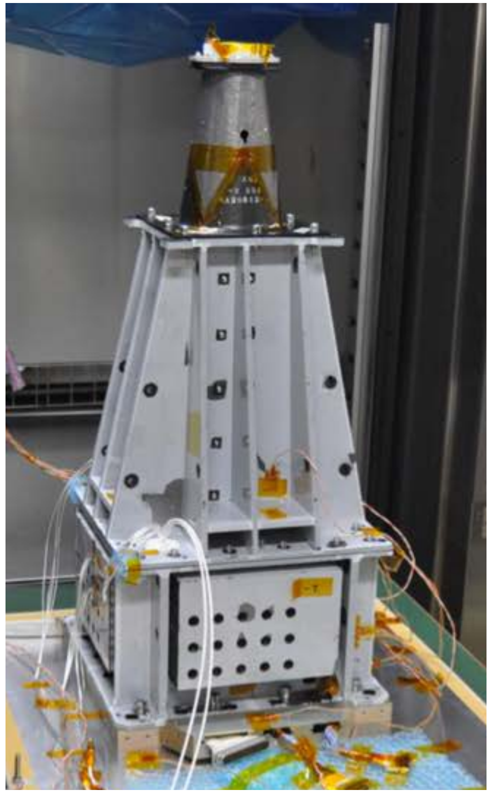
SXS



SXI



HXI



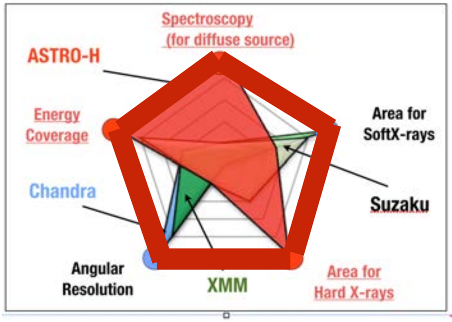
一次嚙み合わせ(2014/6月)

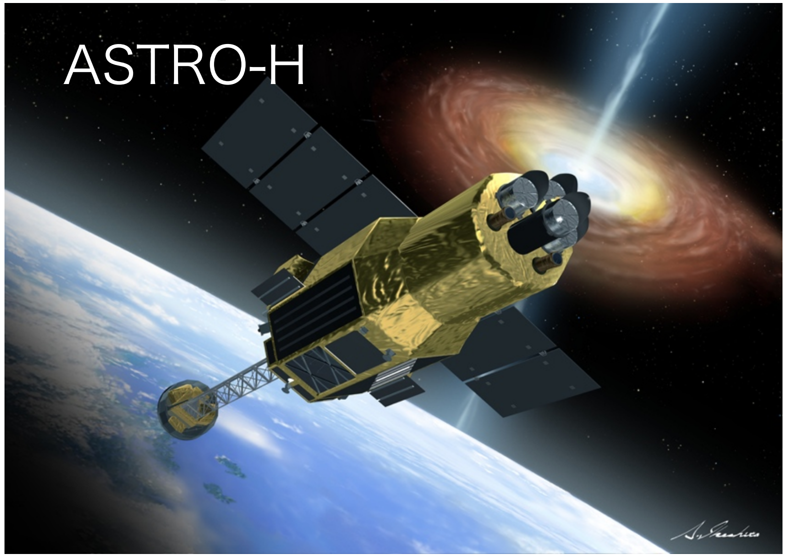
リファービッシュ

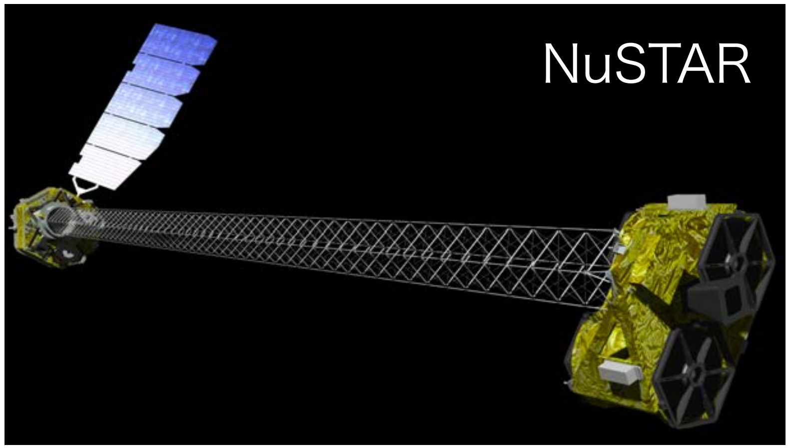
2015/3月

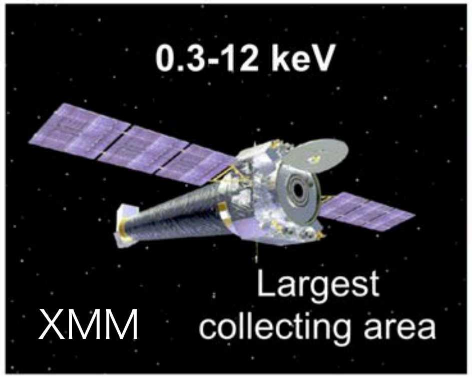
（総合試験/衛星の最終組み上げ）

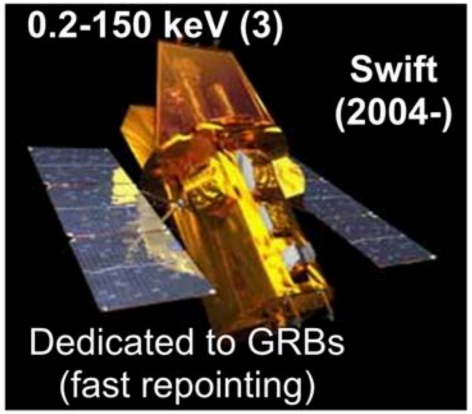
4. X-ray Missions in the next 10 years

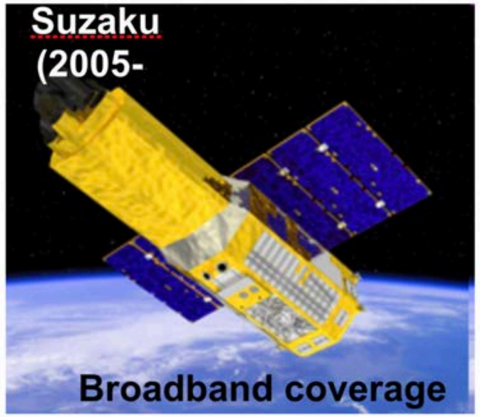


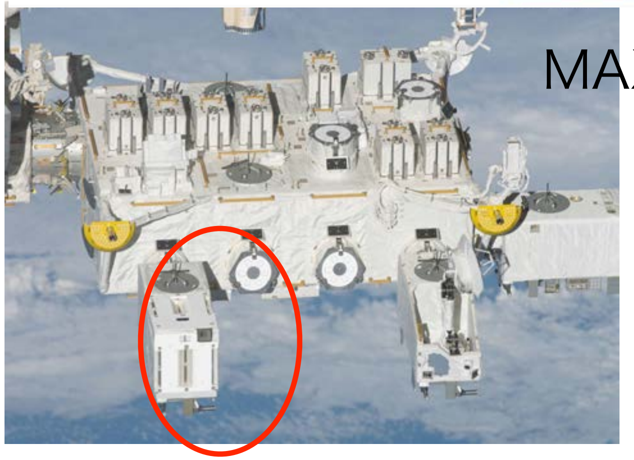












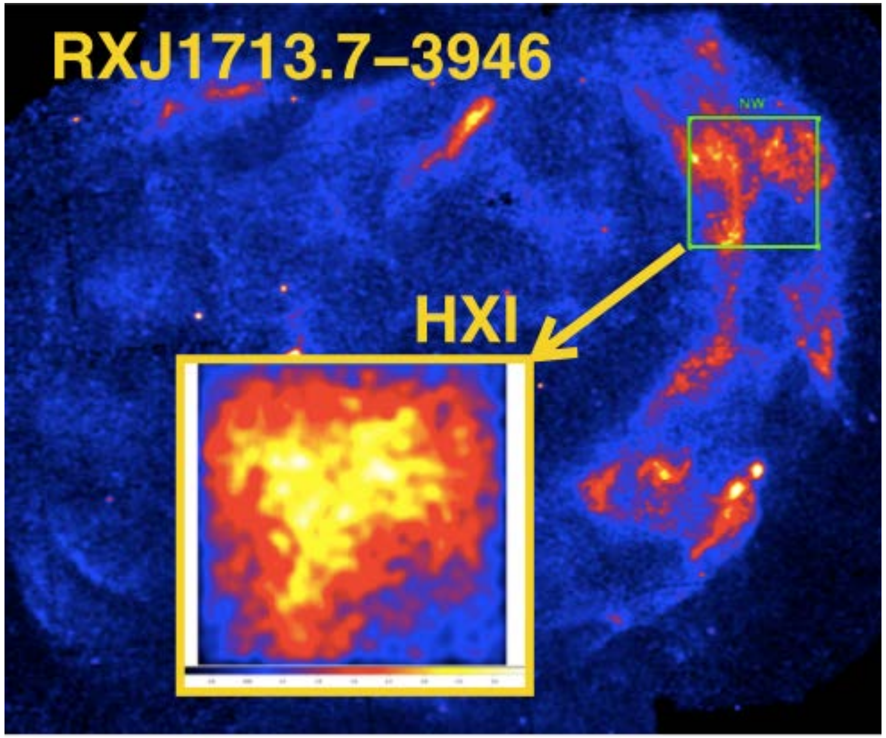
MAXI

and
ASTROSAT
will come soon

Non Thermal Emission

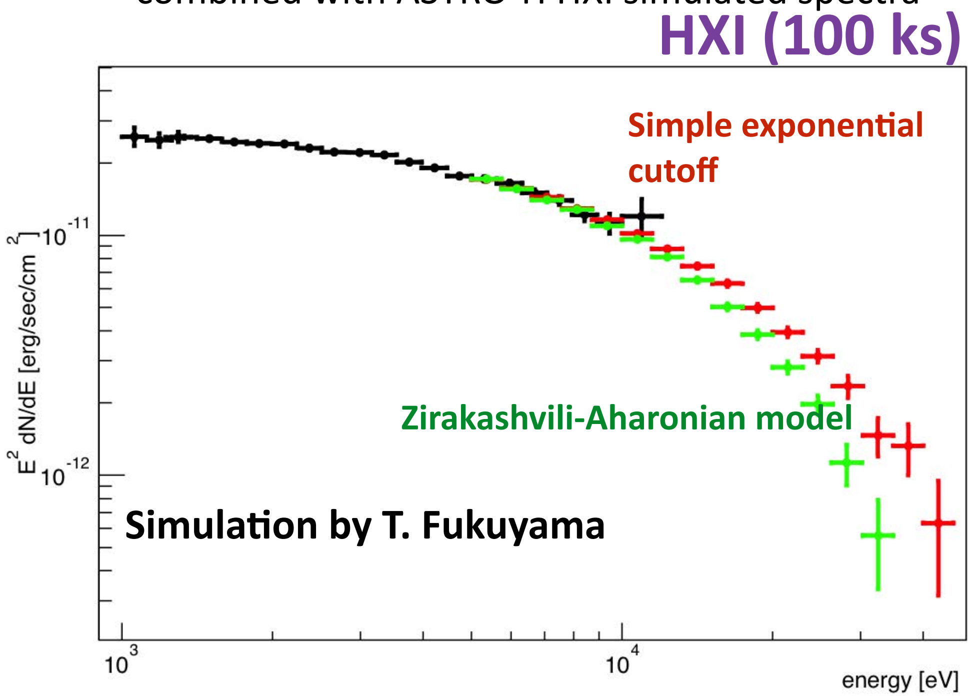
Synchrotron X-ray spectra up to 50 keV

1) High Statistics → discrimination of models
   → determination of physical parameters
2) Image → Spatial structure of the accelerator



