The Next Generation X-ray Satellite: ASTRO-H

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1. Introduction of X-ray astronomy

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1. What is X-ray astronomy ??

1.1. Why we observe X-ray sky ??

X-ray: ~0.1 keV - 100 keV
(10A - 0.01A)

X-ray observations show us the hot and extreme universe.

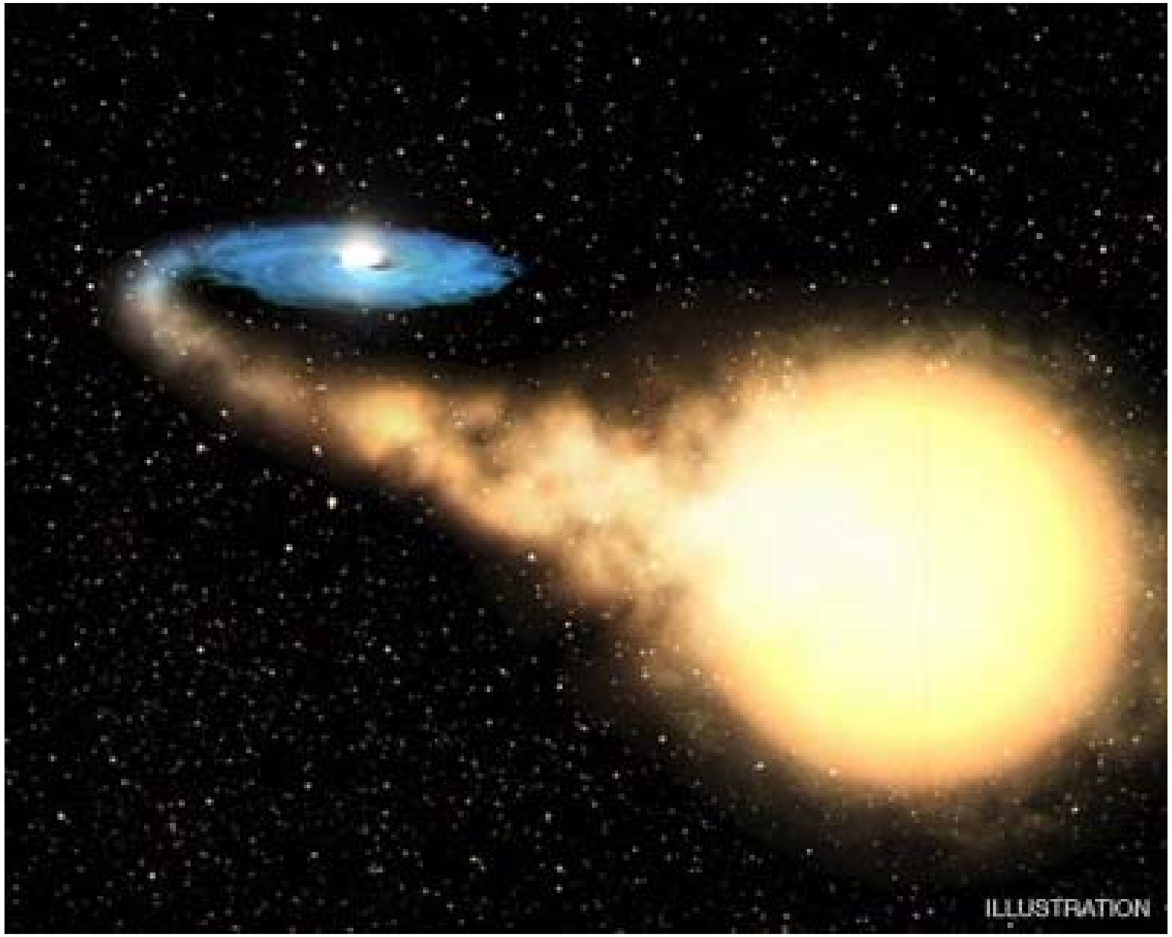
Thermal emission: black body, bremsstrahlung
-> 10^6 - 10^8 K plasma condition
temperature, density, thermal E, ...

Synchrotron: from ~TeV electrons in interstellar B

Line emission: characteristic X-ray lines
amount and condition of heavy elements

1.2. What can we see in X-rays ?

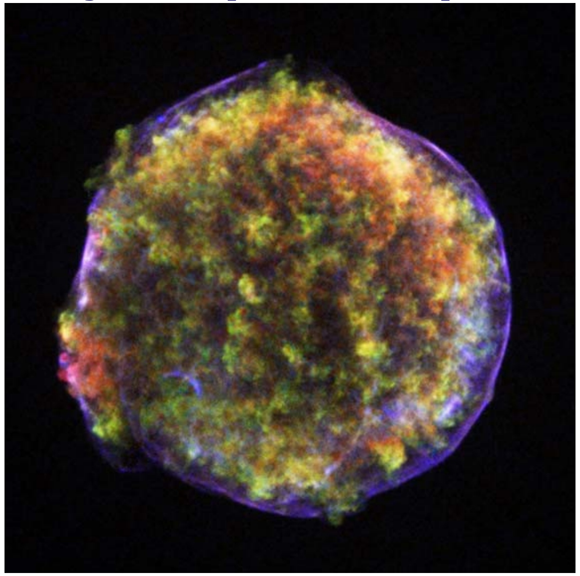
Accretion disks of NS/BH



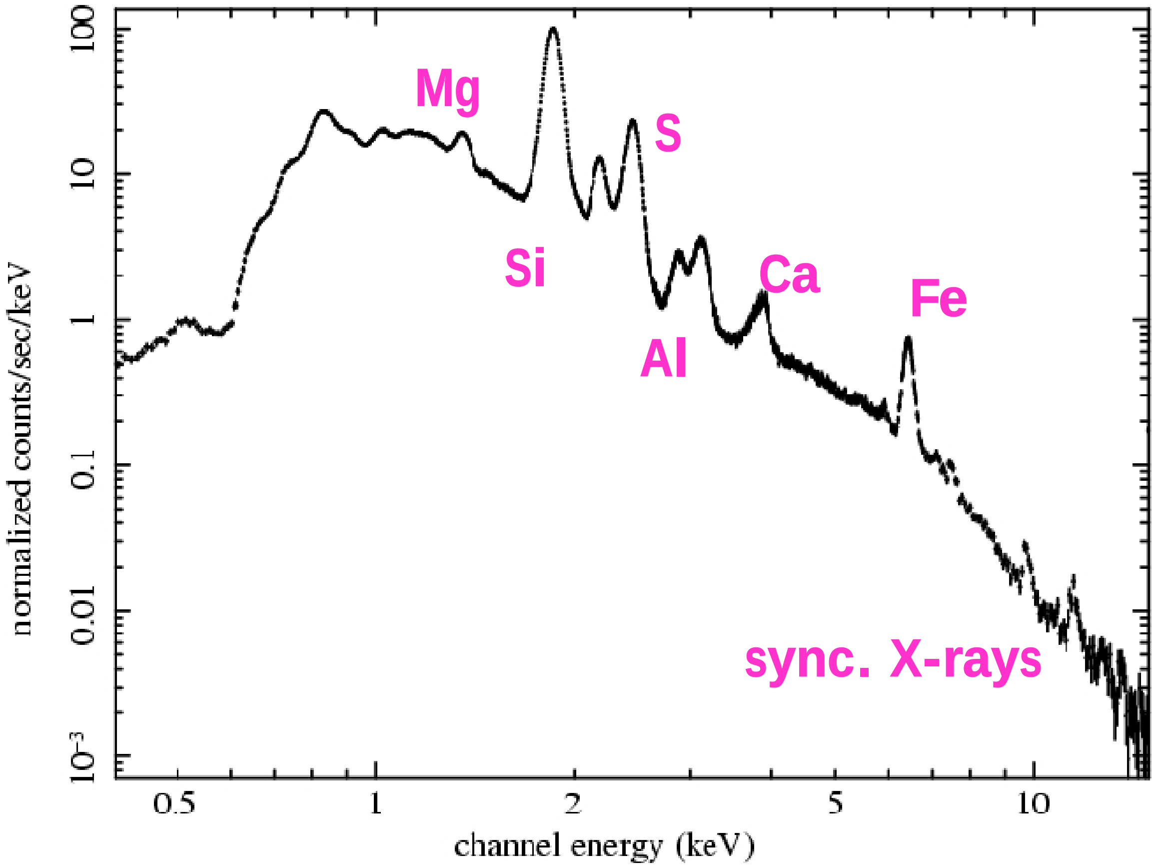
Accreted matter heats up to $10^{7\text{-}8}$ K coverted from the gravitation energy ➡ **the first observational probe of BH**

Supernova remnants

Tycho (Chandra)



Suzaku spectrum



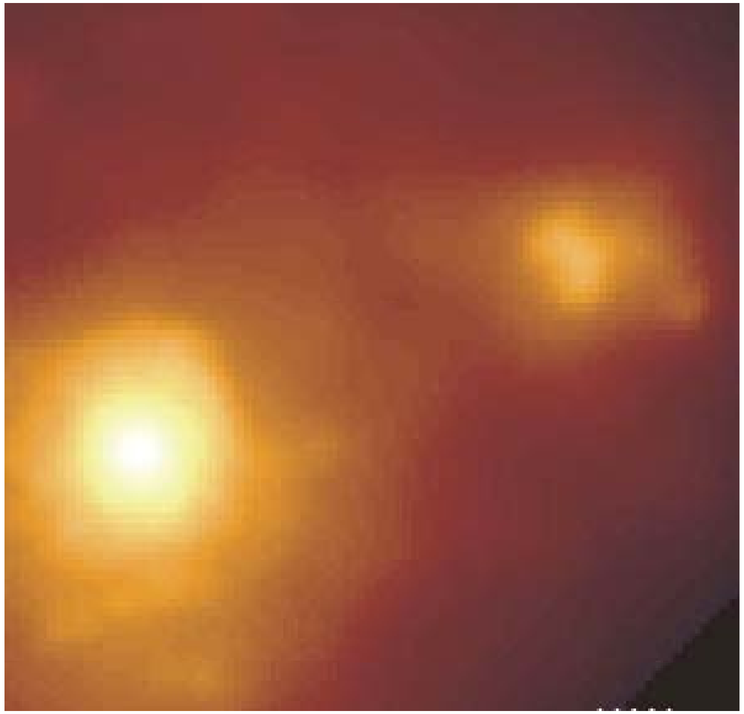
We can resolve characteristic lines from heavy elements.
-> nucleosynthesis, explosion mechanism

Cluster of galaxies

optical image of a cluster

more than 100 galaxies
and empty space

X-ray image of a cluster



$10^{7\text{-}8}$ K thin plasma
heavier than galaxies

gasses are contained in the well of the gravitational potential by dark matter

-> good tracer of dark matter

2. ASTRO-H satellite

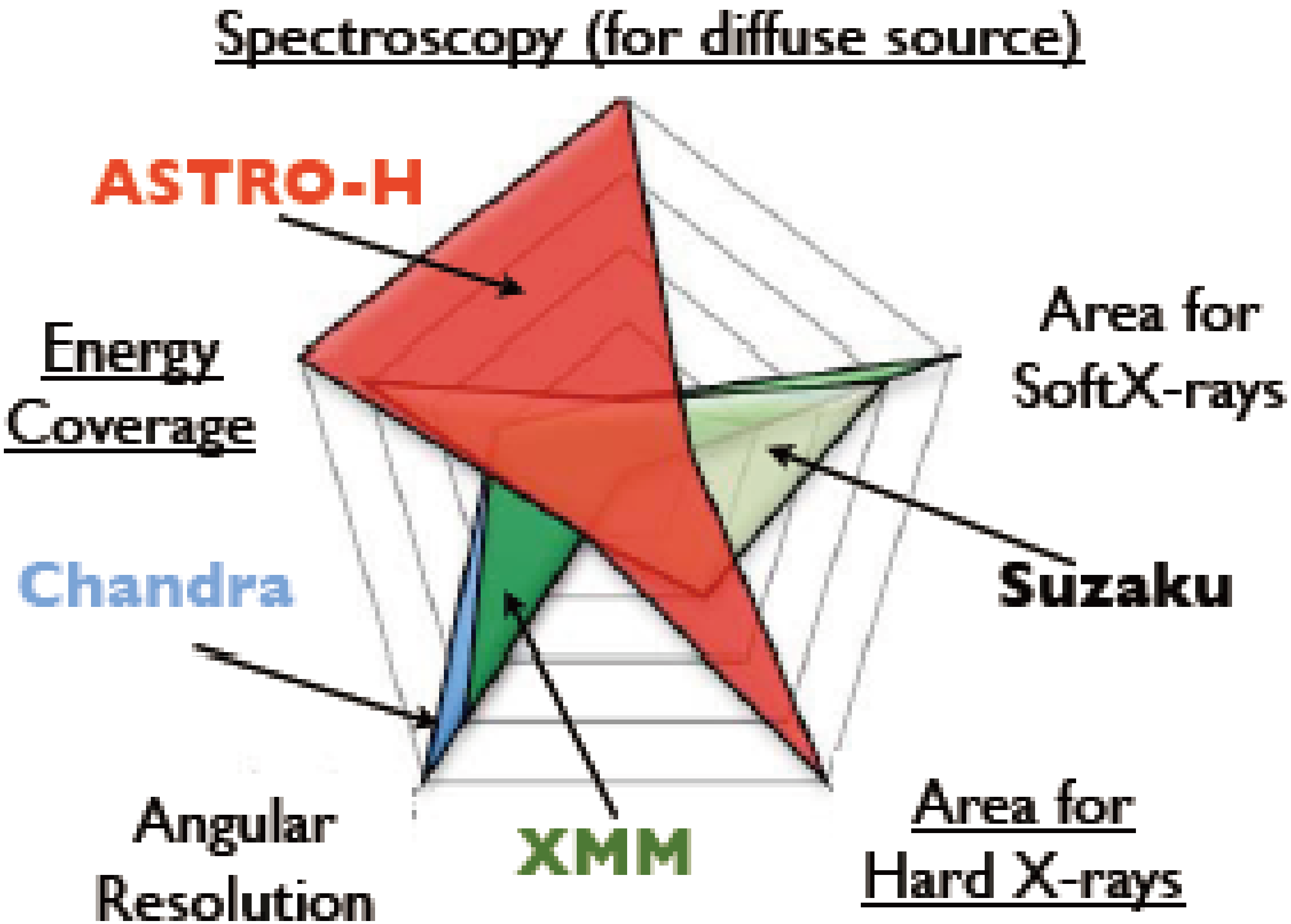
2.1.1. Overview of ASTRO-H

Focal length of HXT is 12 m
-> Optical bench will be extended
after the launch.

