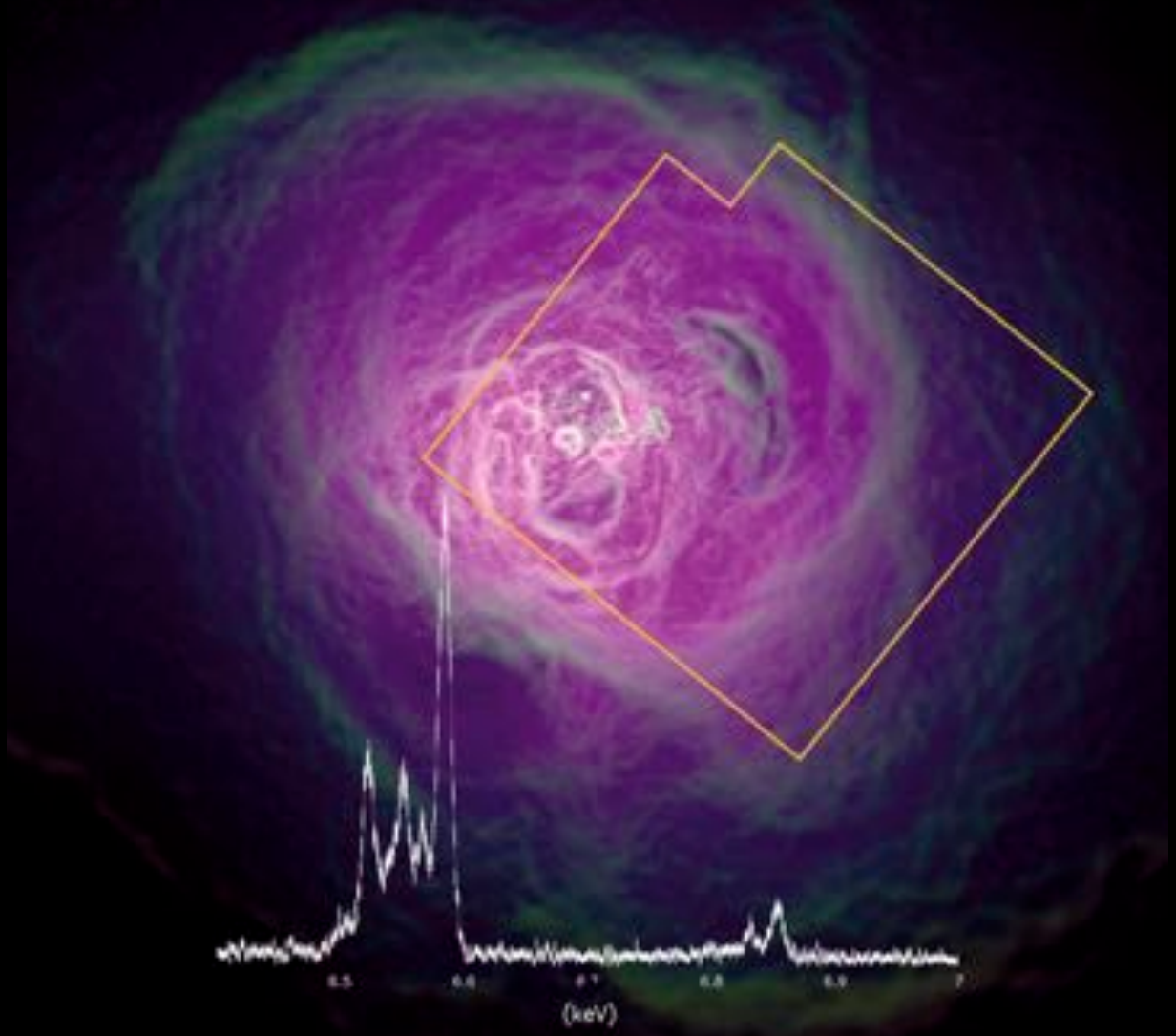
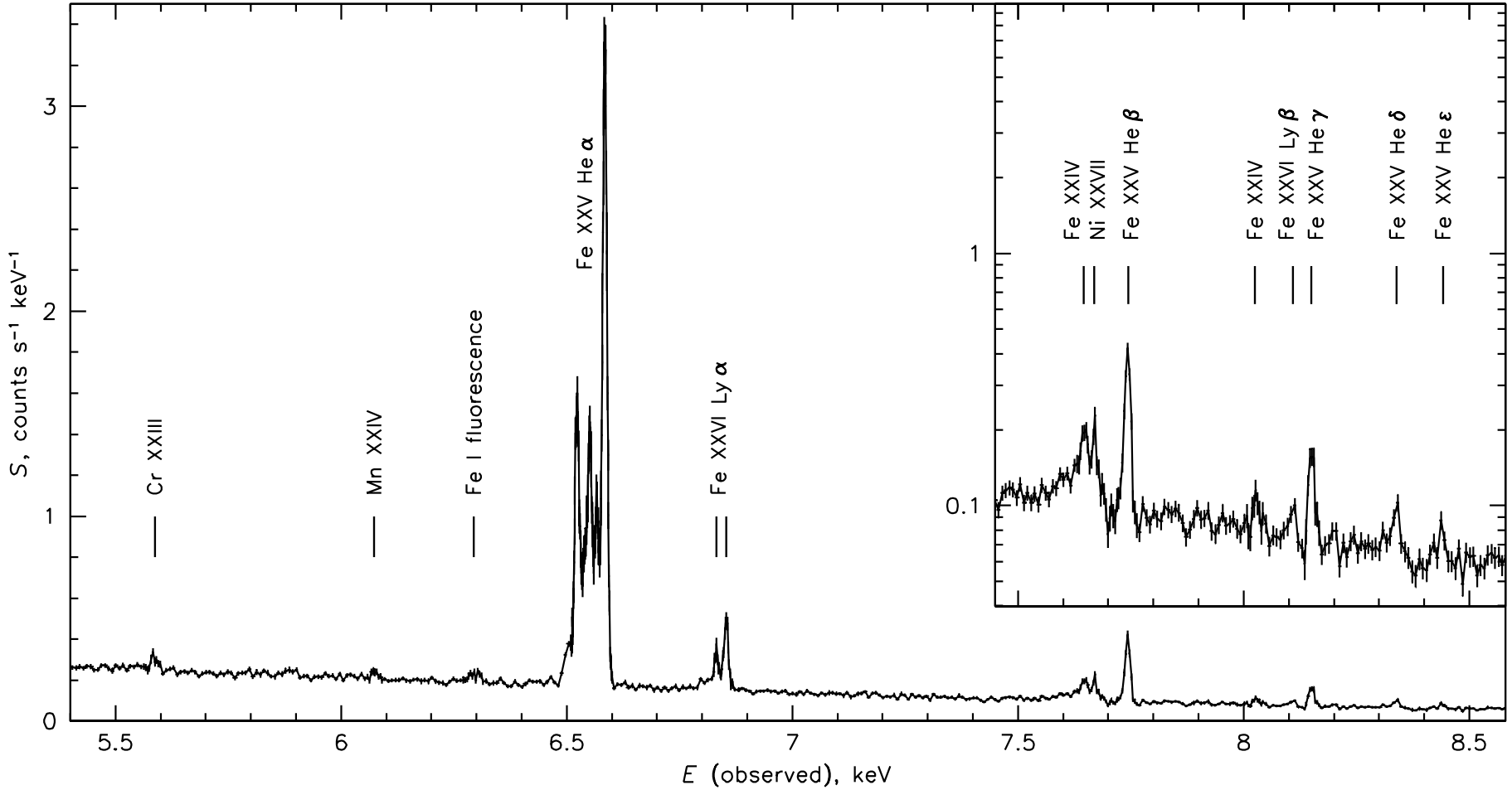
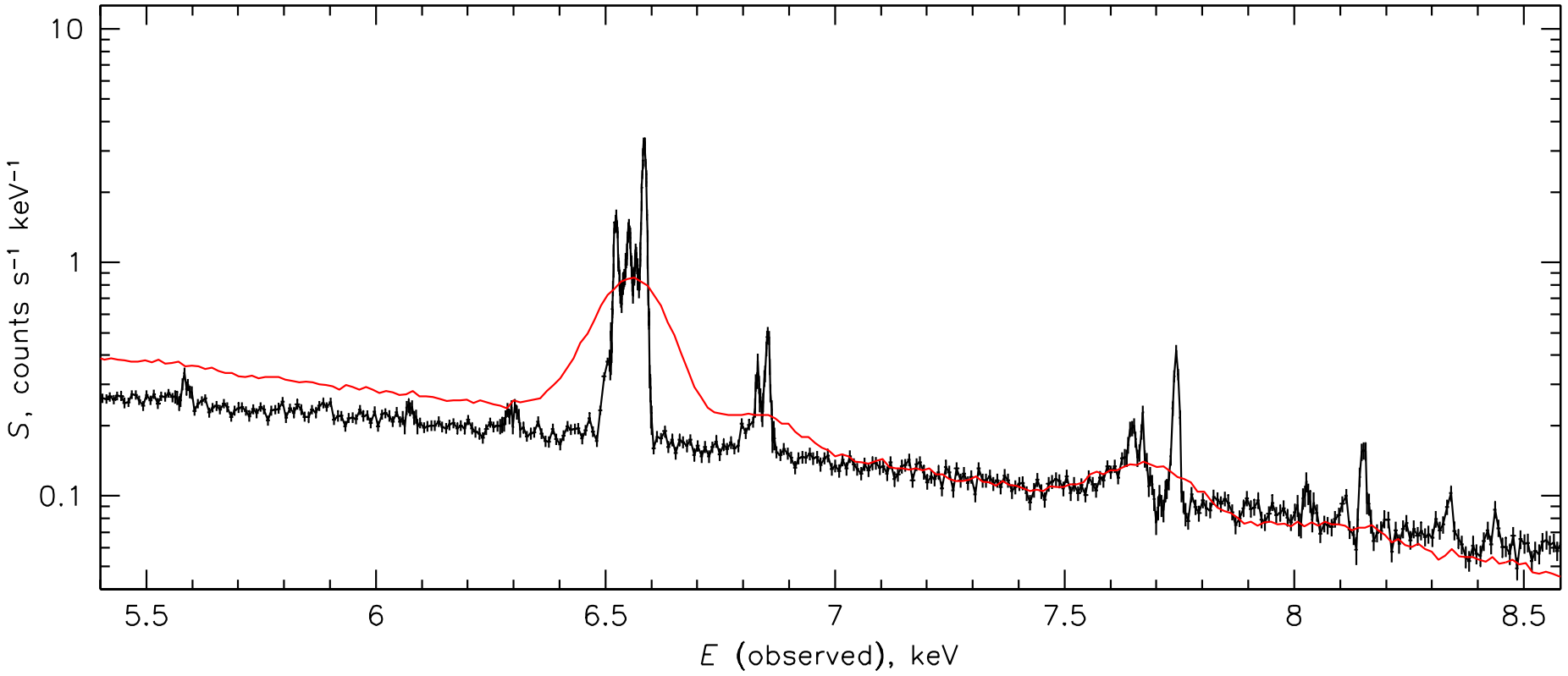
Hitomi, the Perseus Cluster and AGN Feedback

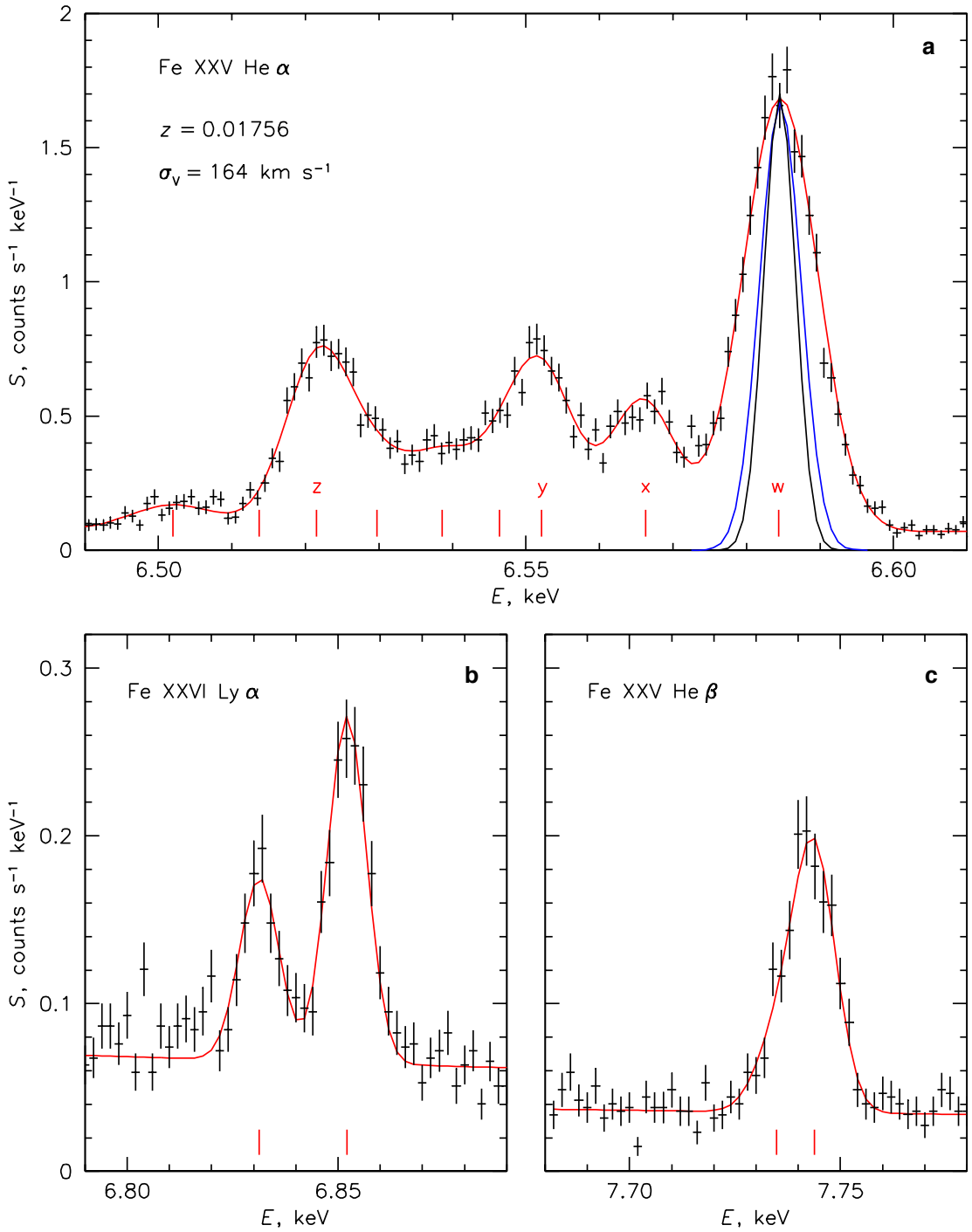
Andy Fabian IoA Cambridge UK

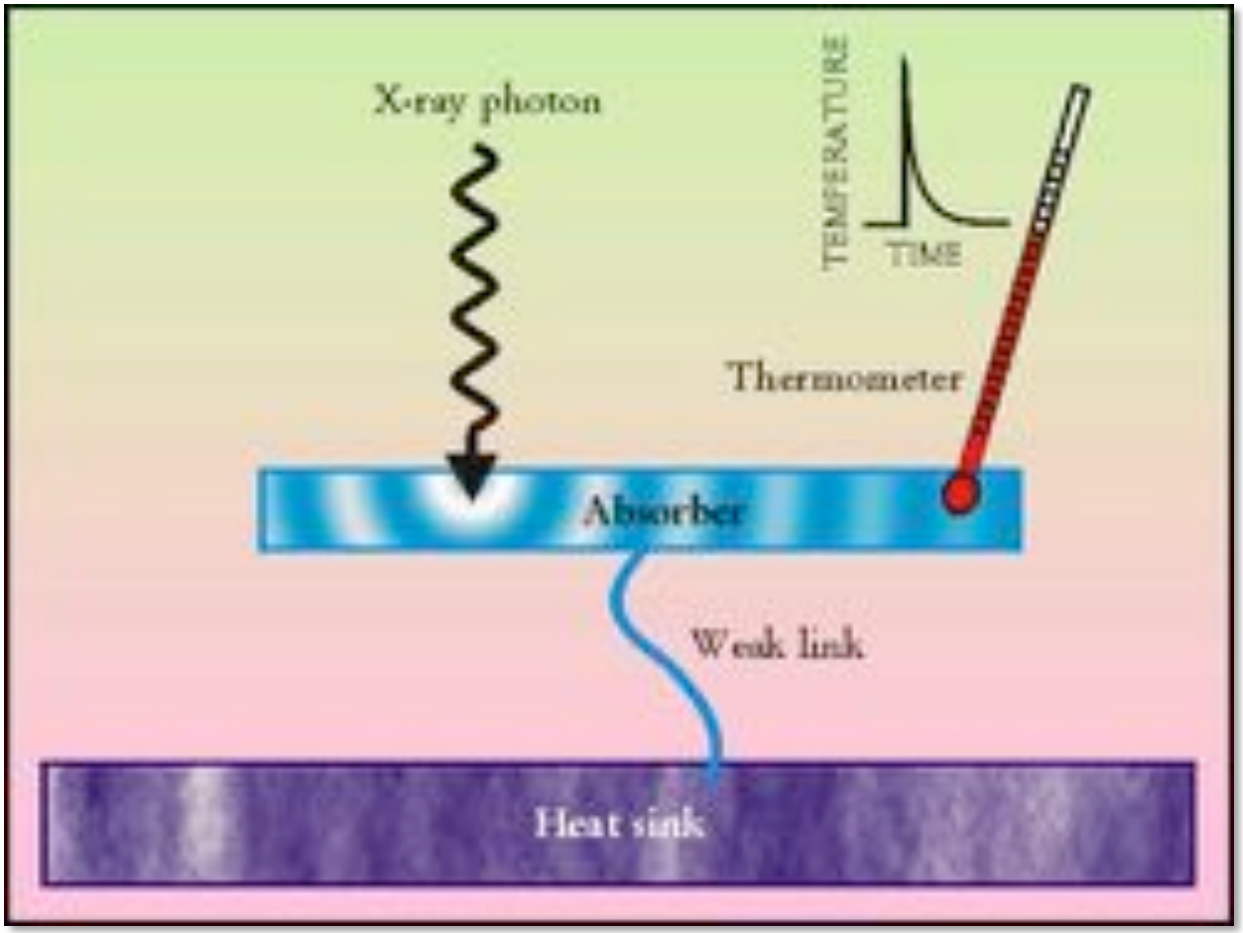
and the HITOMI COLLABORATION


(keV)