The XMM mosaic image w/ a simulated HXI image

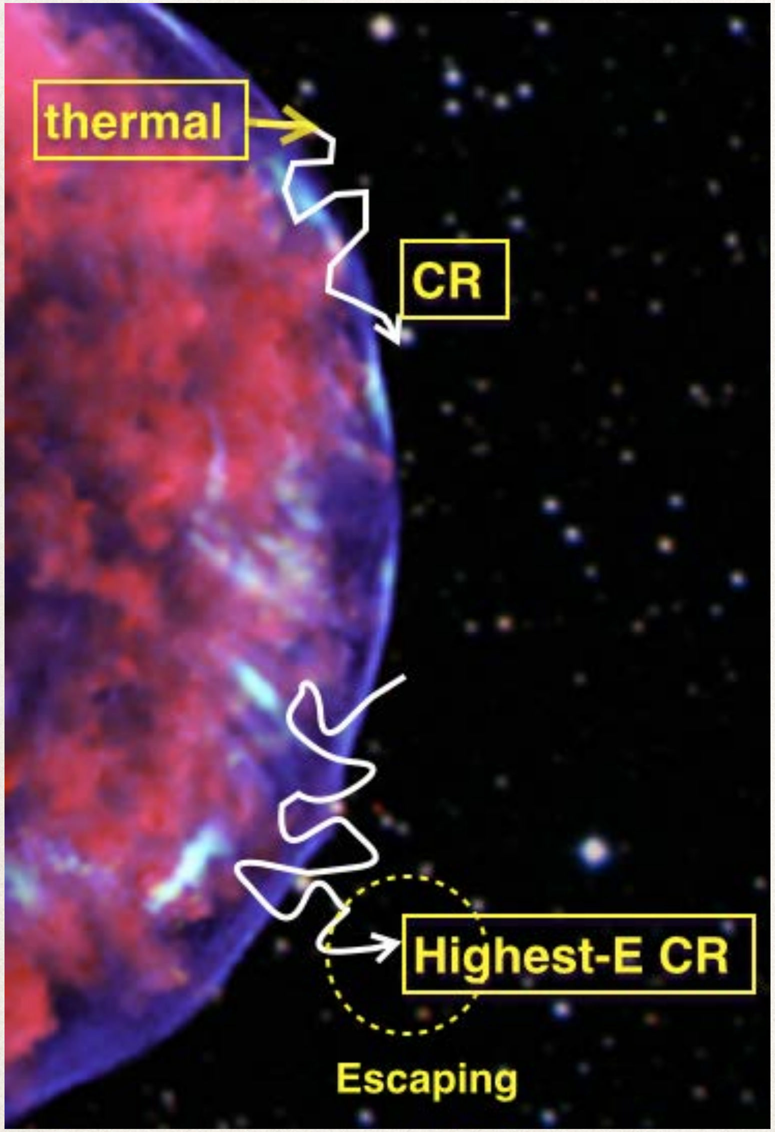
Suzaku XIS observed spectrum (<10 keV)
combined with ASTRO-H HXI simulated spectra



from Y. Uchiyama (ASTRO-H Science Meeting)

Toward Understanding the Origin of Galactic CRs

Diffusive Shock Acceleration



"Efficiency" does matter.

from Y. Uchiyama (ASTRO-H Science Meeting)

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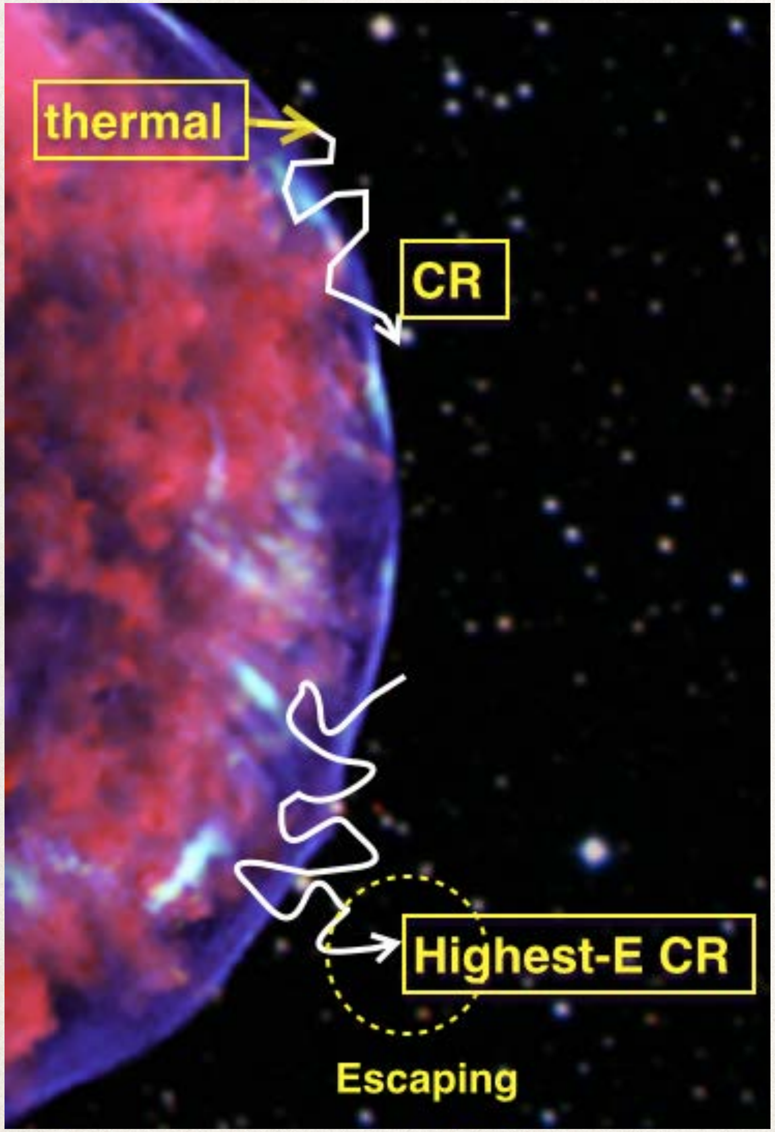

“Efficiency” does matter.

Acceleration Efficiency (1): **“the energy content in CRs”**

✔ How thermal (Maxwellian) particles can be injected into Fermi acceleration?
✔ Depends on **B-field orientation**?
✔ Acceleration of **protons**?
✔ Energy content of **protons**?

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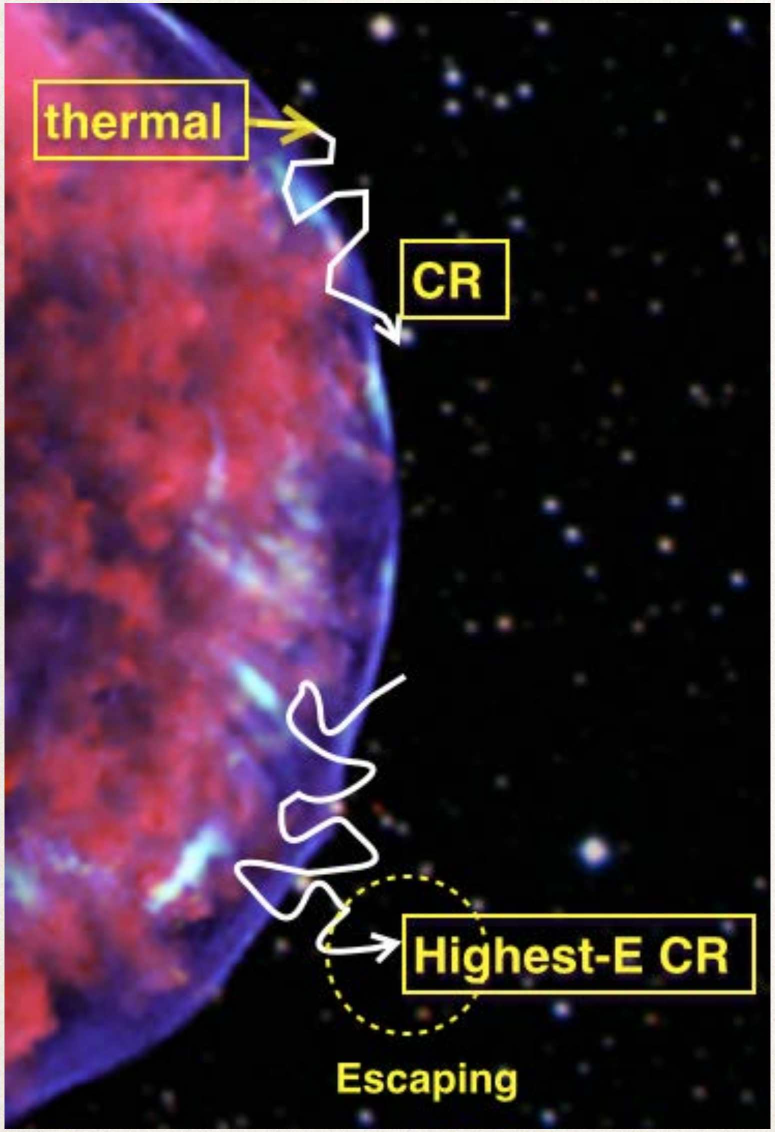

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Acceleration Efficiency (2): **"the maximum attainable energy"**

✔ **B-field amplification**?
✔ Depends on **B-field orientation**?
✔ **Escaping** CRs? (important for protons)

from Y. Uchiyama (ASTRO-H Science Meeting)

Toward Understanding the Origin of Galactic CRs

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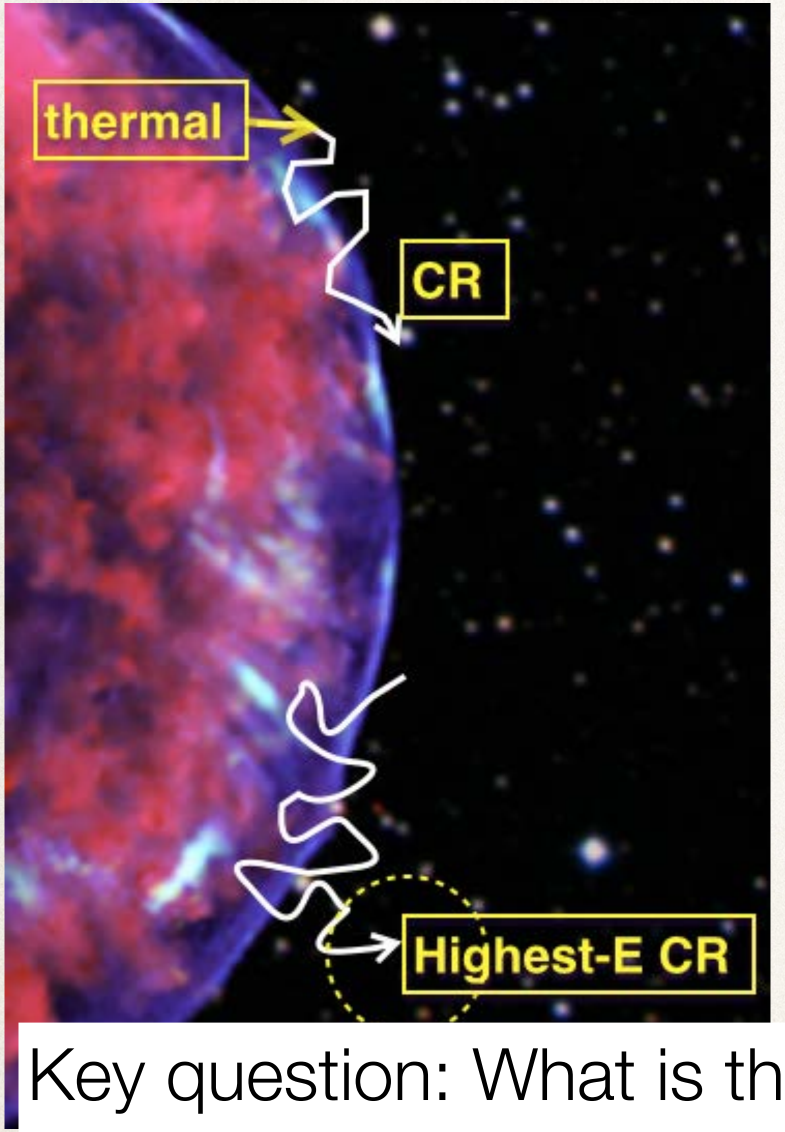

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✔ **B-field amplification**?
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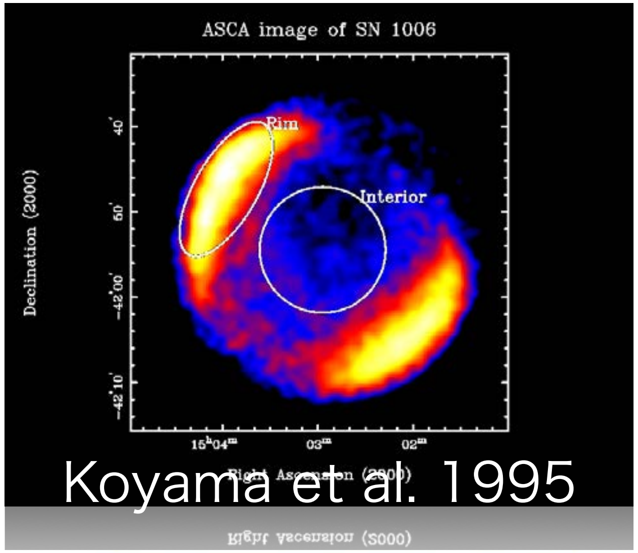
Key question: What is the partition of shock energy into bulk motions, thermal energy, and relativistic particles?