mass:	2.6 t
length:	14 m
orbit:	low earth orbit (550 km)

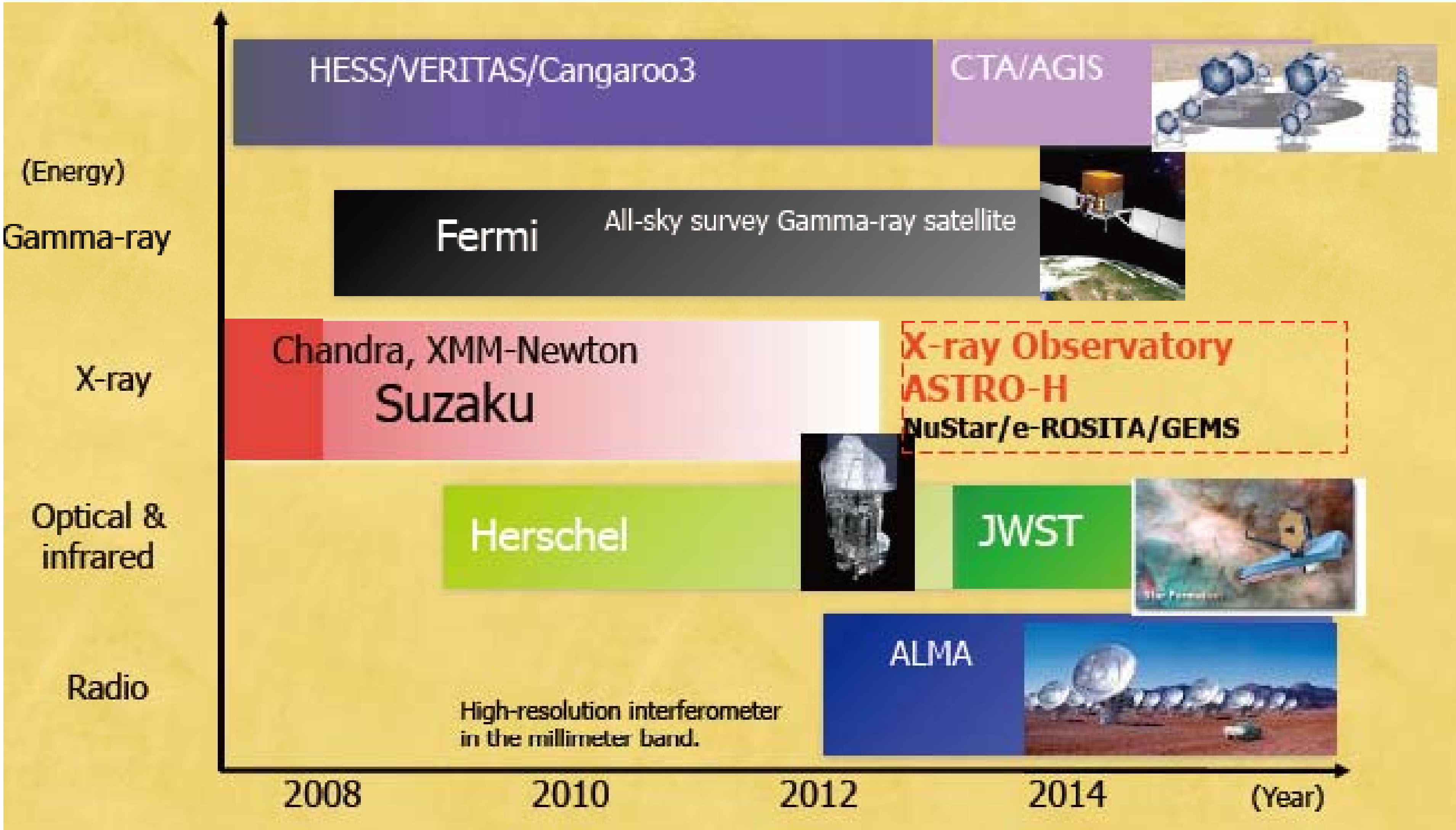
Launch: 2014
(planned)

Comparison between other X-ray observatory



We will achieve high quality observations previous mission never achieved.

2.1.3. ASTRO-H in the world astronomical society



We are now in the golden age of X-ray astronomy.
In the next decade, ASTRO-H will be the only X-ray observatory.
ASTRO-H will have proposal system.

ASTRO-H member institutes

JAXA, NASA, Aoyama Gakuin U., Cambridge U., CEA/DSM/IRFU, CfA/Harvard, Chubu U., Chuo U., Columbia U., Dublin Institute for Advanced Studies, Durham U., Ehime U., ESA, Gunma Astronomical Observatory, Hiroshima U., Kanazawa U., Kobe U., Kogakuin U., Kyoto U., Michigan U., MIT, Miyazaki U. MPIK, Nagoya U., Nara Women's U., Nihon Fukushi U., Nihon U., NIMS, Osaka City U., Osaka U., RIKEN, Rikkyo U., Rutgers U., Saint Mary's U., Saitama U., Shibaura Inst. Tech., SRON, Stanford U./KIPAC, STScI, Toho U., Tokyo Inst. Tech, Tokyo Metropolitan U., Tokyo Science U., Tsukuba U., U. Geneva, U. Maryland, U. of Tokyo, Waseda U., Wisconsin U., Yale U.

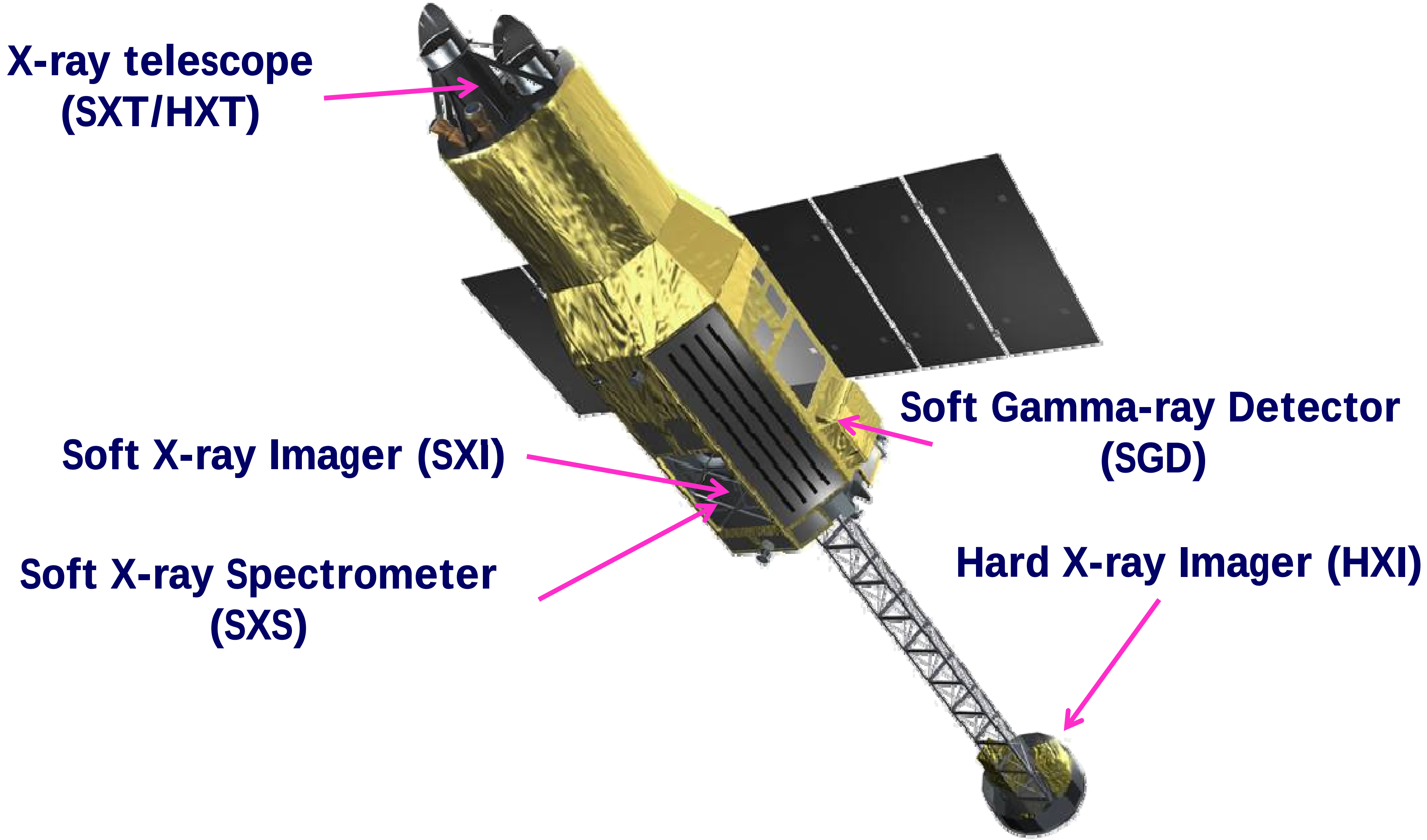
2.1.4. ASTRO-H (official) objectives

Objectives:

1. To observe directly the dynamics and content of clusters of galaxies, which are the largest bound structures in the Universe, and to understand the formation and evolution of such large-scale structures in the expanding Universe.
2. To uncover the hidden super massive black holes at the center of distant galaxies with sensitivity 100 times better than the “Suzaku” satellite. This will give a much better picture of black hole growth throughout the universe, and their role in galaxy formation.
3. To measure the motion in the vicinity of black holes for probing the gravitational twist of space-time predicted by the theory of general relativity.
4. To investigate the physical conditions at the sites of high-energy (cosmic-ray) particle acceleration, towards elucidating the processes that convert energy from gravity, collisions, and explosions to accelerate these particles.
5. To derive the total mass and distribution of dark matter in clusters of galaxies at different distances (ages) towards understanding the role of dark matter and dark energy in the evolution of these clusters.

Visit http://astro-h.isas.jaxa.jp/ !!!

2.2. Detectors of ASTRO-H



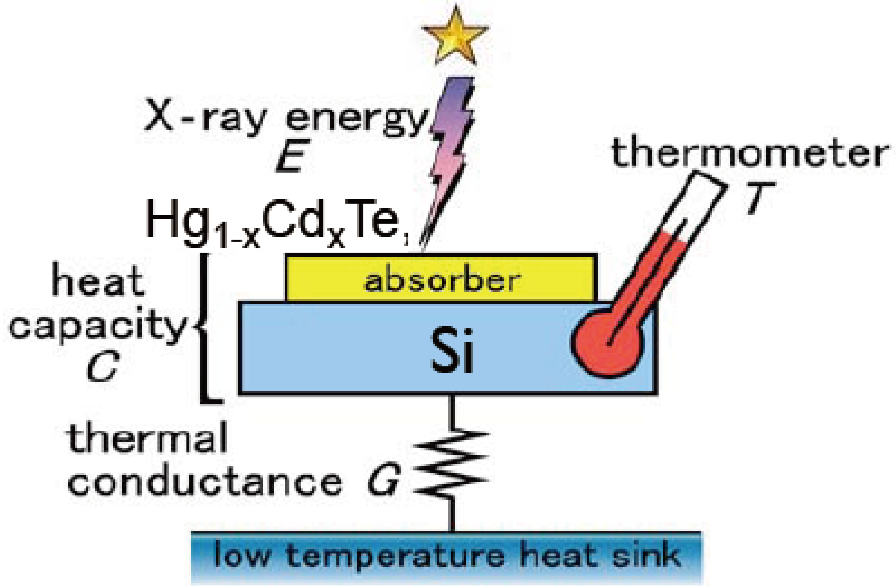
Each detector has strong points compared with previous X-ray missions.