S, counts s⁻¹ keV⁻¹
E (observed), keV
Cr XXIII
Mn XXIV
Fe I fluorescence
Fe XXV He α
Fe XXVI Ly α
Fe XXIV
Ni XXVII
Fe XXV He β
Fe XXIV
Fe XXVI Ly β
Fe XXV He γ
Fe XXV He δ
Fe XXV He ε

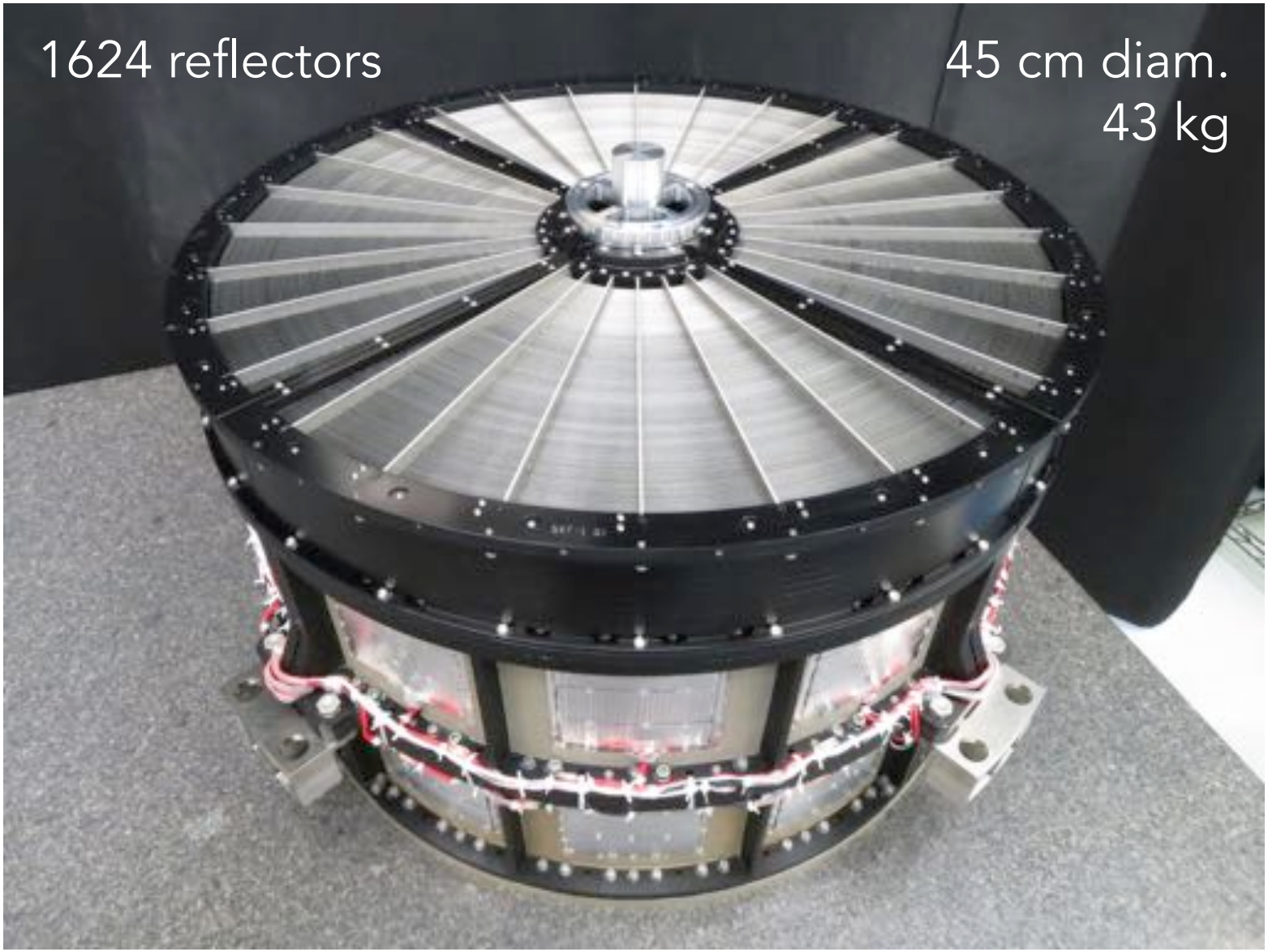

10
1
0.1
S, counts s⁻¹ keV⁻¹
5.5
6
6.5
7
7.5
8
8.5
E (observed), keV


a
Fe XXV He α
z = 0.01756
σv = 164 km s−1
S, counts s−1 keV−1
E, keV
z
y
x
w
b
Fe XXVI Ly α
c
Fe XXV He β

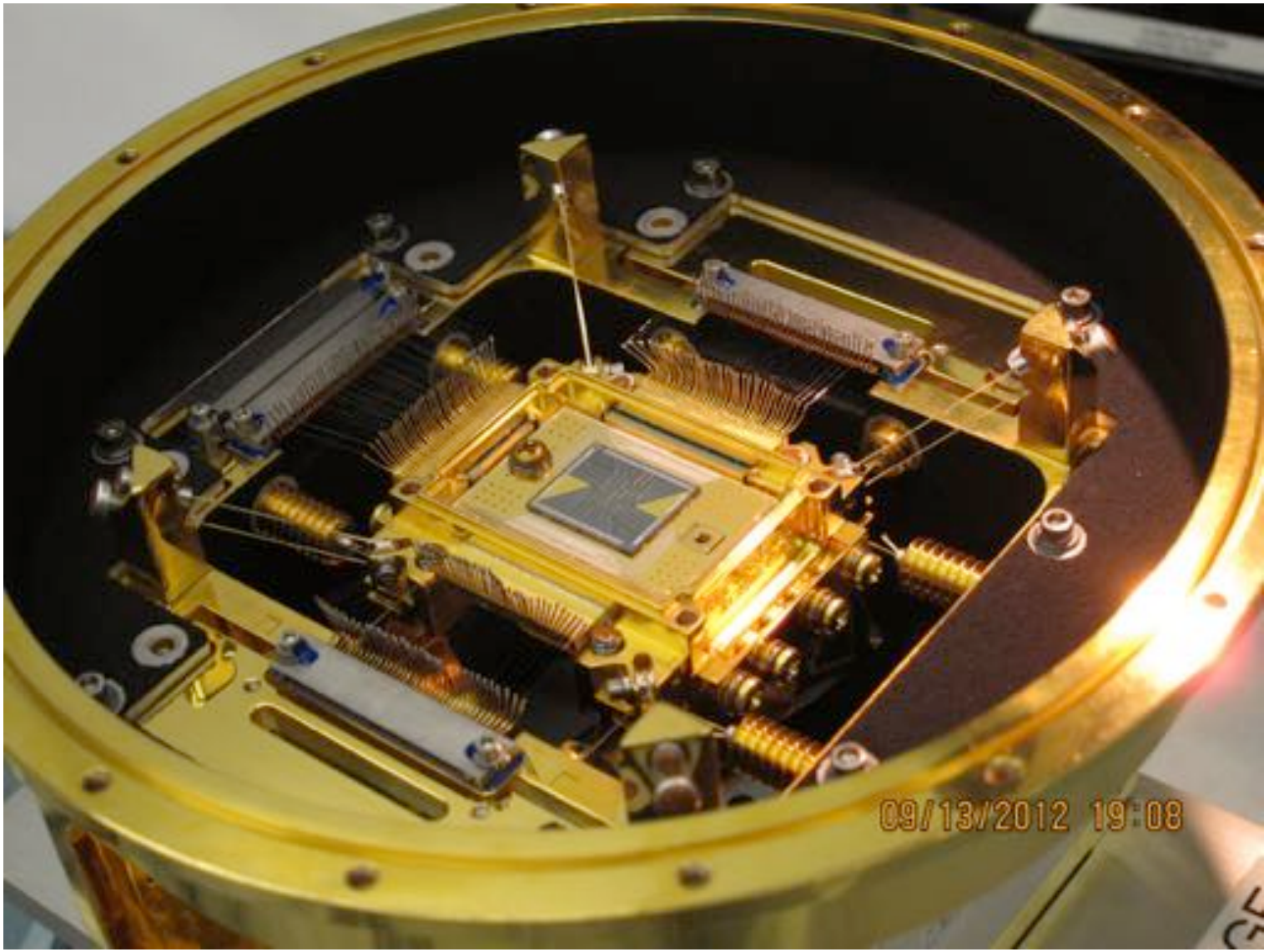


X-ray Calorimeter

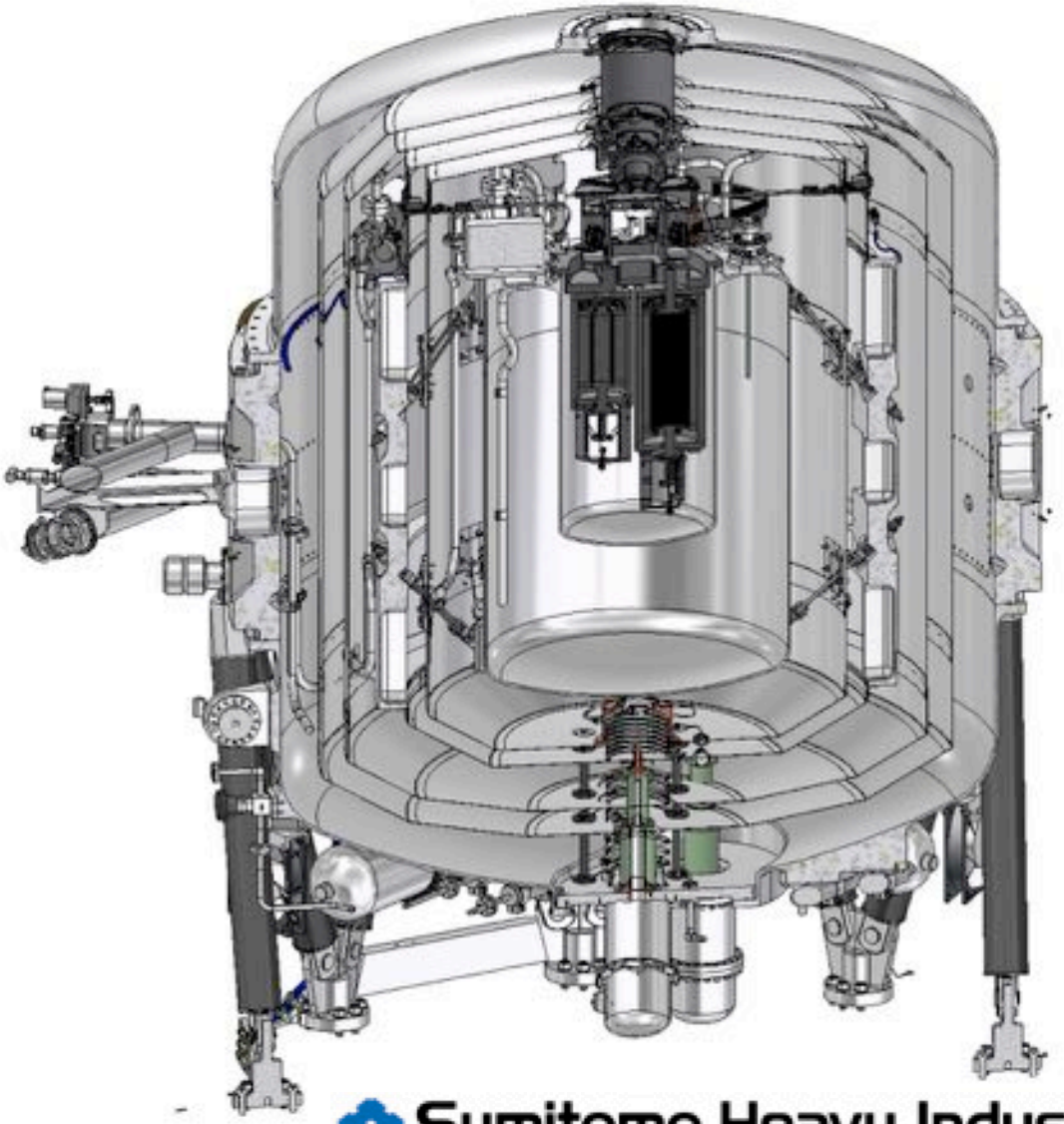
Hitomi Soft X-Ray Telescope



Detector Assembly (FM)



SXS Cryogenic System

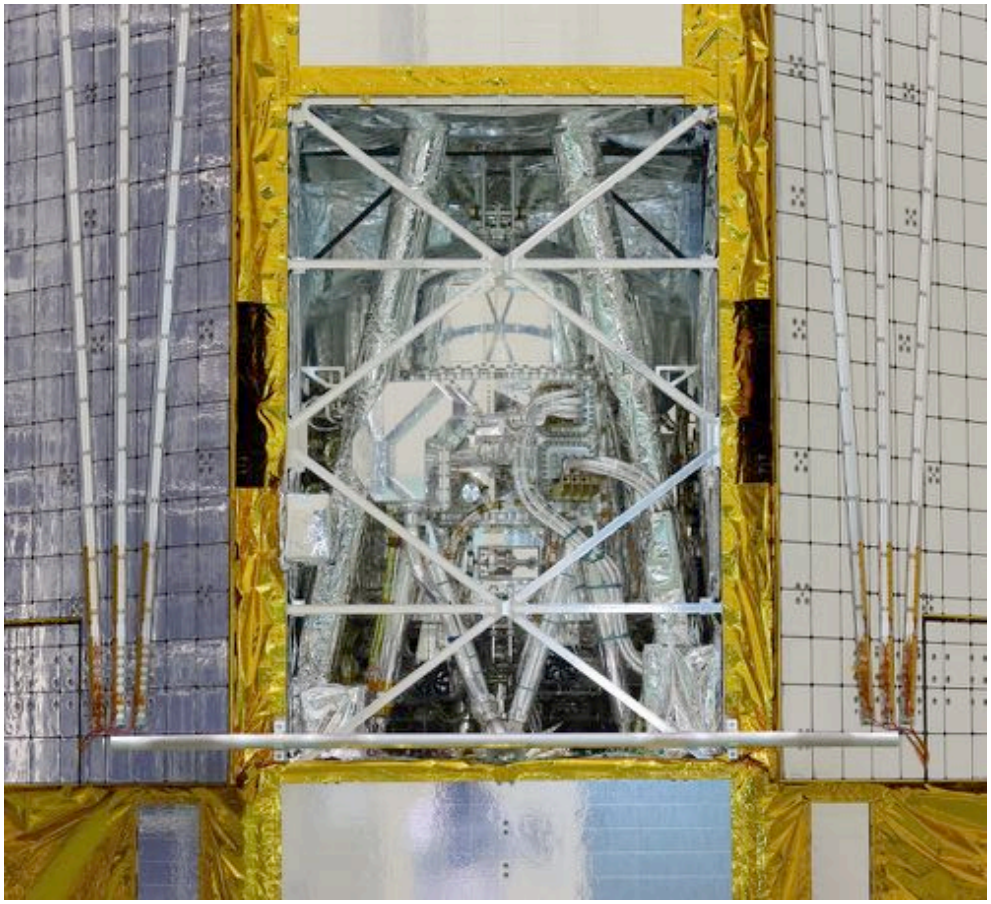


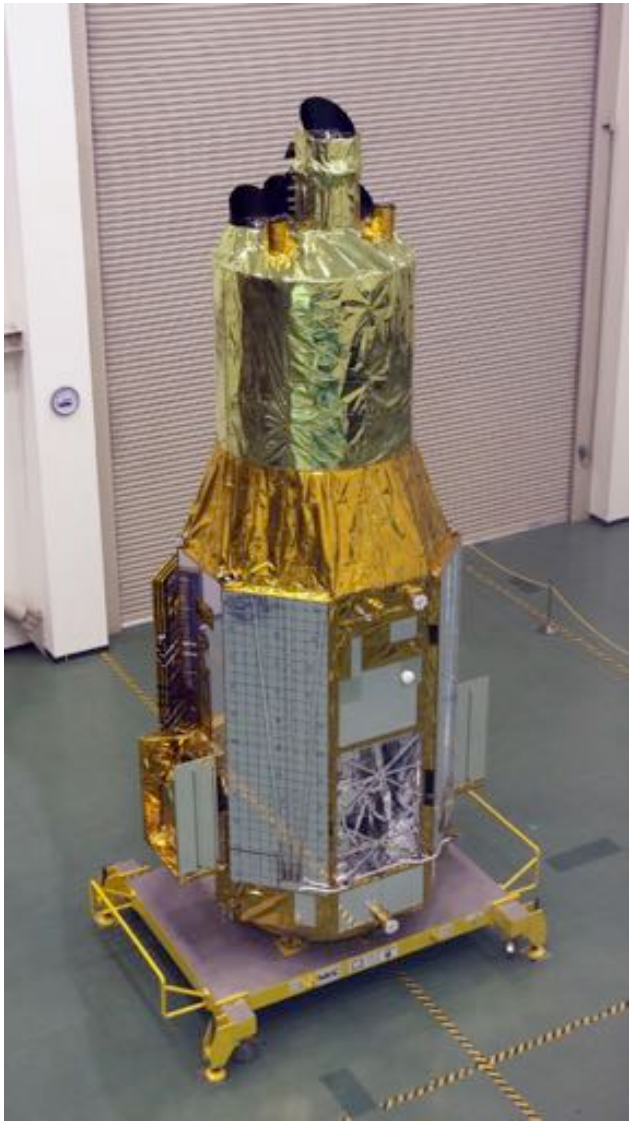
Sumitomo Heavy Industries, Ltd.