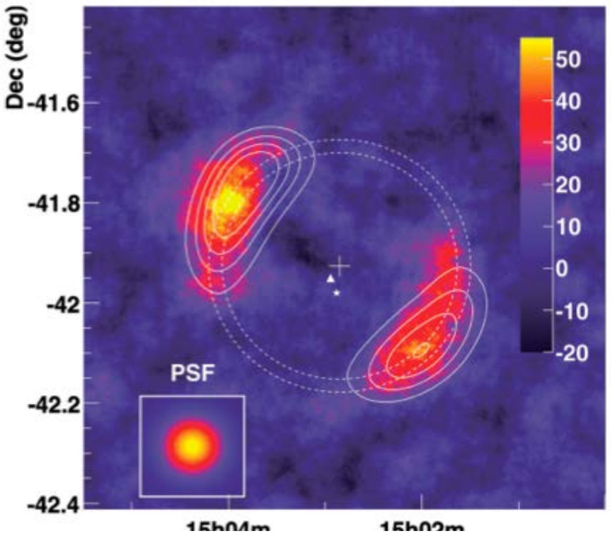
Bilateral SNR: a good keV-TeV correlation?

SN1006

ASCA



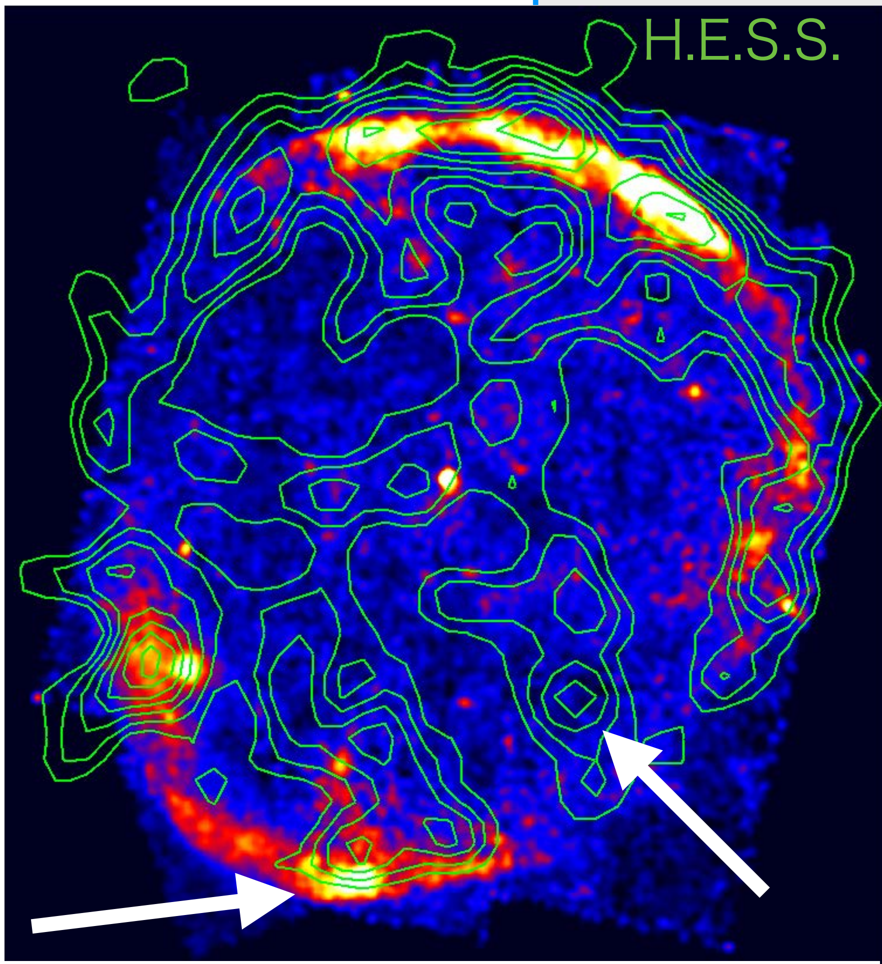
H.E.S.S.



Vela Jr. (Suzaku/H.E.S.S.)

RX H0852.0-4622

Fukuyama+ (2015)

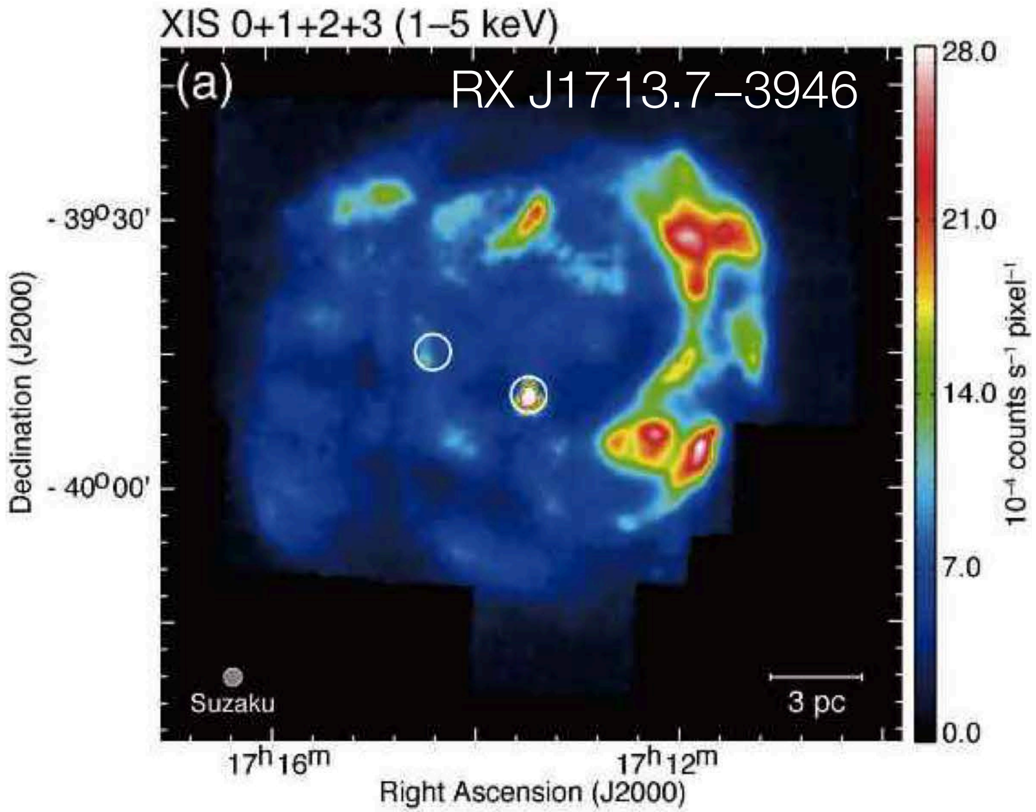


Spatially resolved spectral data (vs model!) will help disentangle leptonic and hadronic components

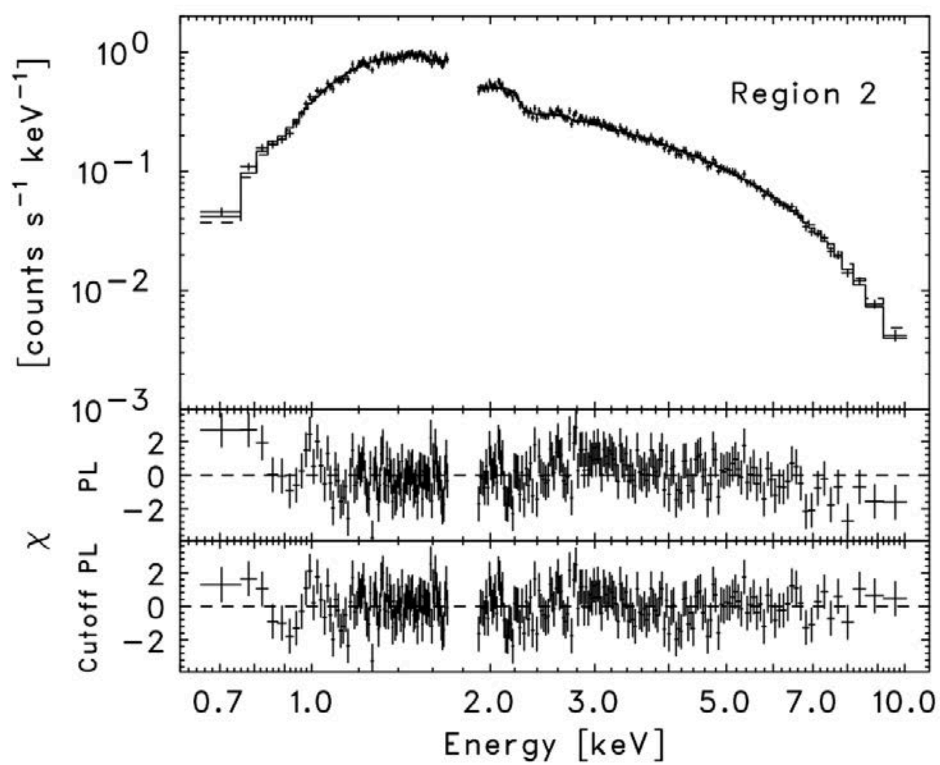
Thermal Emission from Non-thermal SNR

- 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)

RXJ1713



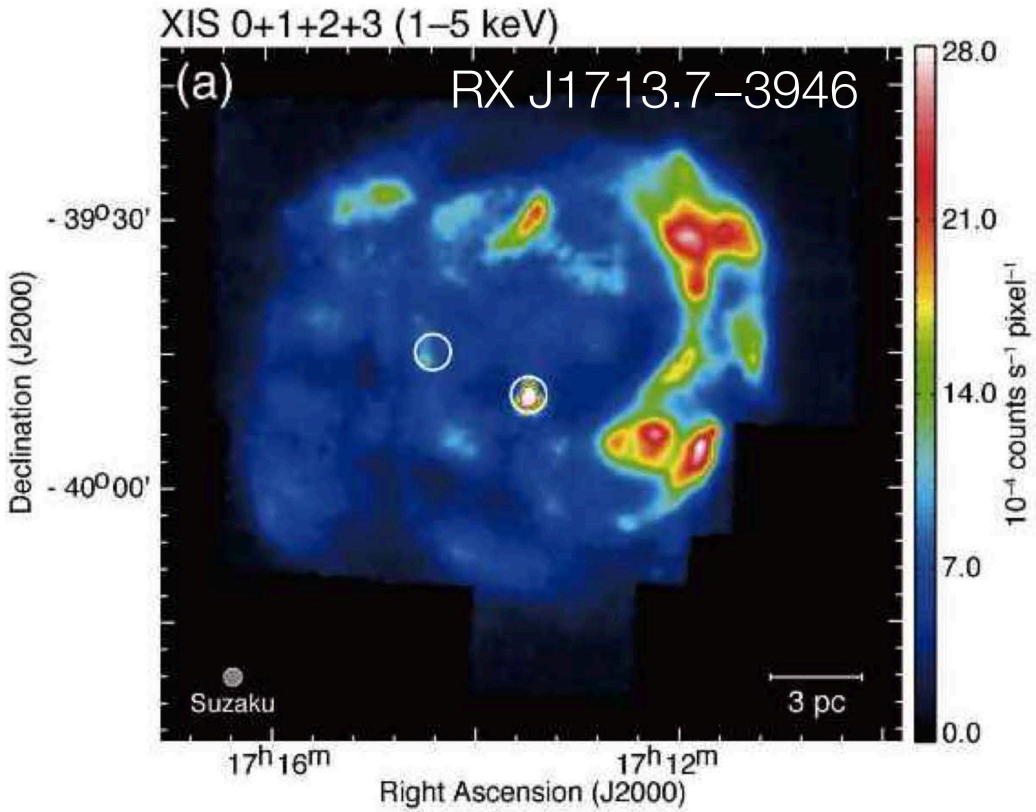
Suzaku (Sano+, 2013)



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

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.