2.2.1. Soft X-ray Spectrometer (SXS)

Principle of the SXS

Measuring the temperature of Si heated by single X-ray photon

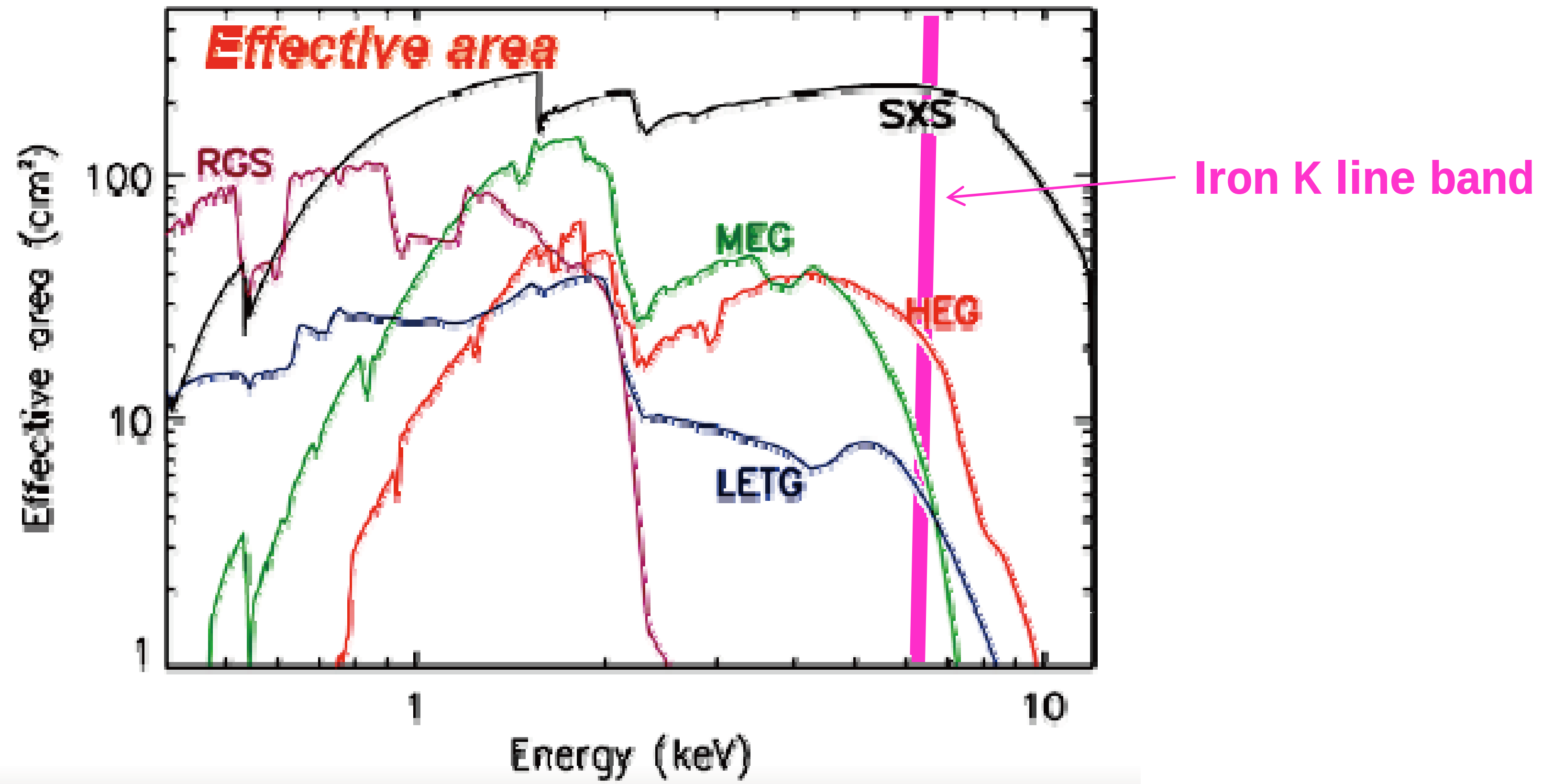
We need very cold environment!
SXS is cooled down to 50 mK.



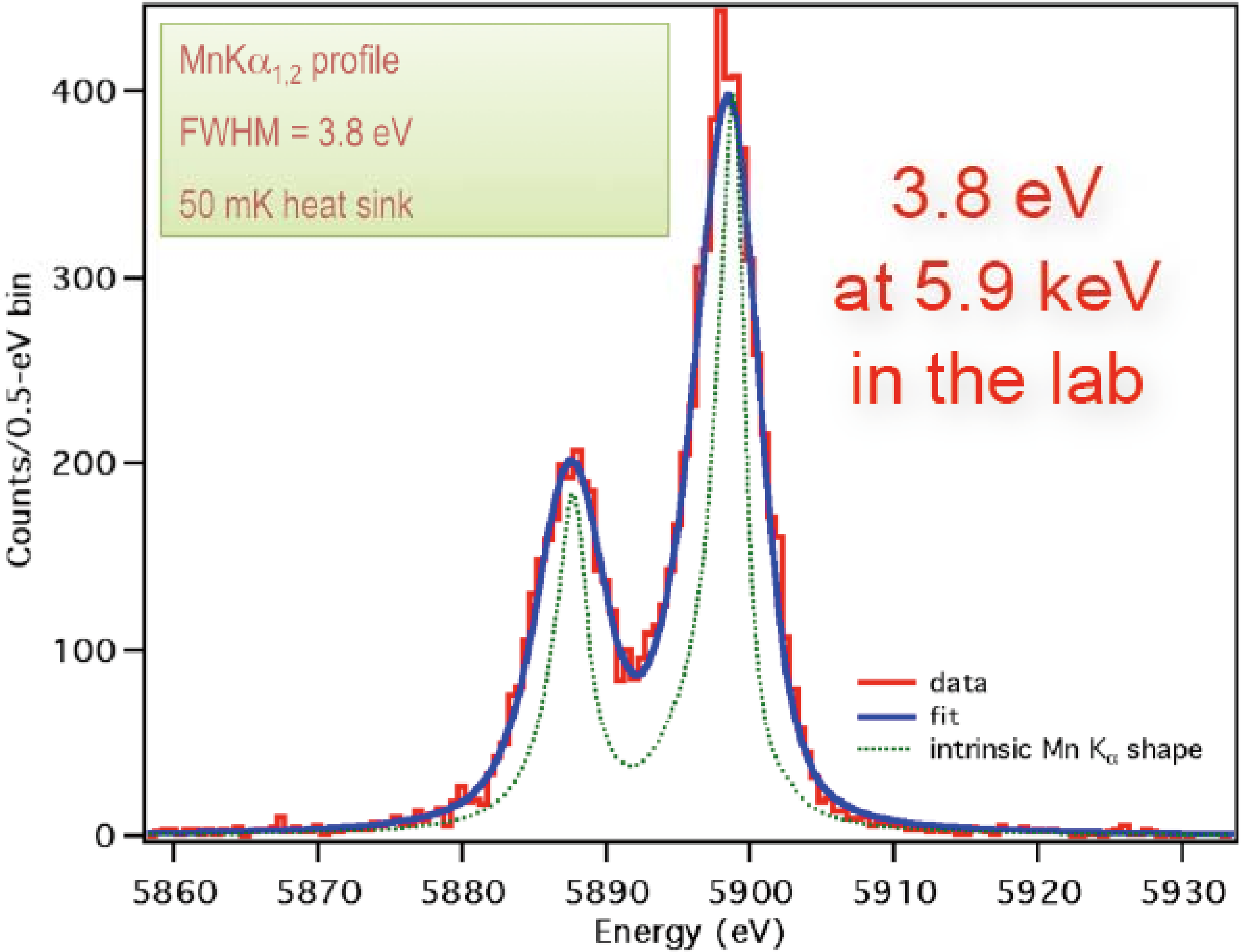
Energy resolution:	**7 eV (Goal: 4 eV)**
Energy range:	**0.3 - 12 keV**
Spatial resolution:	**1.7 arcmin**
Field of View:	**3 arcmin x 3 arcmin**
Effective area:	**210 cm^2 at 6 keV**
Life time:	**> 3 years**

Comparison between grating observations

We can use grating only for point sources.
-> SXS is the only way to achieve excellent energy resolution
for diffuse sources (clusters of galaxies, SNRs, ...)
Grating observation is difficult for higher energy band
-> SXS is the only way to study iron K line (6.4 – 6.9 keV).

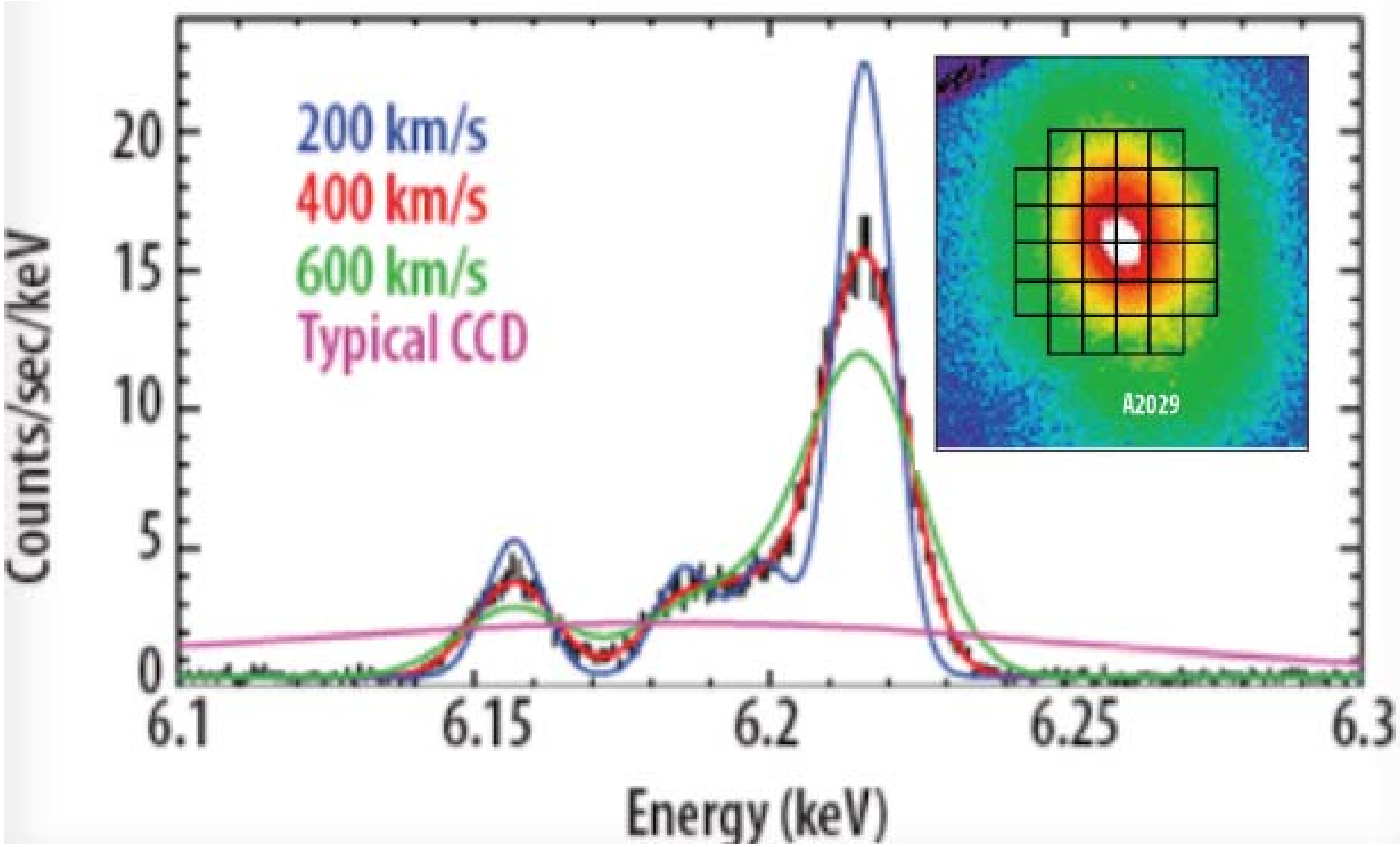


We already achieved the goal energy resolution!



Example of SXS spectrum

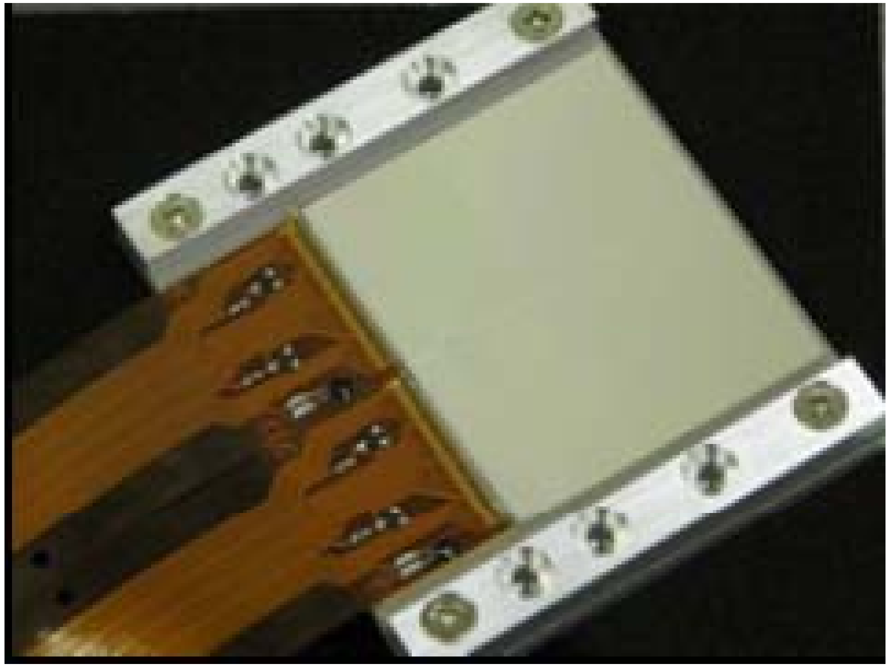
Gasses in clusters of galaxies should have turbulent motion



We can measure the gas turbulence in clusters of galaxies.