Dewar Integration

Soft X-ray Spectrometer

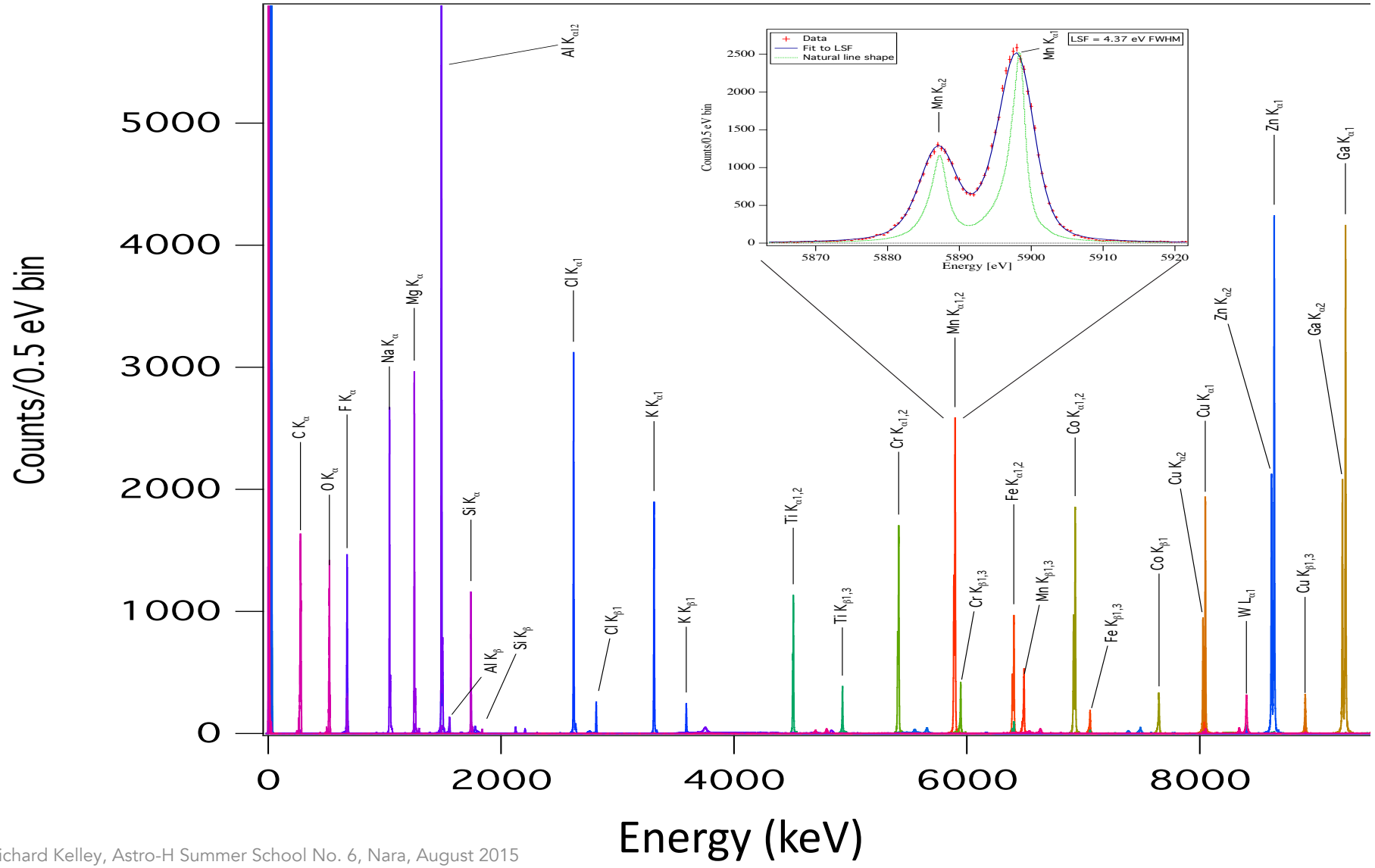
November 2015, Tsukuba Space Center, Japan
(photos courtesy of JAXA)

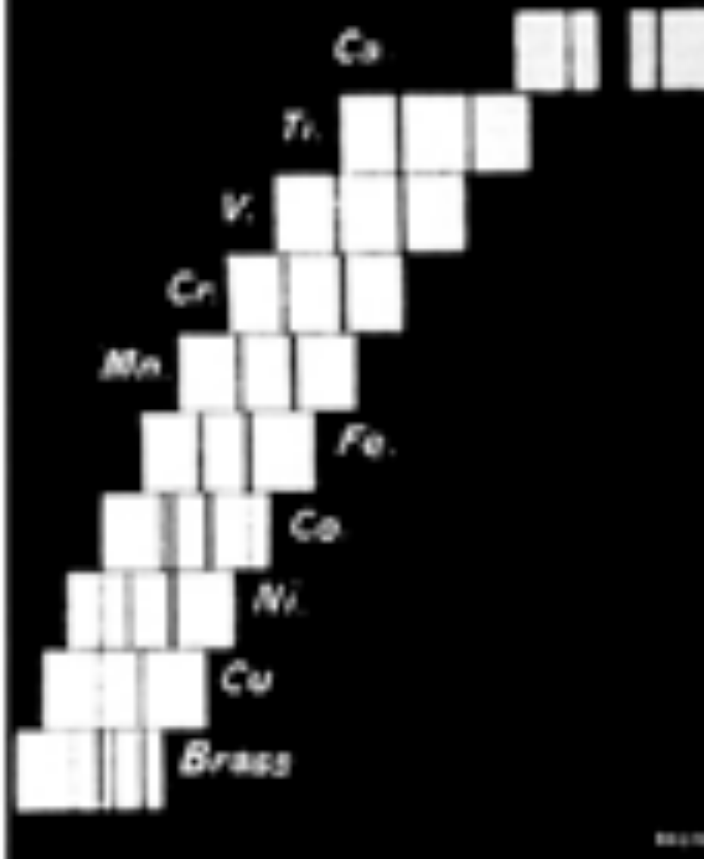




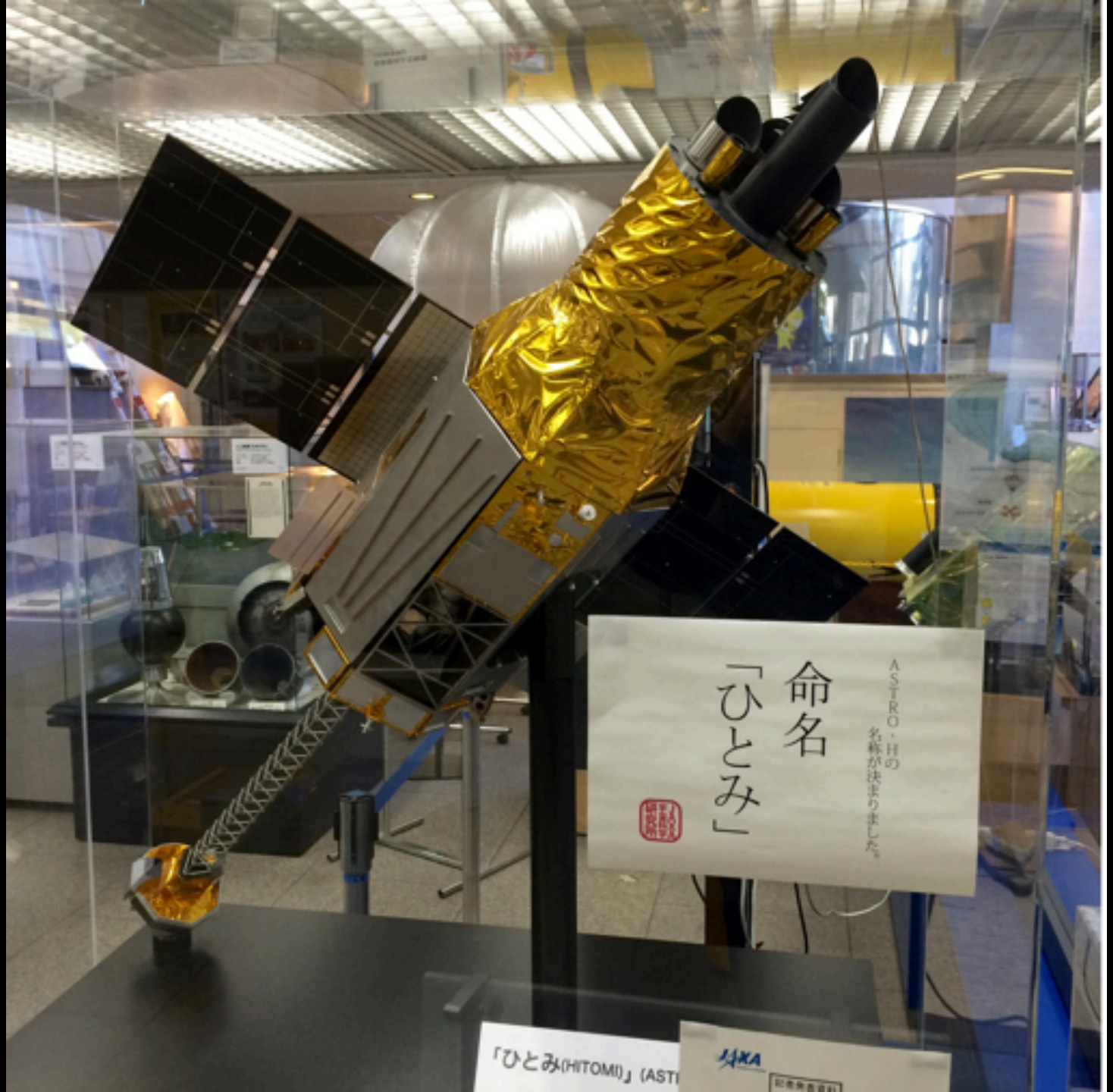
Energy Scale

Lots of spectral dynamic range!



