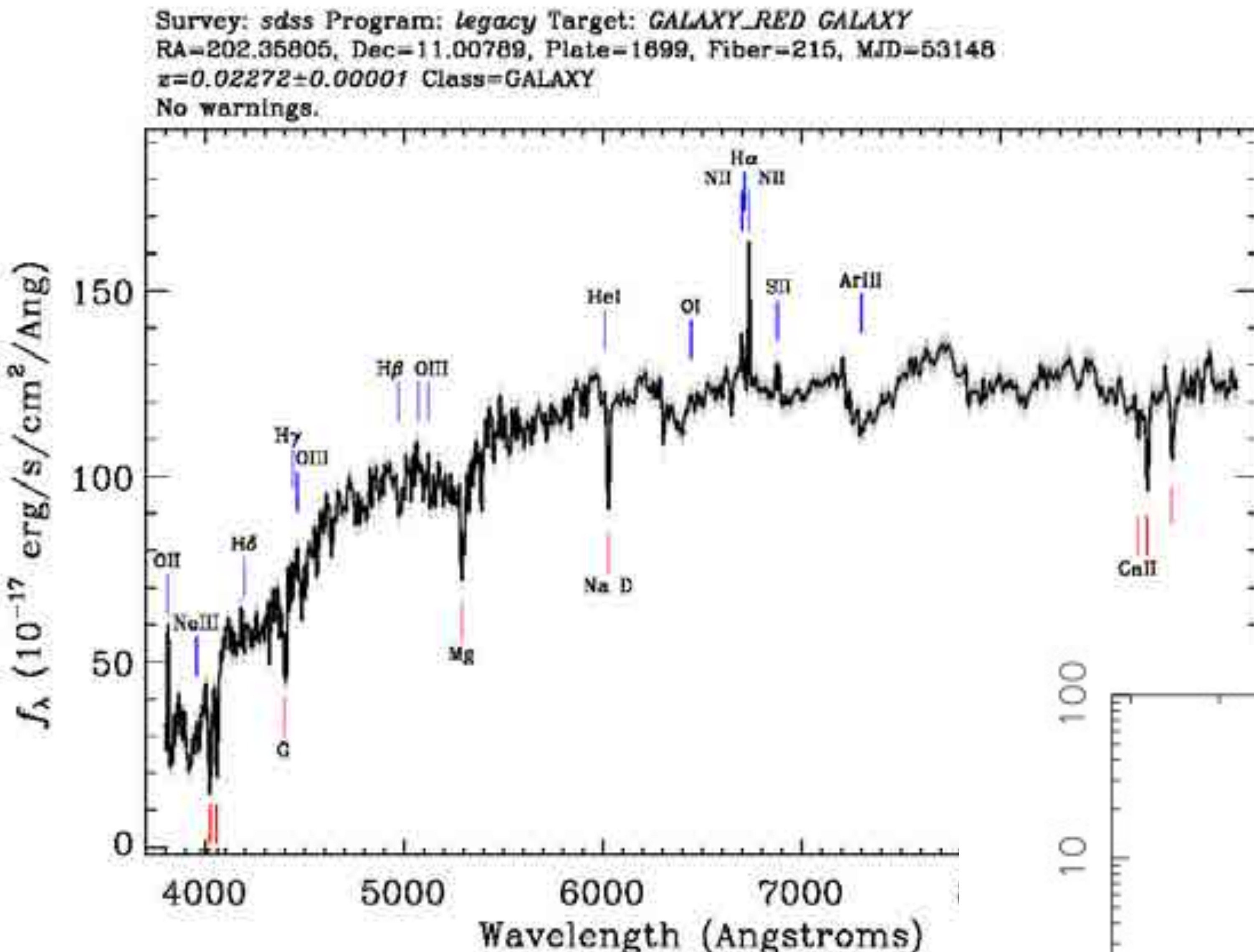
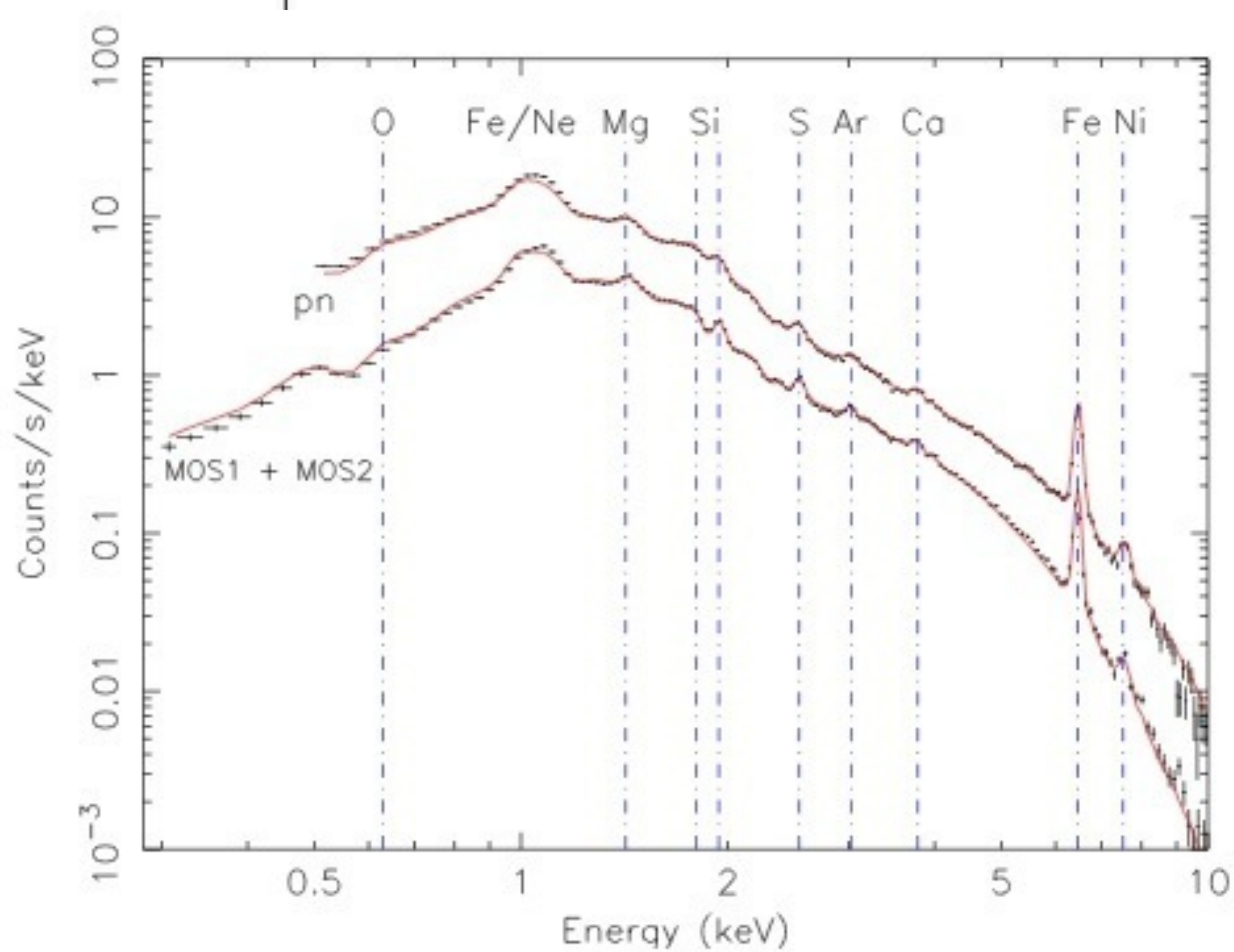
HIGH RESOLUTION X-RAY SPECTROSCOPY: legacy from the Hitomi observatory

AURORA SIMIONESCU
ISAS/JAXA

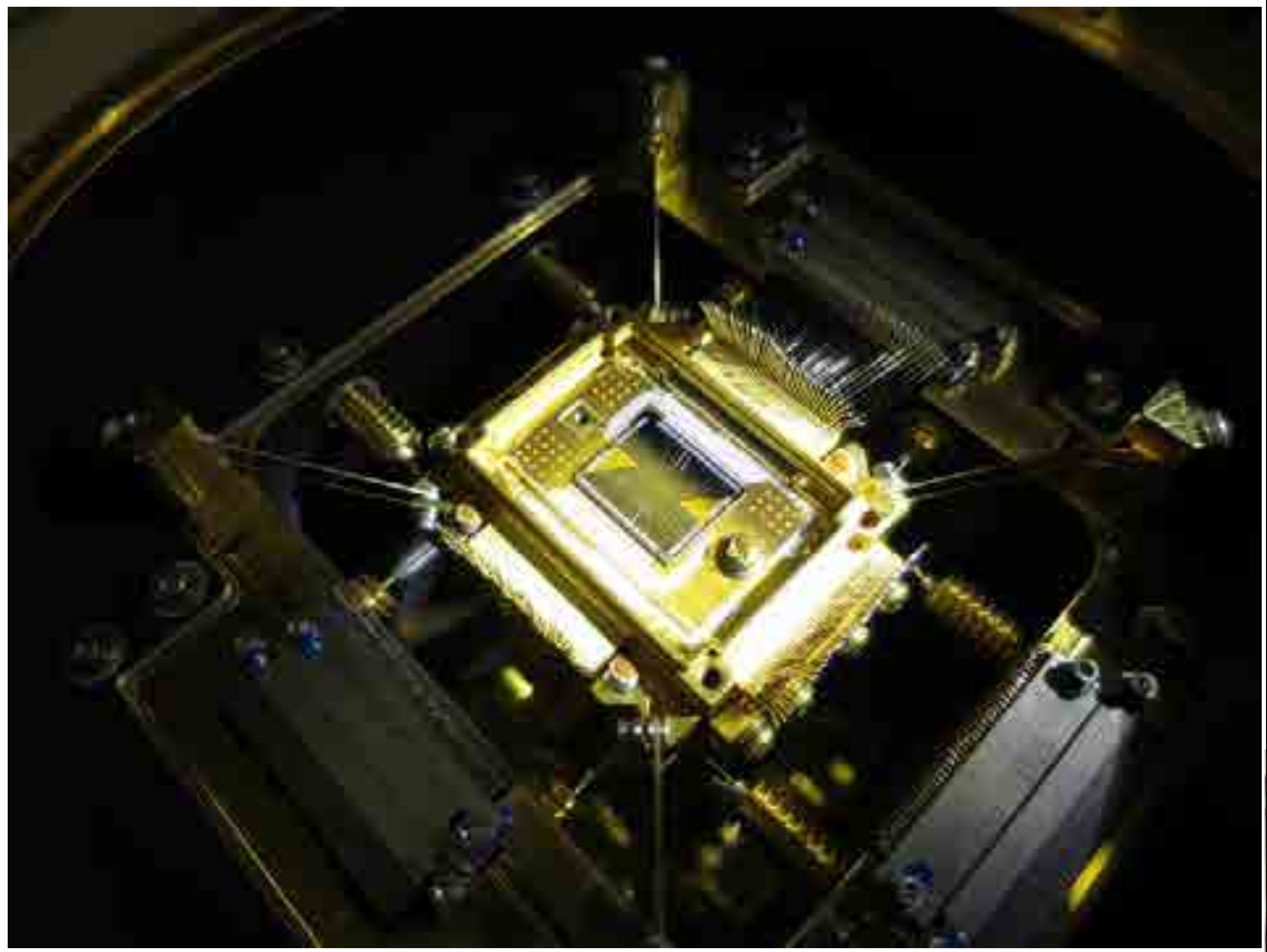


optical spectroscopy



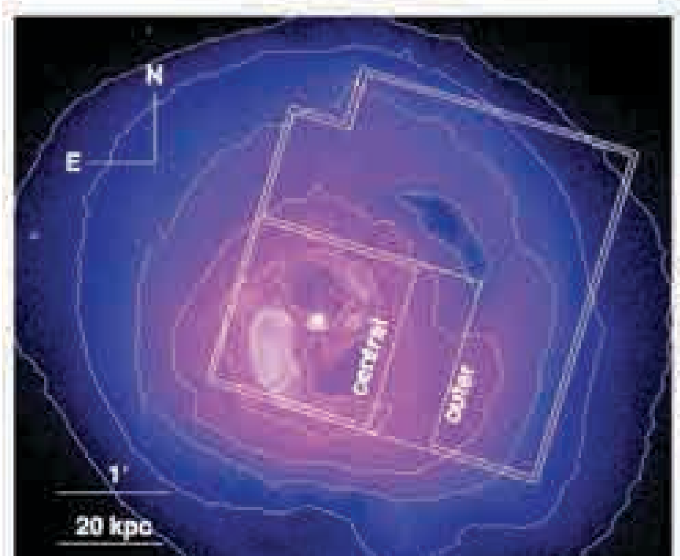
X-ray spectroscopy
with conventional CCDs

The Hitomi Soft X-ray Spectrometer (SXS)