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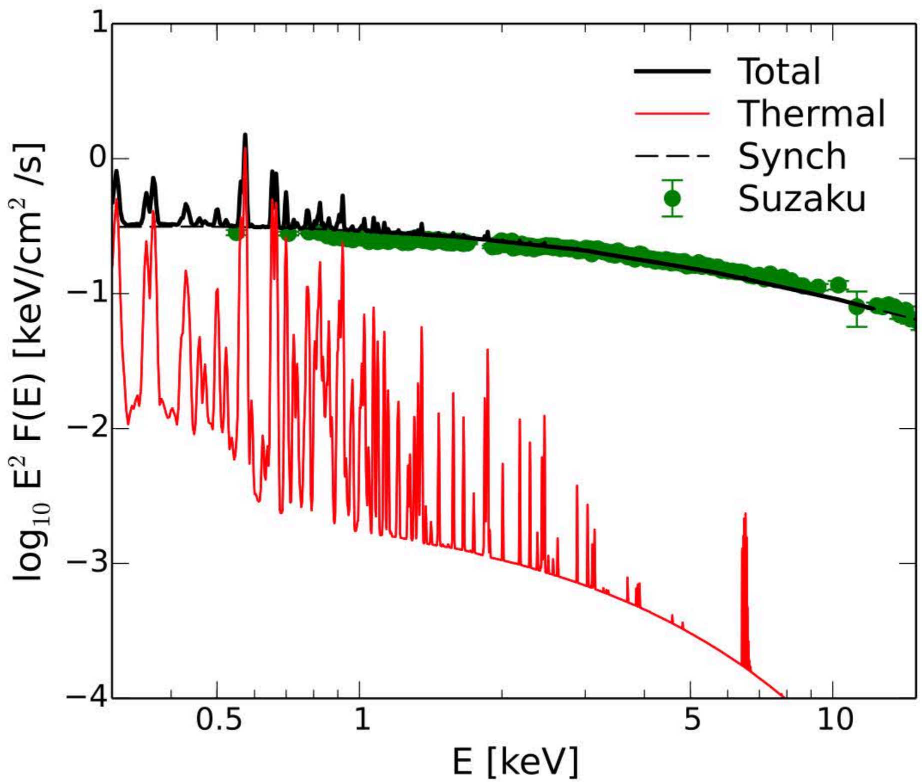
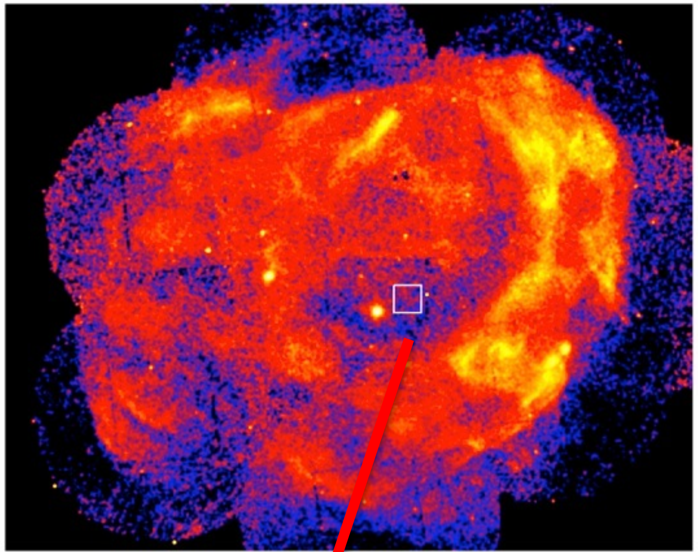
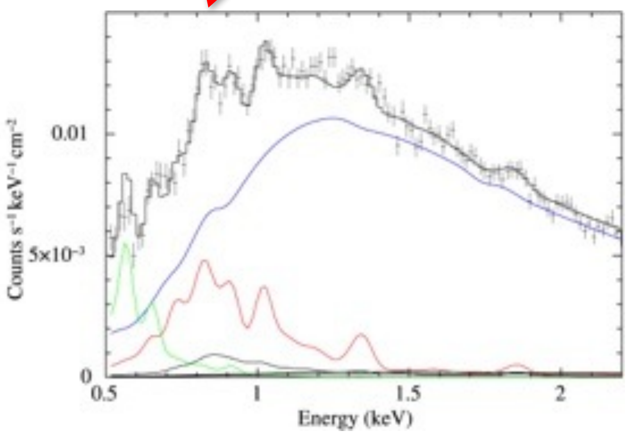


ASTRO-H Simulation

(Herman Lee+ (2014))

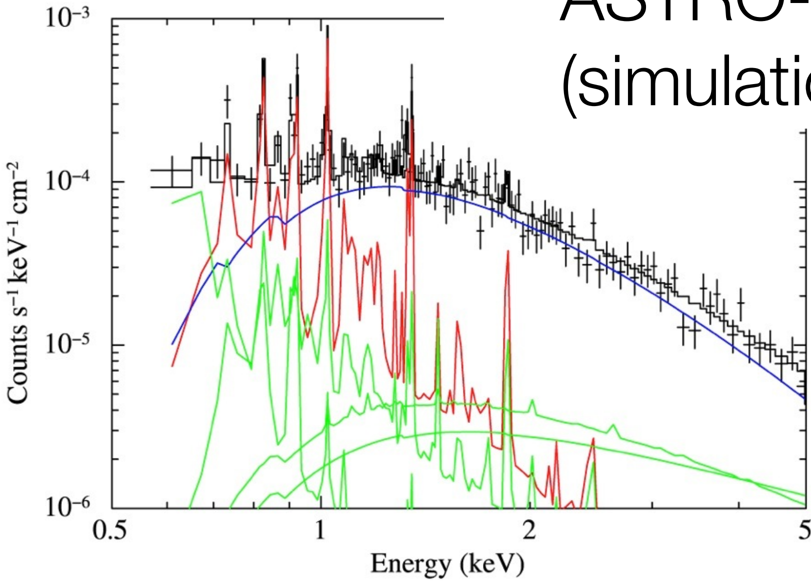
Recent Detection of thermal lines



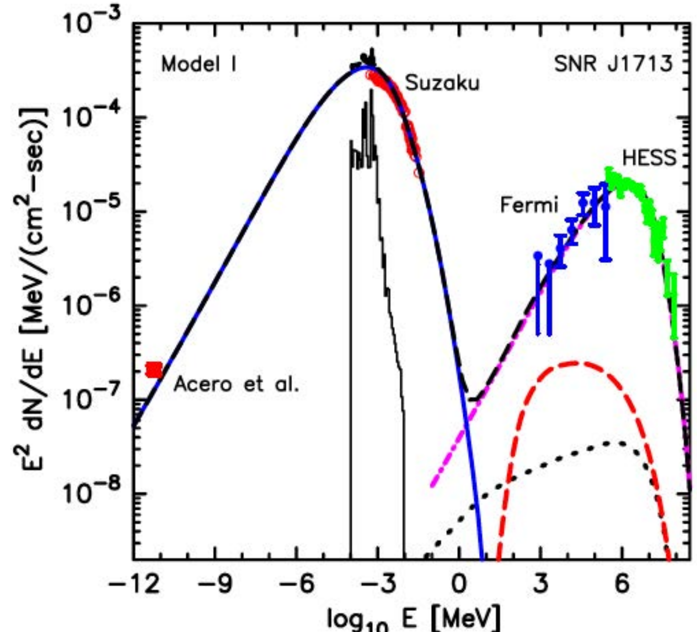


[XMM/S. Katsuda, 2015]

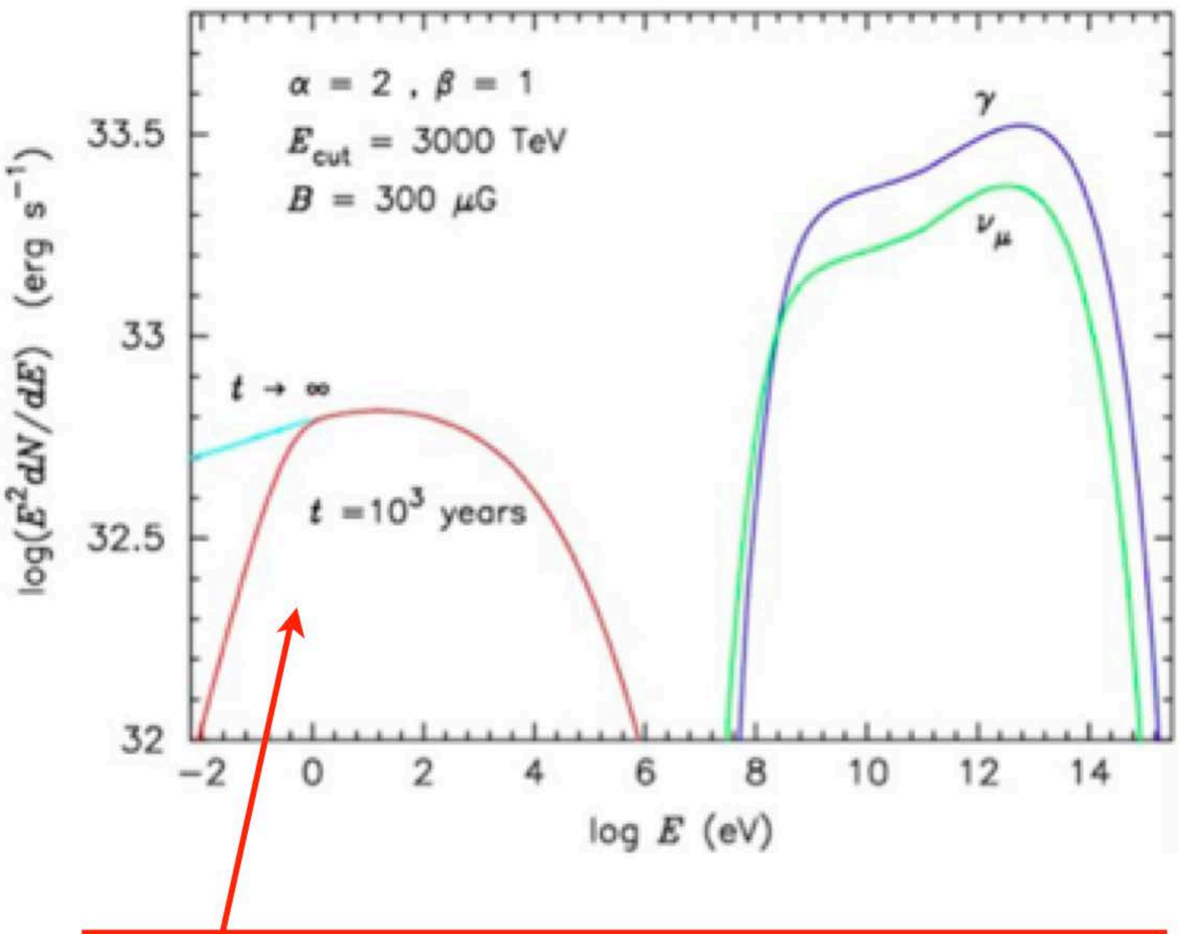
ASTRO-H SXS 50 ks (simulation)



CR-hydro model (Lee et al. 2012)



X-ray emission of Secondary electrons



synchrotron by secondary e± :
(synchrotron by primary electrons with an unavoidable cutoff of $h\nu_0 \sim 1$ keV is expected to be steep at hard X-rays.)