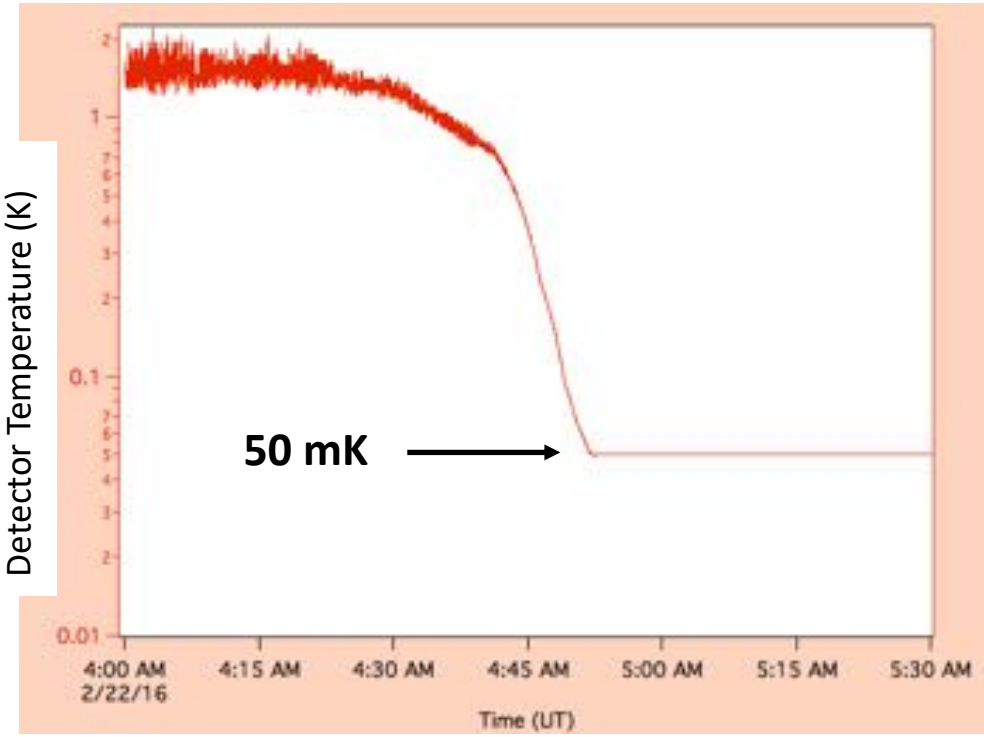


H Moseley


命名
「ひとみ」
ASTRO-Hの
名称が決まりました。
「ひとみ(HITOMI)」(AST
JAXA

Initial Operations

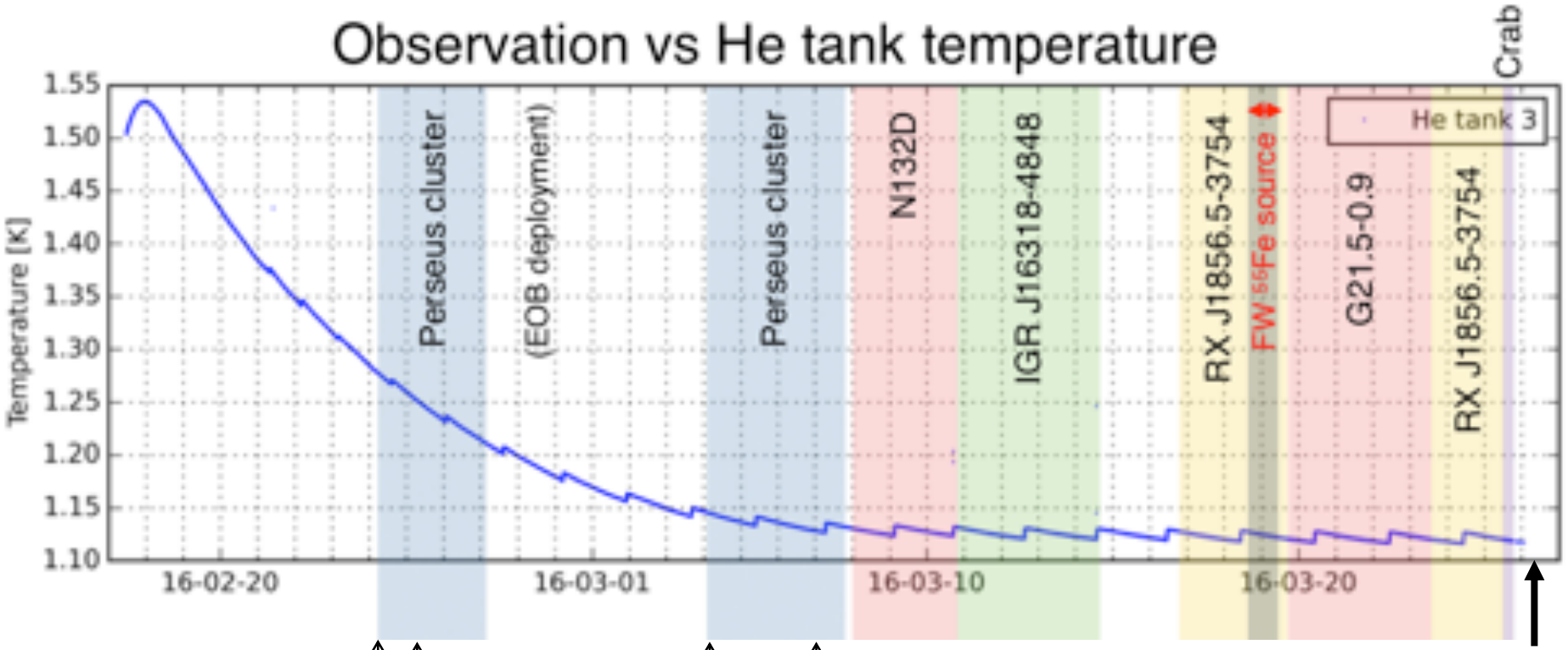
First de-mag to 50 mK on Day 5



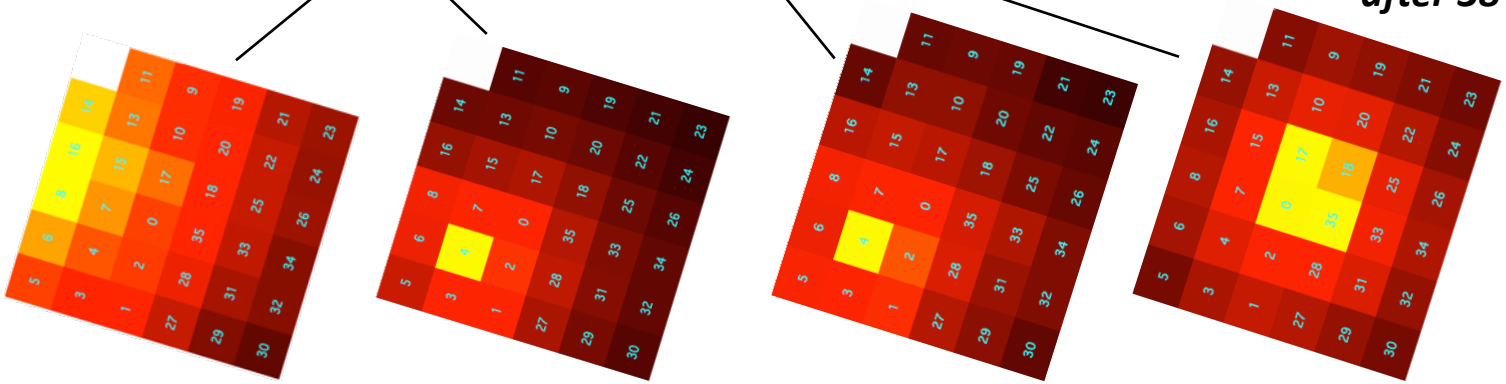
Initial projected helium lifetime > 4 years

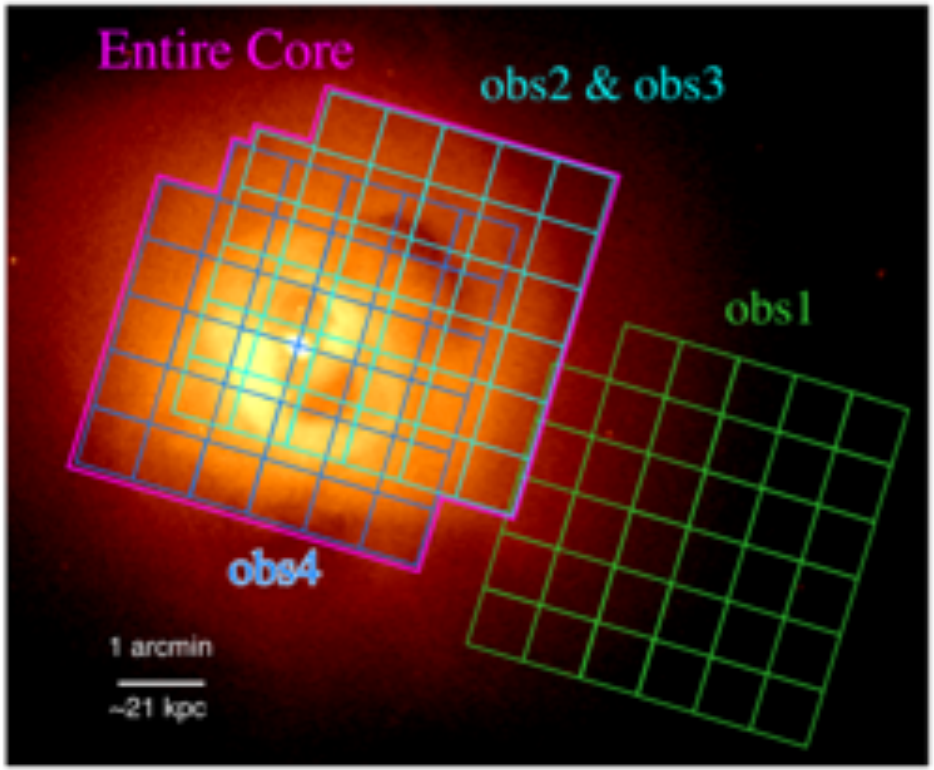
Also demonstrated cryogen-free mode during ground testing

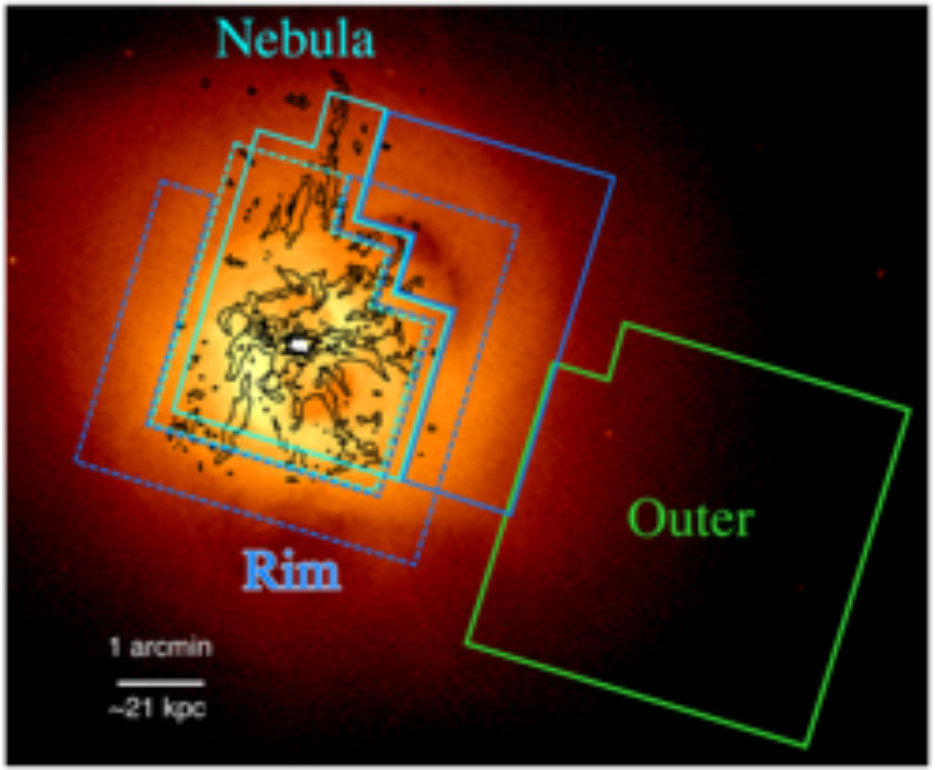
Shirron+2016… 9905-100 SPIE
Sneiderman+2016… 9905-99 SPIE



Mission lost due to operations mishap after 38 days!