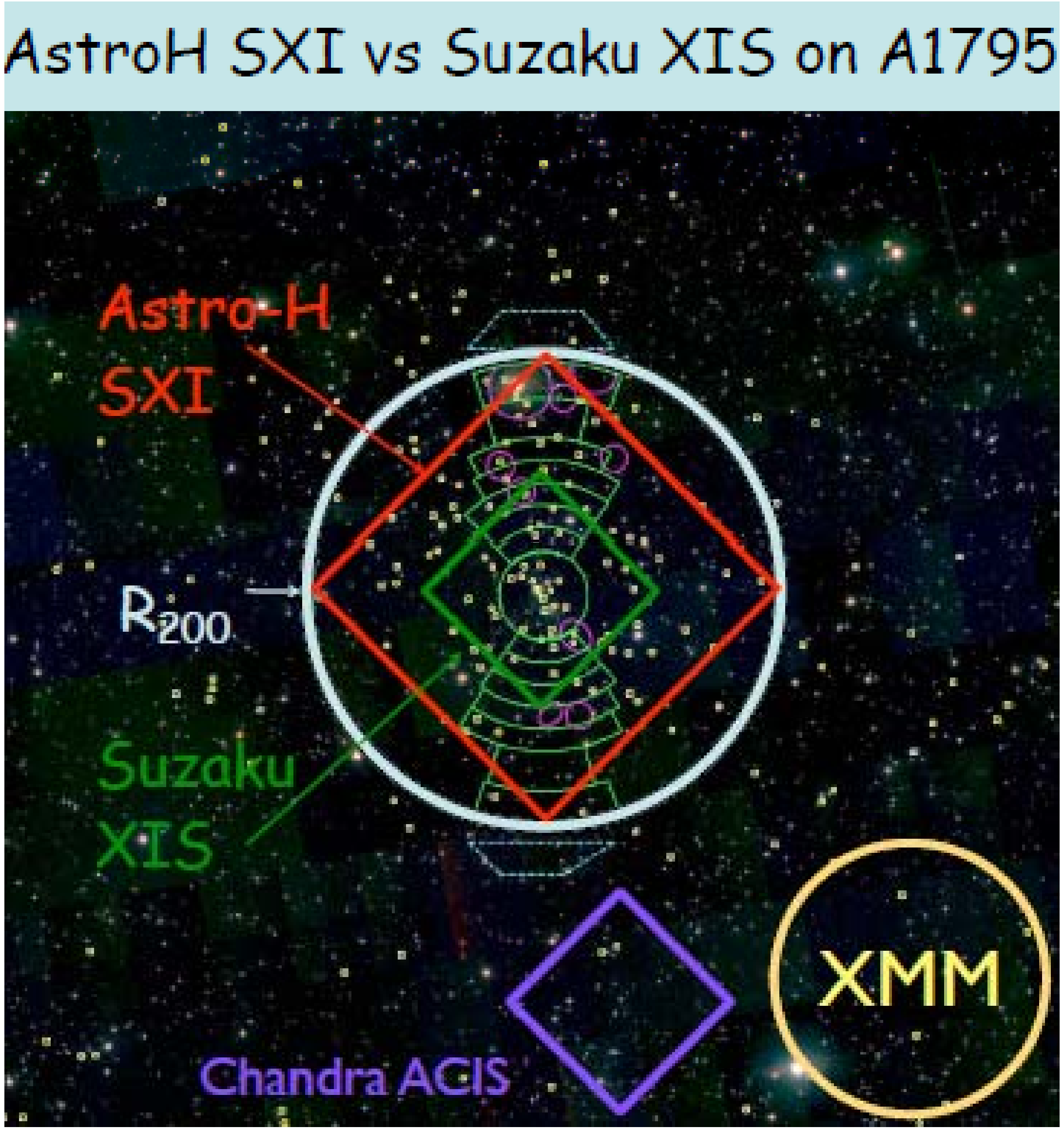
2.2.3. Soft X-ray Imager (SXI)

X-ray CCD developed by Hamamatsu Photonics
Energy band: 0.2 - 12 keV
Energy resolution: ~150 eV @ 5.9 keV
Point spread function: ~1 arcmin (TBD)
The deepest depletion layer of 200 um
-> Large quantum efficiency around 10 keV
Field of View: 38 arcmin -> Widest among X-ray CCDs



X-ray CCD chip by Hamamatsu Photonics

SXI has wide field of view



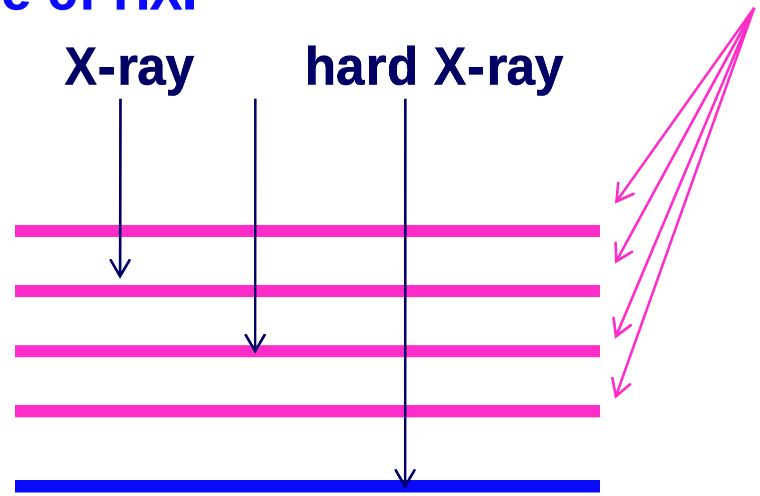
SXI can cover
wide field of view
with single observation

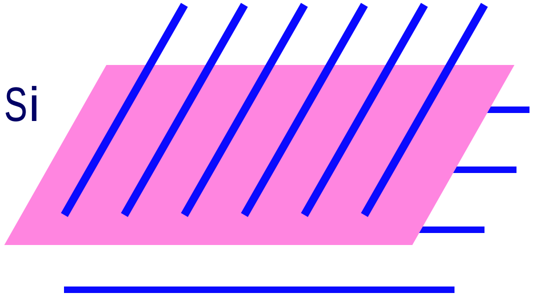
Important for study of
- **clusters of galaxies**
- **supernova remnants**
- **galactic ridge**

....

Helping other detectors
to check contamination
from nearby sources

2.2.3. Hard X-ray Imager (HXI)



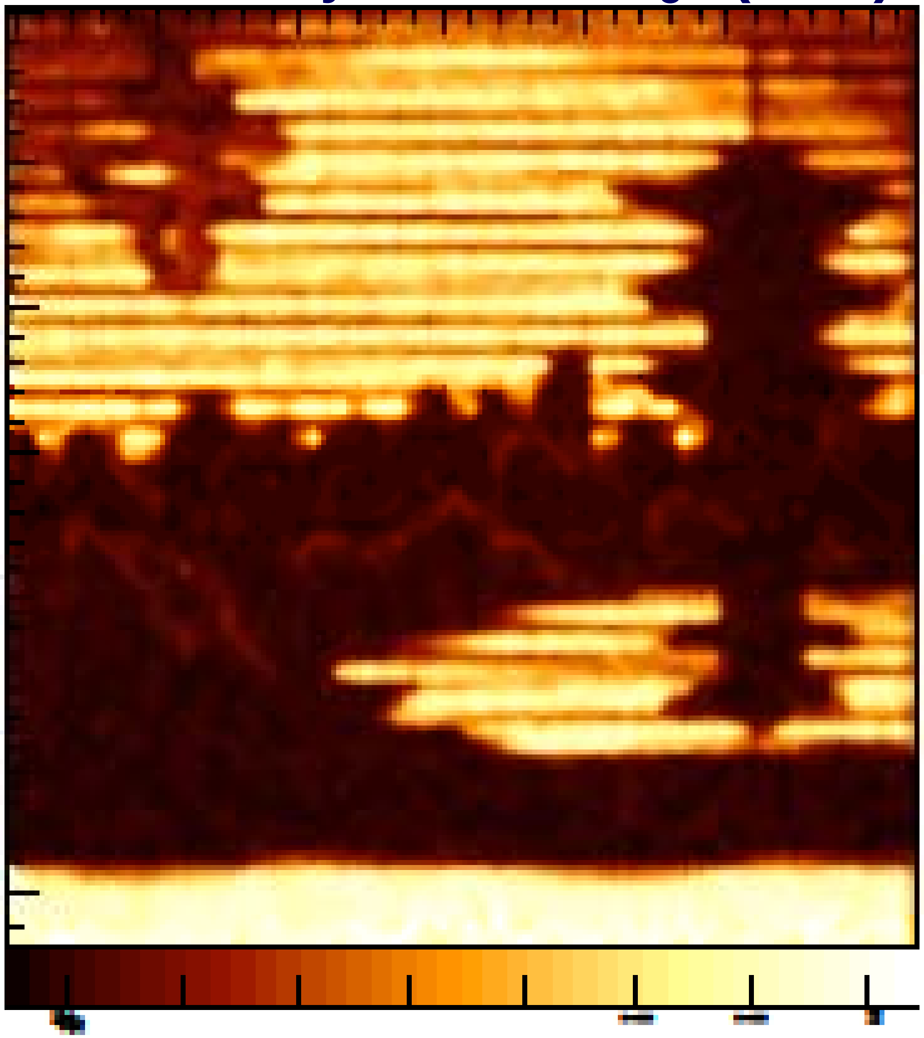


prototype model:
(400 um pitch, 2.6 cmx2.6 cm)

The first fine imaging above 10 keV !!
Double side strips can determine the photon position

We already achieved fine imaging.

30 keV X-ray shadow image (^{133}Ba)

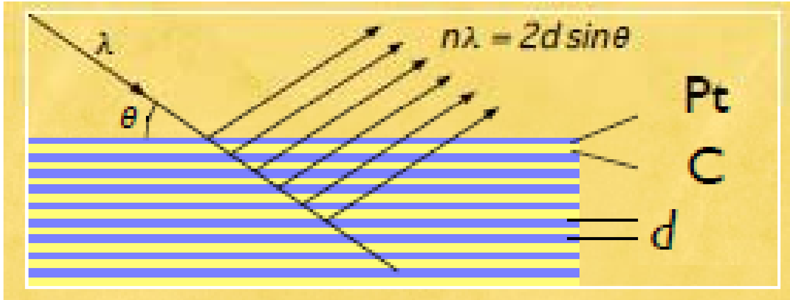


Bookmark(0.3 mm thick brass with gold plating)

Detectors works very well without many dead strips.

2.2.4. Telescope for HXI: Hard X-ray telescope (HXT)

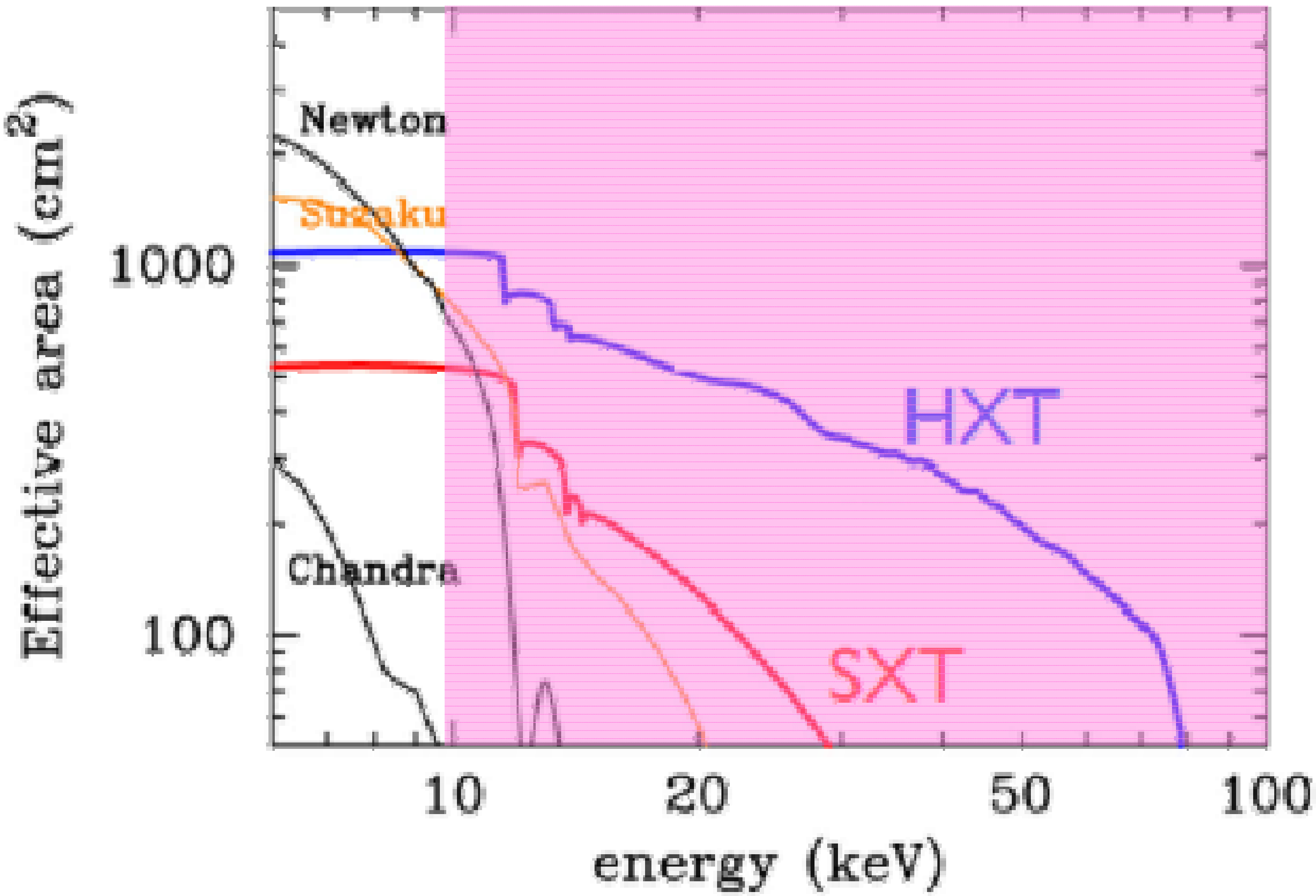
In order to make hard X-ray reflect efficiently, we use multi-layered Pt + C for the hard X-ray mirror.



In order to make the effective area larger, we use thousands of mirror foils.