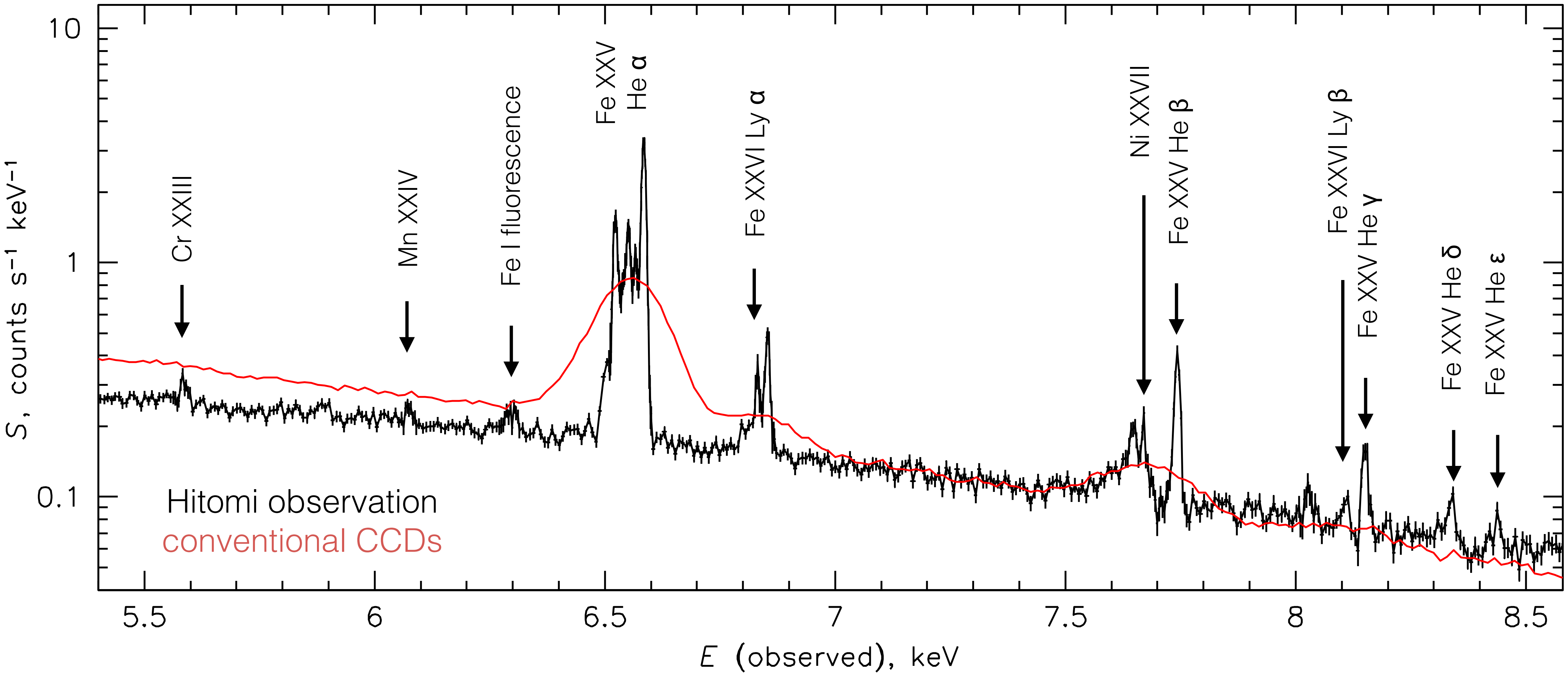


- array of 36 micro-calorimeter pixels (3x3' FOV)
- cryogenically cooled to 50mK
- spectral resolution of 5eV around Fe-K line

HITOMI First Light Spectrum of the Perseus Cluster



Hitomi FWHM 4.9 eV
CCD FWHM ~150 eV



Hitomi Collaboration, Nature, 2016

2016Natur.535..117H 1.000 07/2016 A E X R C S N U
Hitomi Collaboration; Aharonian, Felix; Akamatsu, Hiroki; Akimoto, Fumie; Allen, Steven W.; Anabuki, Naohisa; Angelini, Lorella; Arnaud, Keith; Audard, Marc; Awaki, Hisamitsu; and 206 coauthors
The quiescent intracluster medium in the core of the Perseus cluster

2017arXiv171004648H 1.000 10/2017 A X C U
Hitomi Collaboration; Aharonian, Felix; Akamatsu, Hiroki; Akimoto, Fumie; Allen, Steven W.; Angelini, Lorella; Audard, Marc; Awaki, Hisamitsu; Axelsson, Magnus; Bamba, Aya; and 185 coauthors
Measurements of resonant scattering in the Perseus cluster core with Hitomi SXS

2017arXiv171100240H 1.000 11/2017 A X R C U
Hitomi Collaboration; Aharonian, Felix; Akamatsu, Hiroki; Akimoto, Fumie; Allen, Steven W.; Angelini, Lorella; Audard, Marc; Awaki, Hisamitsu; Axelsson, Magnus; Bamba, Aya; and 188 coauthors
Atmospheric gas dynamics in the Perseus cluster observed with Hitomi

dynamics and turbulence in the intergalactic medium

2017arXiv171205407H 1.000 12/2017 A X R C U
Hitomi Collaboration; Aharonian, Felix; Akamatsu, Hiroki; Akimoto, Fumie; Allen, Steven W.; Angelini, Lorella; Audard, Marc; Awaki, Hisamitsu; Axelsson, Magnus; Bamba, Aya; and 185 coauthors
Atomic data and spectral modeling constraints from high-resolution X-ray observations of the Perseus cluster with Hitomi

atomic physics

2017arXiv171206612H 1.000 12/2017 A X R C U
Hitomi Collaboration; Aharonian, Felix; Akamatsu, Hiroki; Akimoto, Fumie; Allen, Steven W.; Angelini, Lorella; Audard, Marc; Awaki, Hisamitsu; Axelsson, Magnus; Bamba, Aya; and 185 coauthors
Temperature Structure in the Perseus Cluster Core Observed with Hitomi

temperature structure and test of collisional ionisation equilibrium

2017Natur.551..478H 1.000 11/2017 A E X D R C S U
Hitomi Collaboration; Aharonian, Felix; Akamatsu, Hiroki; Akimoto, Fumie; Allen, Steven W.; Angelini, Lorella; Audard, Marc; Awaki, Hisamitsu; Axelsson, Magnus; Bamba, Aya; and 184 coauthors
Solar abundance ratios of the iron-peak elements in the Perseus cluster

supernova nucleosynthesis

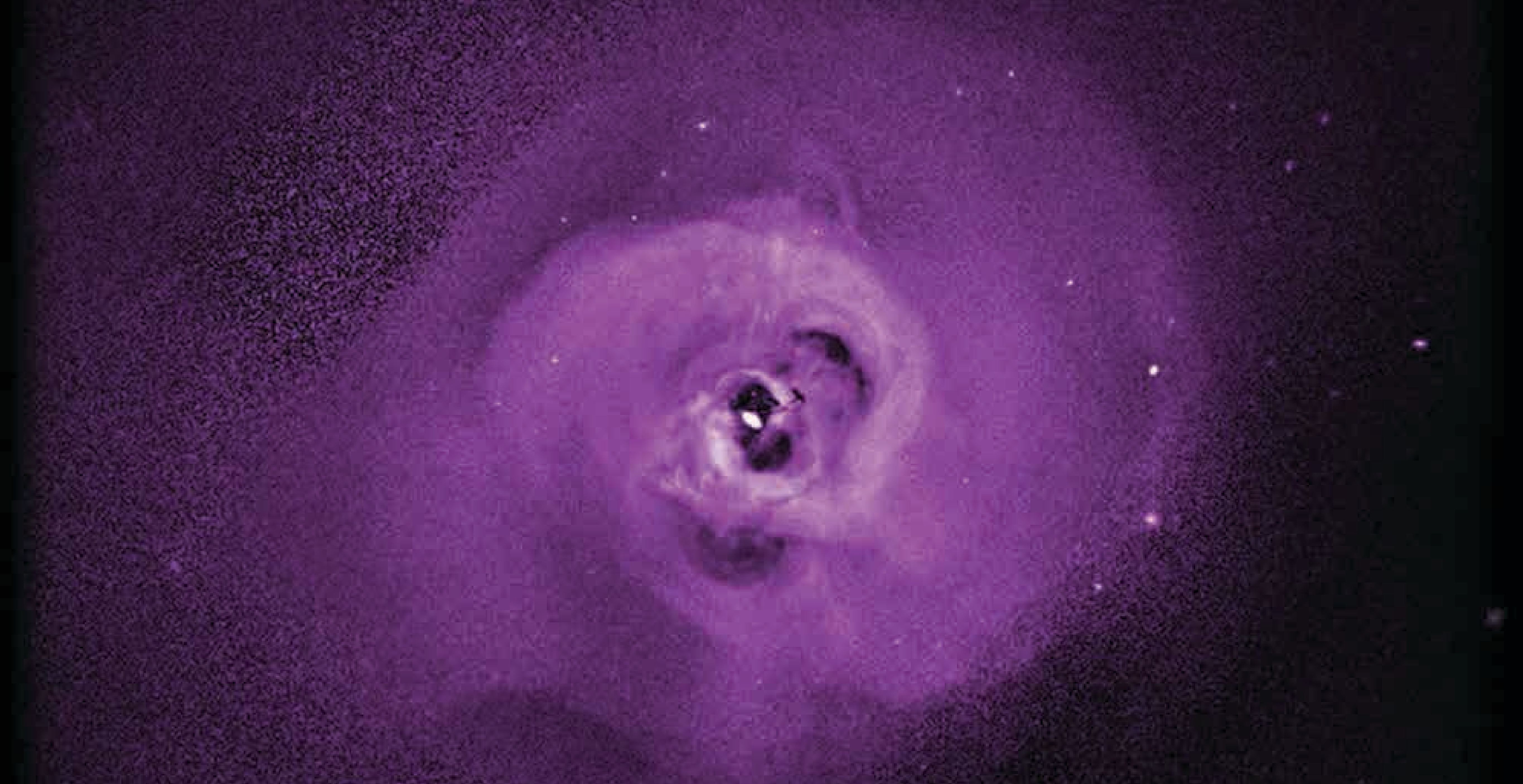
2017arXiv171106289H 1.000 11/2017 A X R C U
Hitomi Collaboration; Aharonian, Felix; Akamatsu, Hiroki; Akimoto, Fumie; Allen, Steven W.; Angelini, Lorella; Audard, Marc; Awaki, Hisamitsu; Axelsson, Magnus; Bamba, Aya; and 184 coauthors
Hitomi Observation of Radio Galaxy NGC 1275: The First X-ray Microcalorimeter Spectroscopy of Fe-K{alpha} Line Emission from an Active Galactic Nucleus

circumnuclear environment around supermassive black hole

2017ApJ...837L..15A 1.000 03/2017 A E F X D R C S N U
Aharonian, F. A.; Akamatsu, H.; Akimoto, F.; Allen, S. W.; Angelini, L.; Arnaud, K. A.; Audard, M.; Awaki, H.; Axelsson, M.; Bamba, A.; and 208 coauthors
Hitomi Constraints on the 3.5 keV Line in the Perseus Galaxy Cluster