From PeVatron

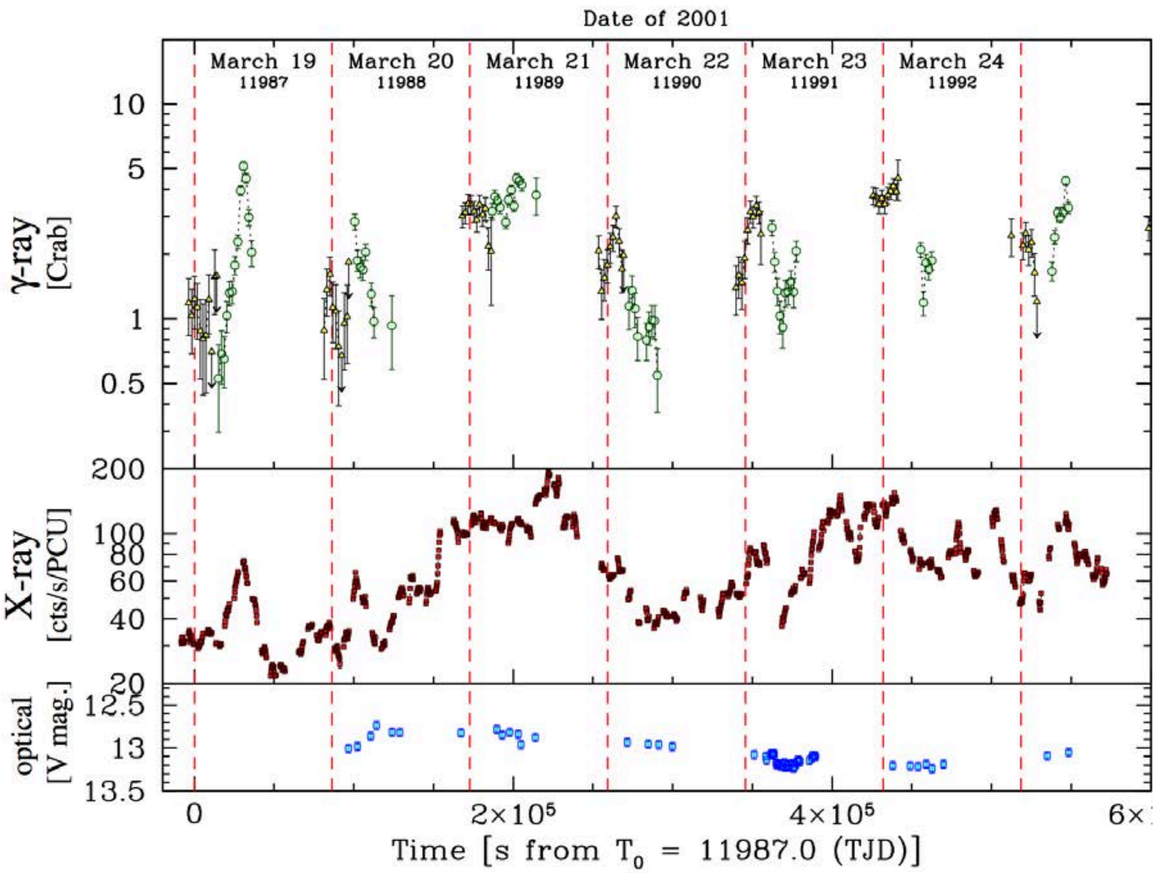
The broad-band radiation of a PeVatron initiated by interactions of protons with the ambient gas

F. Aharonian (2012)

Blazars (BL Lacs)

Correlation

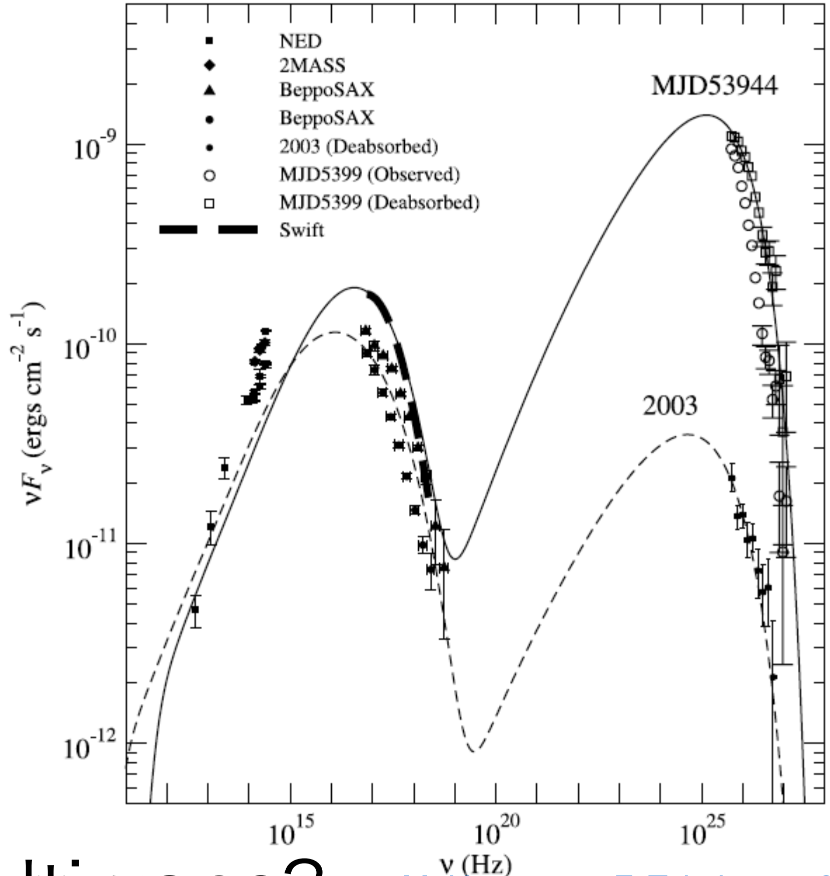
Mrk421



Fossati et al. 2008

Correlation?

PKS2155

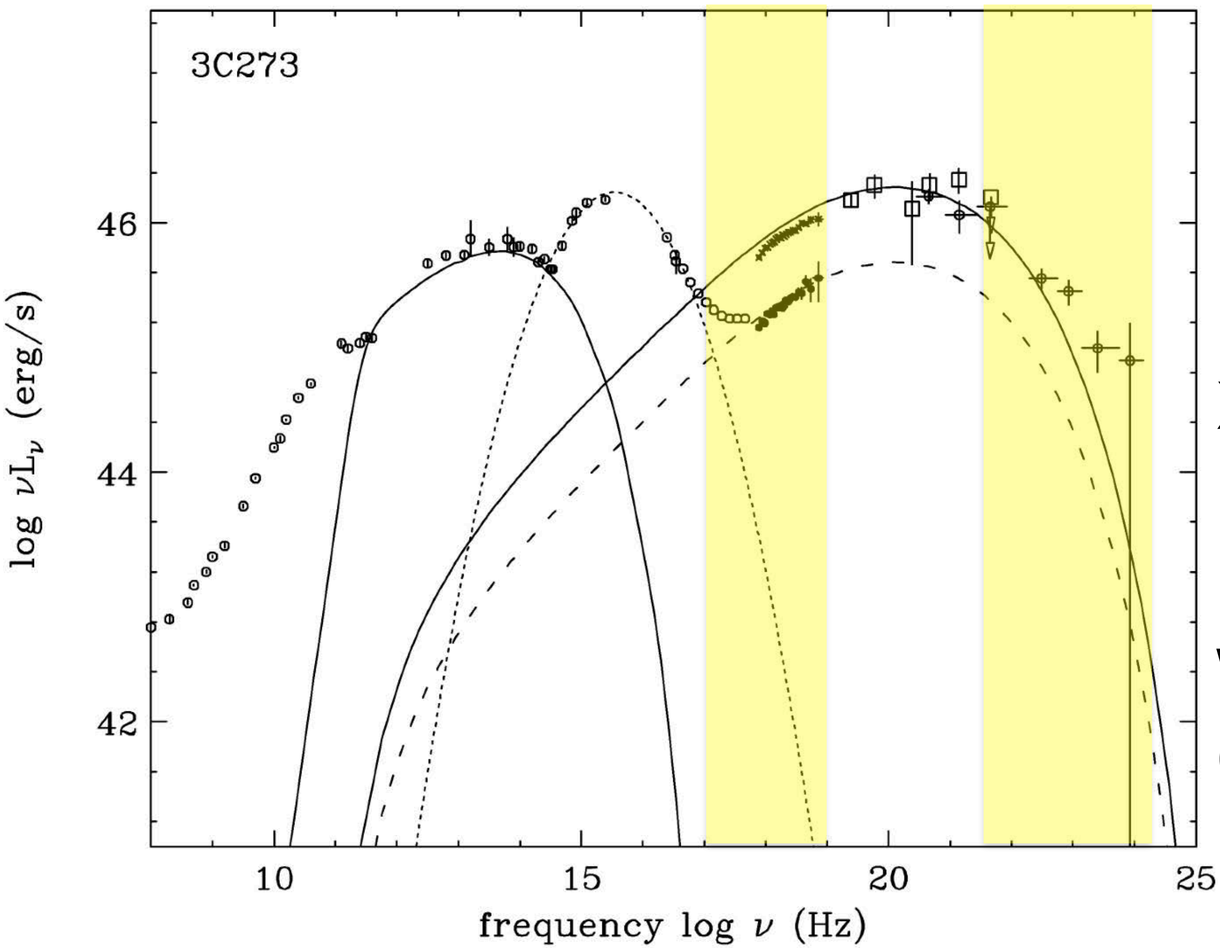


M. Kusunose, F. Takahara, 2008

One zone? or Multi zone?