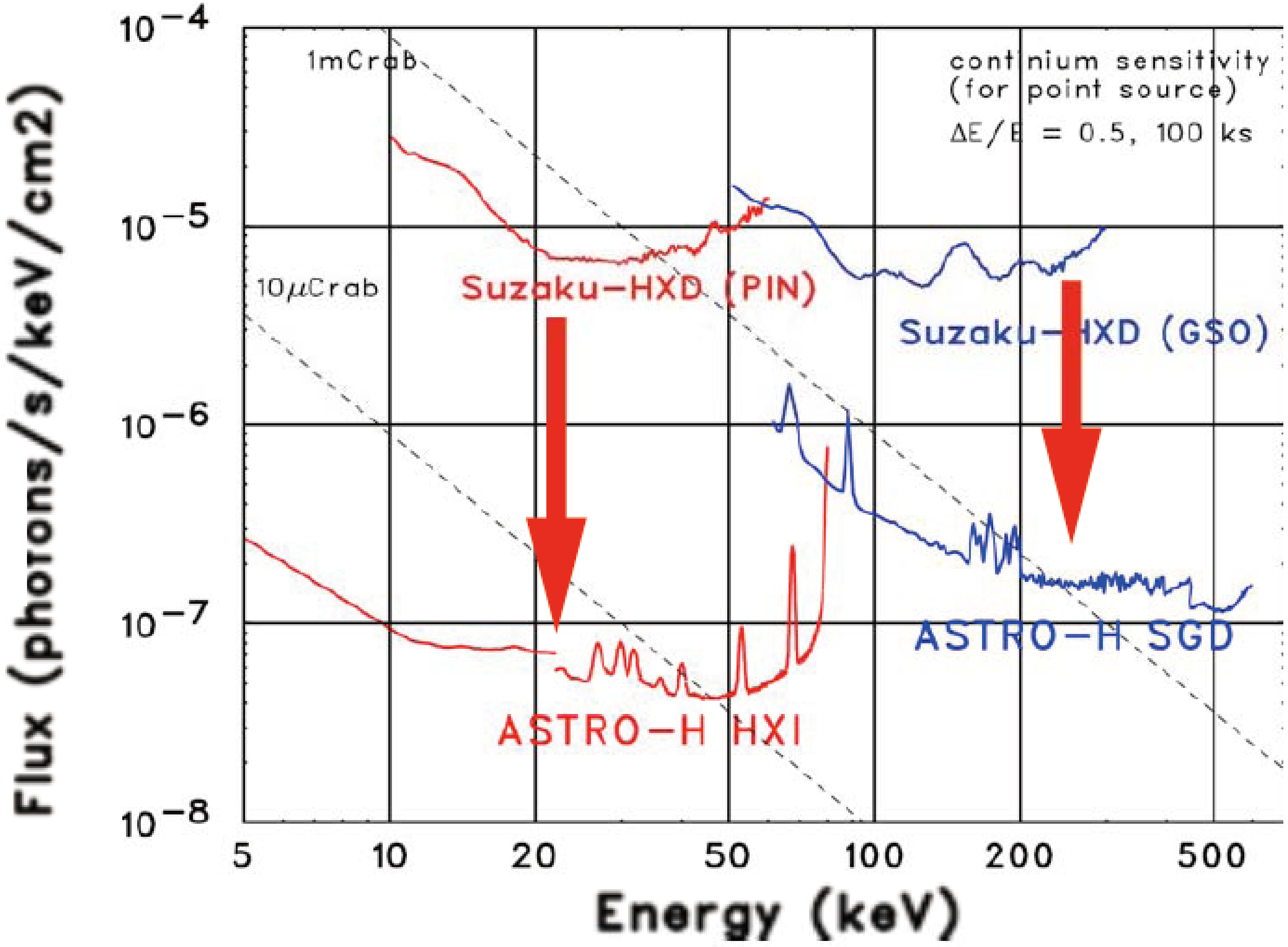
energy range: 5 - 80 keV
Field of view: 9arcmin

Effective area of HXT



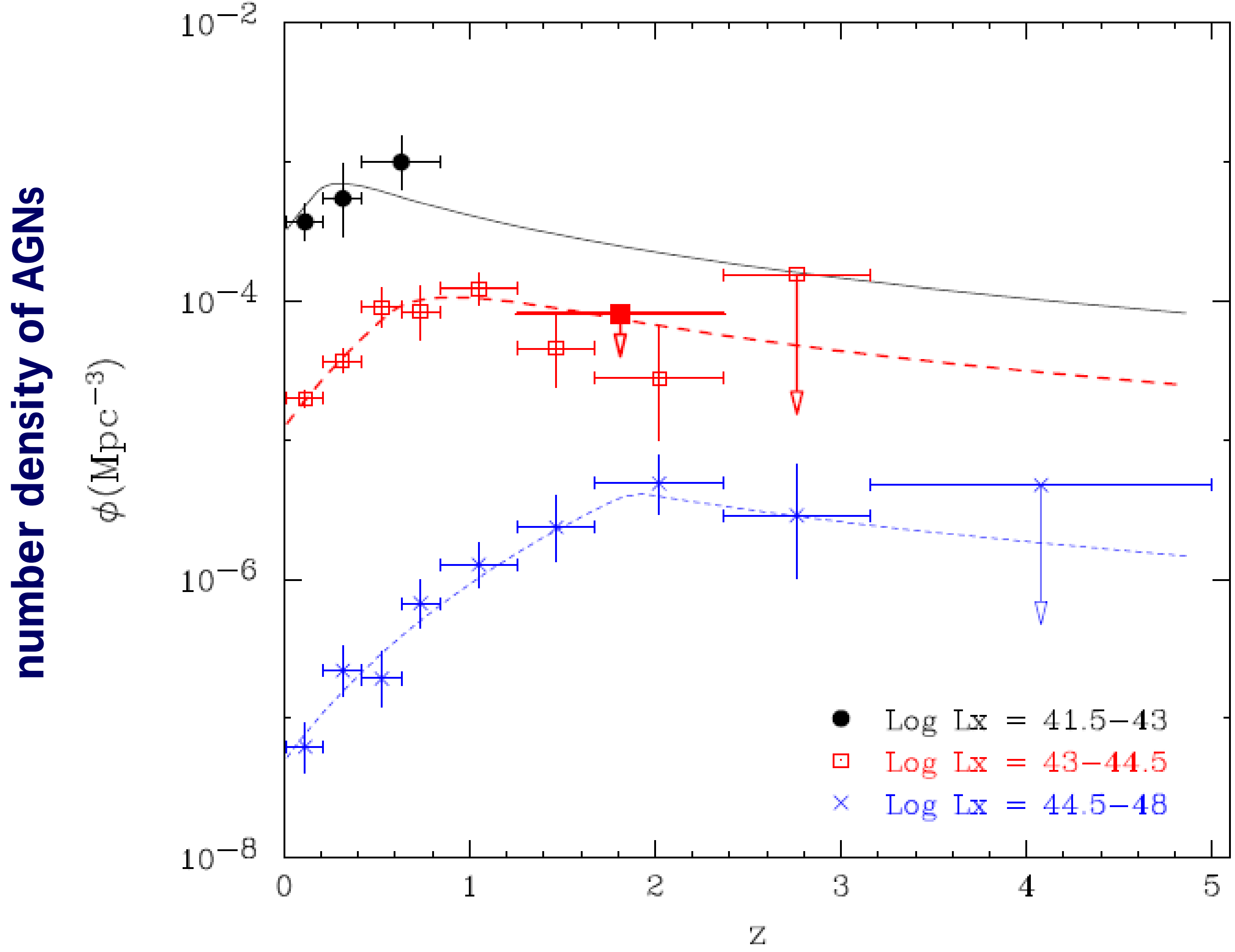
First image above 10 keV with large effective area.
Spatial resolution is ~ 2 arcmin.

Two orders better sensitivity than present satellites.



HXI/HXT will be able to detect distant AGNs.
Half of cosmic X-ray background will be resolved by HXI/HXT.

Excellent sensitivity enables us to see the evolution of AGNs

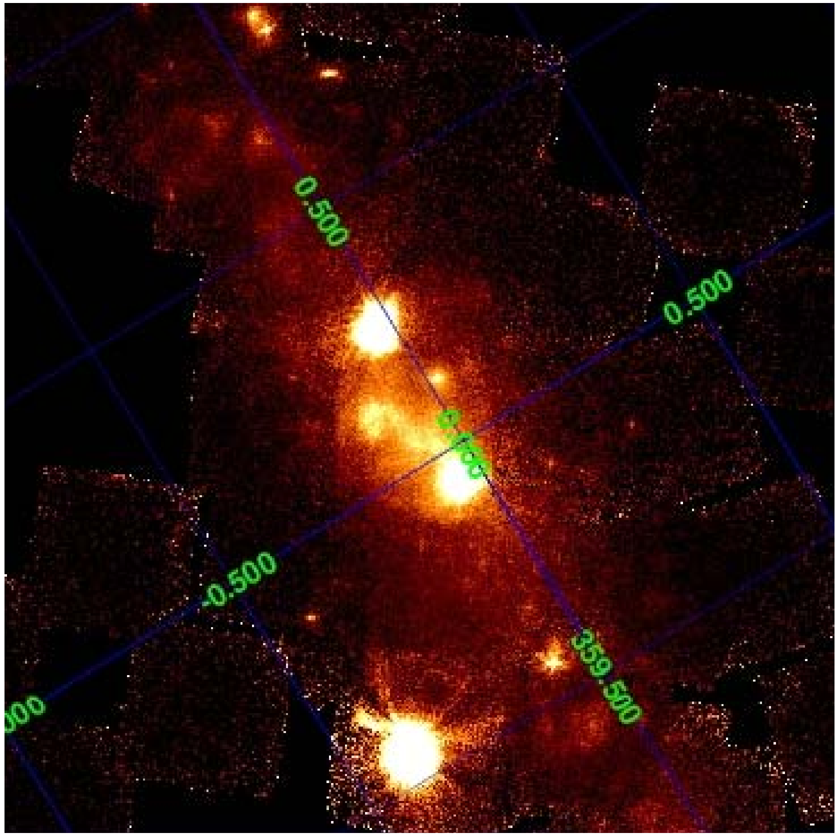


(Ueda+03)

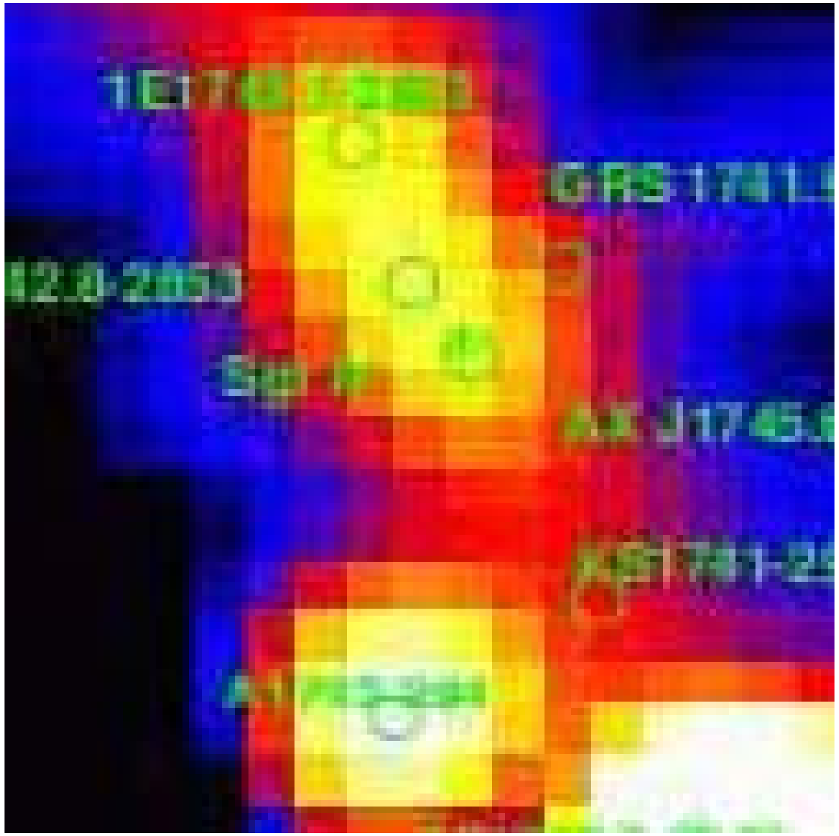
brighter AGNs are formed in earlier universe ?
ASTRO-H sensitivity allows us to see the evolution.