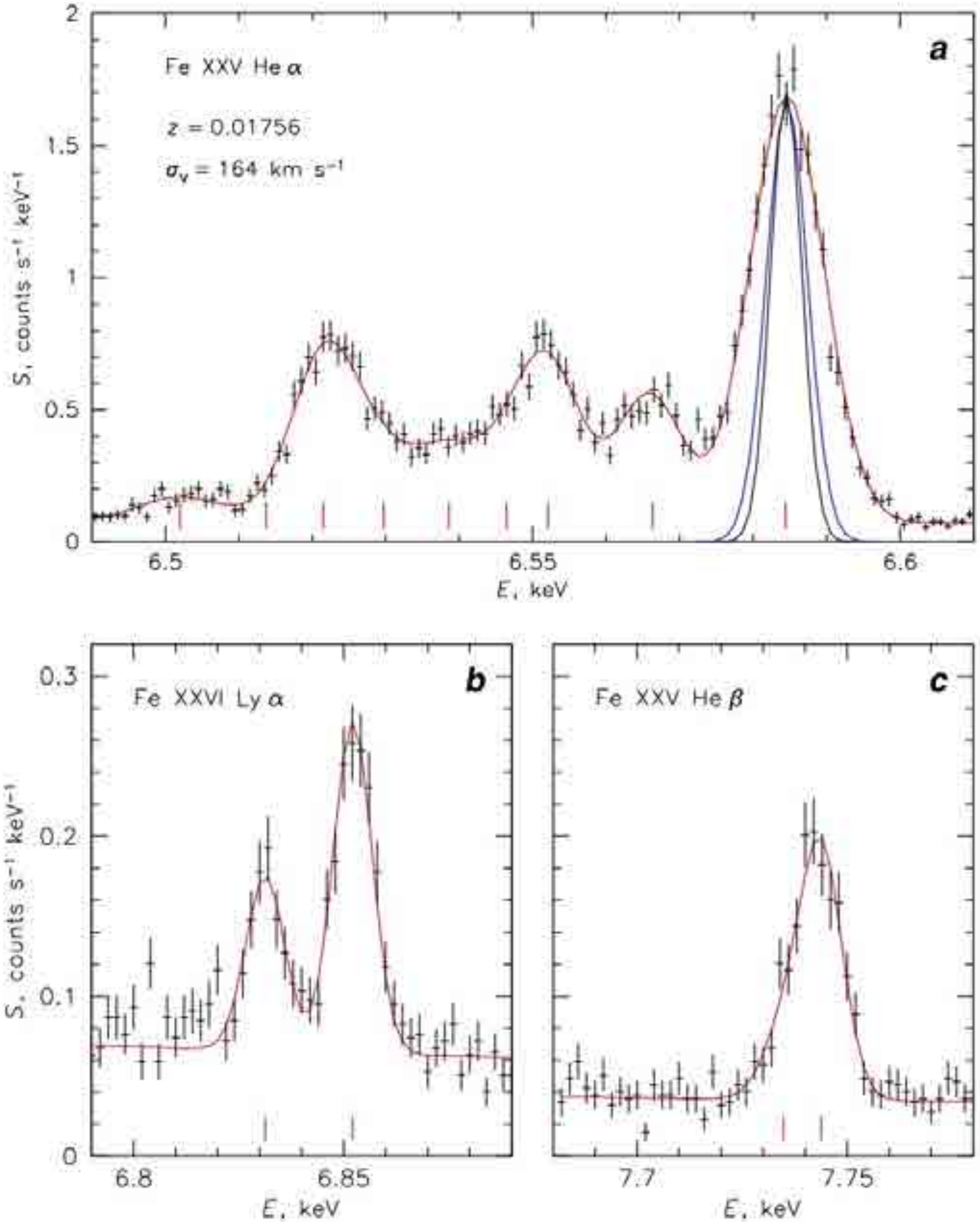
search for dark matter candidates

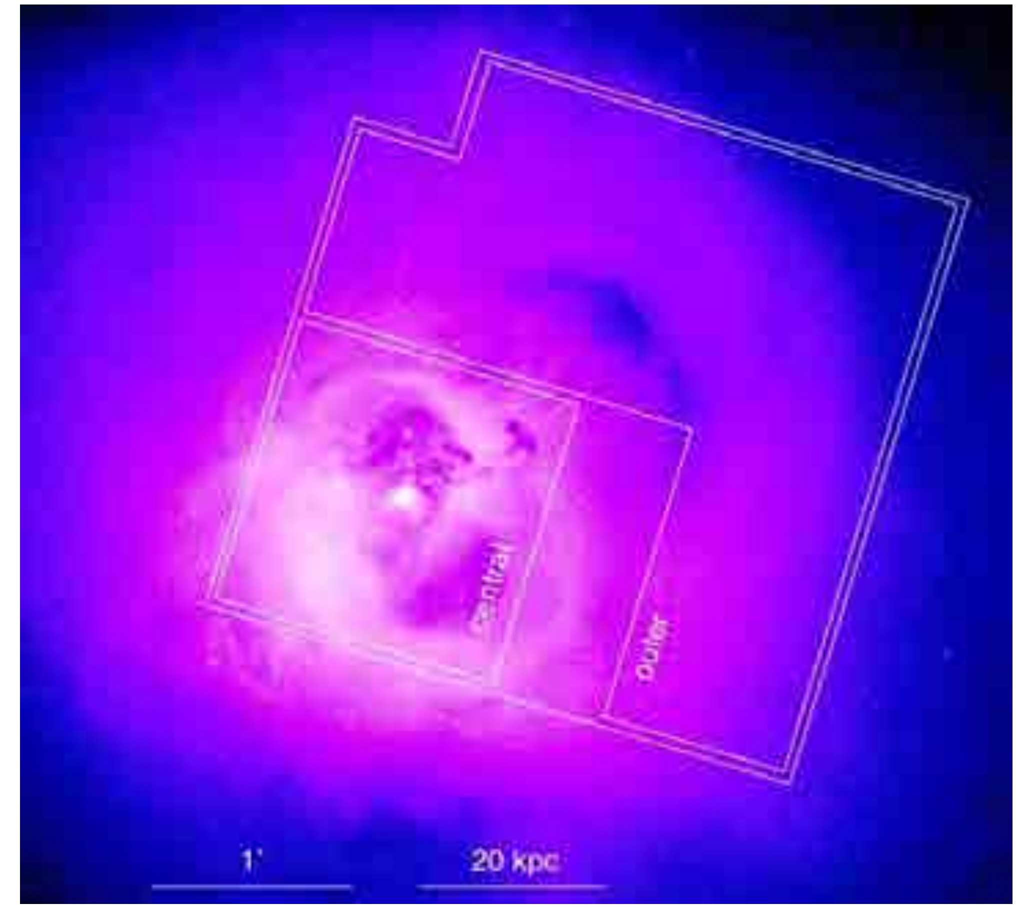
Dynamics and turbulence in the intergalactic medium



(1) what is the dynamical impact of the supermassive black hole on the surrounding X-ray emitting medium?
(2) how accurate is the hydrostatic equilibrium assumption?

ESTIMATES OF GAS TURBULENCE FROM LINE BROADENING MEASUREMENTS

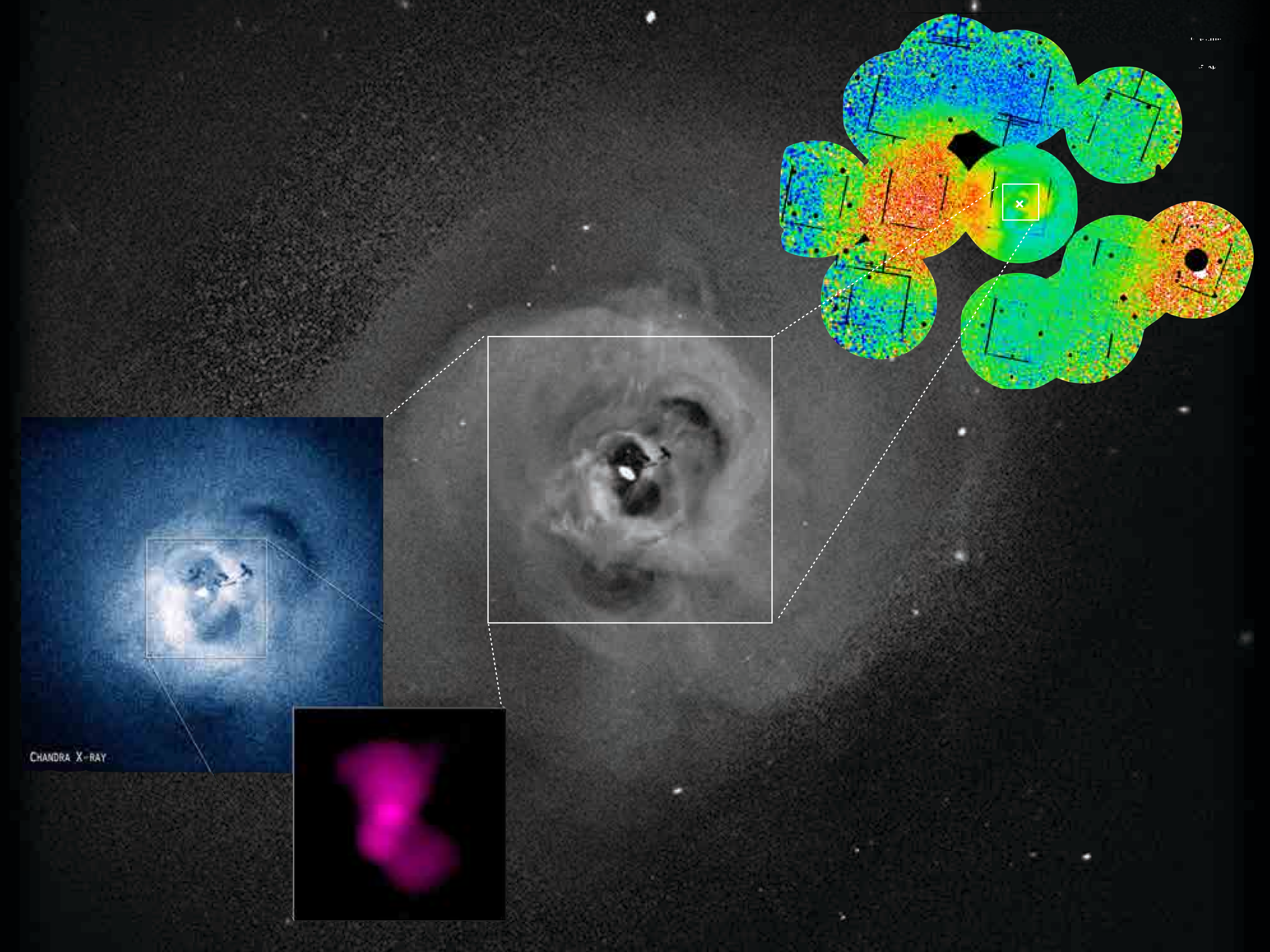




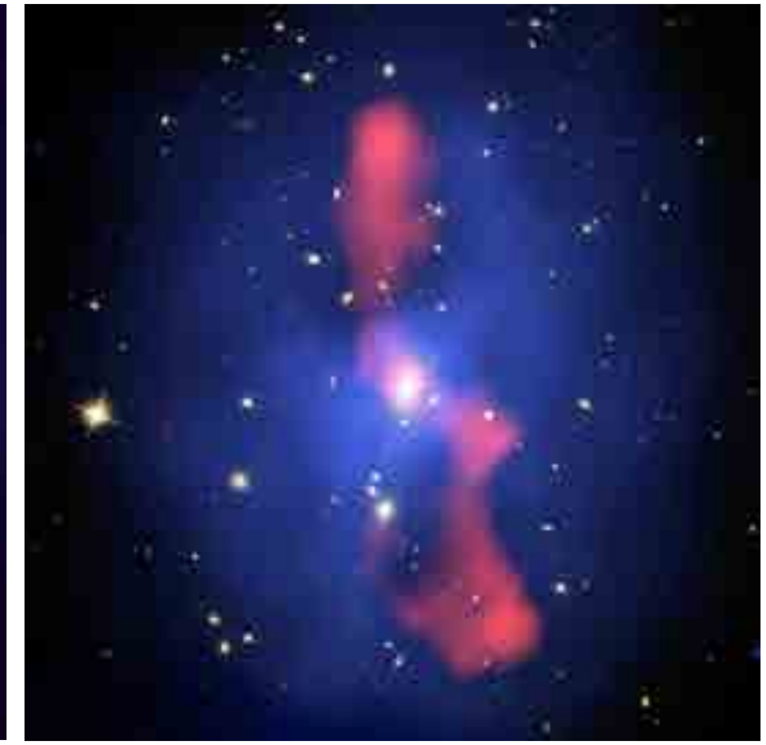
Fit with power-law continuum plus lines represented by Gaussians at fixed rest energies from theory (H-like Fe) and lab measurements (He- and Li-like Fe).