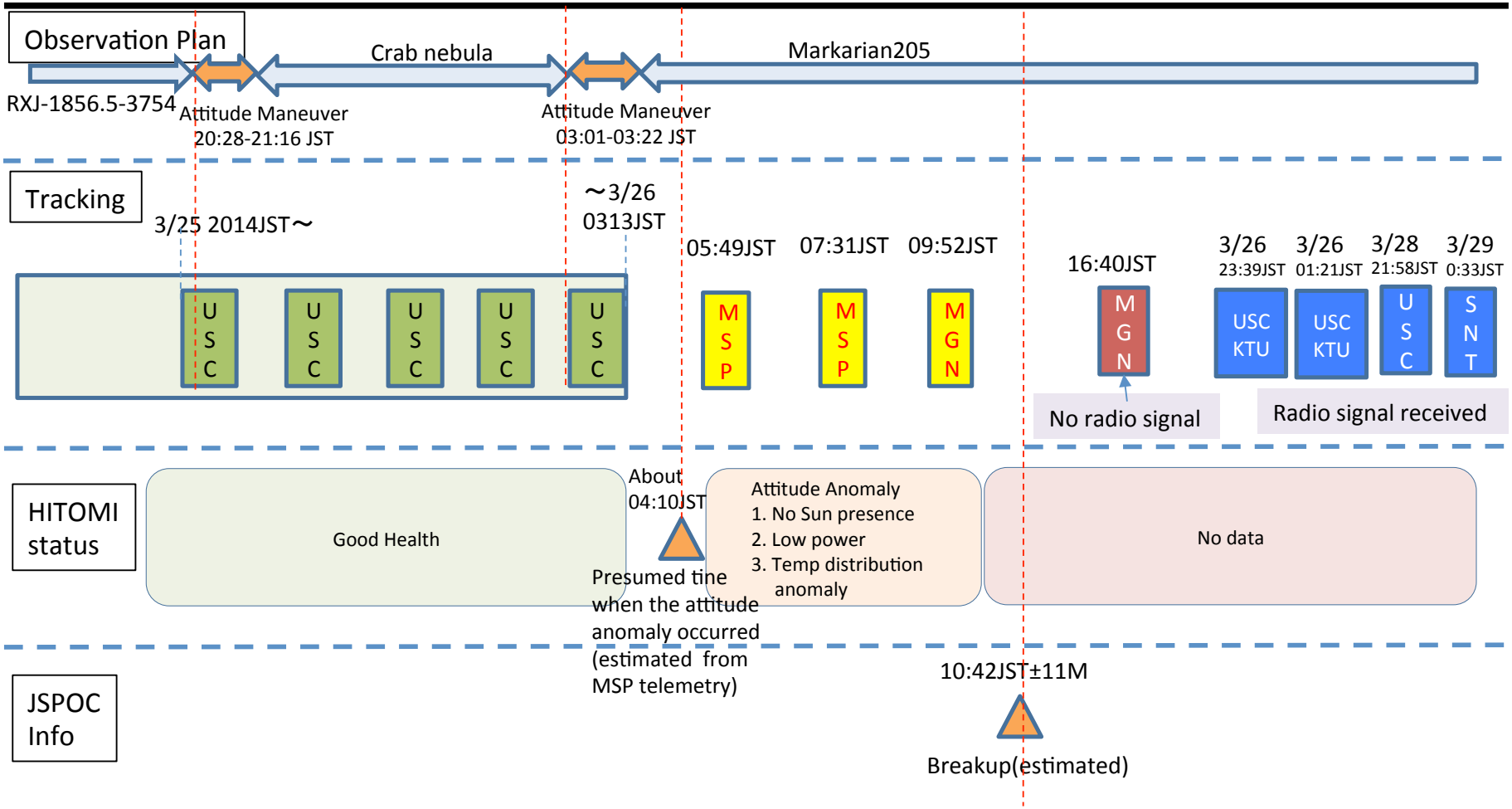


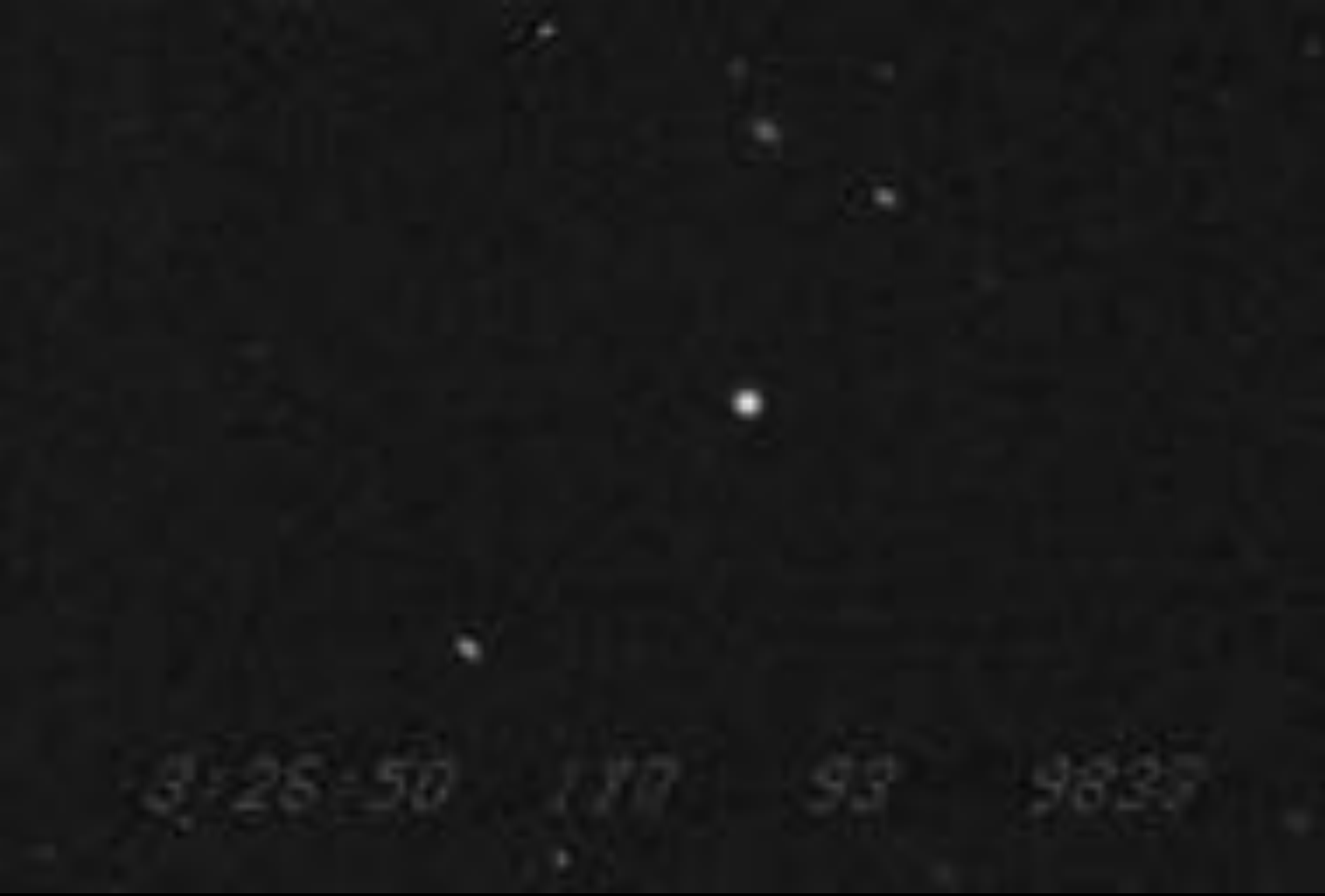

Entire Core
obs2 & obs3
obs1
obs4
1 arcmin
~21 kpc


Nebula
Outer
Rim
1 arcmin
~21 kpc

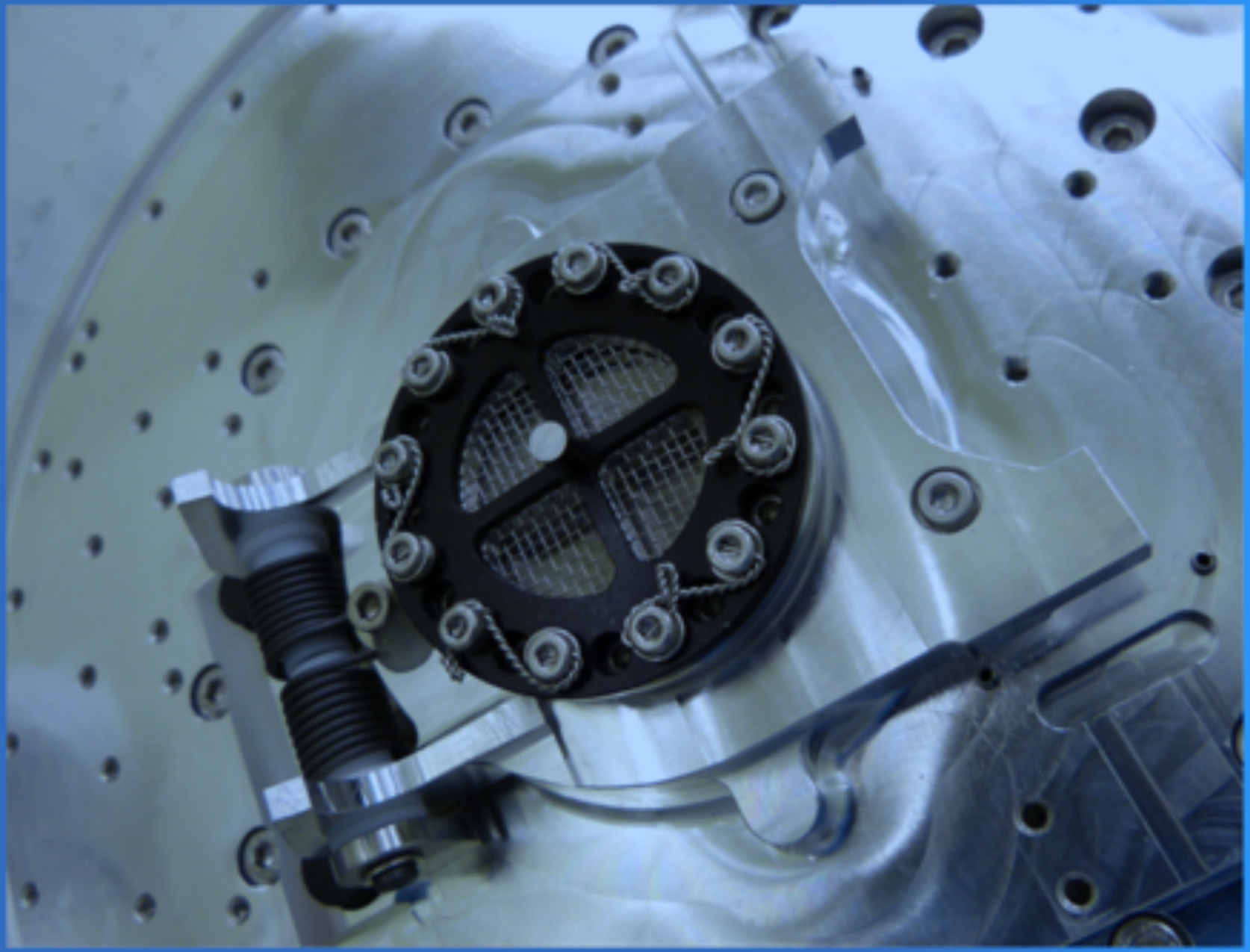
Sequence of Event

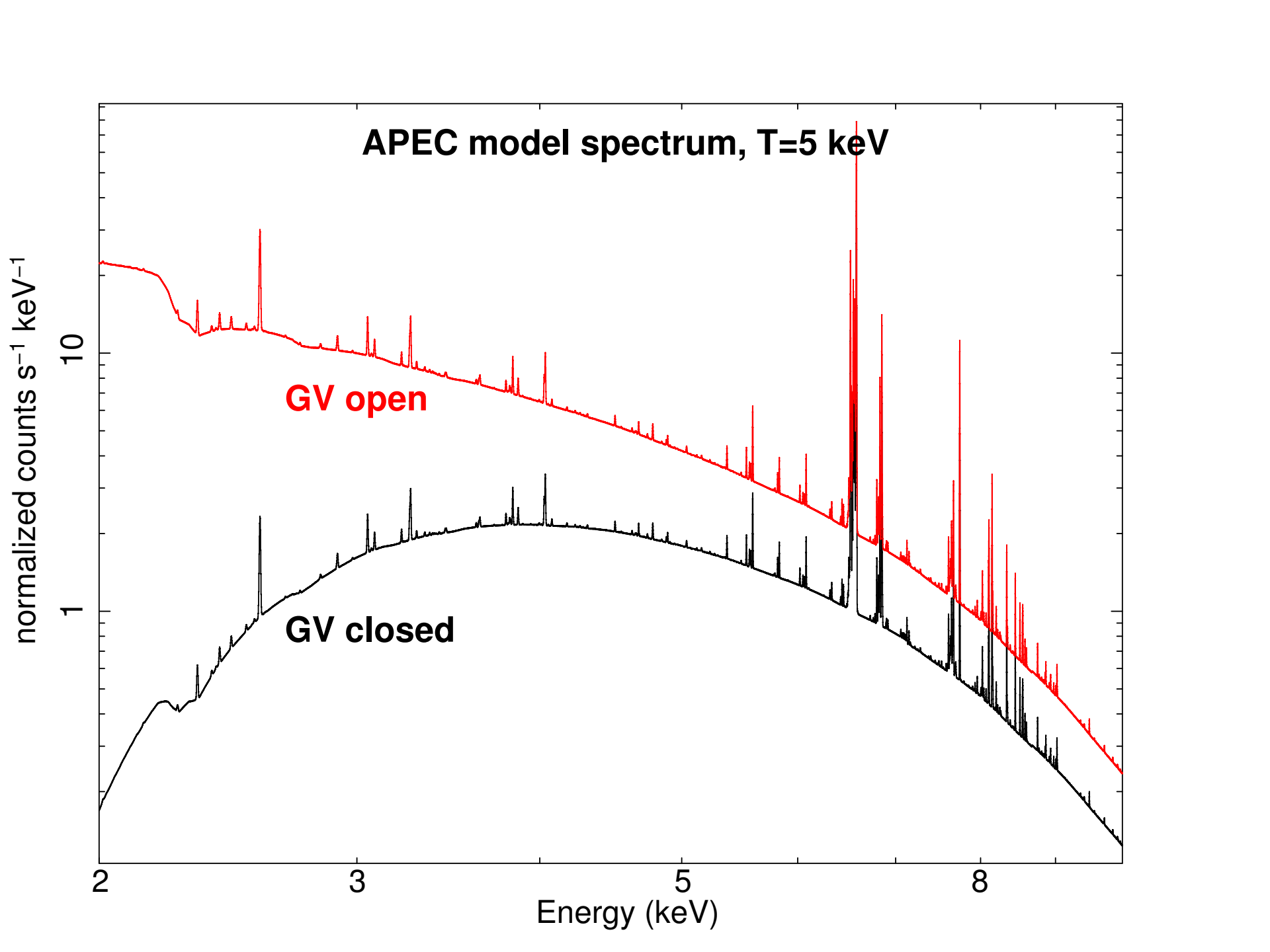
2016.4.1



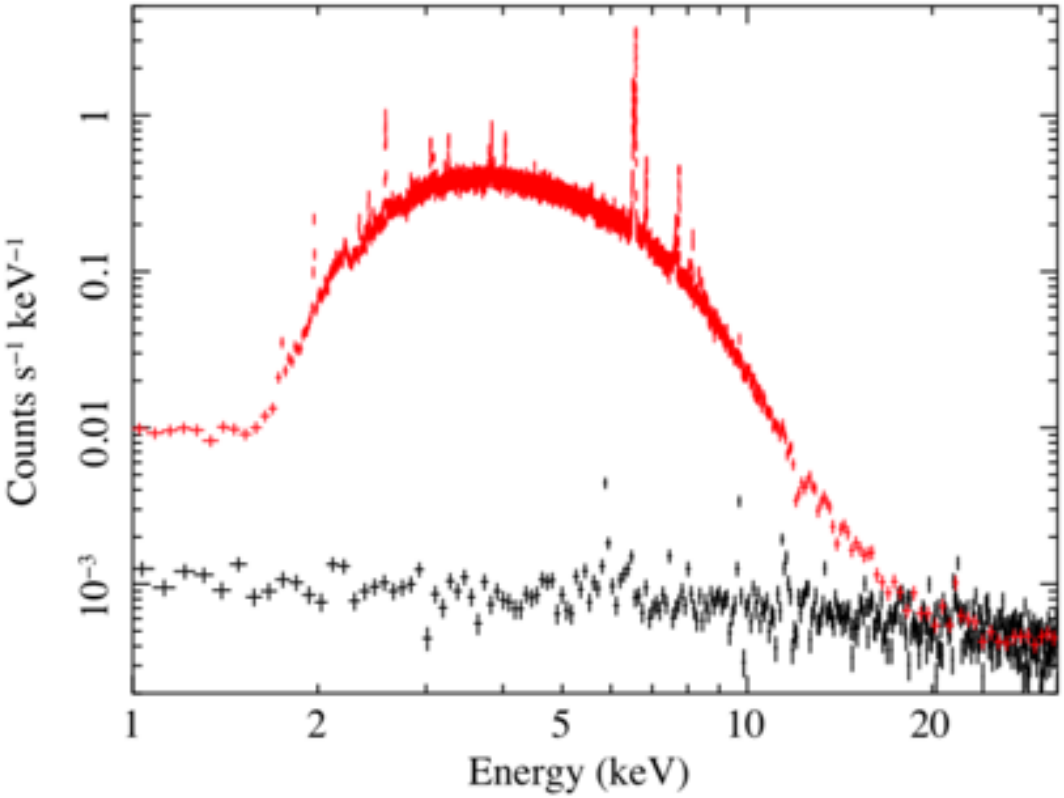

9:26:50 /17 93 9837

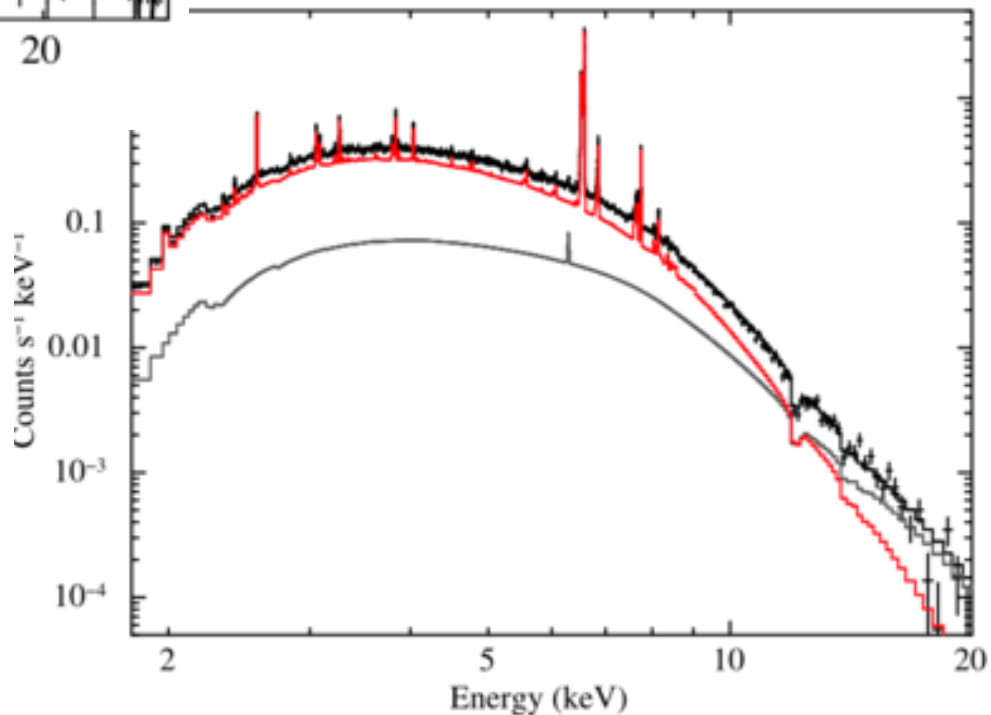
We are observing through the Gate Valve




APEC model spectrum, T=5 keV
GV open
GV closed
normalized counts s^{-1} keV^{-1}
10
1
2
3
5
8
Energy (keV)