Expected imaging capability

ASTRO-H HXI



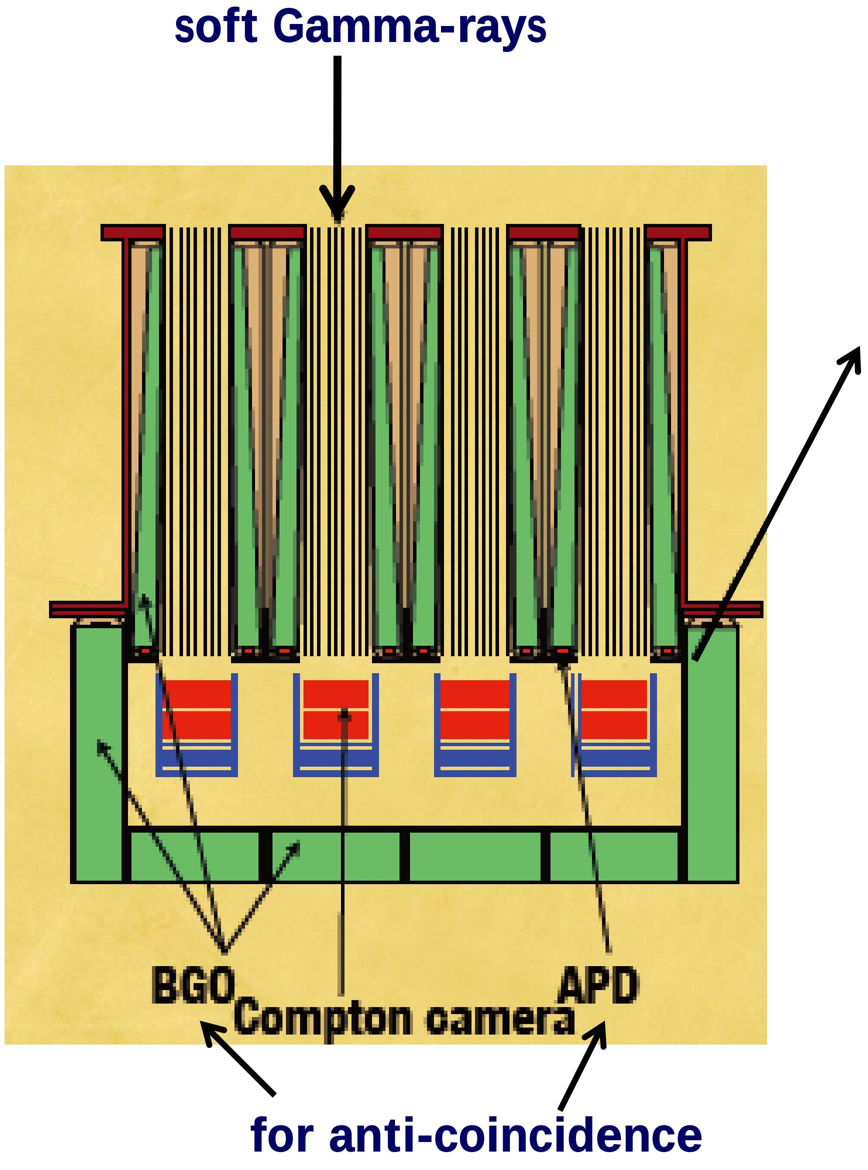
INTEGRAL IBIS



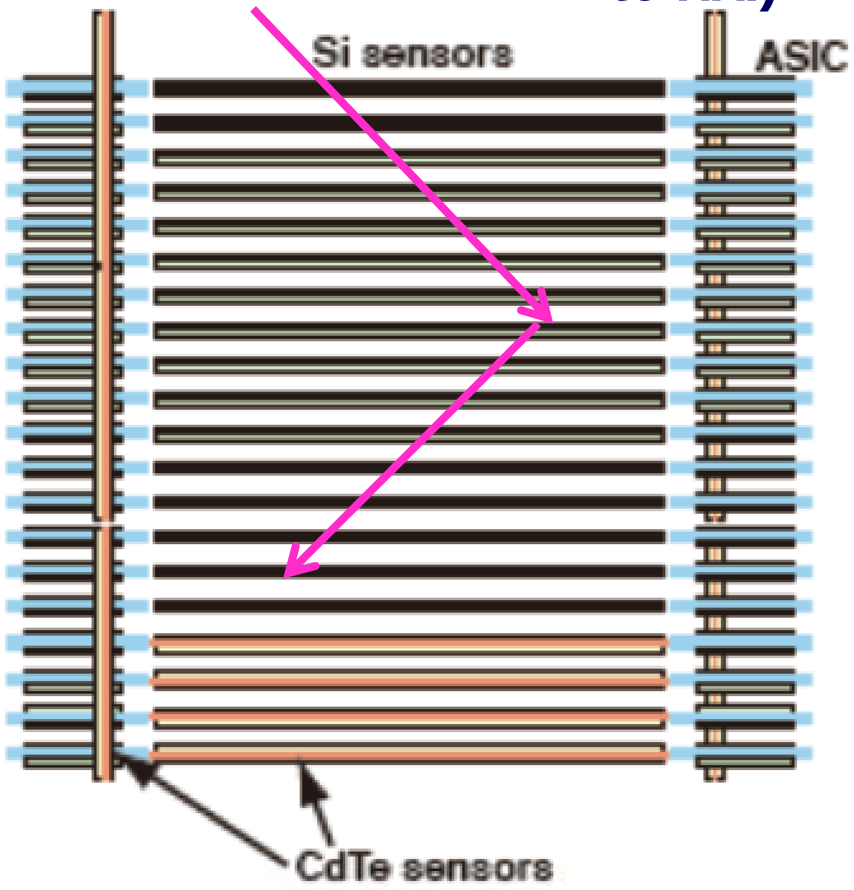
(Revnivtsev+04)

ASTRO-H HXI will show us beautiful Galactic center in the hard X-ray band.

2.2.4. Soft Gamma-ray Detector (SGD)

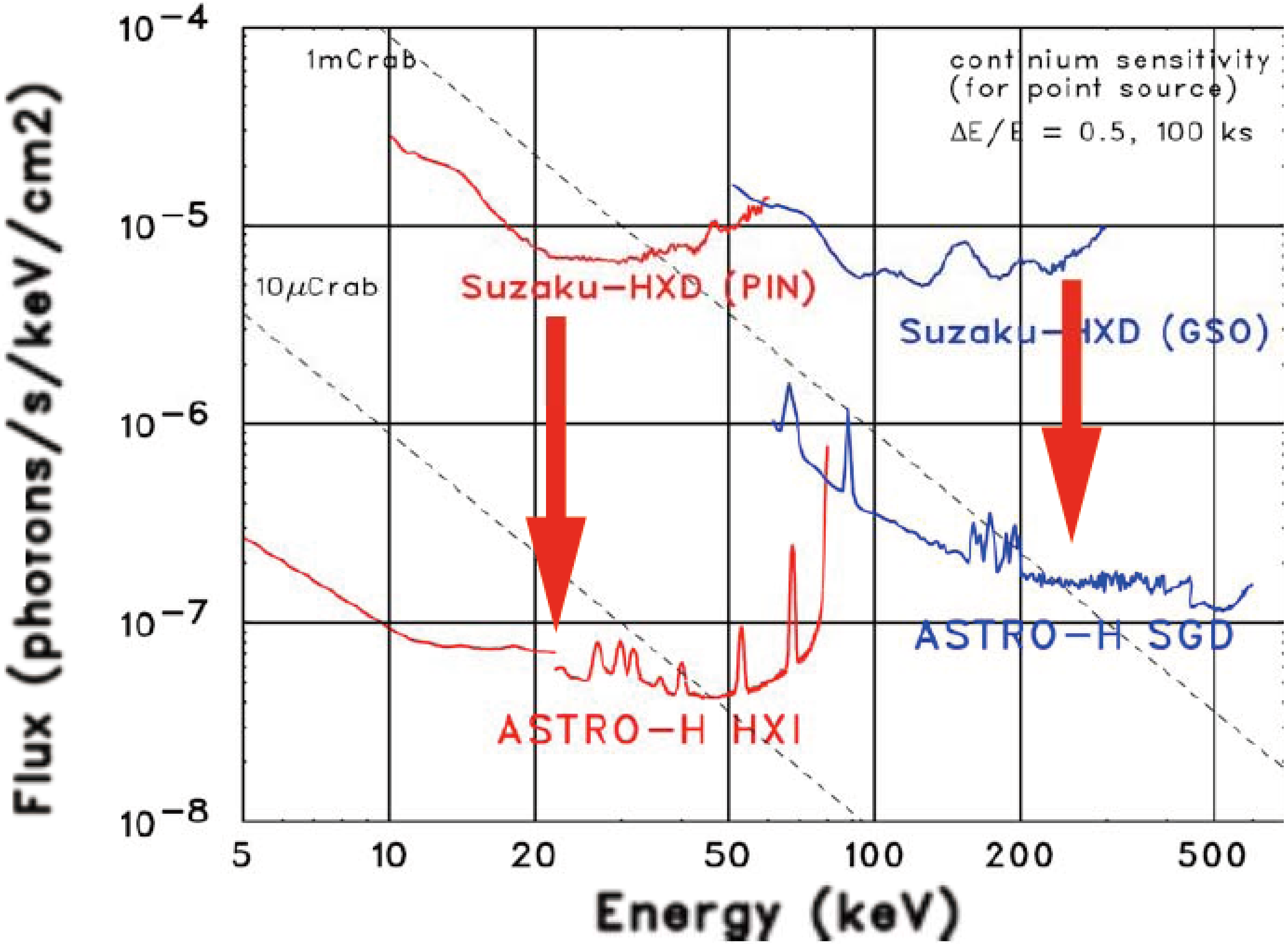


Si strips (basically same technology to HXI)



We can reject background with condition of Compton kinematics

Two orders better sensitivity than present satellites.



energy range: 50 – 600 keV

SGD cover the annihilation line (511 keV) band.

-> important to search for dark matter etc.

3. Example of science with ASTRO-H
--- SNRs with ASTRO-H ---

3.1. Measuring the energy injection from shock of SNRs to CRs

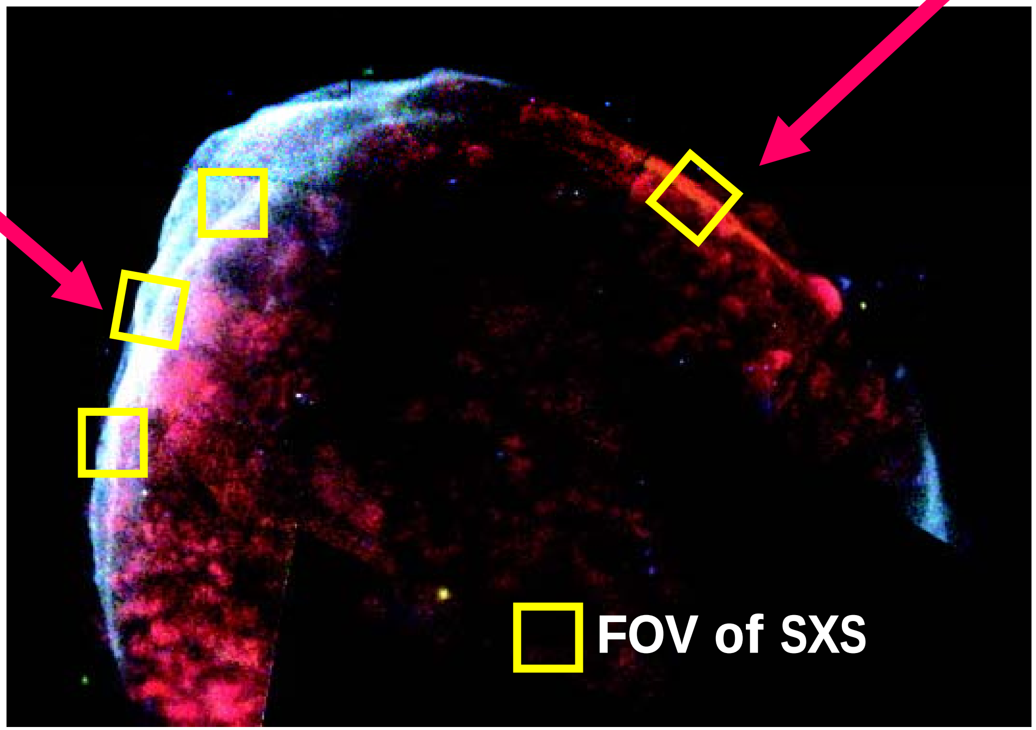
Measuring thermal energy of SNRs is quite difficult because of strong non-equilibrium state -> SXS !!

SN1006: Both acceleration and non-acceleration sites

-> We can measure the injection energy to CRs

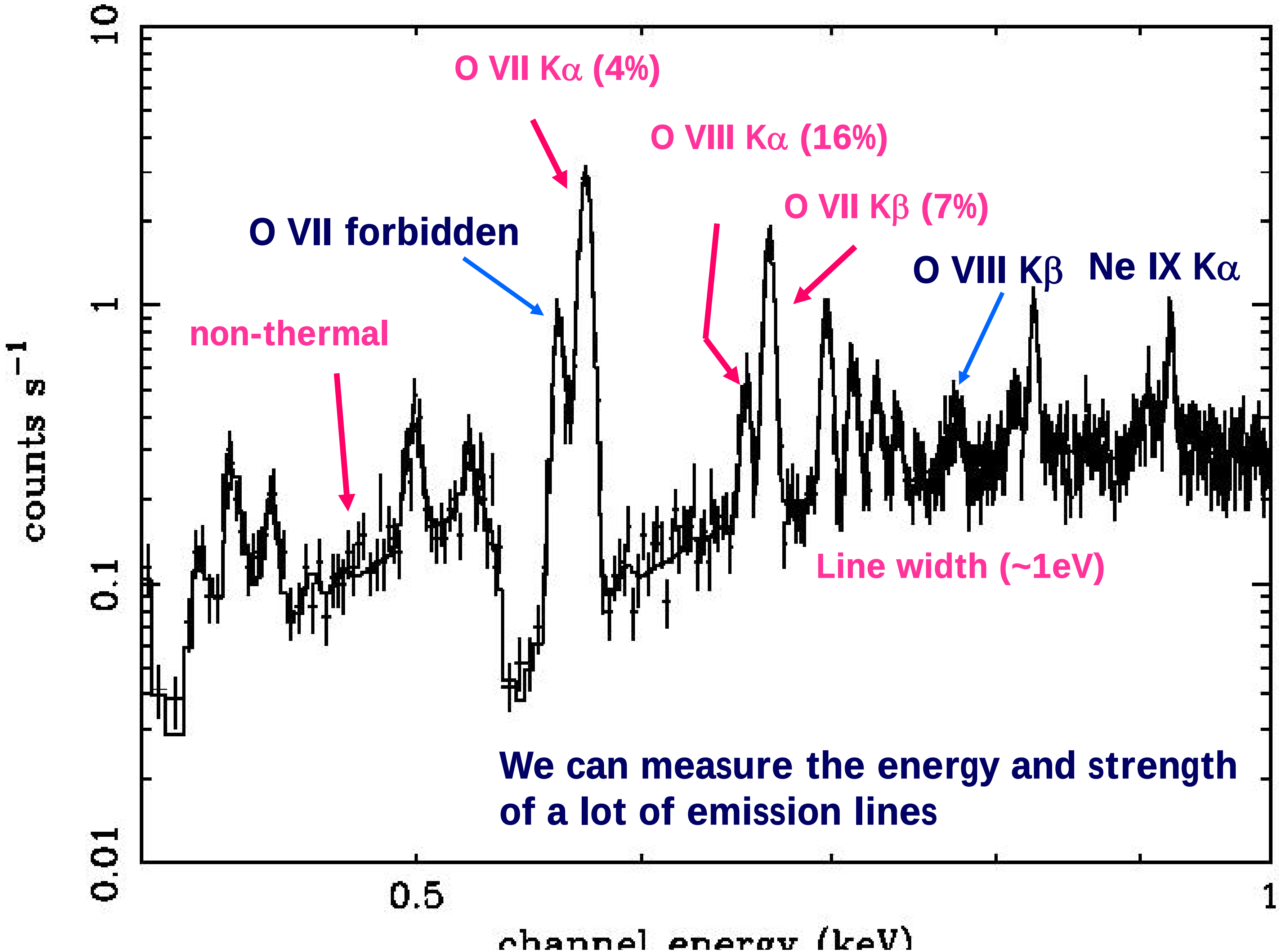
Northeastern (NE) shell
sync. (+thermal) X-rays

Northwestern (NW) shell
thermal X-rays



difference between
- **NE and SW**
- **in NE**

Expected spectrum (NE shell: 80ks exposure)



Measuring thermal parameter -> estimating injection

1. Measuring kT_e, kT_{ion}, n_et

   He-like O Kα
   He-like O Kβ ➡ kT_e (30% acc.)