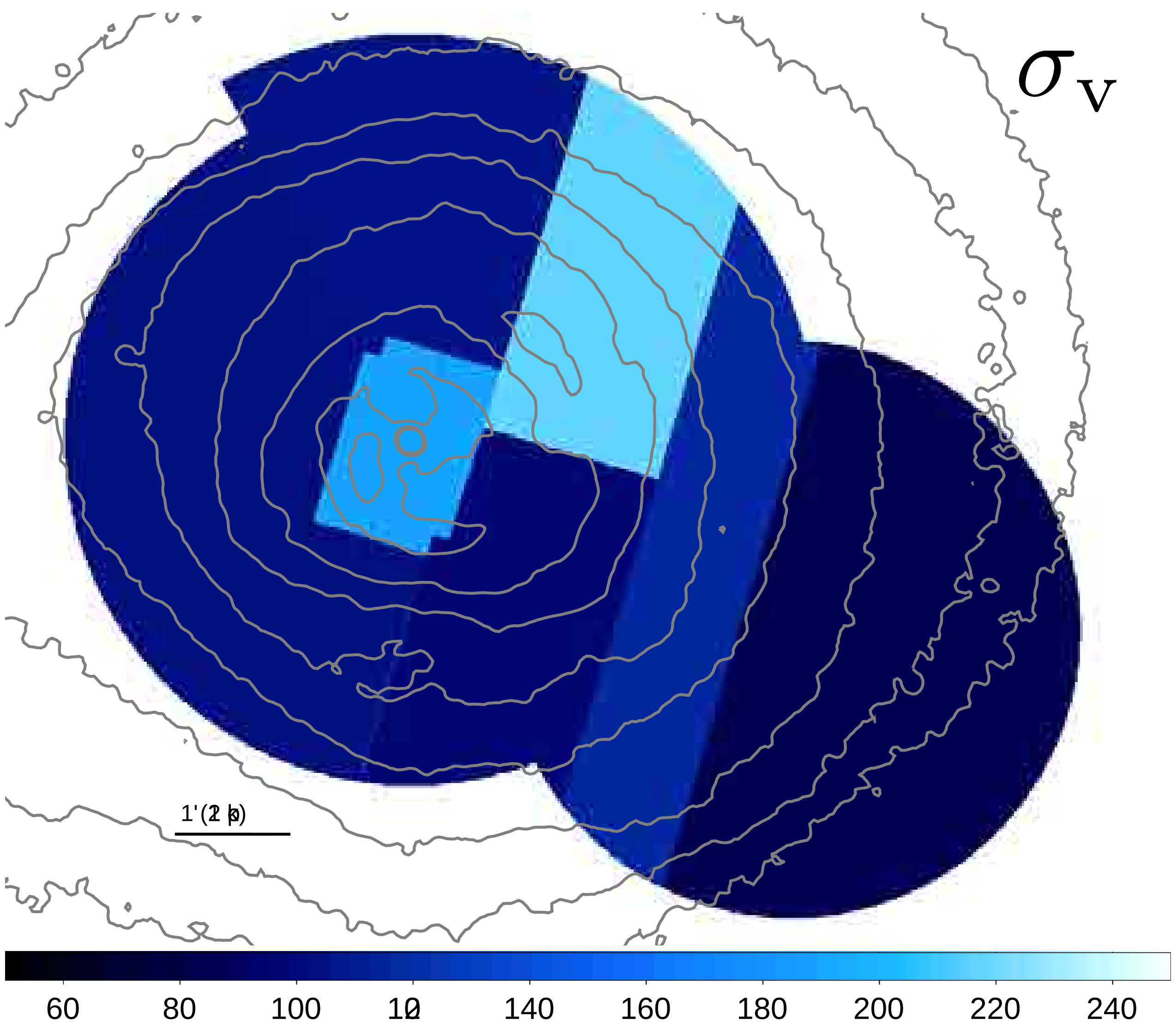
σ_V=164+/-10 km/s

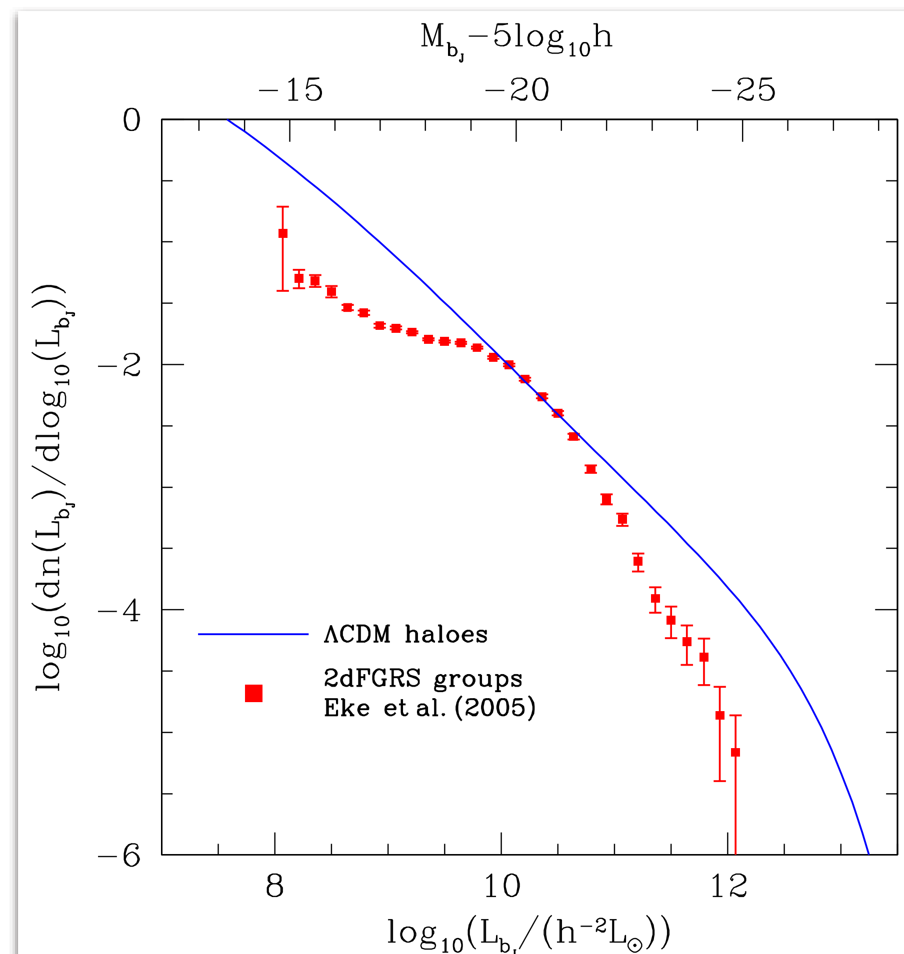
turbulent pressure support = 4% of thermal pressure


CHANDRA X-RAY

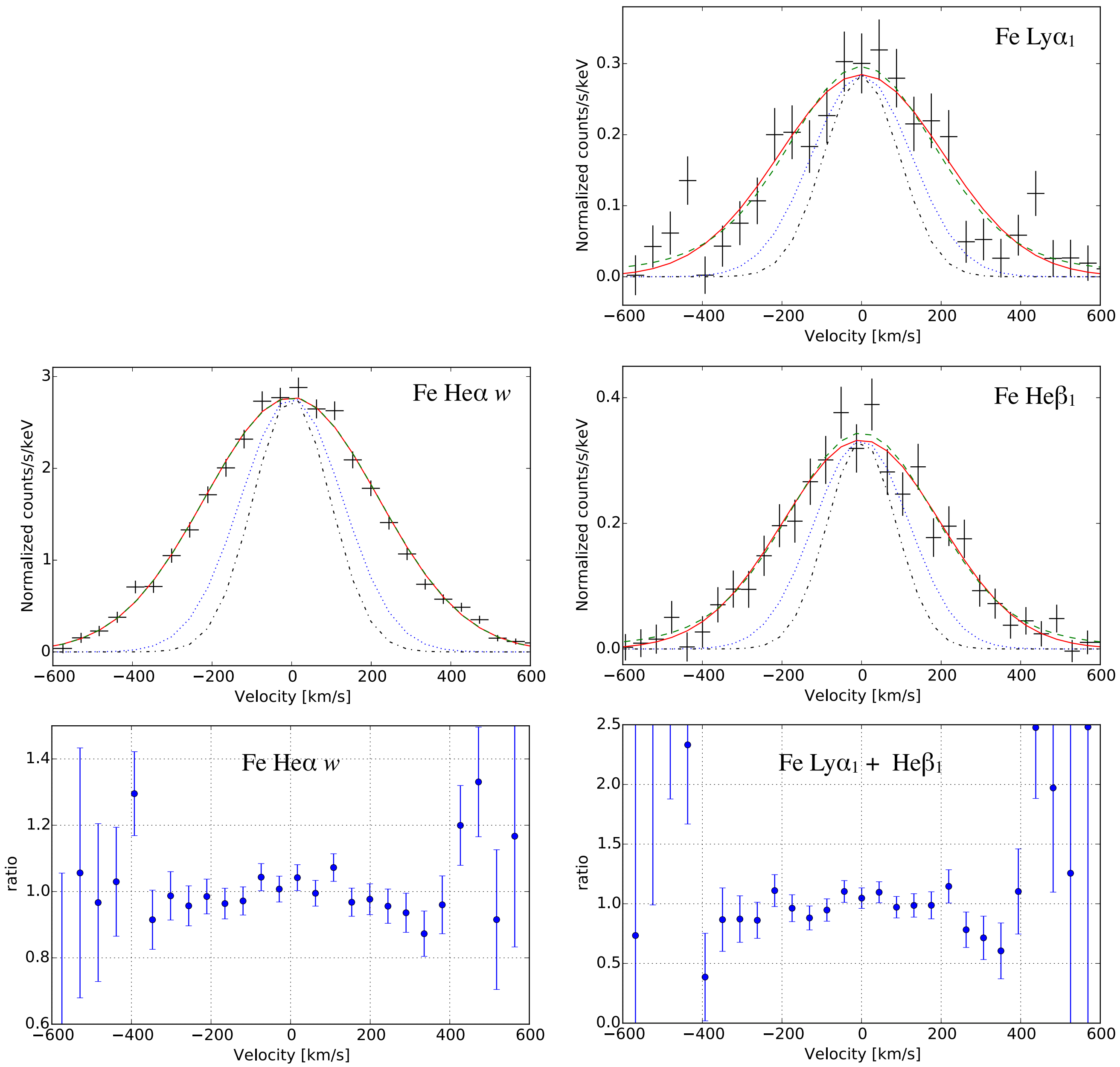
WHAT IS DRIVING THE TURBULENCE?

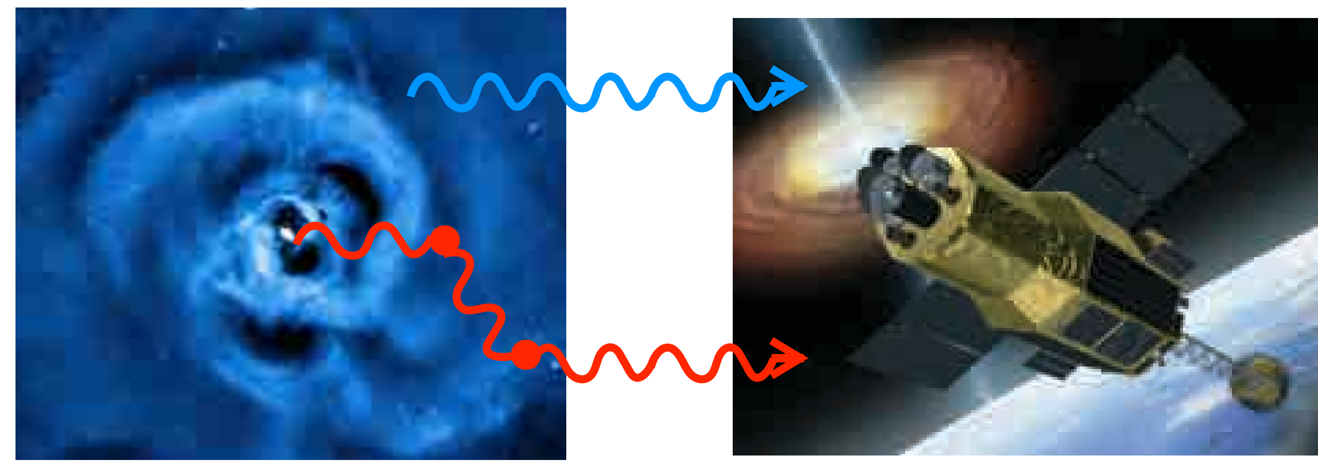


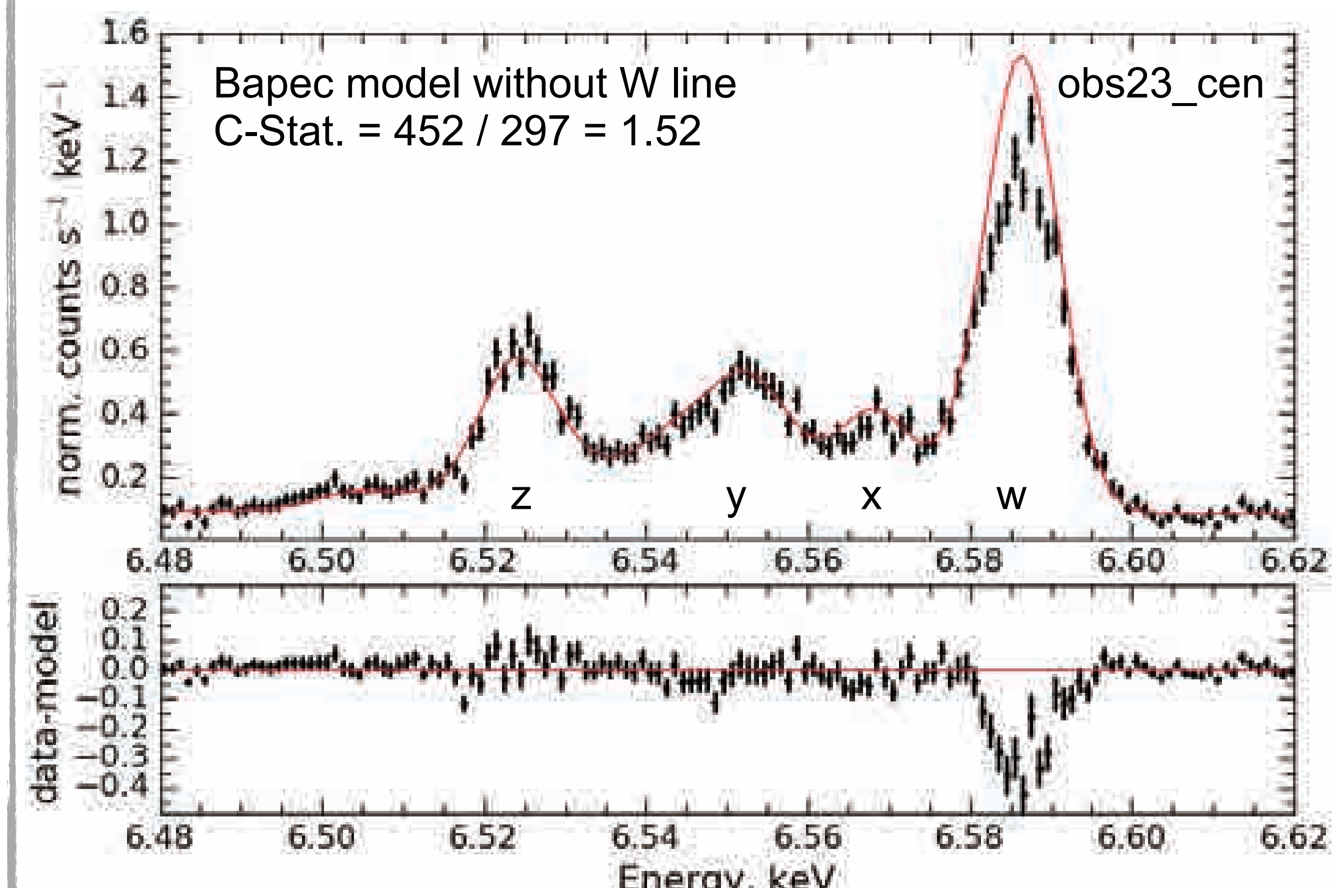




Is this even really turbulence?