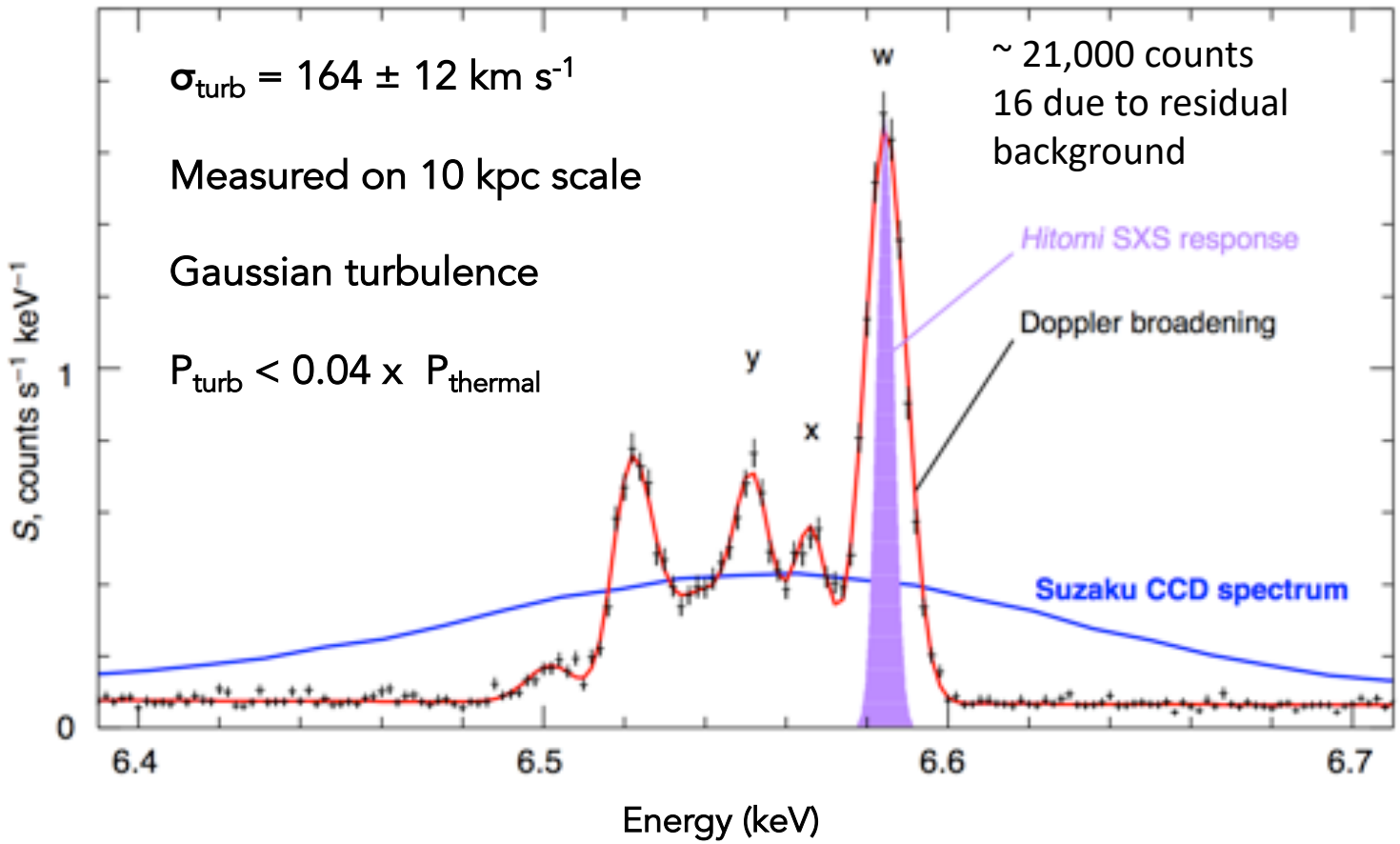
Spectrum from whole array





Perseus: Fe XXV (He-like) complex

5 eV energy resolution achieved in orbit, full array

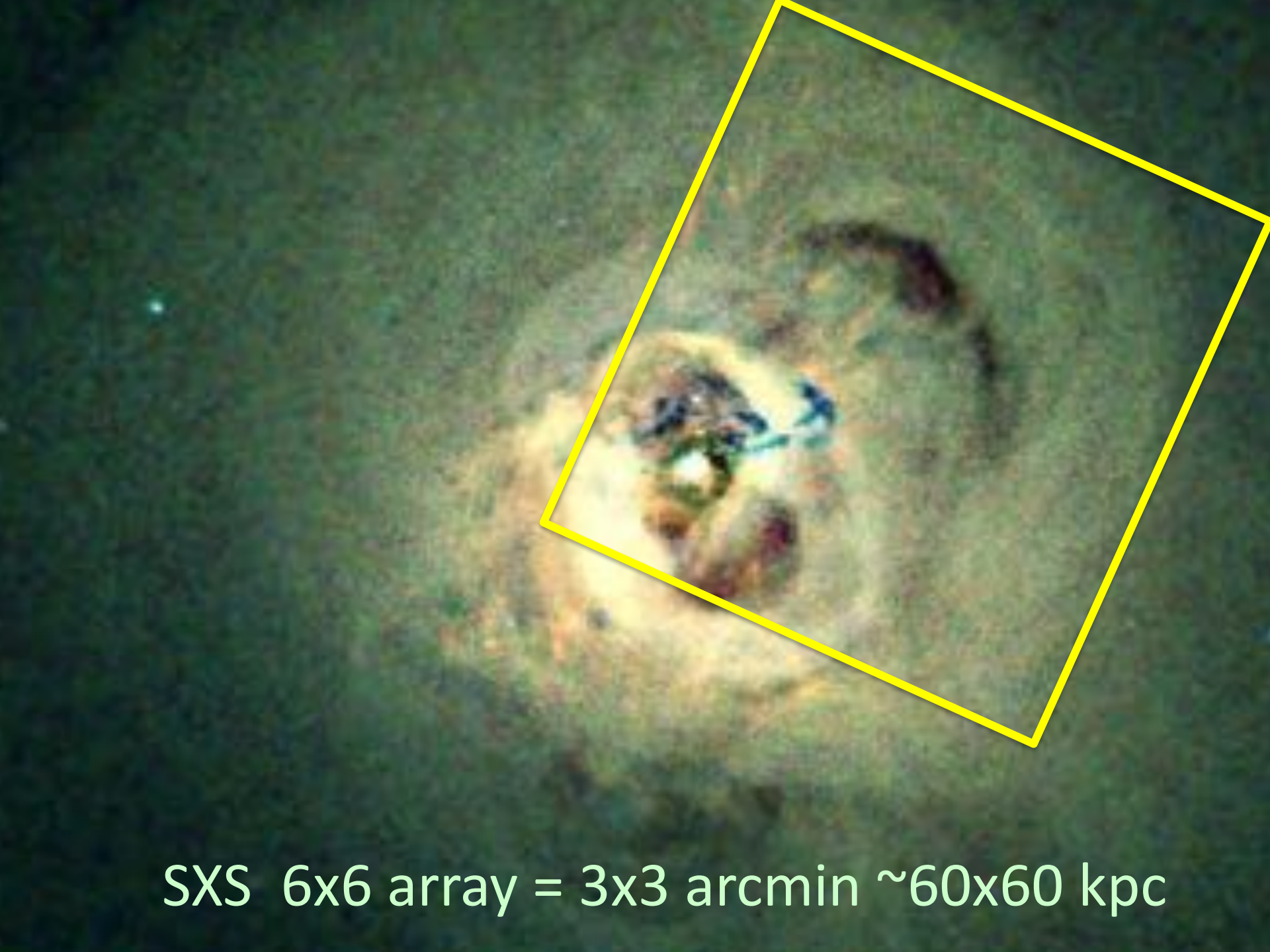


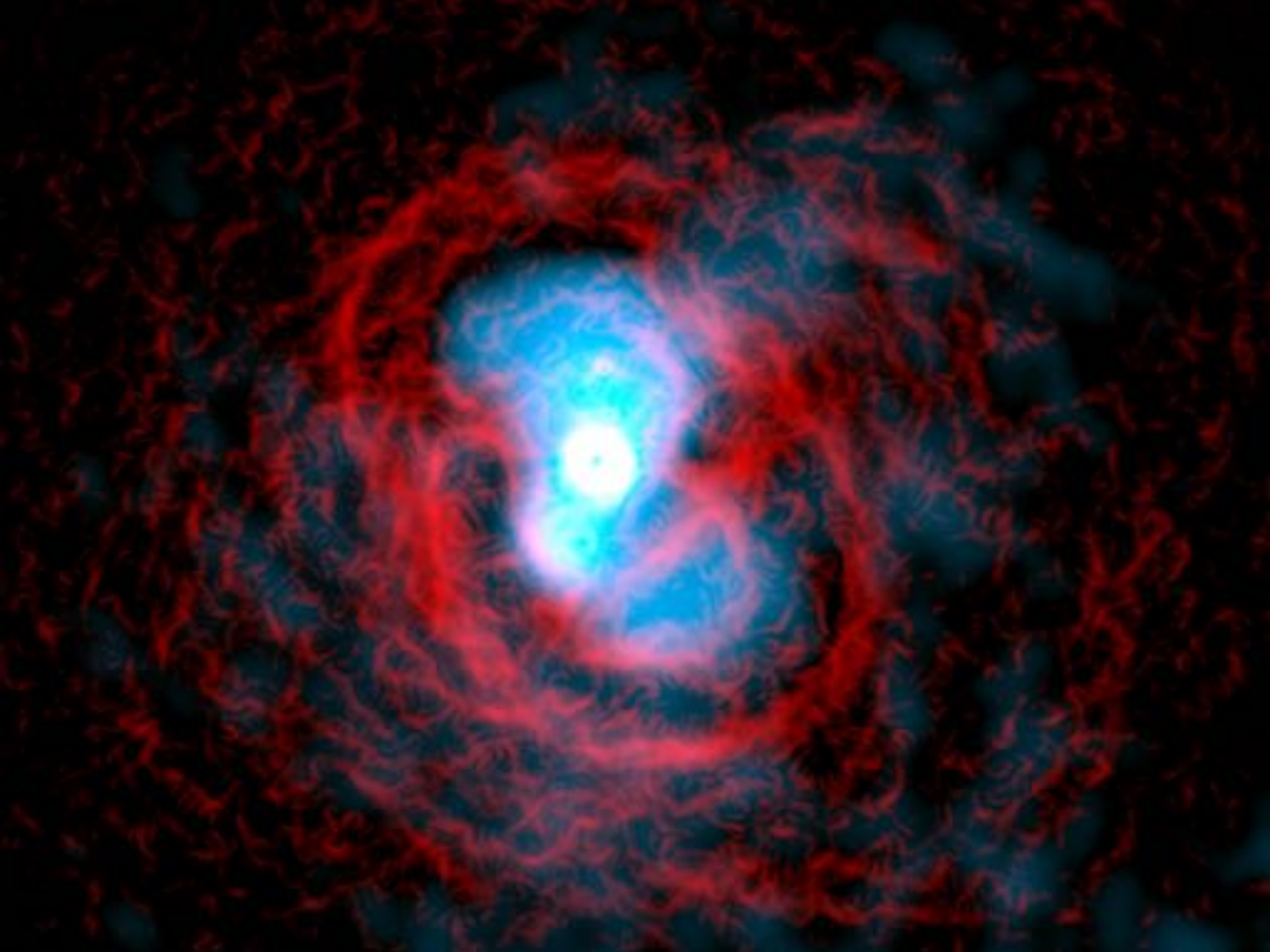
BLACK: Hitomi SXS data

PURPLE: Hitomi SXS line response function

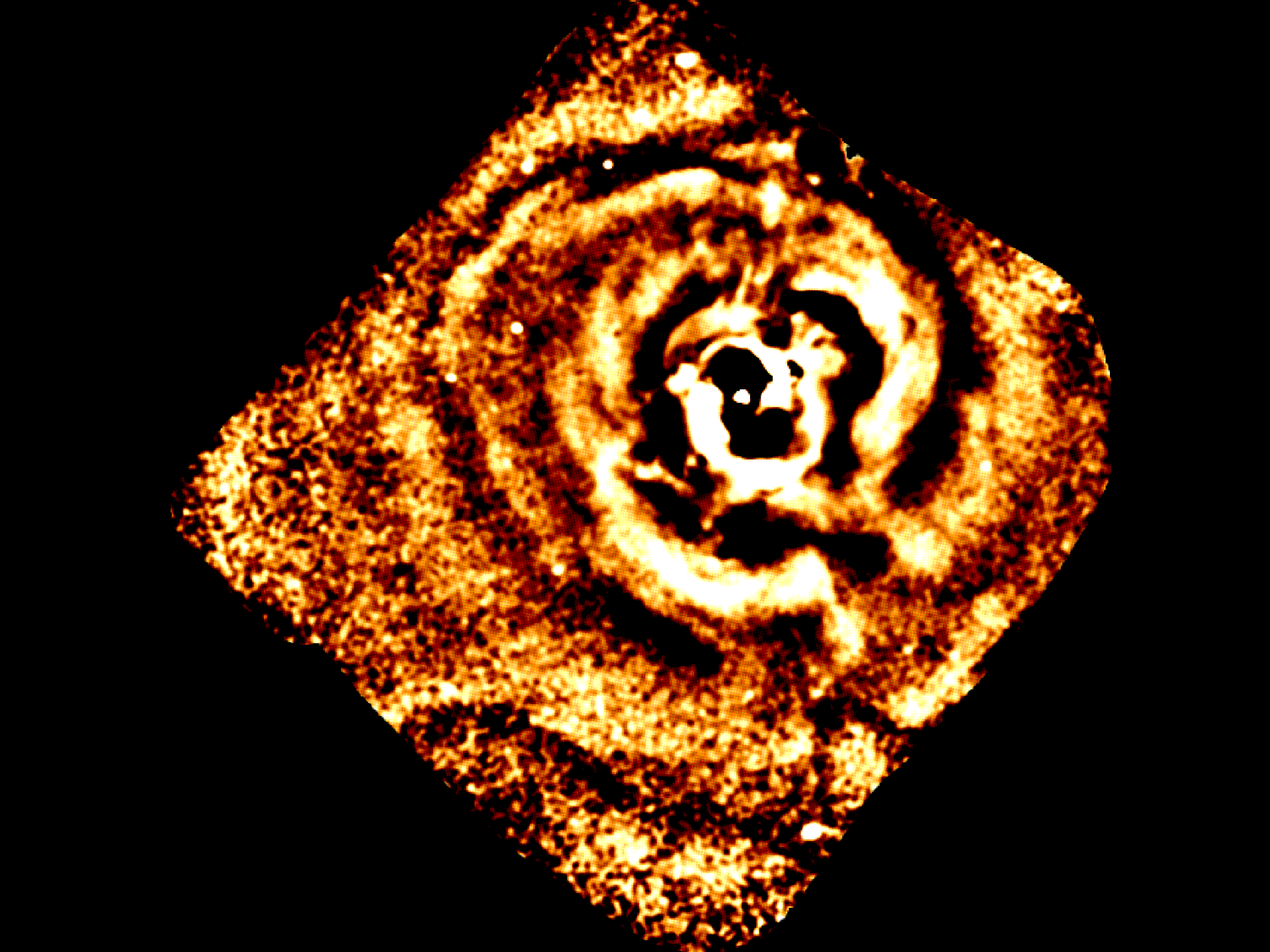
BLUE: Best previous spectrum (Suzaku CCD)

Hitomi Collaboration, Nature 2016


SXS 6x6 array = 3x3 arcmin ~60x60 kpc




~3.5PV measured in thick rims (Graham+08)




M87


Centaurus

General implications

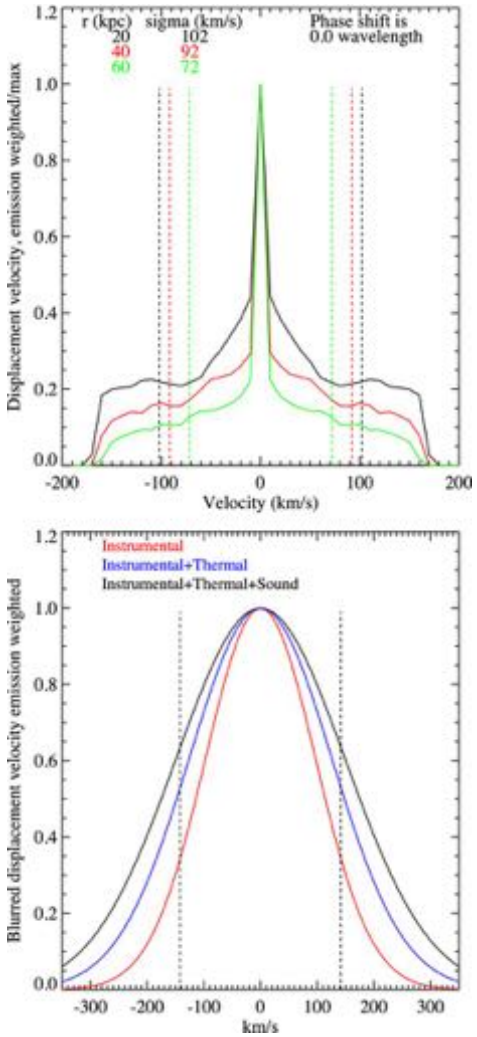
- Energy content due to small scale motions (turbulence) ~4%
- Motions could be due to bubbles, sound waves, sloshing, cold front, turbulence.
- Gas is relatively quiet for such an active region!
- X-ray observations of clusters should be good as cosmological probes.

Energy in "turbulence" is 4% thermal energy, Cooling time over region is 1-2 billion yr. Take 2 billion yr, then time to replenish energy is 8×10^7yr. Speed with which energy must flow to spread over whole region is 750 km/s.

This is >>160 km/s and close to sound speed (~1000 km/s). Turbulence can't propagate the energy! Therefore energy transported by sound waves? Consistent with data (F+17).

See also talks by C Pinto and C Bambic…

Top: simulated line profiles due to the effect of the displacement velocity of sound waves in the ICM of the Perseus cluster.



A. C. Fabian et al. MNRAS 2017;464:L1-L5

MONTHLY NOTICES
of the Royal Astronomical Society
LETTERS

Published Refereed Papers from the Hitomi Perseus Data

The quiescent intracluster medium in the core of the Perseus cluster (Hitomi Collab.)

Hitomi Constraints on the 3.5 keV Line in the Perseus Galaxy Cluster

Solar abundance ratios of the iron-peak elements in the Perseus cluster

Atmospheric gas dynamics in the Perseus cluster observed with Hitomi

Measurements of resonant scattering in the Perseus Cluster core with Hitomi SXS

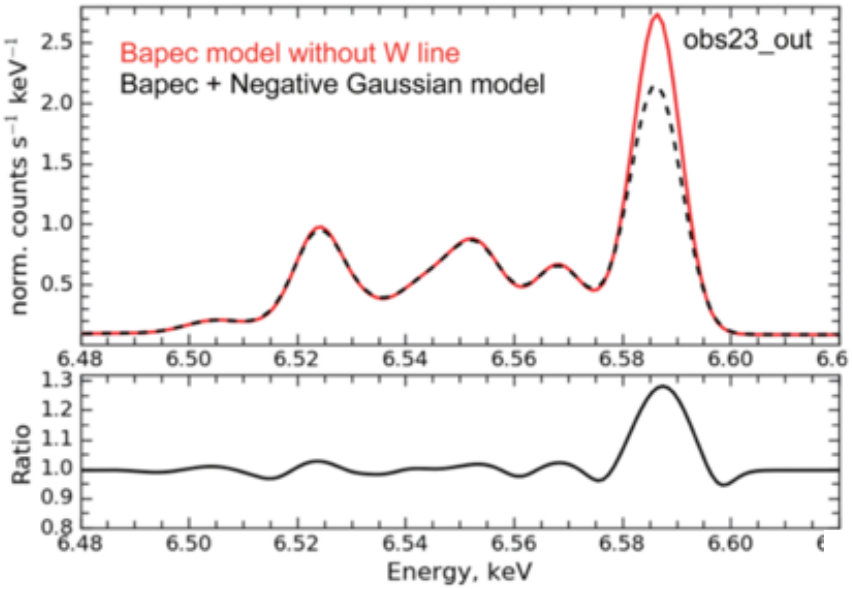
Temperature structure in the Perseus cluster core observed with Hitomi

Atomic data and spectral modeling constraints from high-resolution X-ray observations of the Perseus cluster with Hitomi

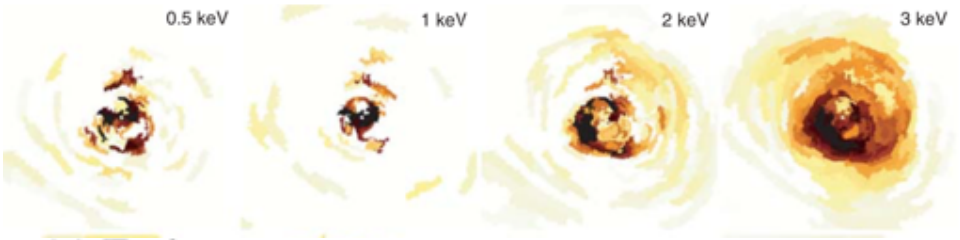
Hitomi observation of radio galaxy NGC 1275: The first X-ray microcalorimeter spectroscopy of Fe-Kα line emission from an active galactic nucleus

An X-ray spectroscopic search for dark matter and unidentified line signatures in the Perseus cluster with Hitomi (Tamura+)