   H-like O Kα
   He-like O Kα ➡ kT_{ion} (10% acc.)

   kT_e, kT_{ion} ➡ n_et (11% acc.)

2. age: 1000(+α) years
   -> determination of plasma density, compression ratio
   (15% acc.)

   We can know the background plasma condition
   in NE and SW shells.

➡ Determination of energy injection
into thermal E/kinetic E/CR E

Determination of the maximum energy of accelerated e

We can estimate the $E_{max,e}$
in each background plasma condition

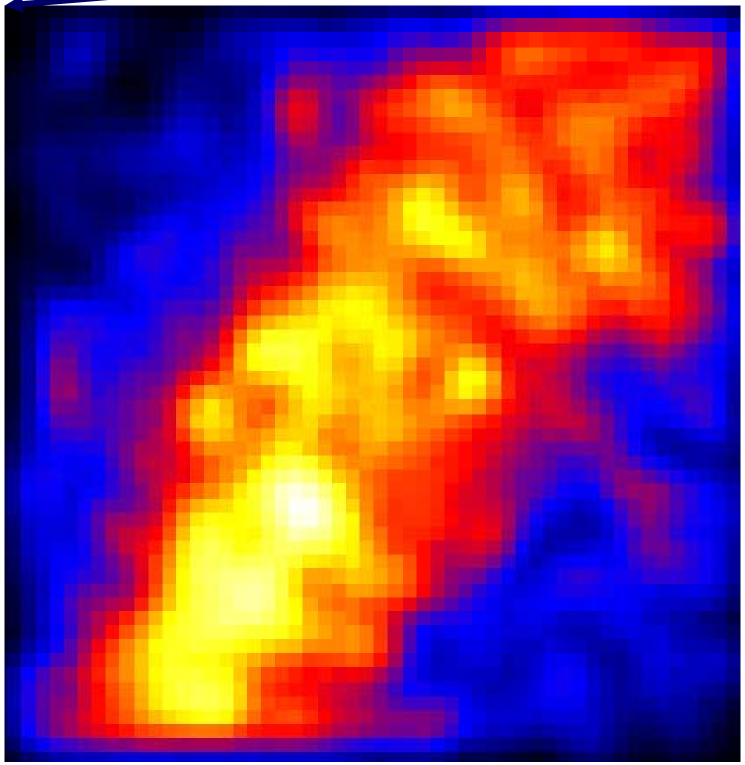
Cut-off of synchrotron X-ray $\propto E_{max,e}B^2$
-> We can estimate $E_{max,e}$ if we can detect cut-off

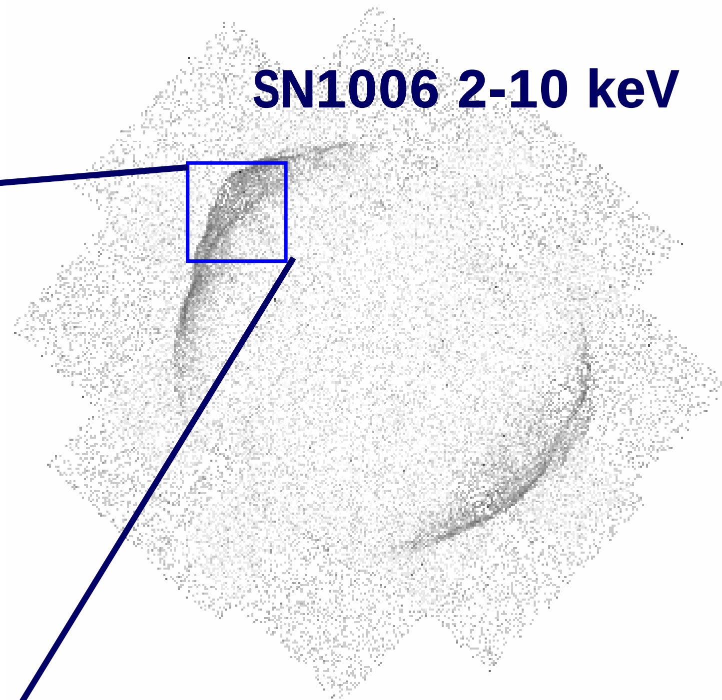
It was very difficult for previous observations due to
-. limited energy band
-. contamination of thermal energy

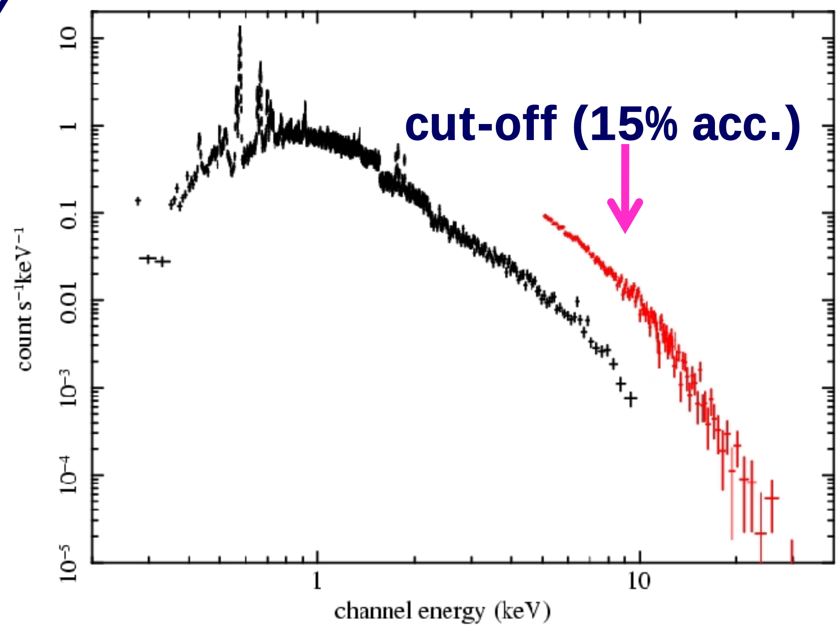
-> ASTRO-H SXS + HXI can determine both component !

SN1006 with SXS + HXI

HXI 10-40 keV (100ks)

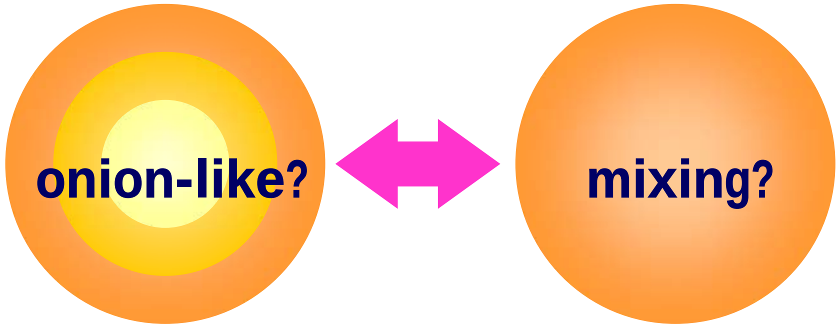






pos. difference of cutoff ?
thermal parameters w. SXS
-> acc. efficiency

3.2. Heavy element distribution in SNRs

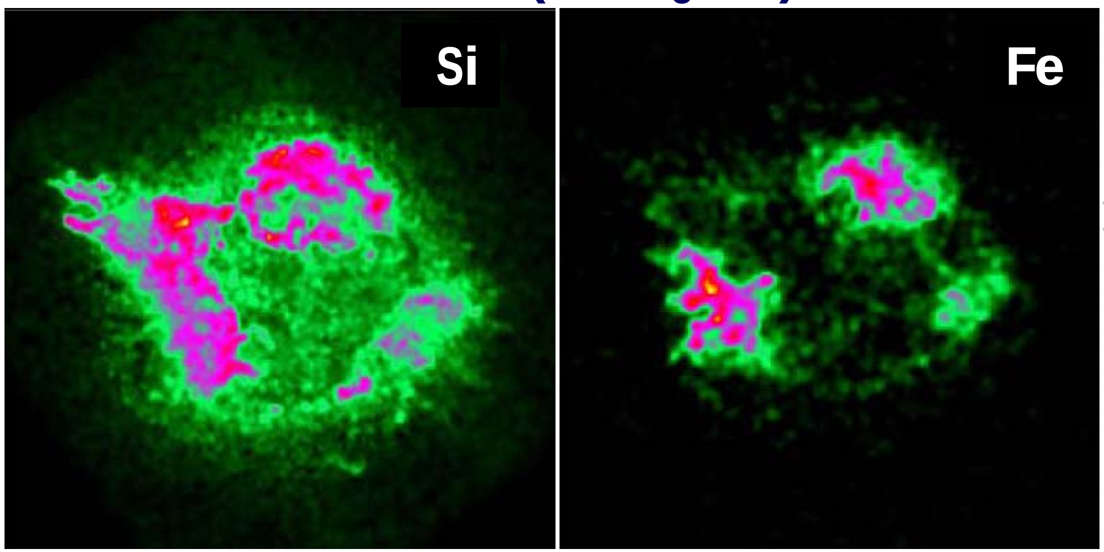


It should have have information of SNe !

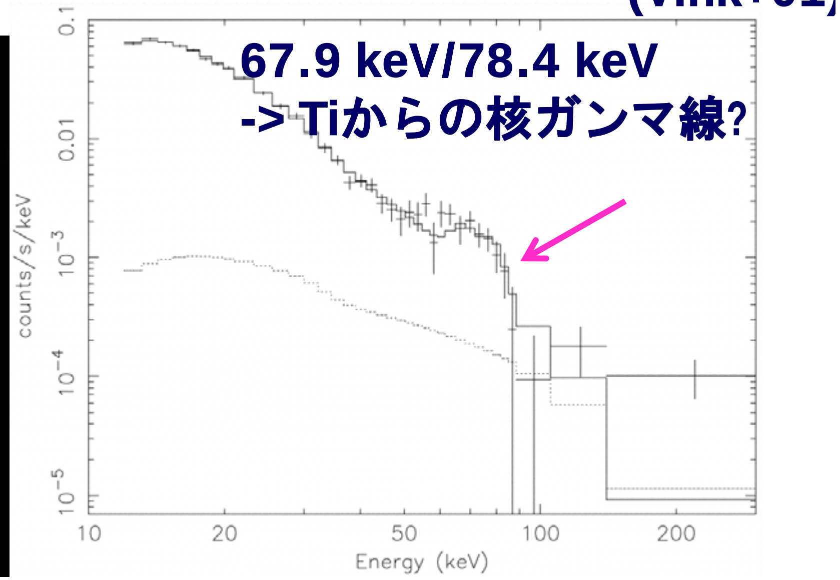
We only have marginal 2D information on major elements (Si, Fe etc.)

No information of mass-cut elements like Ti

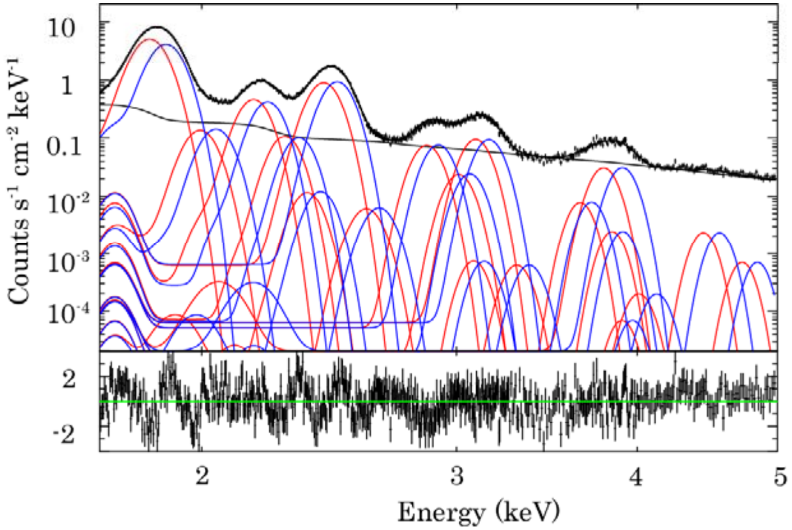
Cas A Si and Fe image by Chandra (Hwang+04)