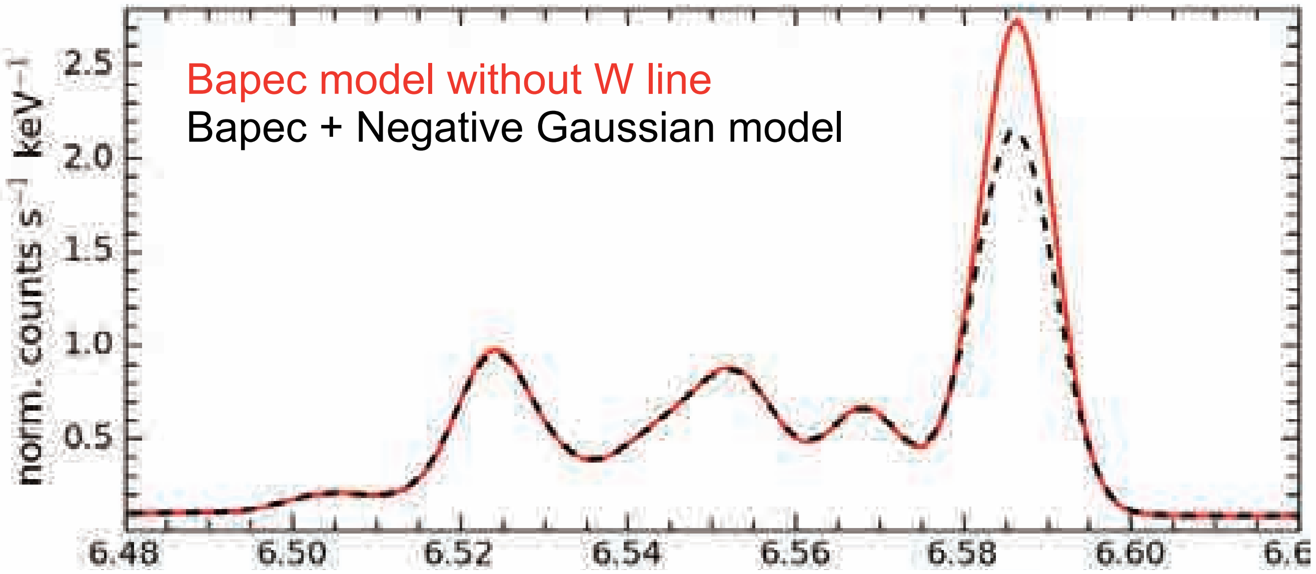




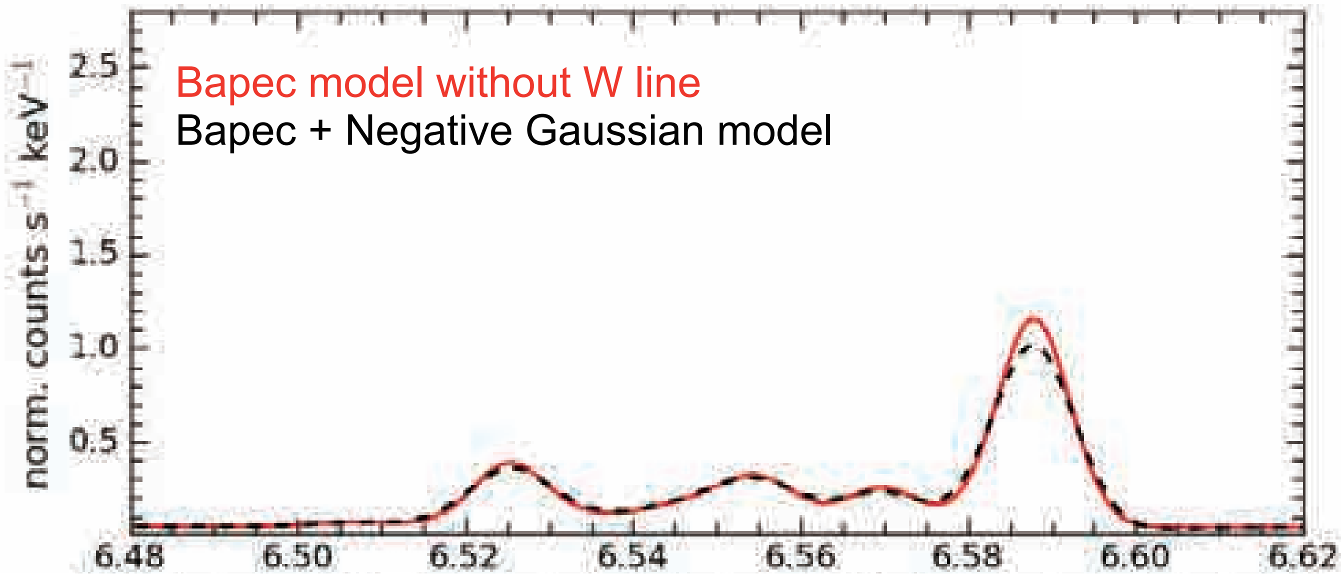
Test #1: Line Gaussianity

Test #2: Resonant scattering

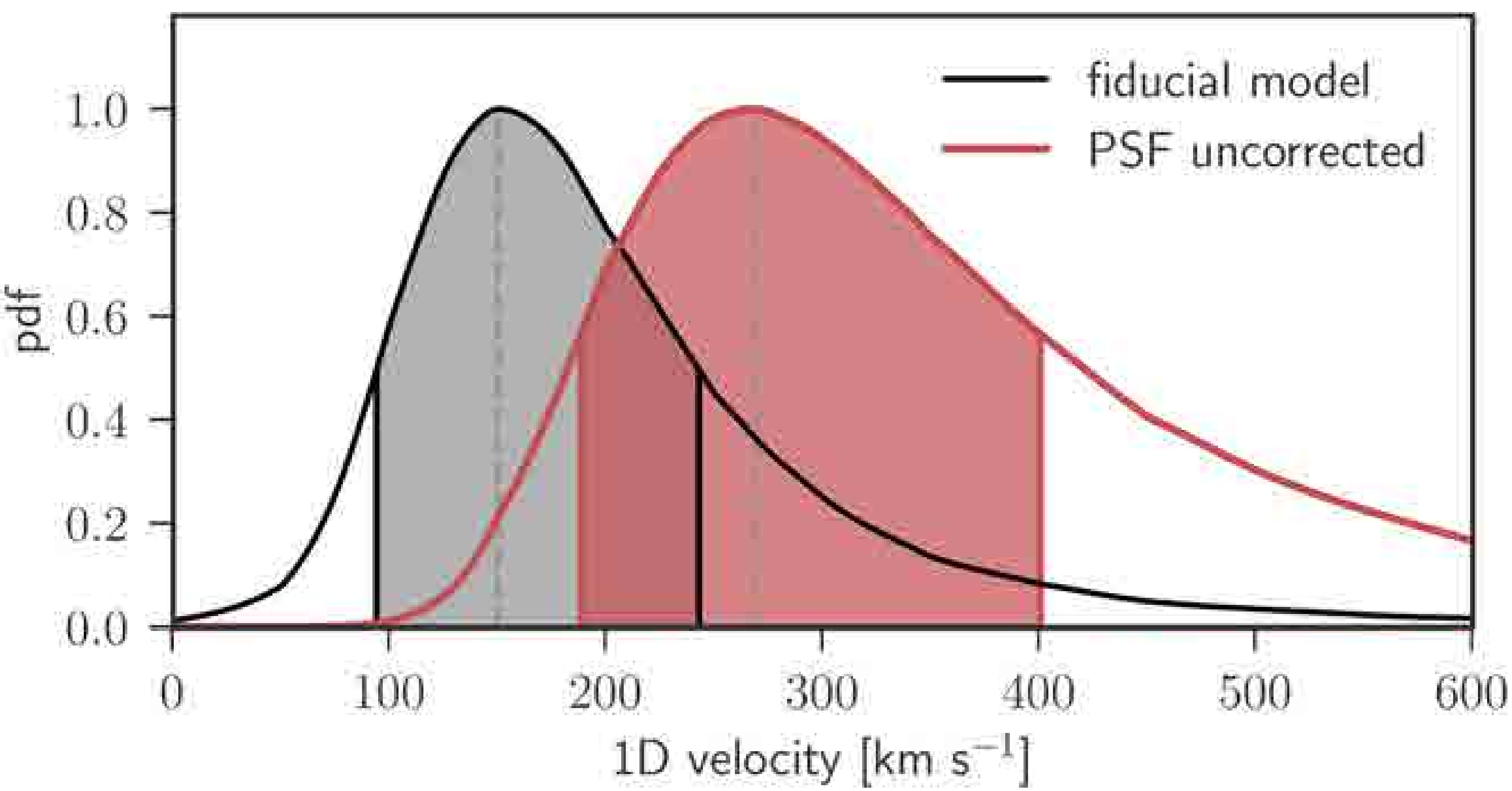
Resonant Scattering in the core of the Perseus Cluster