Electron → Synchrotron(X-ray), Inv. Compton (TeV)

Jet-Disk Coupling in Active Galaxies



3C273

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

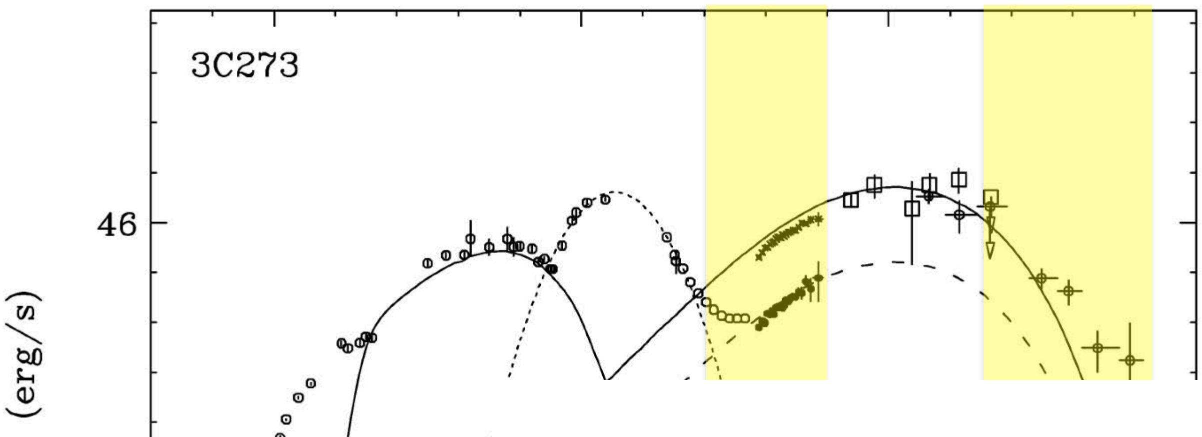
X-ray:
Continuum from disk/corona and jets)

Weak fluorescent Fe line (detectable with micro-calormeter)

RXTE + EGRET (Kataoka, TT+, 2002)

Jet/Outflow
Launching
Feedback

Jet-Disk Coupling in Active Galaxies



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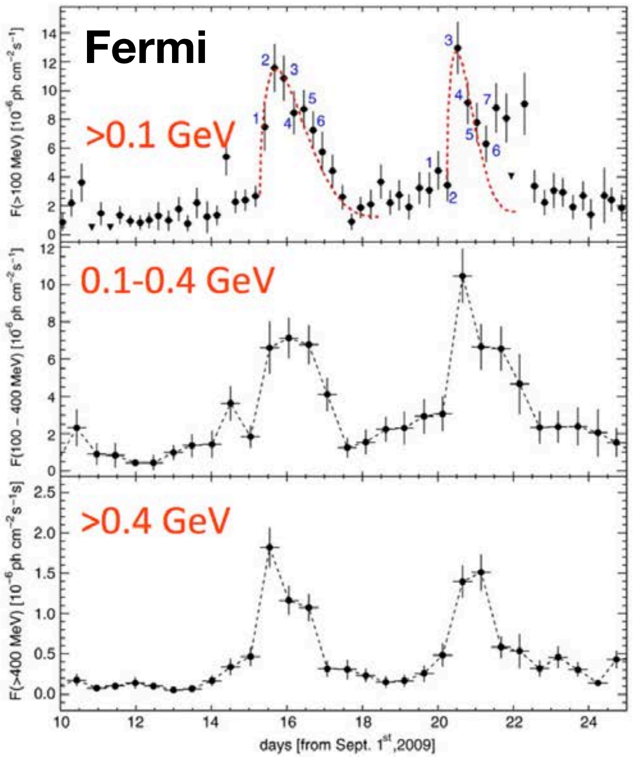
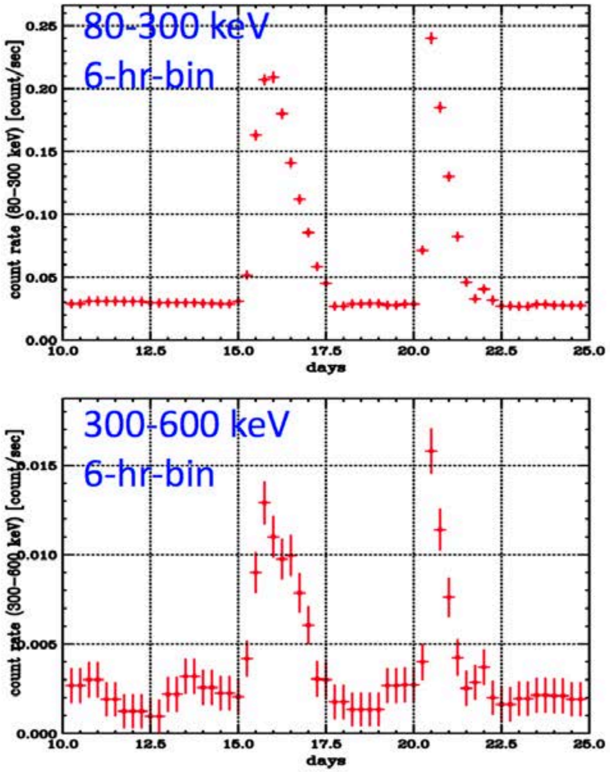




Jet/Outflow Launching Feedback

Abdo et al. 2010

SGD simulation

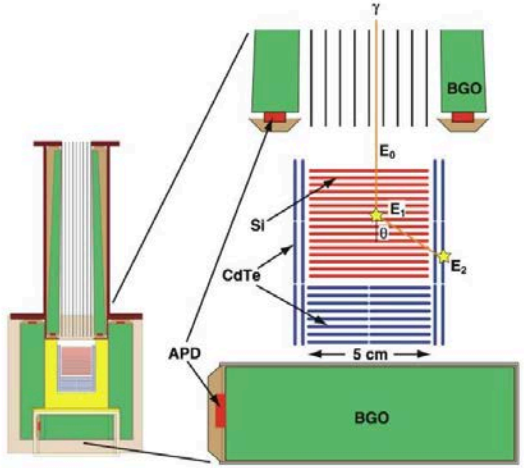
Gamma-ray Detector onboard ASTRO-H

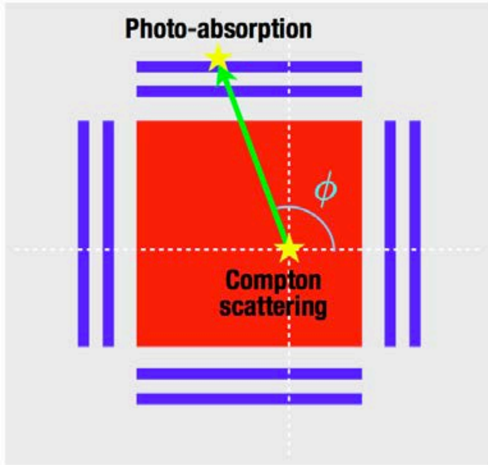
Energy dependent polarization measurement from

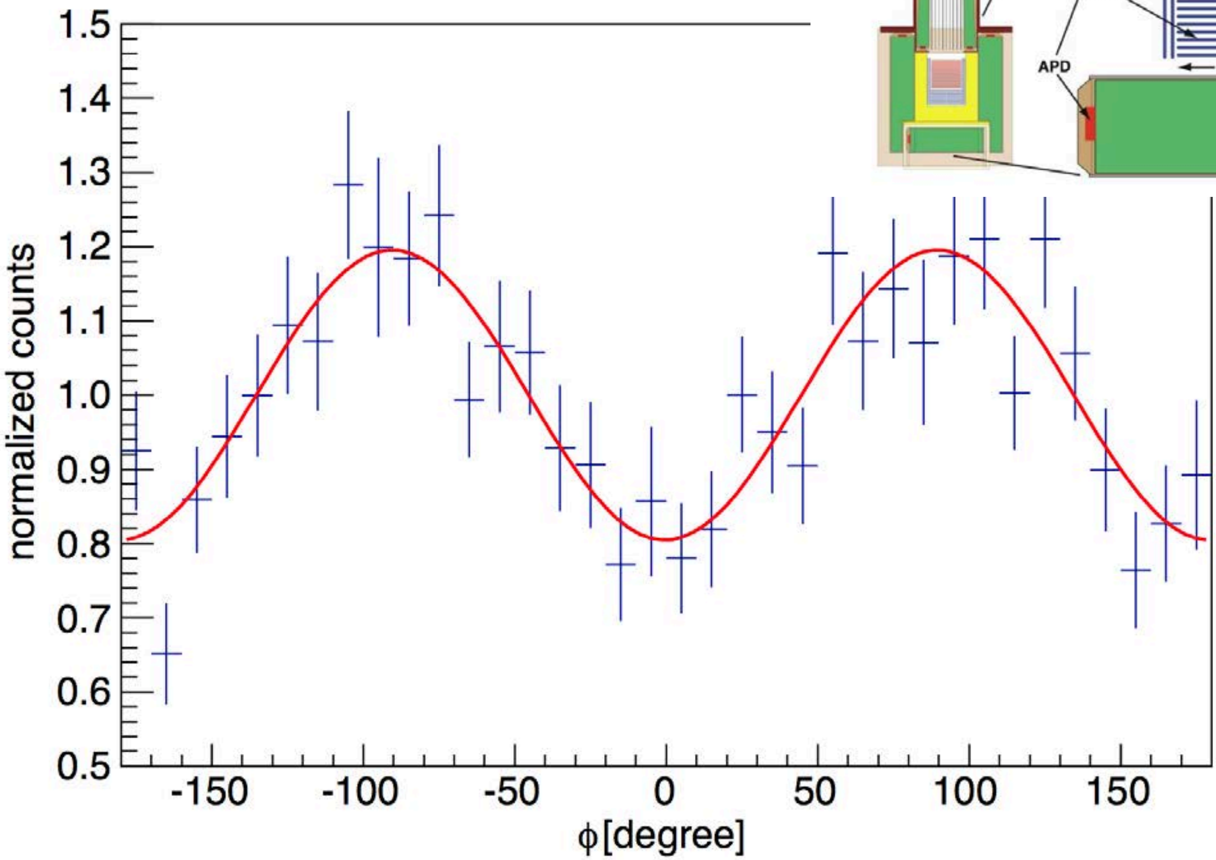
Crab Pulsar/Nebula

Microquasars

Blazars







Mrk 501 (Outburst)