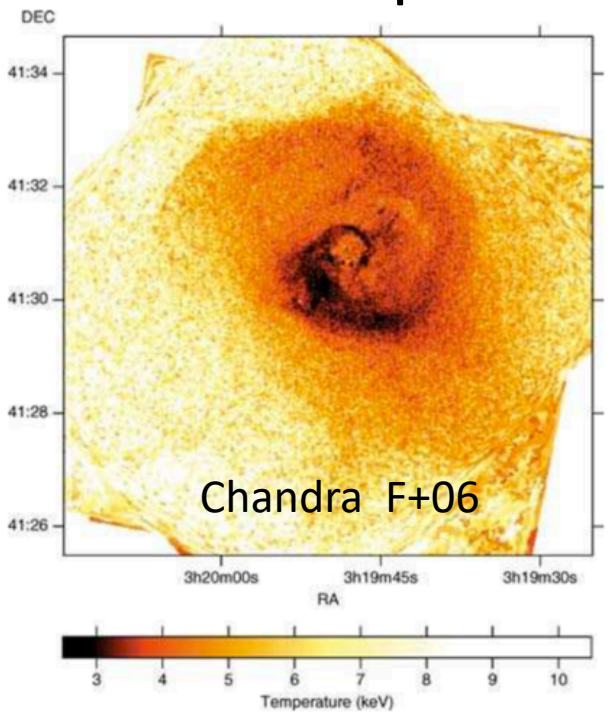
Resonance Scattering



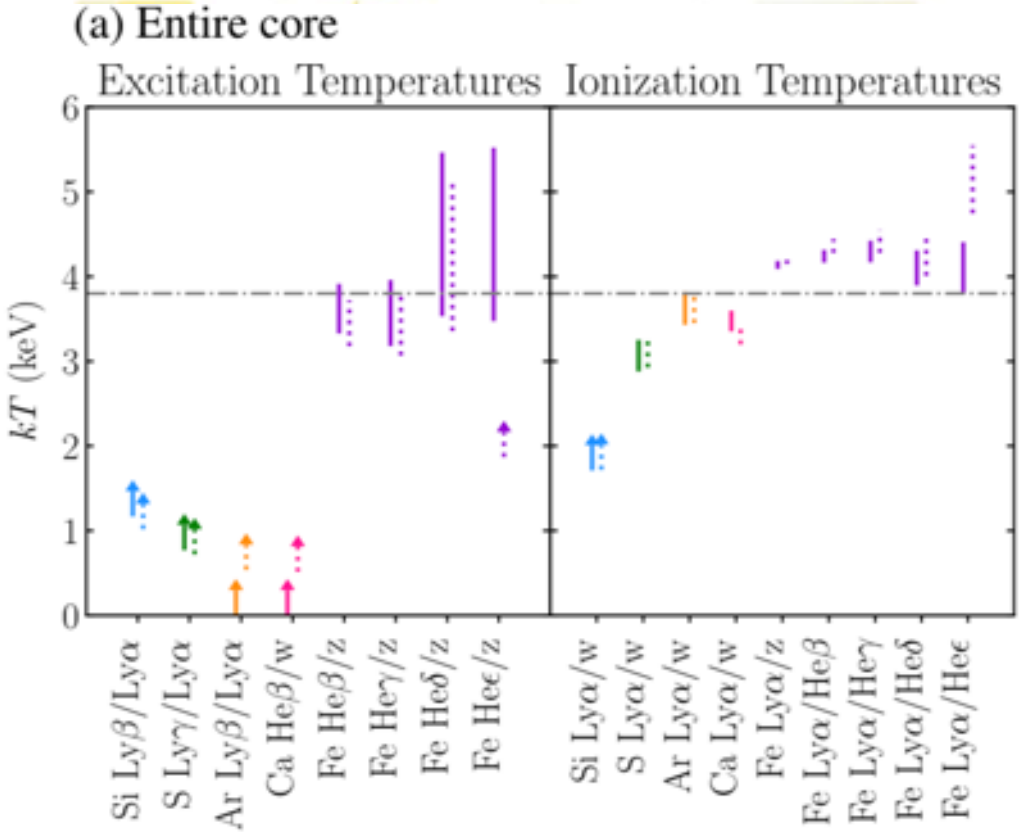
J. S. Sanders and A. C. Fabian 07



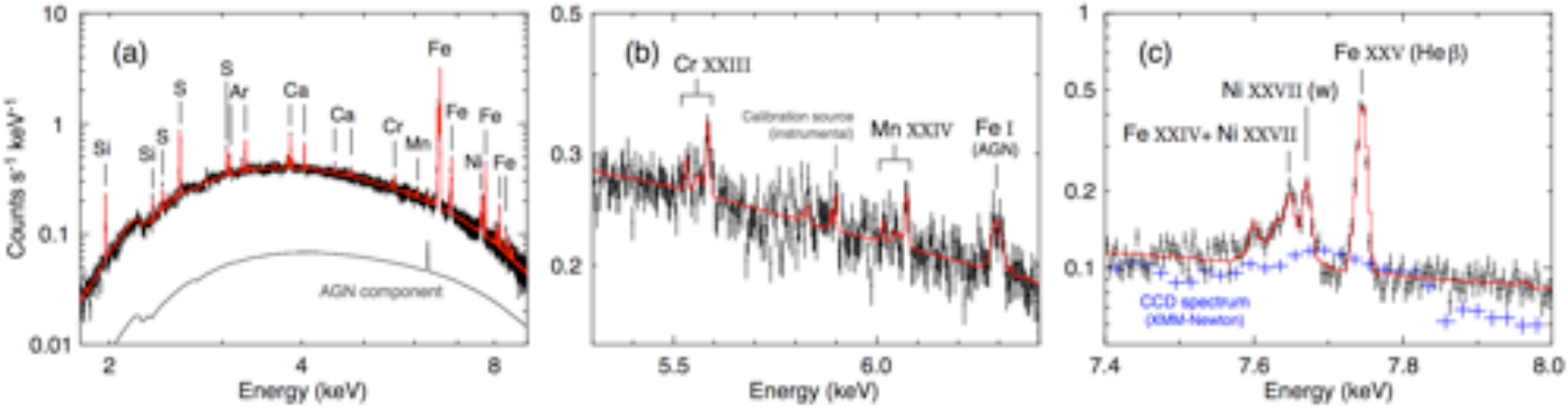
Temperatures

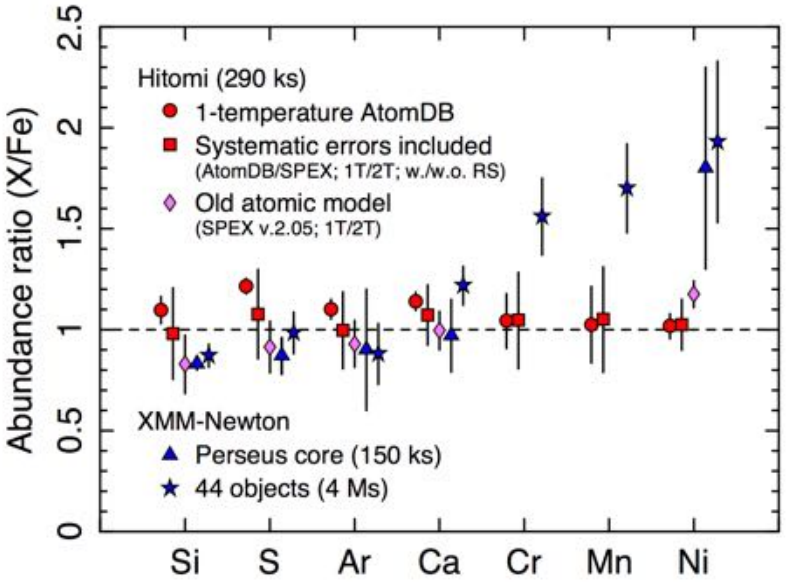


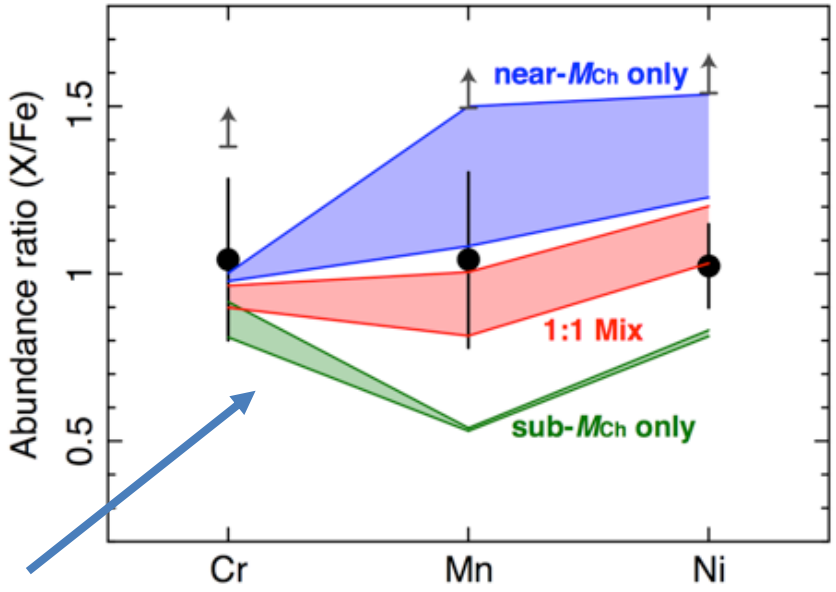
Chandra F+06



Nature Paper 2







Strong evidence for 2 types of Type Ia to produce the elements

Hitomi Collaboration, Nature 2017

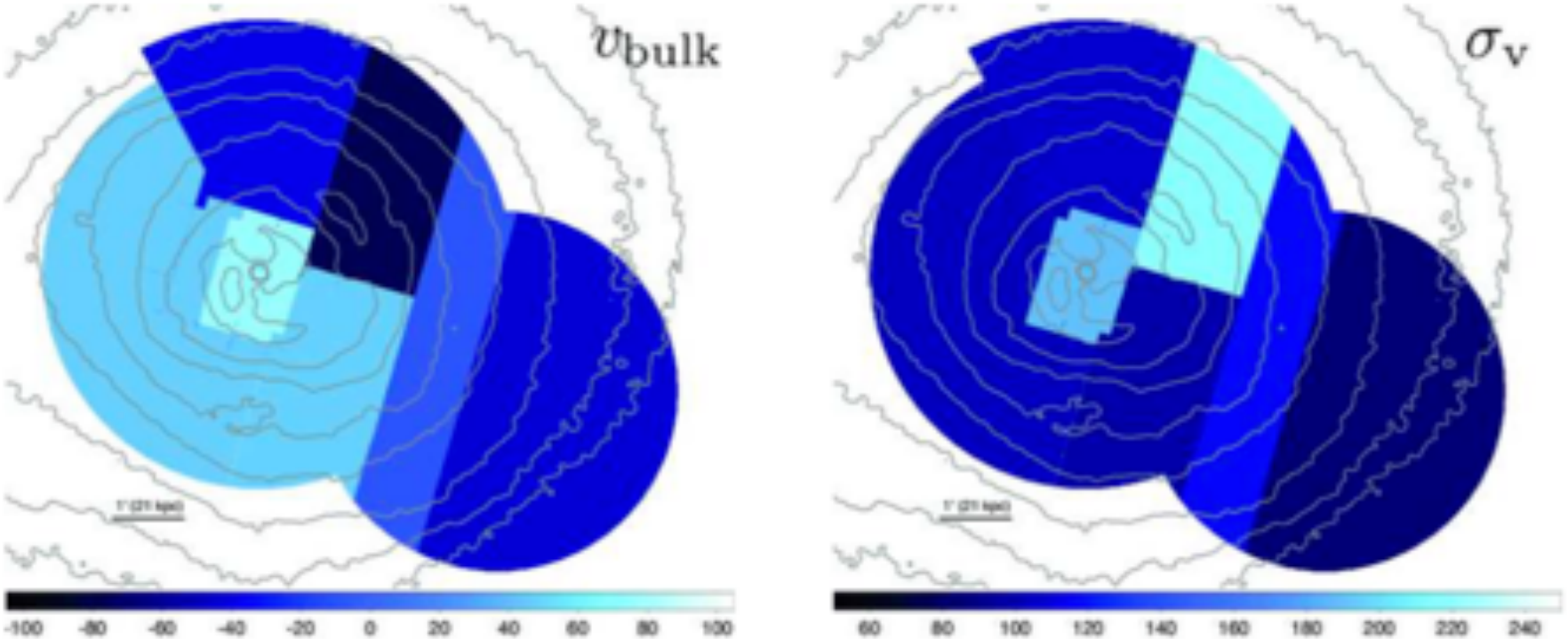
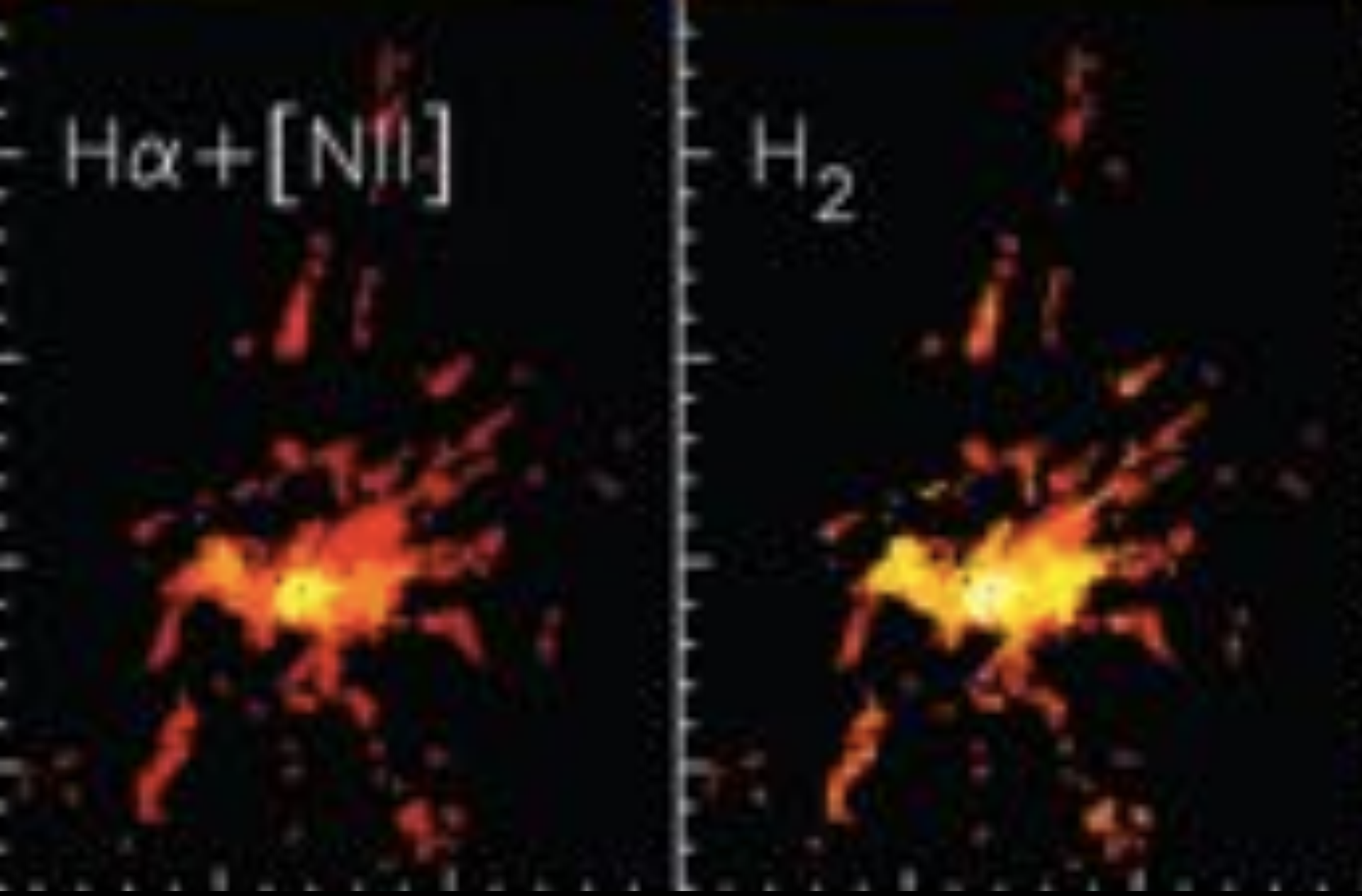


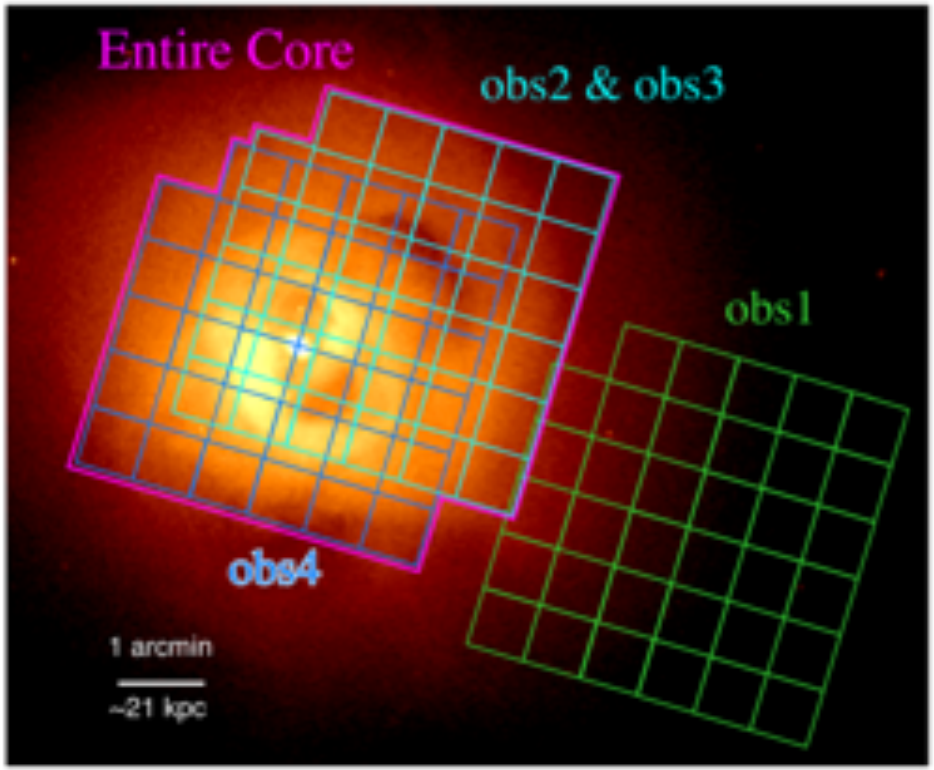
Fig. 6. *Left:* PSF corrected bulk velocity ($v_{\rm bulk}$) map with respect to $z = 0.017284$ (heliocentric correction applied). *Right:* PSF corrected LOS velocity dispersion ($\sigma_{\rm v}$) map. The unit of the values is km s^{-1}. The Chandra X-ray contours are overlaid.