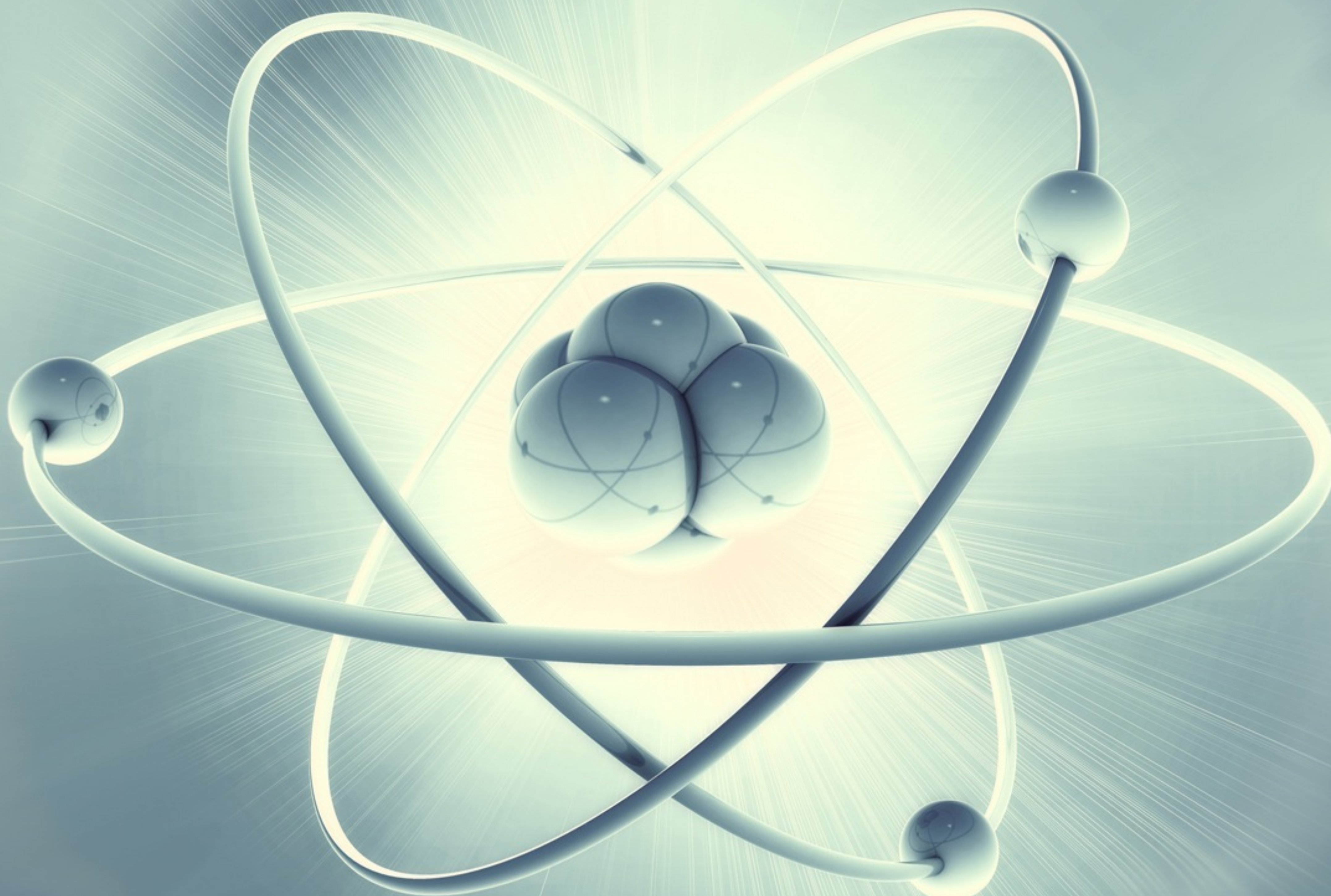
central pixels



as far out as we can go with the existing Hitomi data

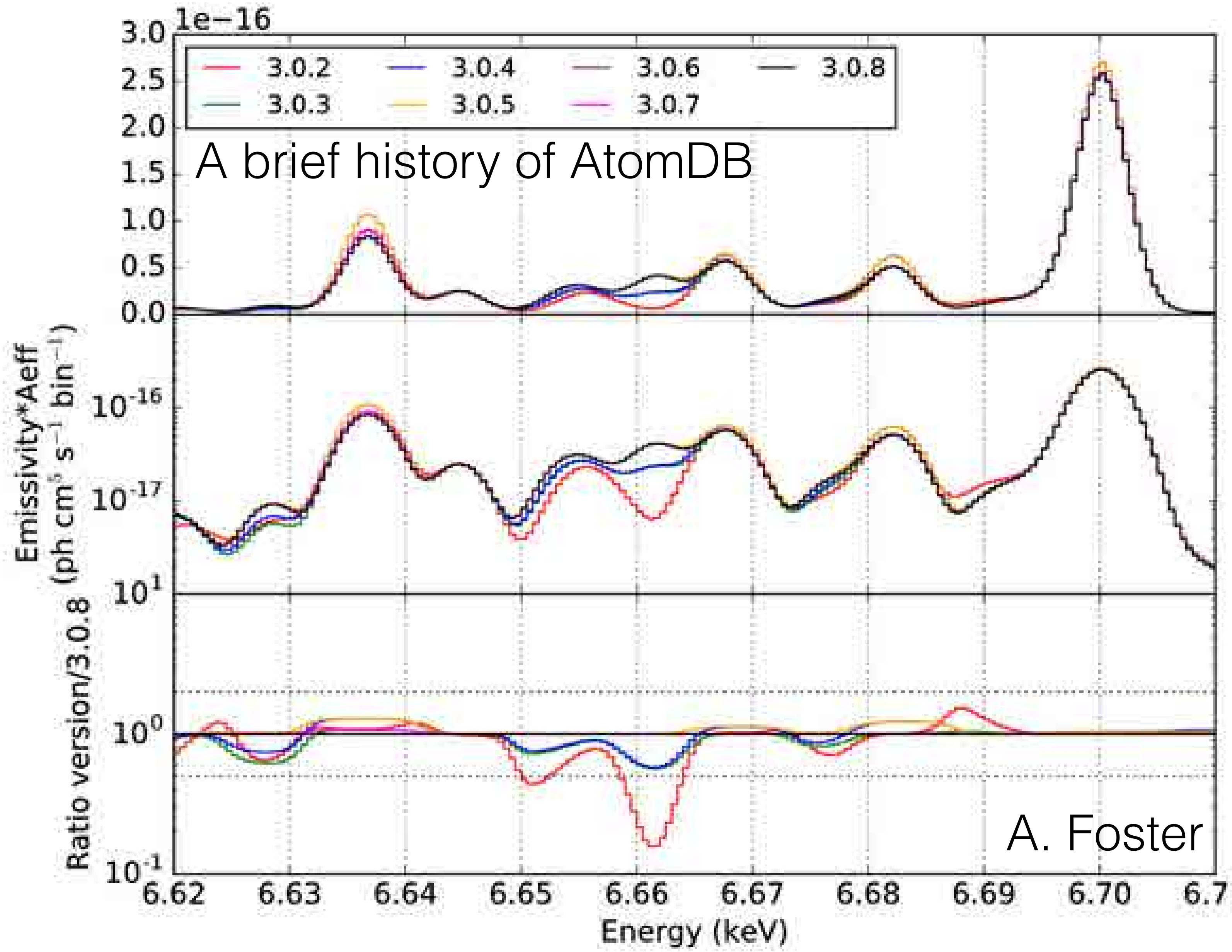


Atomic physics



Name	Transition		Energy (keV)	
	Lower	Upper	SPEX	ATOMDB
Ni$_{\rm XXVII}$ Heα	1s^2 (^{1}S$_0$)	1s.2s (^{3}S$_1$)	7.73153	7.74420
Mn$_{\rm XXIV}$ Heα		1s.2p (^{1}P$_1$)	6.18019	6.19011
Ni$_{\rm XXVII}$ Heα		1s.2p (^{3}P$_2$)	7.78637	7.79885
Cr$_{\rm XXIII}$ Heα		1s.2p (^{1}P$_1$)	5.68205	5.69068
Mn$_{\rm XXIV}$ Heα		1s.2s (^{3}S$_1$)	6.12105	6.12998
		1s.2p (^{3}P$_2$)	6.16284	6.17171
Cr$_{\rm XXIII}$ Heα		1s.2s (^{3}S$_1$)	5.62691	5.63471
		1s.2p (^{3}P$_2$)	5.66506	5.67284
Mn$_{\rm XXIV}$ Heα		1s.2p (^{3}P$_1$)	6.15071	6.15891
Cr$_{\rm XXIII}$ Heα			5.65484	5.66217

Progress in Atomic Line Emission Models



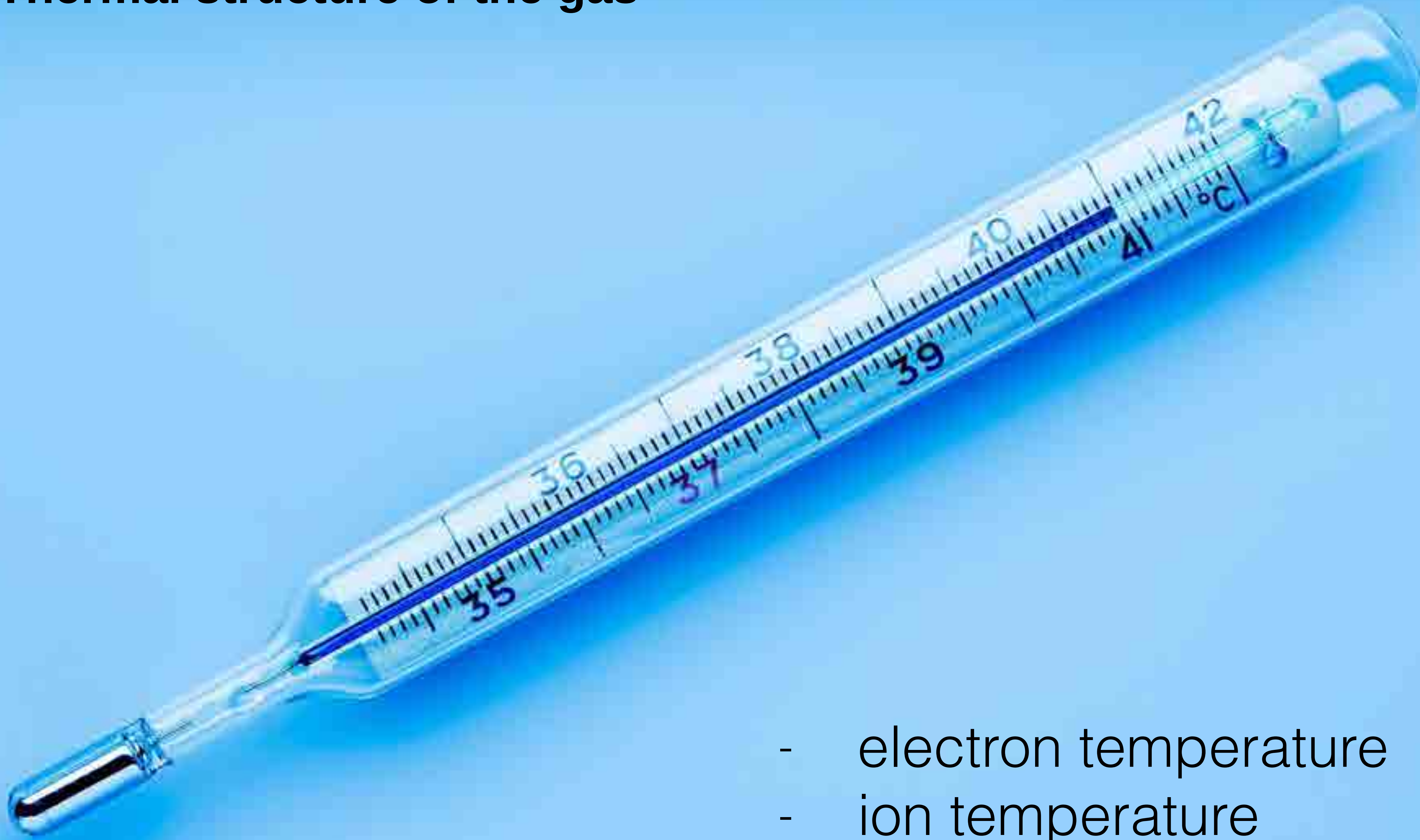
Meanwhile in SPEX:

Updated radiative recombination data (Mao et al. 2016)

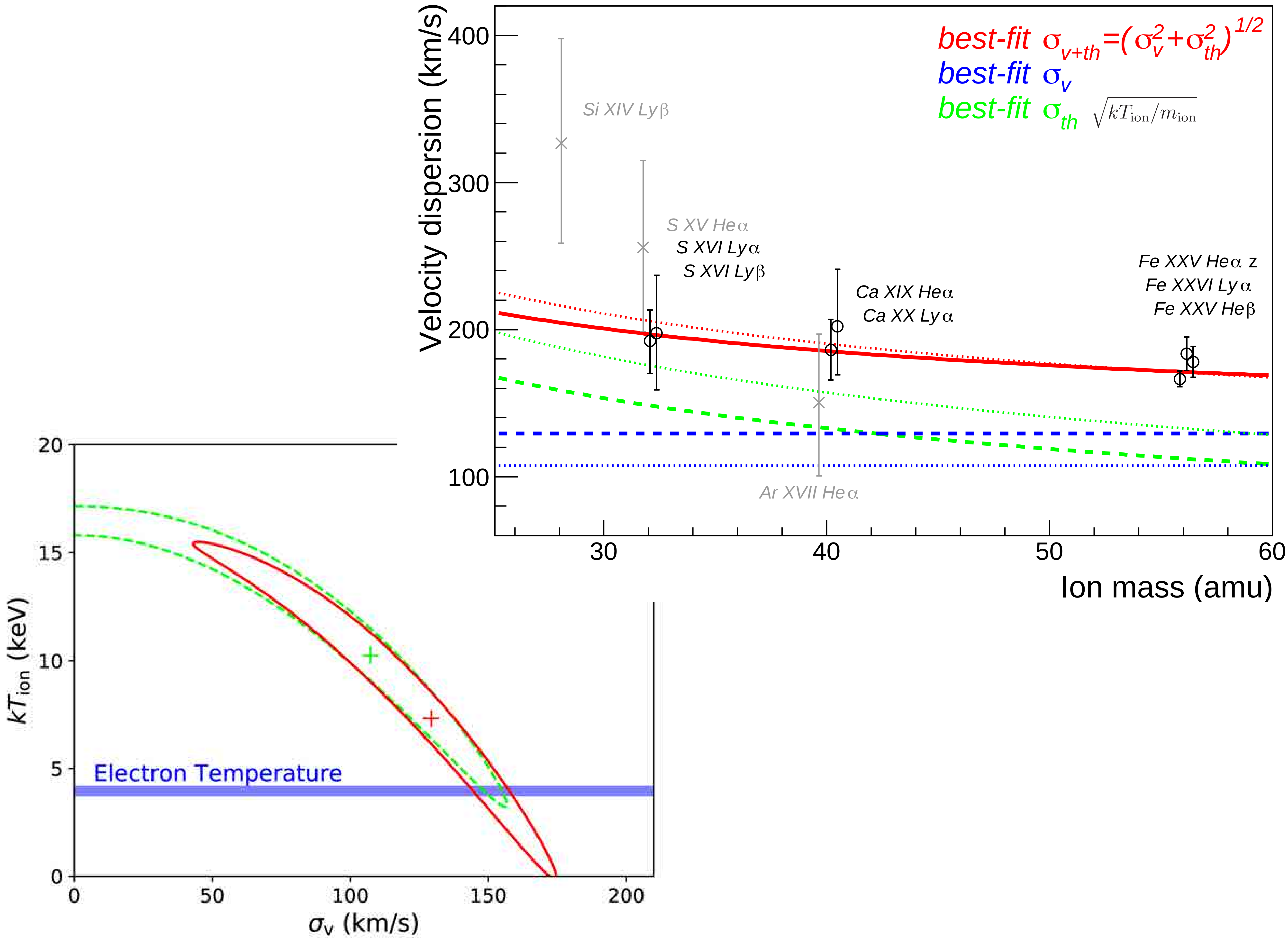
New collisional ionisation data (Urdampilleta et al. 2017)

Sophisticated charge exchange model (Gu et al.)