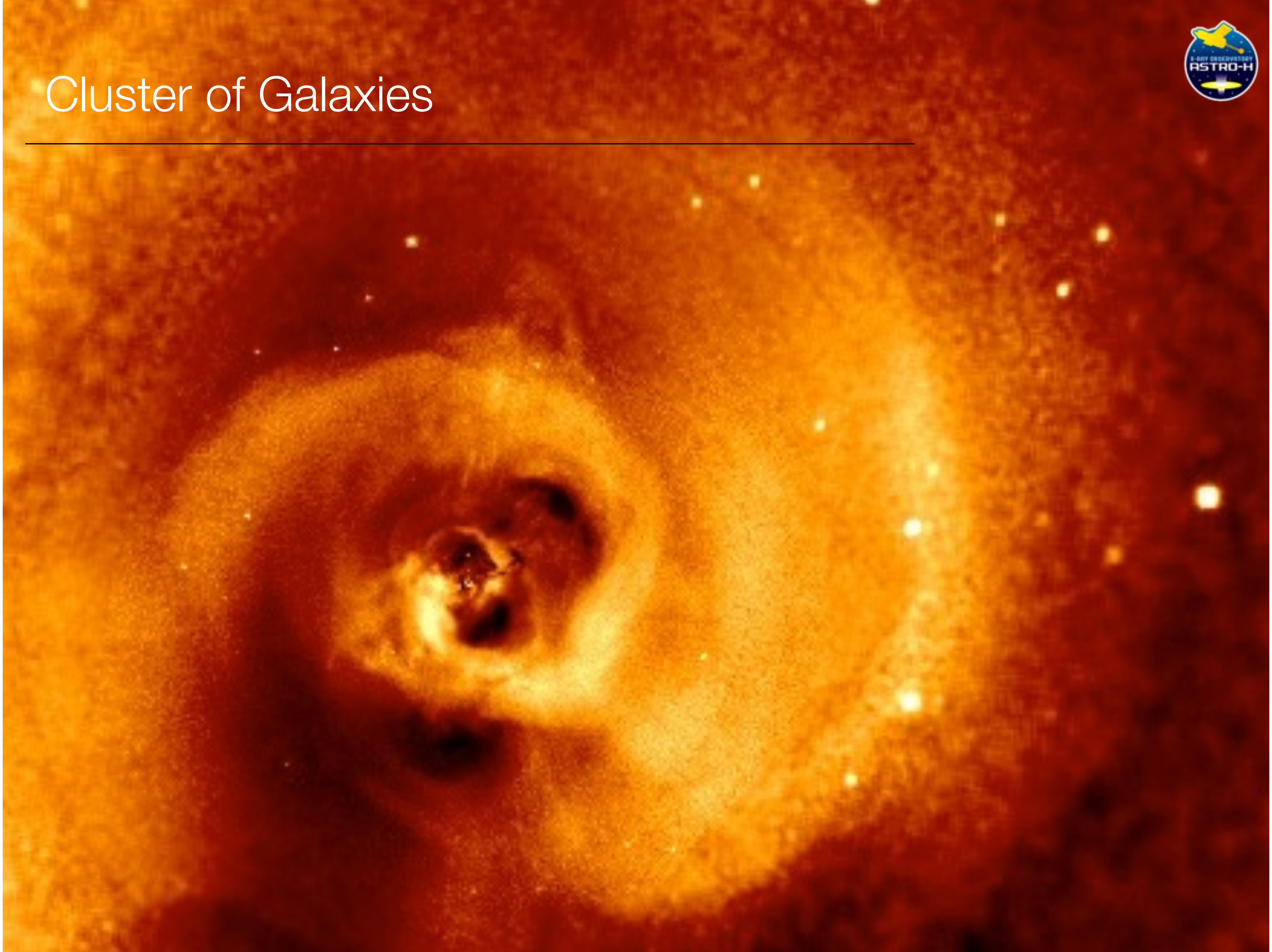
60-100 keV energy band

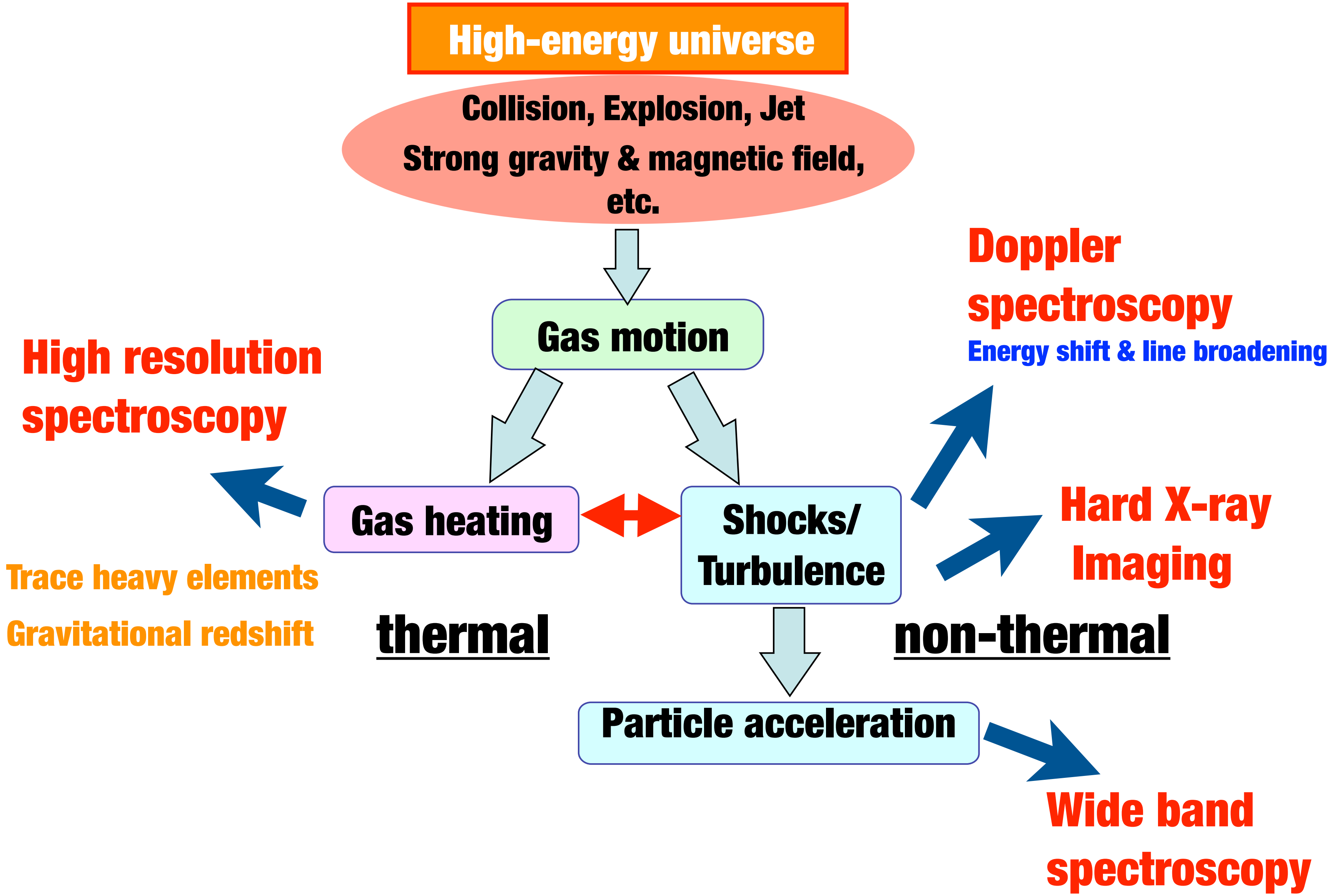
$F_{13\text{-}200keV}$=16 x 10^{-10} erg/s/cm^2

Degree of polarization 30 %

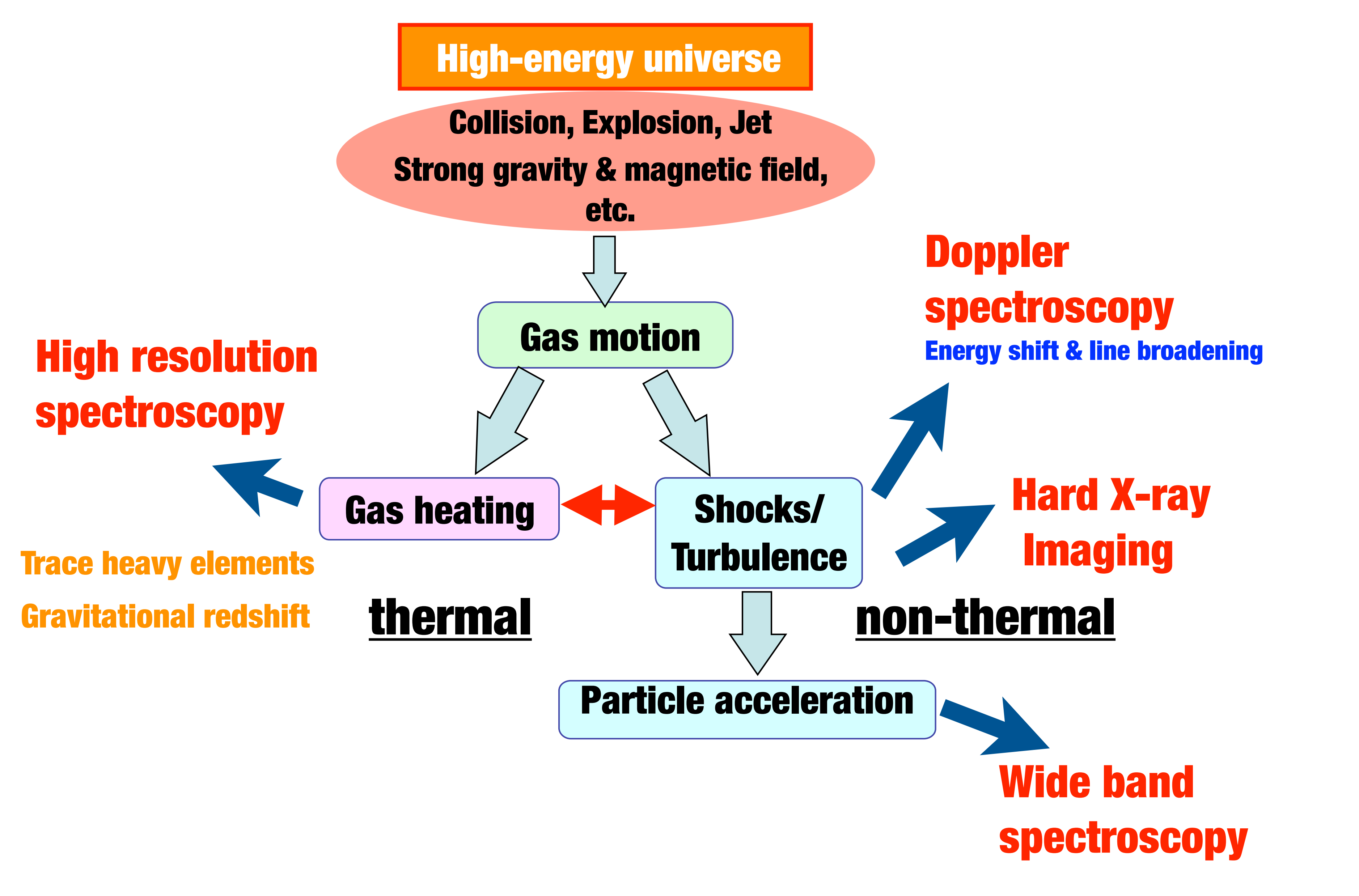
From ASTRO-H White Paper (Broad band Spectroscopy and Polarimetry) L. Stawarz et al.

Cluster of Galaxies

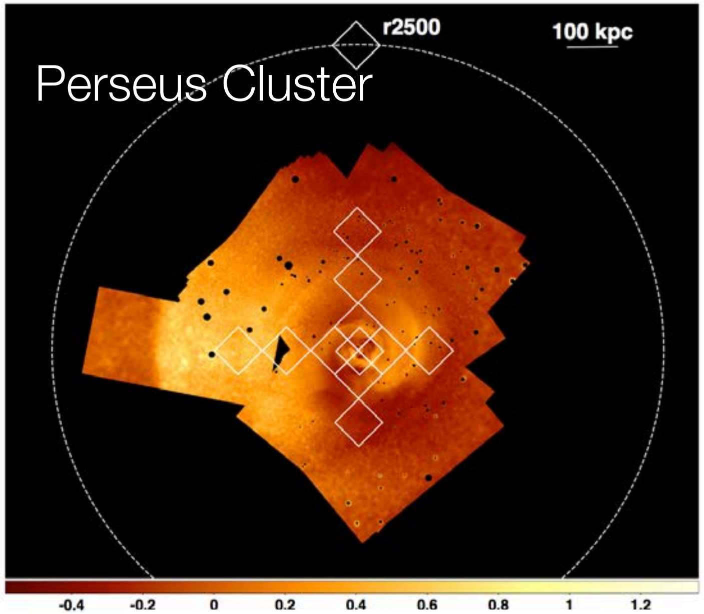



High-energy universe
Collision, Explosion, Jet
Strong gravity & magnetic field, etc.
Gas motion
High resolution spectroscopy
Gas heating
Shocks/ Turbulence
Doppler spectroscopy
Energy shift & line broadening
Hard X-ray Imaging
Trace heavy elements
Gravitational redshift
thermal
non-thermal
Particle acceleration
Wide band spectroscopy

Cluster of Galaxies



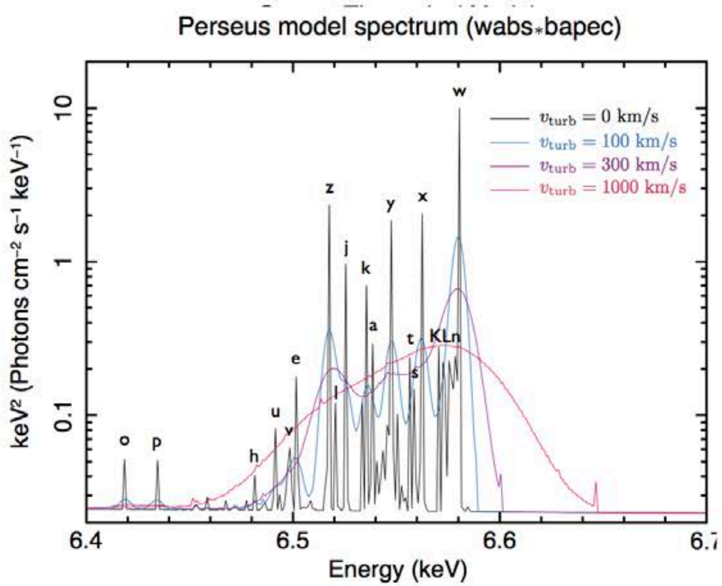
Turbulent and bulk motions in Cluster of Galaxies