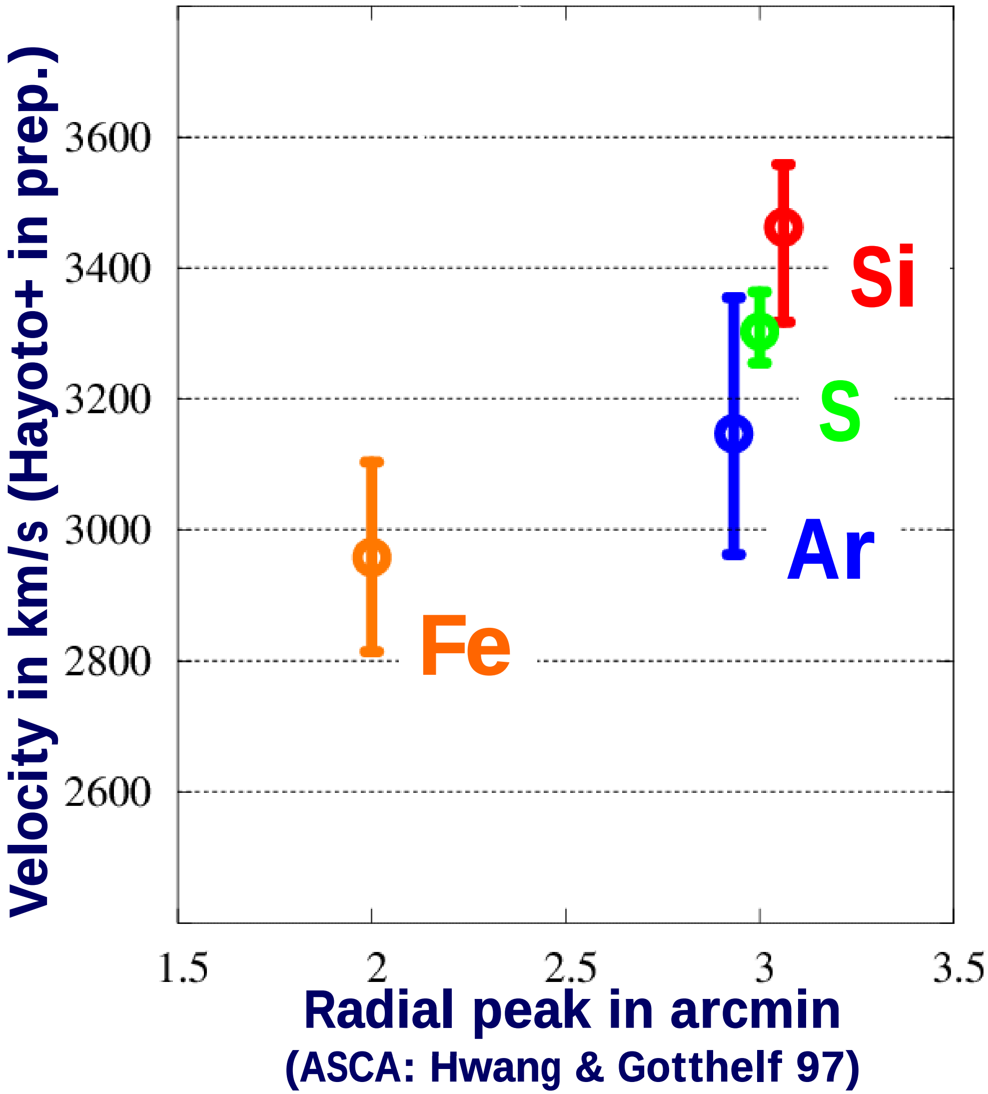
^{44}Ti from Cas A by BeppoSAX (Vink+01)



Doppler blue and red shifts of lines in Tycho by Suzaku



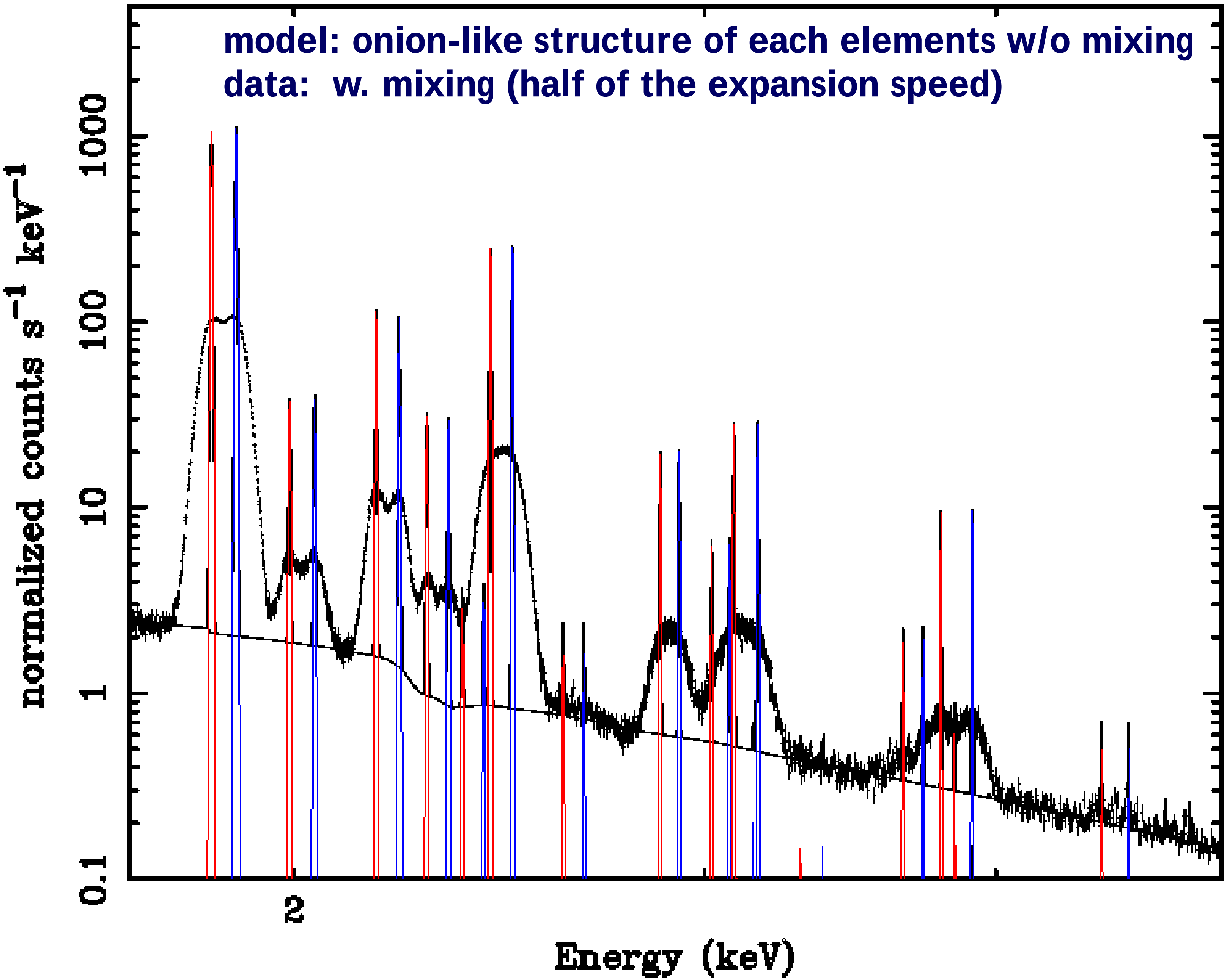
The line
->blue and red shift
by expansion
Heavier elements are
located more inner side?
discovery of onion-like shape ??



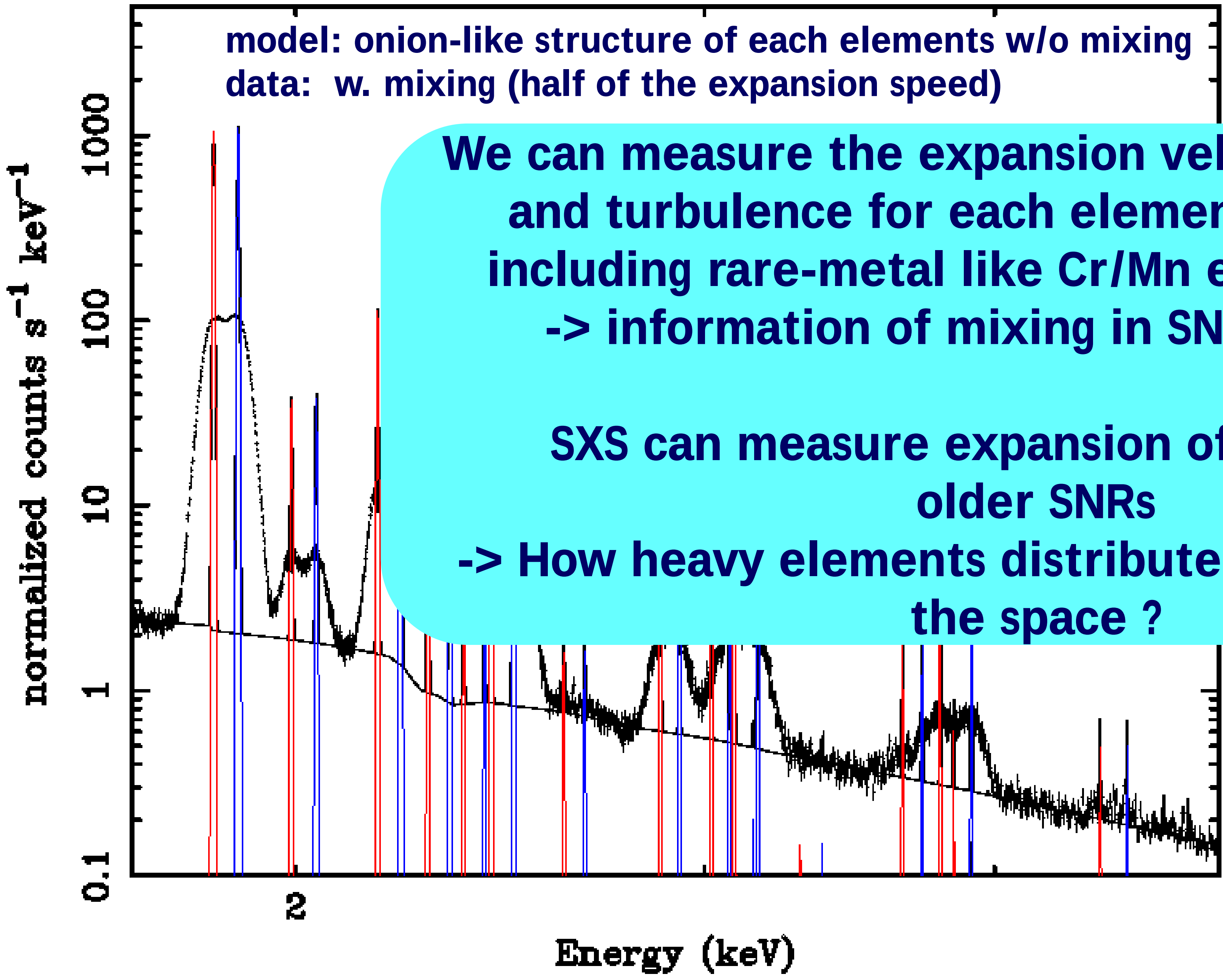
The result is still marginal
Only for major elements
Can we see effect of mixing?

(Furuzawa+09, Hayato+ in prep.)

ASTRO-H SXS observation of Tycho (100 ks)



ASTRO-H SXS observation of Tycho (100 ks)



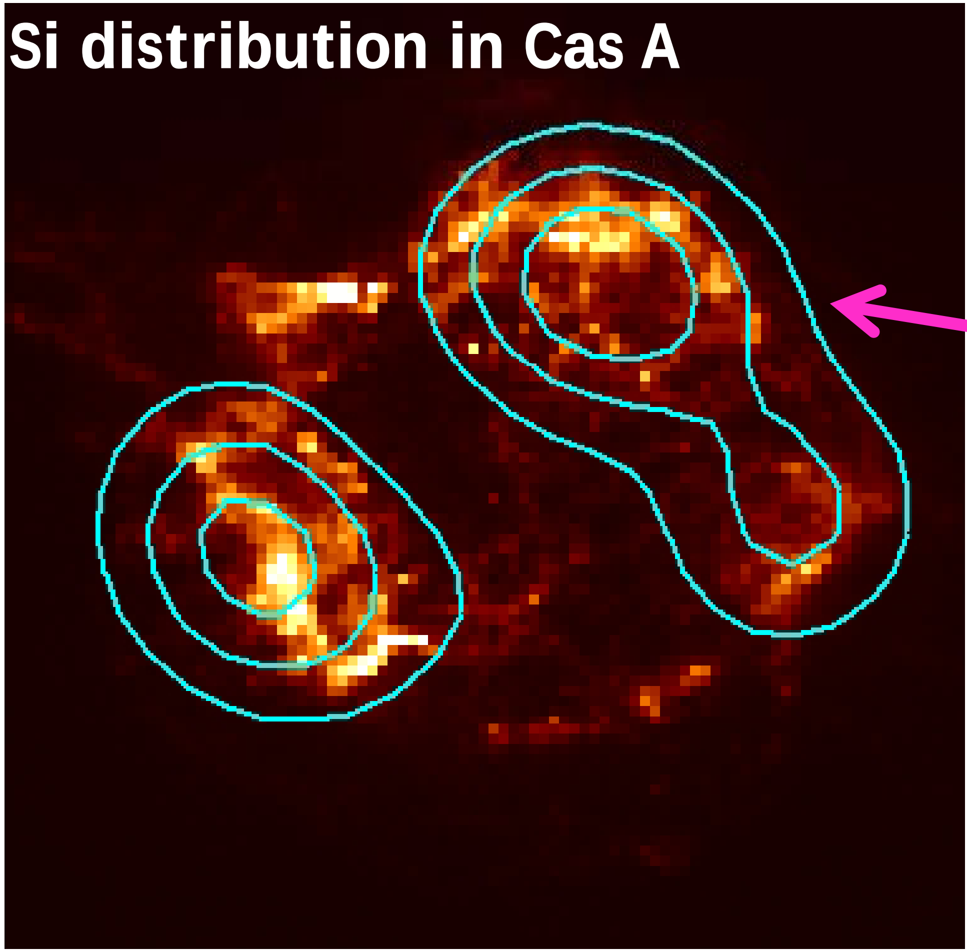
We can measure the expansion velocity and turbulence for each element, including rare-metal like Cr/Mn etc.
-> information of mixing in SNe

SXS can measure expansion of older SNRs
-> How heavy elements distribute into the space ?

Mass-cut element: Ti

HXI can detect nuclear gamma-ray line from ^{44}aTI.

-> The first imaging of ^{44}Ti distribution



Cas A obs. by HXI (100ks)
-> 140cnt ^{44}Ti gamma-rays

Expected map w. assumption that ^{44}Ti is in the same region of Fe

Where is Ti?
w. Si ? Fe ? or jet ?

important constraint of explosion mechanism

Summary

-. ASTRO-H will be the only X-ray observatory
in the next 10 years.

-. ASTRO-H have four detectors,
SXS (Soft X-ray spectrometer), SXI (Soft X-ray imager),
HXI (Hard X-ray imager), SGD (Soft Gamma-ray detector).
each detector has strength compared with previous detectors

-. Variety of science topics will be solved with ASTRO-H.

-. We need your help !!
We need physics to understand what the data implies
BEFORE the launch.

-. You can check the status of ASTRO-H and get simulation tool
from http://astro-h.isas.jaxa.jp/