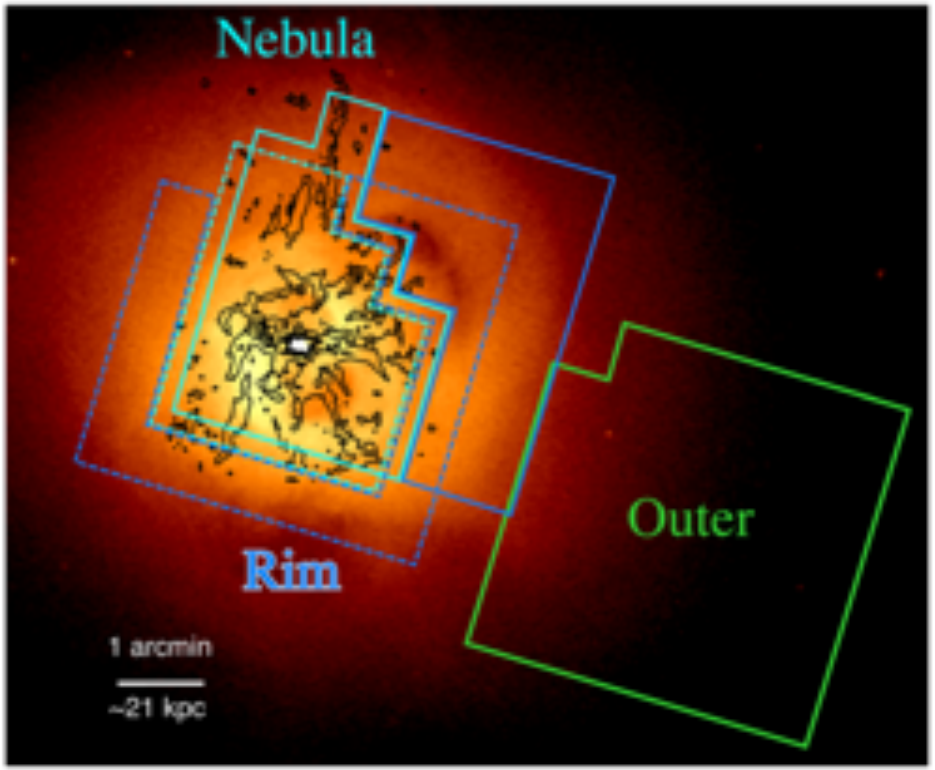
Most turbulence has velocity~100 km/s or less

HST Fabian+08



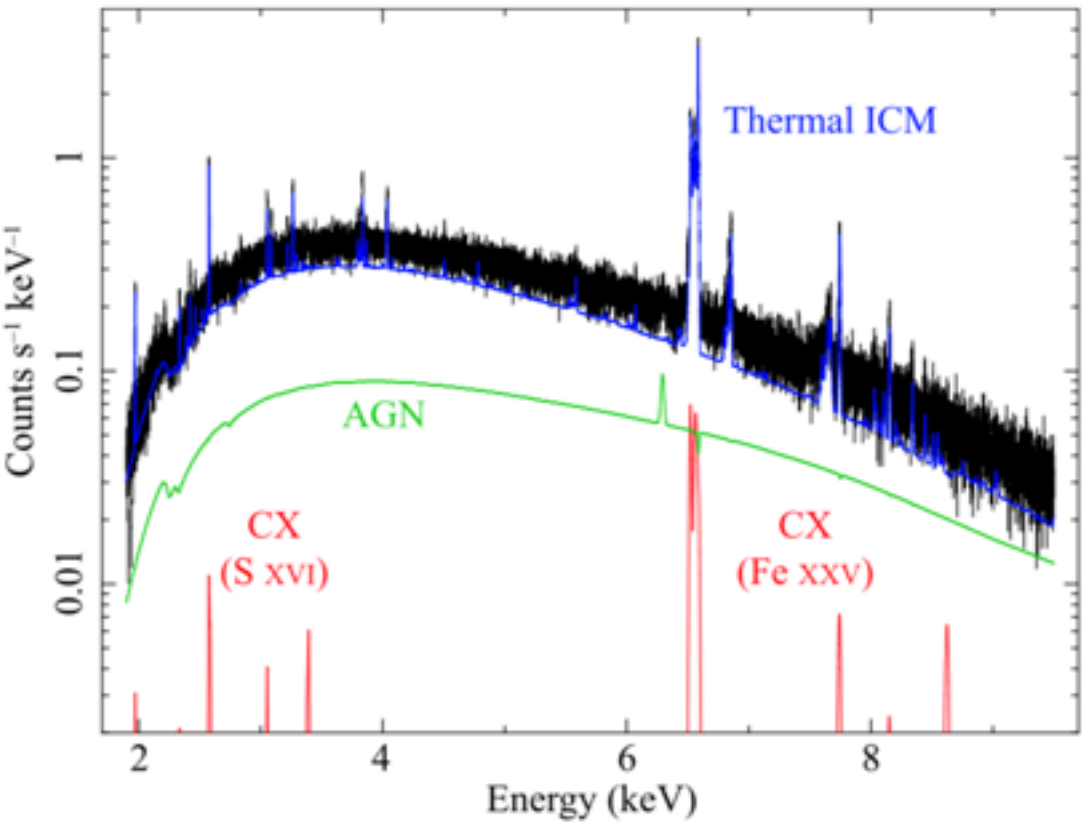
Lim+12

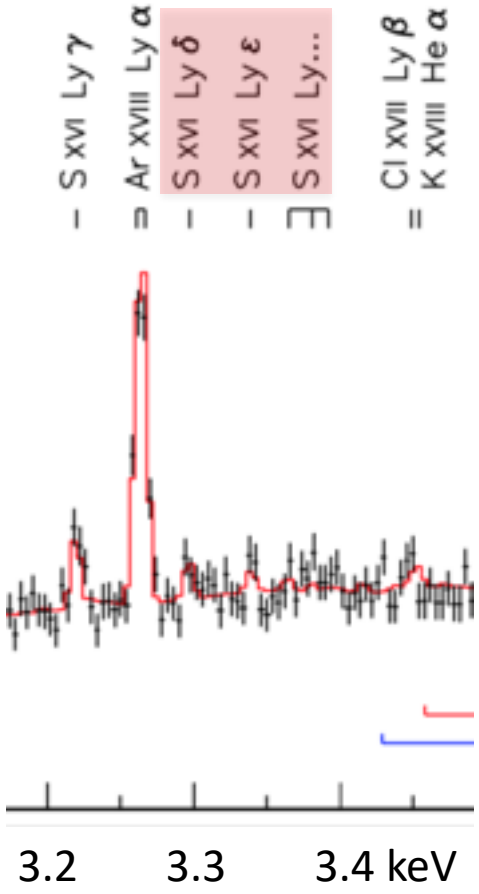

Entire Core
obs2 & obs3
obs1
obs4
1 arcmin
~21 kpc


Nebula
Outer
Rim
1 arcmin
~21 kpc

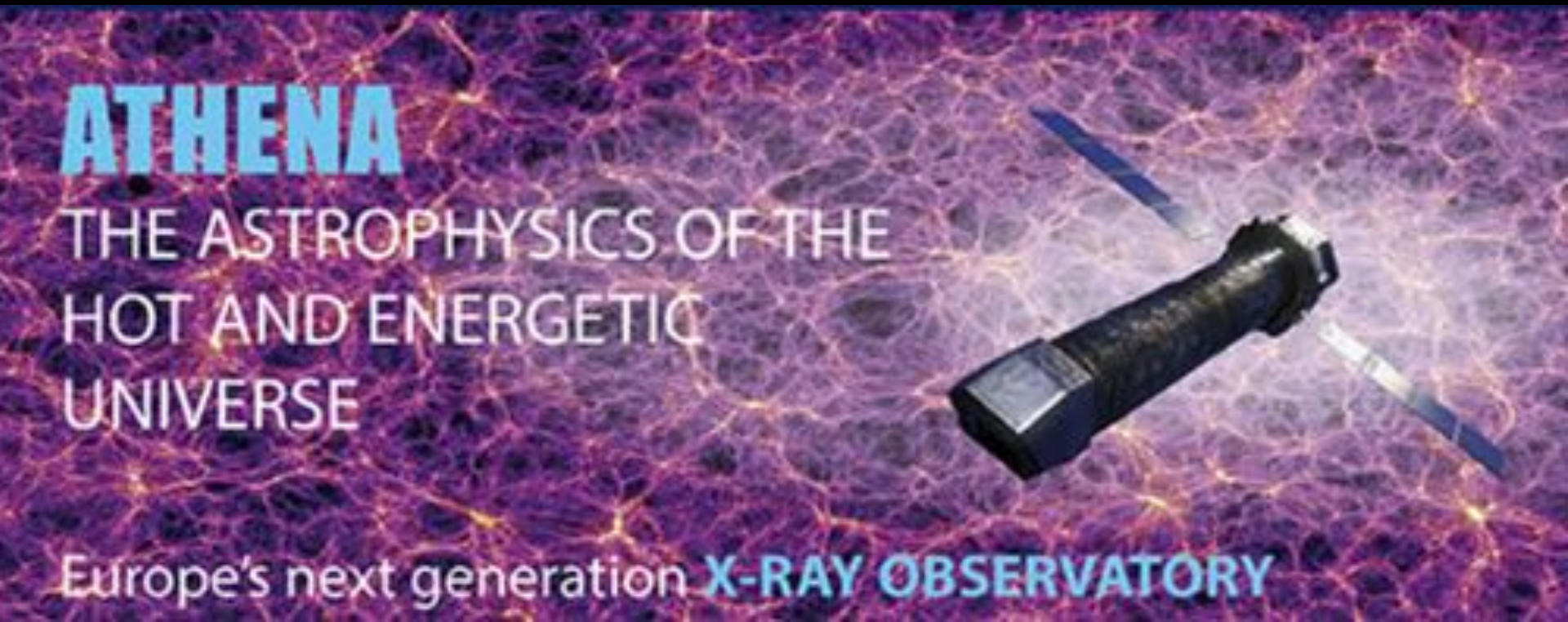
Spectrum of these filaments is unlike anything in Galaxy, other than Crab and due to energetic particles (the hot gas?)
Ferland+08/9

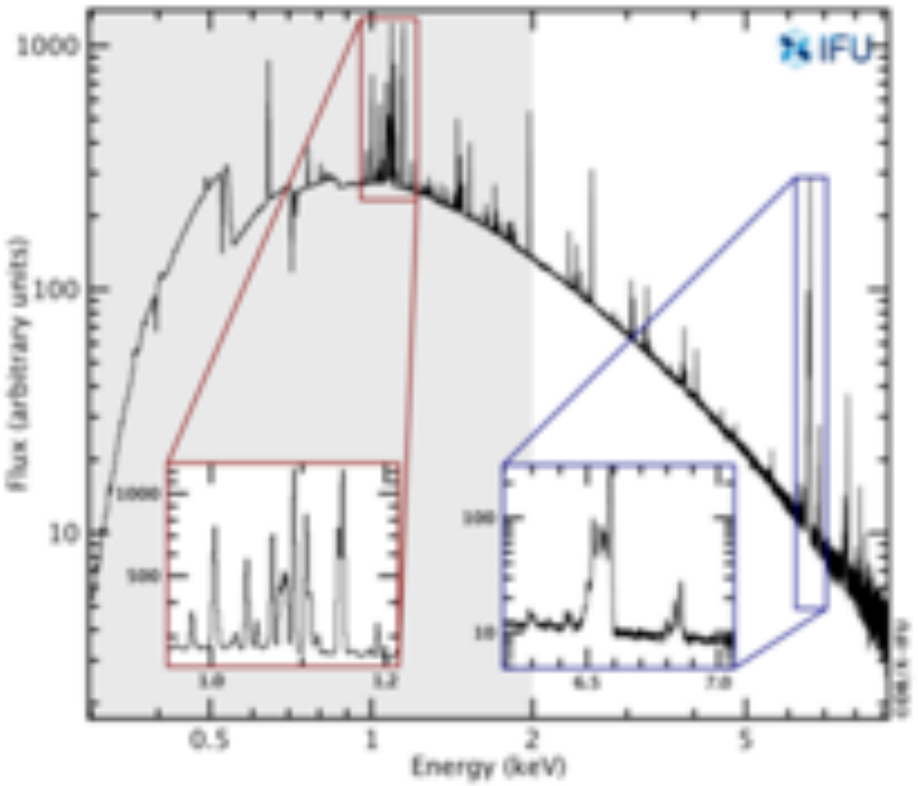
Charge Exchange?

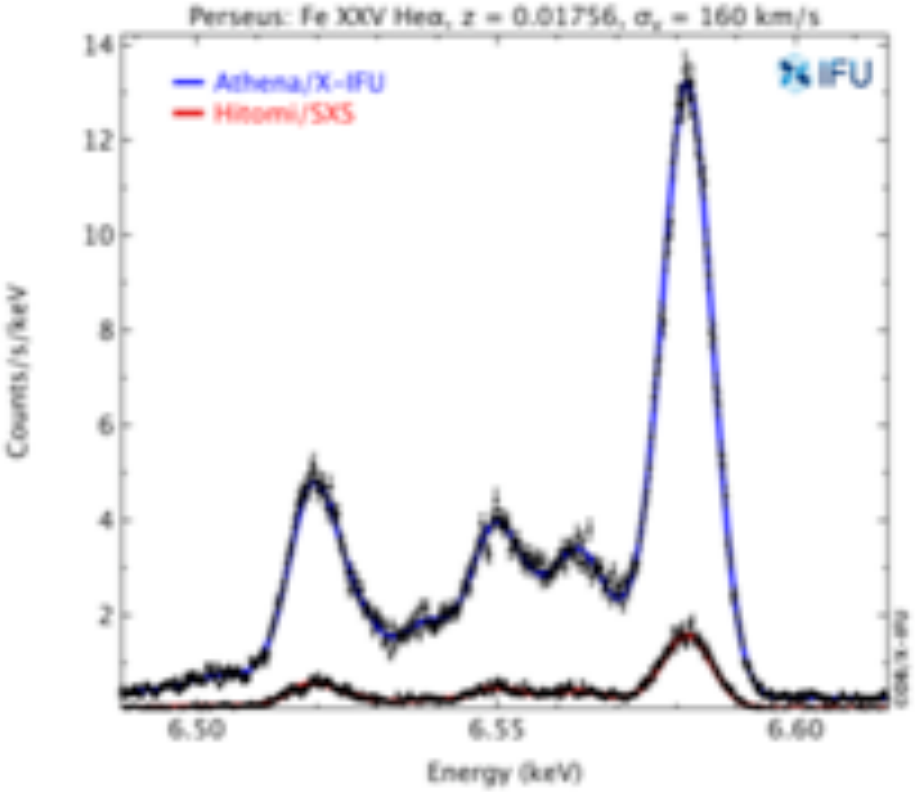




Future is XRISM (launch 2022) then




IFU
1000
100
10
Flux (arbitrary units)
0.5
1
2
5
Energy (keV)
1000
500
1.0
1.2
100
10
6.5
7.0


Perseus: Fe XXV Heα, z = 0.01756, σv = 160 km/s
Athena/X-IFU
Hitomi/SXS
IFU
14
12
10
8
6
4
2
Counts/s/keV
6.50
6.55
6.60
Energy (keV)