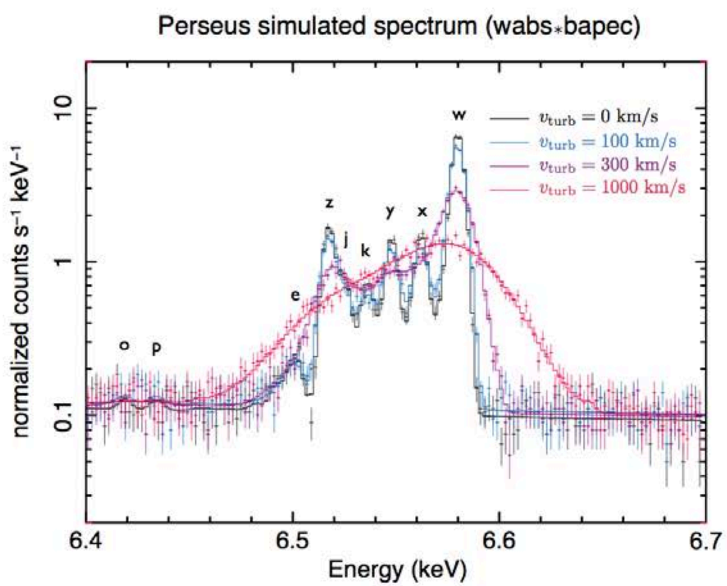


ASTRO-H can obtain dynamical information about the ICM from line shifts, widths

First ever probe of:

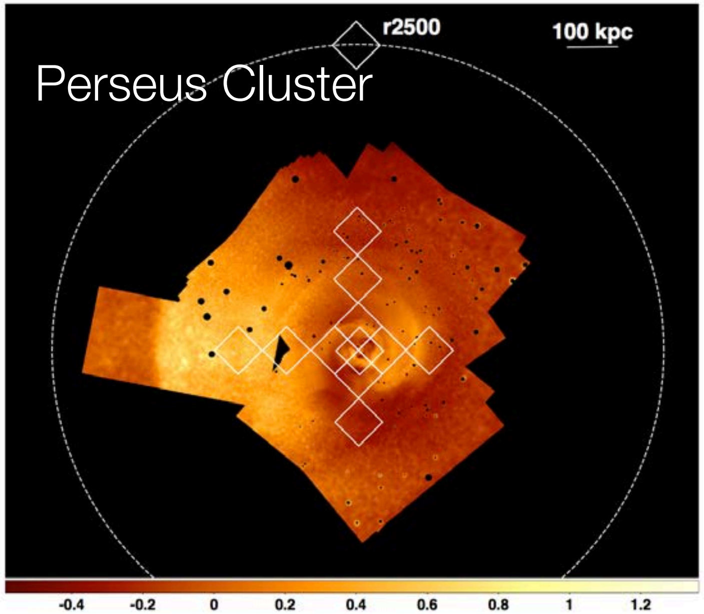
- plasma viscosity
- turbulent pressure support
- merger dynamics
- motions induced by AGN feedback

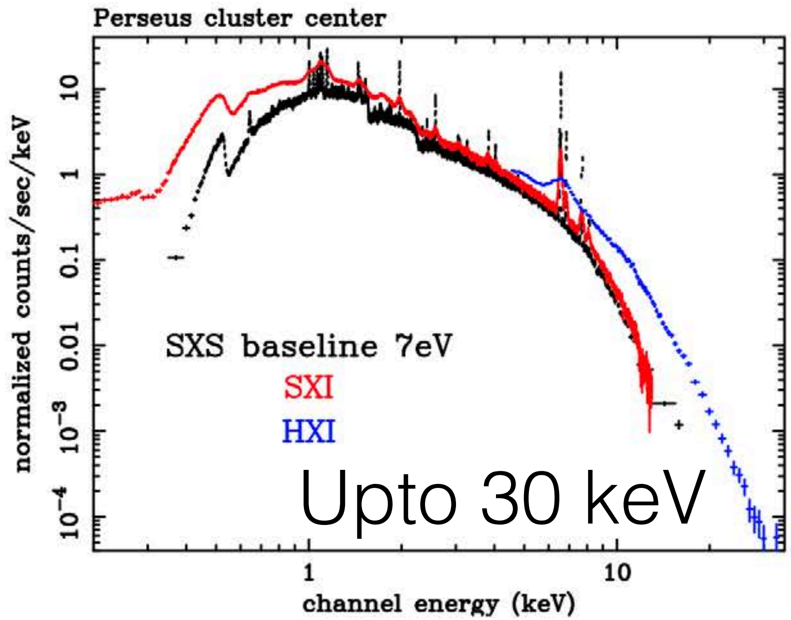


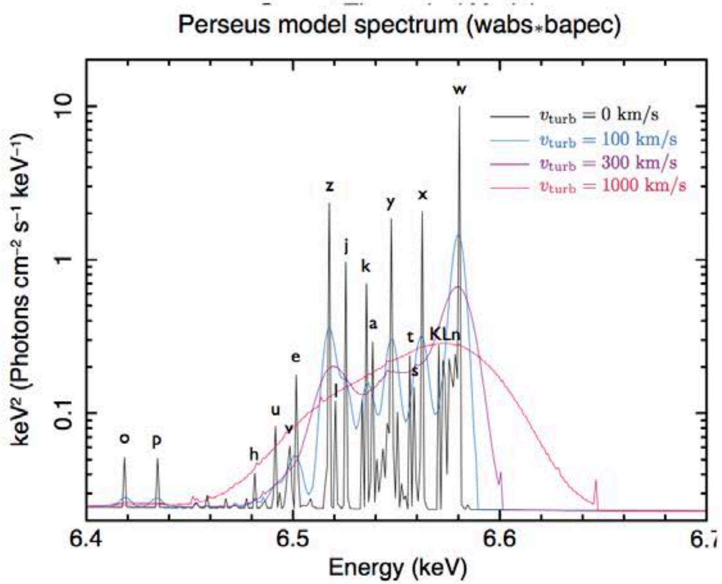


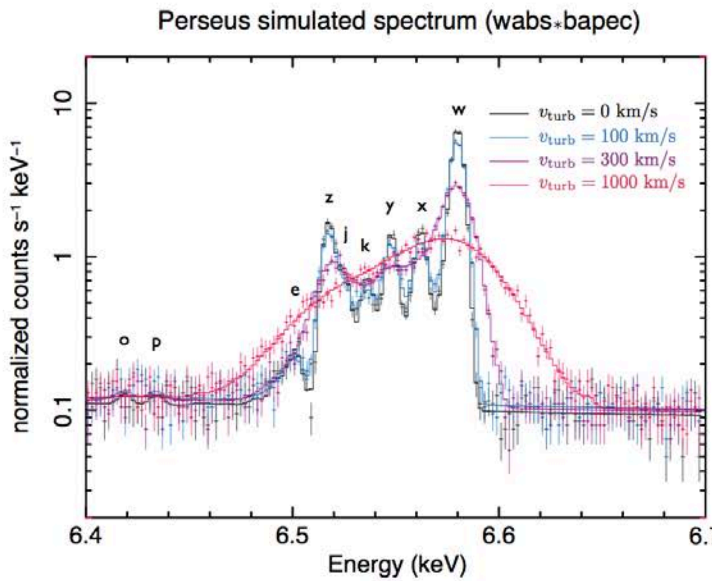
From ASTRO-H White Paper (Cluster related science) S. Allen, T. Kitayama, M. Markevitch et al.

Turbulent and bulk motions in Cluster of Galaxies









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

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. Wide-band observations from 0.3 keV-600 keV are important to constrain non-thermal electron spectra.
2) 7eV energy resolution of SXS/ASTRO-H gives strong constraint on thermal emission.
3) Synergy with VHE gamma-ray observatories, such as CTA, is obviously important. Truly simultaneous observations are crucial for blazar-type objects. Observations in faint phase with comparable sensitivity are important to understand the nature of blazer jet.

ASTRO-H International Team

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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

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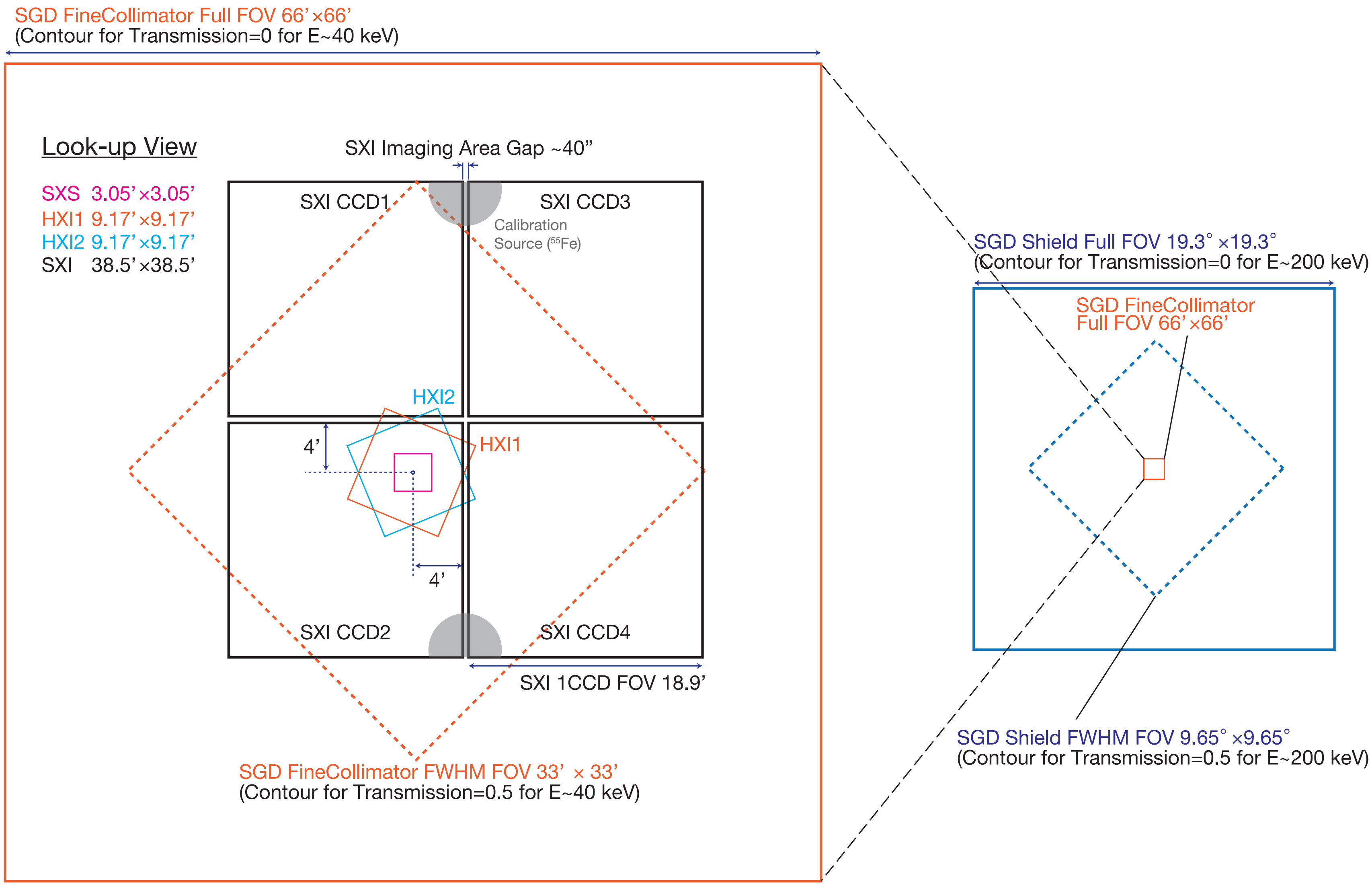
A. Appendix

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)