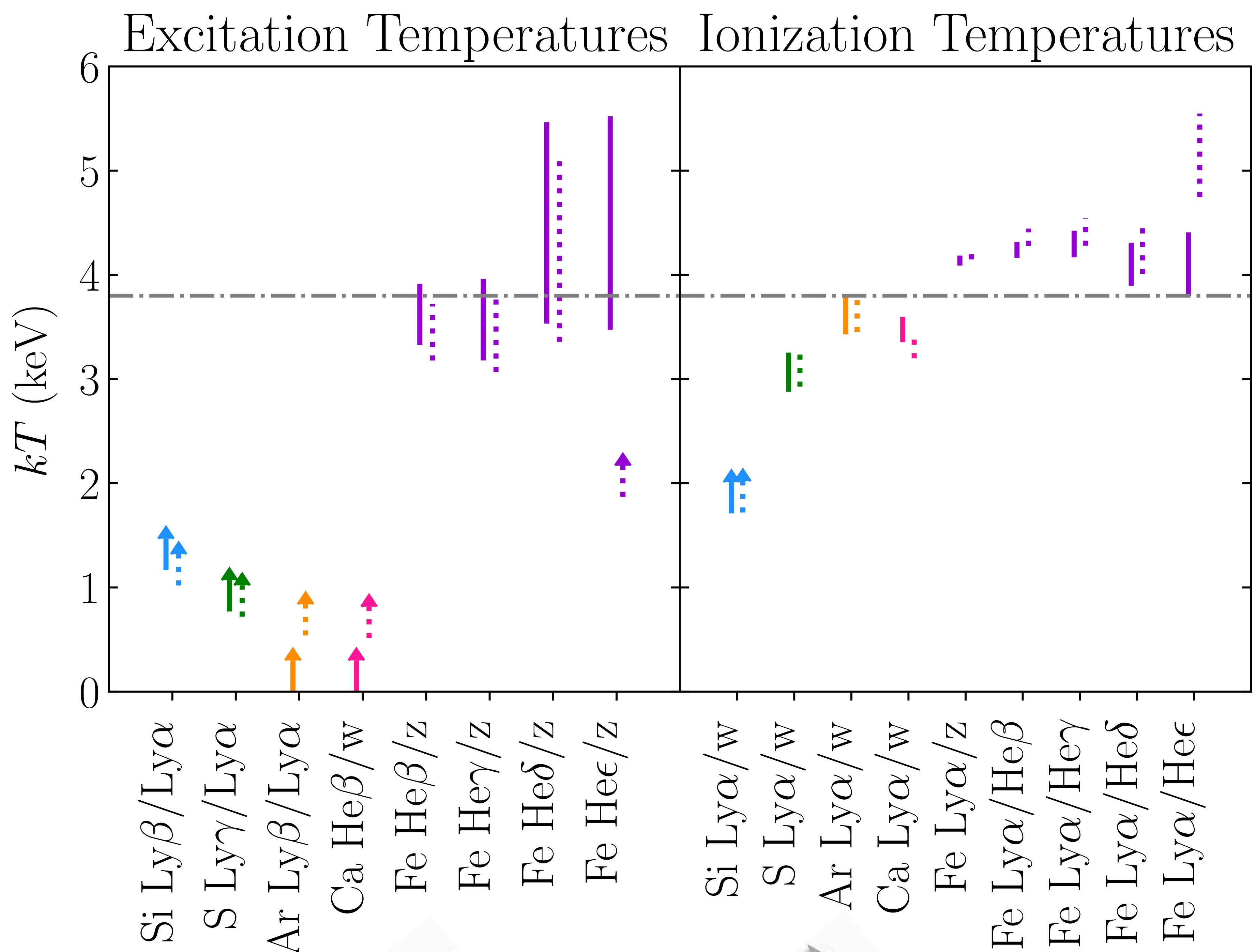
Thermal structure of the gas



- electron temperature
- ion temperature
- excitation temperature
- ionization temperature



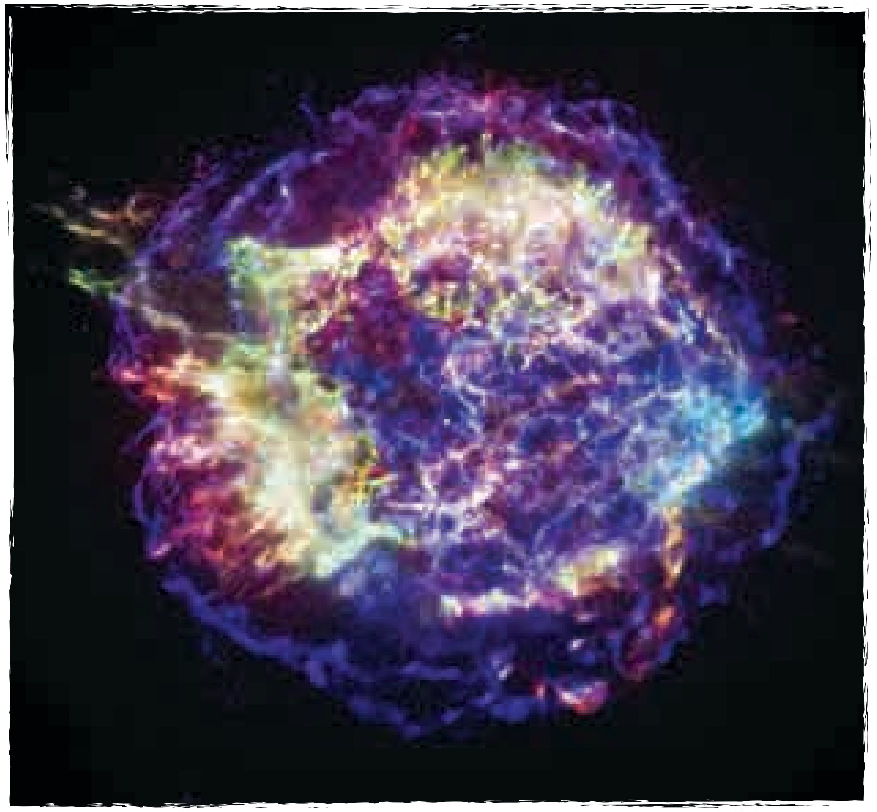
best-fit $\sigma_{v+th}=(\sigma_v^2+\sigma_{th}^2)^{1/2}$
best-fit σ_v
best-fit σ_{th} $\sqrt{kT_{\rm ion}/m_{\rm ion}}$
Velocity dispersion (km/s)
Ion mass (amu)
Si XIV Lyβ
S XV Heα
S XVI Lyα
S XVI Lyβ
Ca XIX Heα
Ca XX Lyα
Ar XVII Heα
Fe XXV Heα z
Fe XXVI Lyα
Fe XXV Heβ
Electron Temperature
$kT_{\rm ion}$ (keV)
σ_v (km/s)

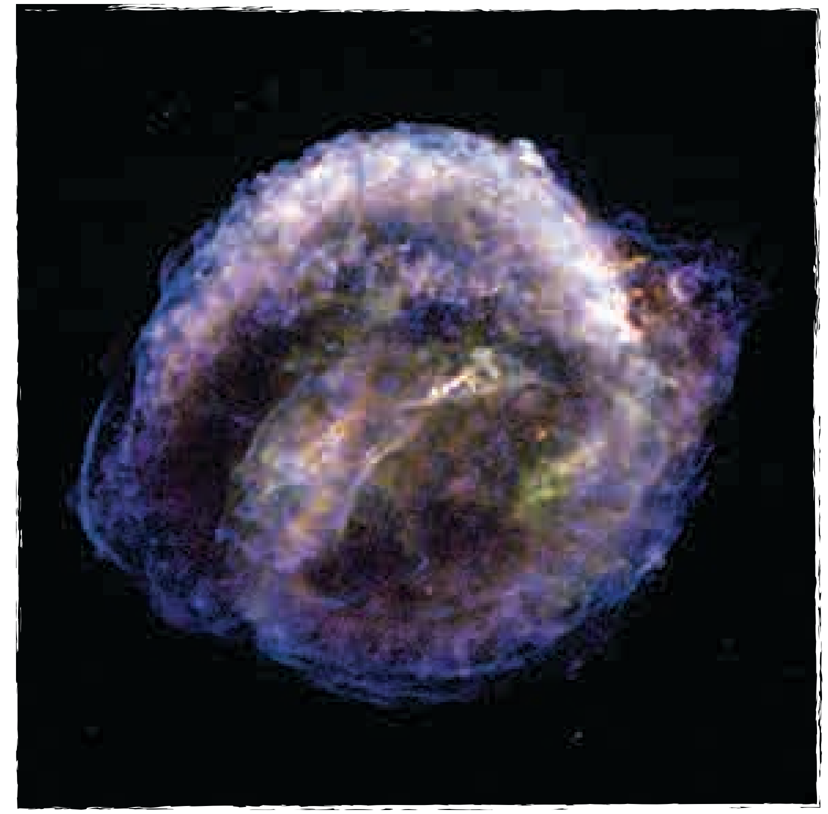


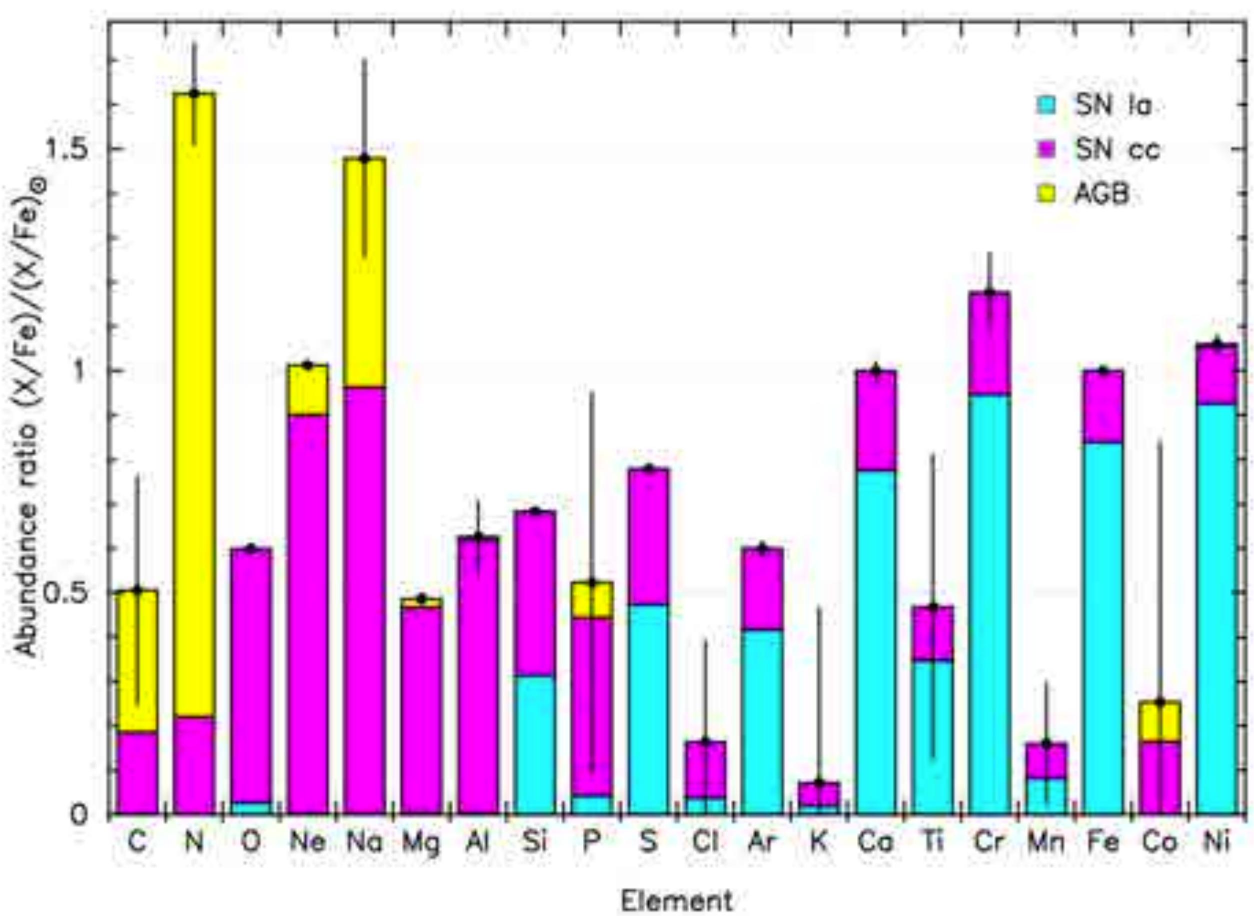
different transitions of
same ionisation state

relative line strength of
H-like versus He-like ions

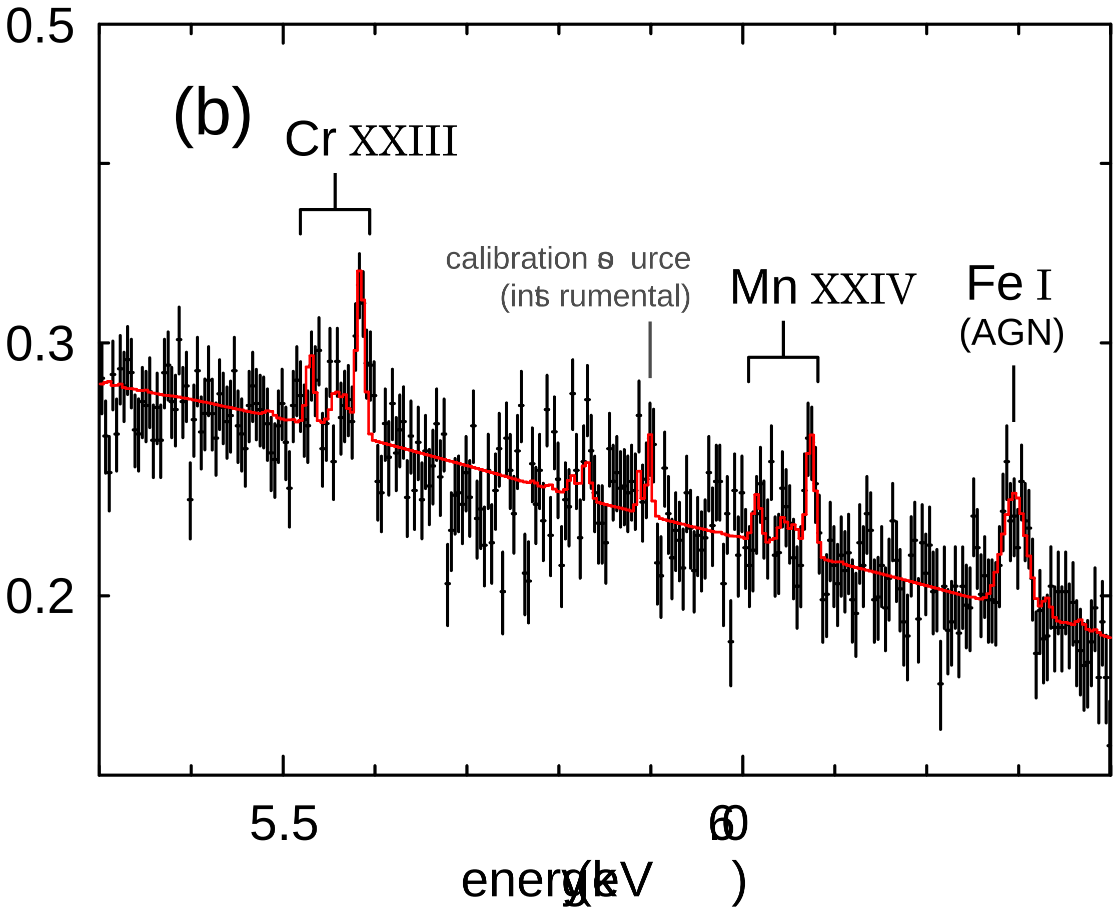
Supernova nucleosynthesis

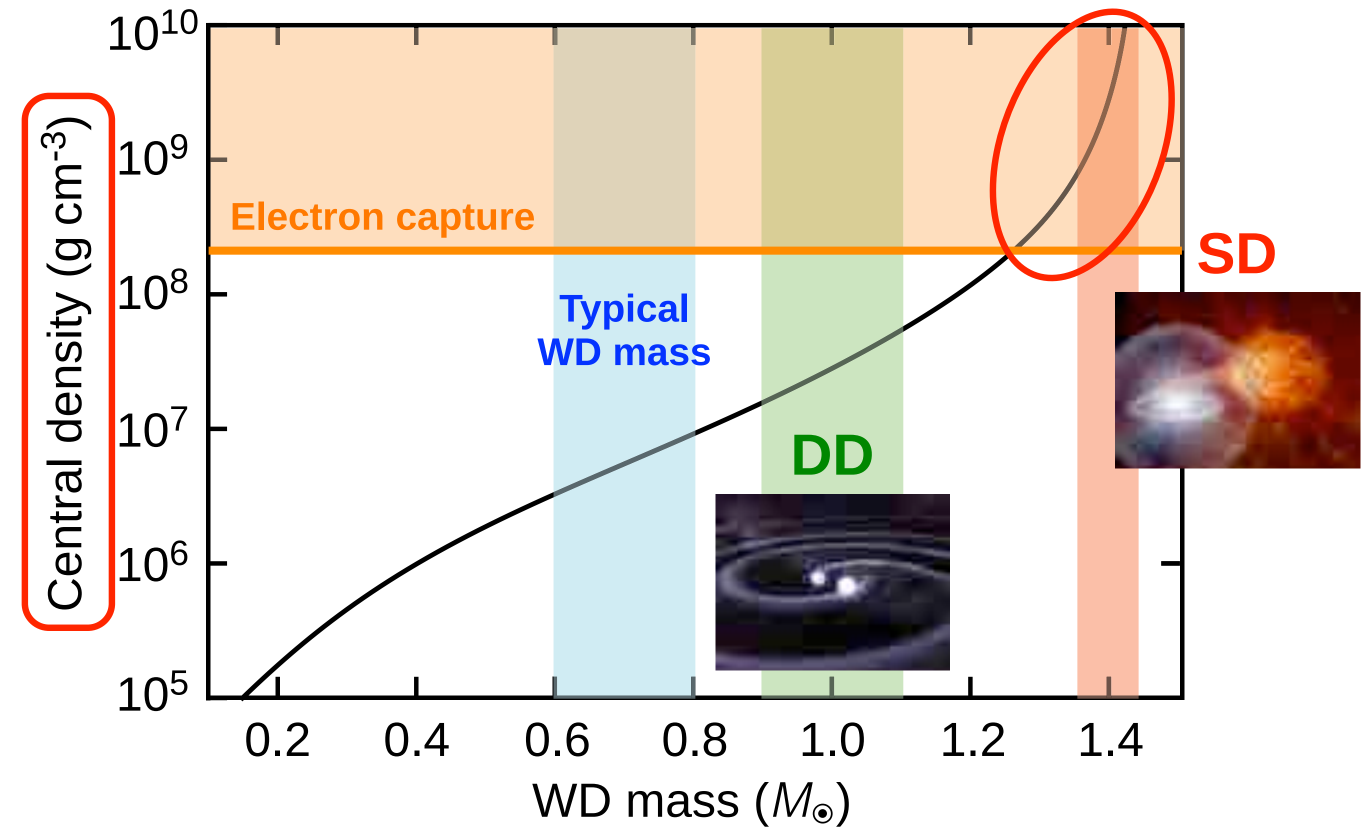


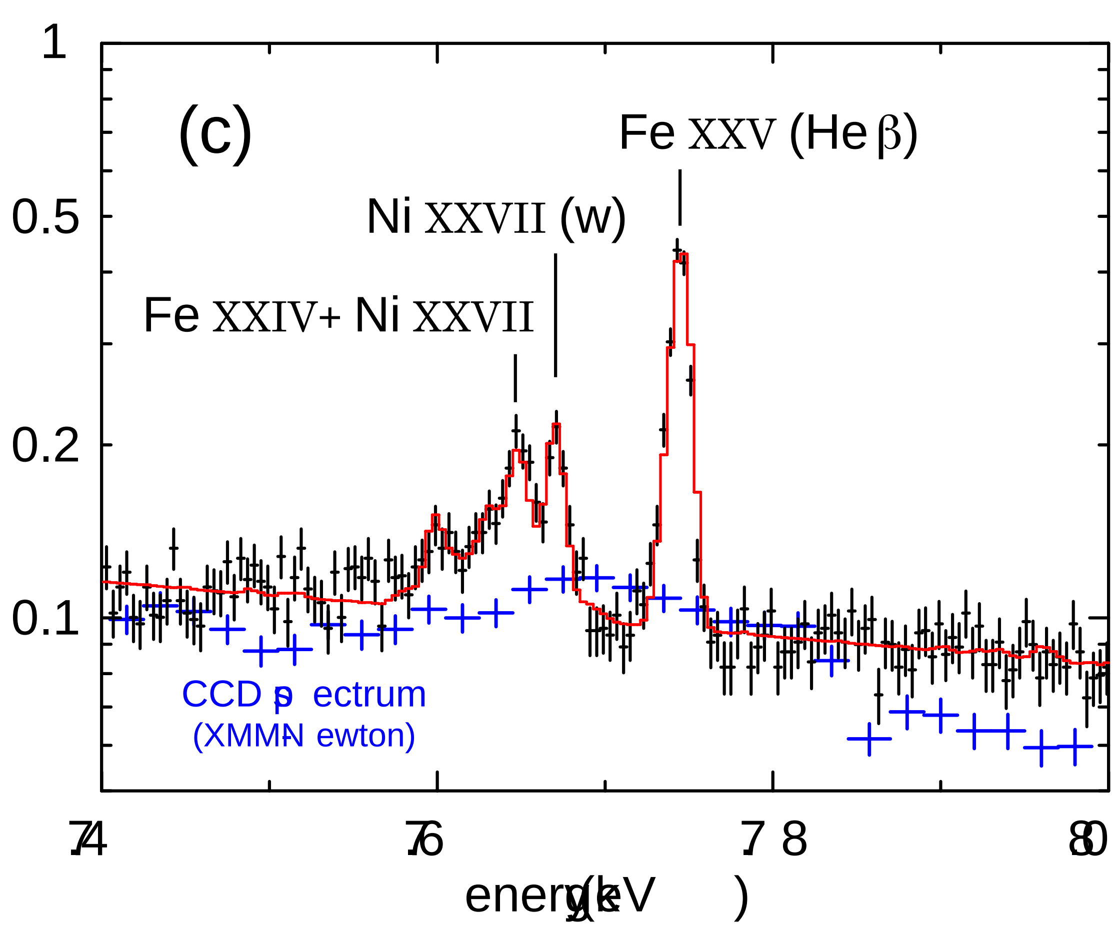


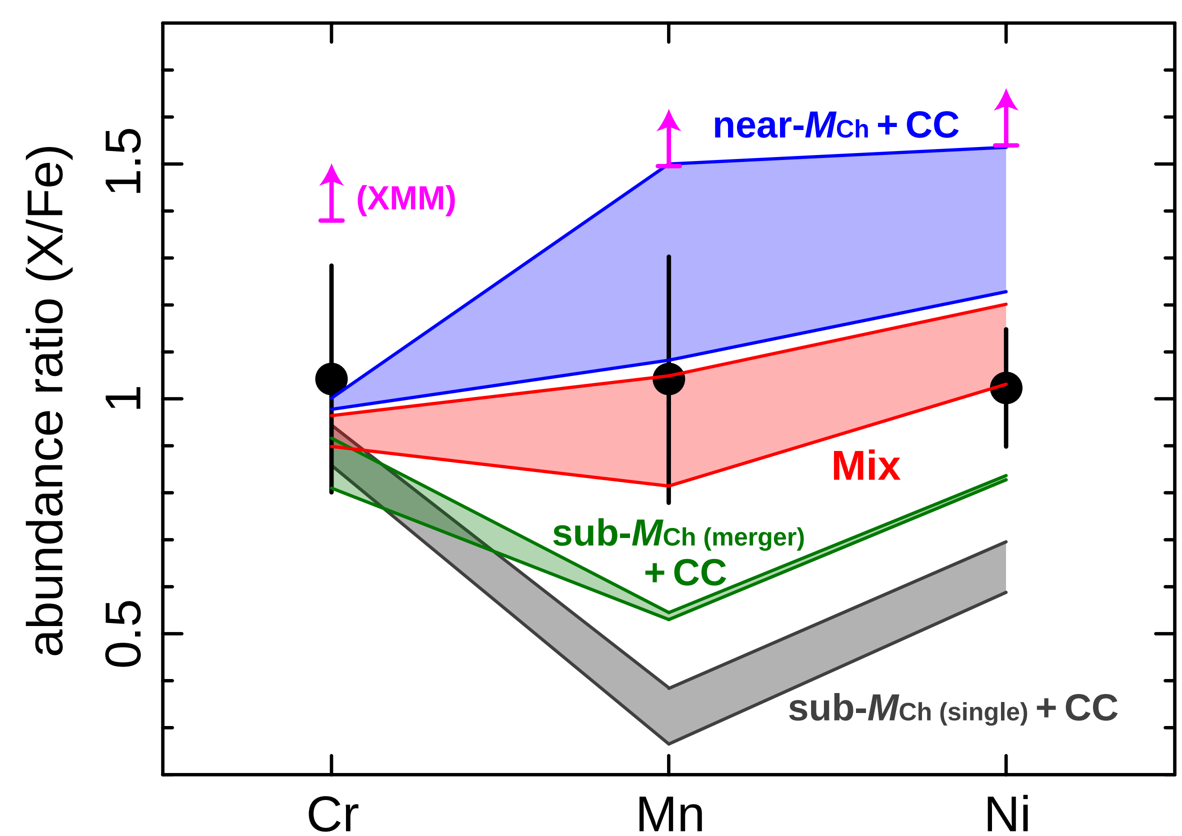


SNIa nucleosynthesis constraints from Hitomi



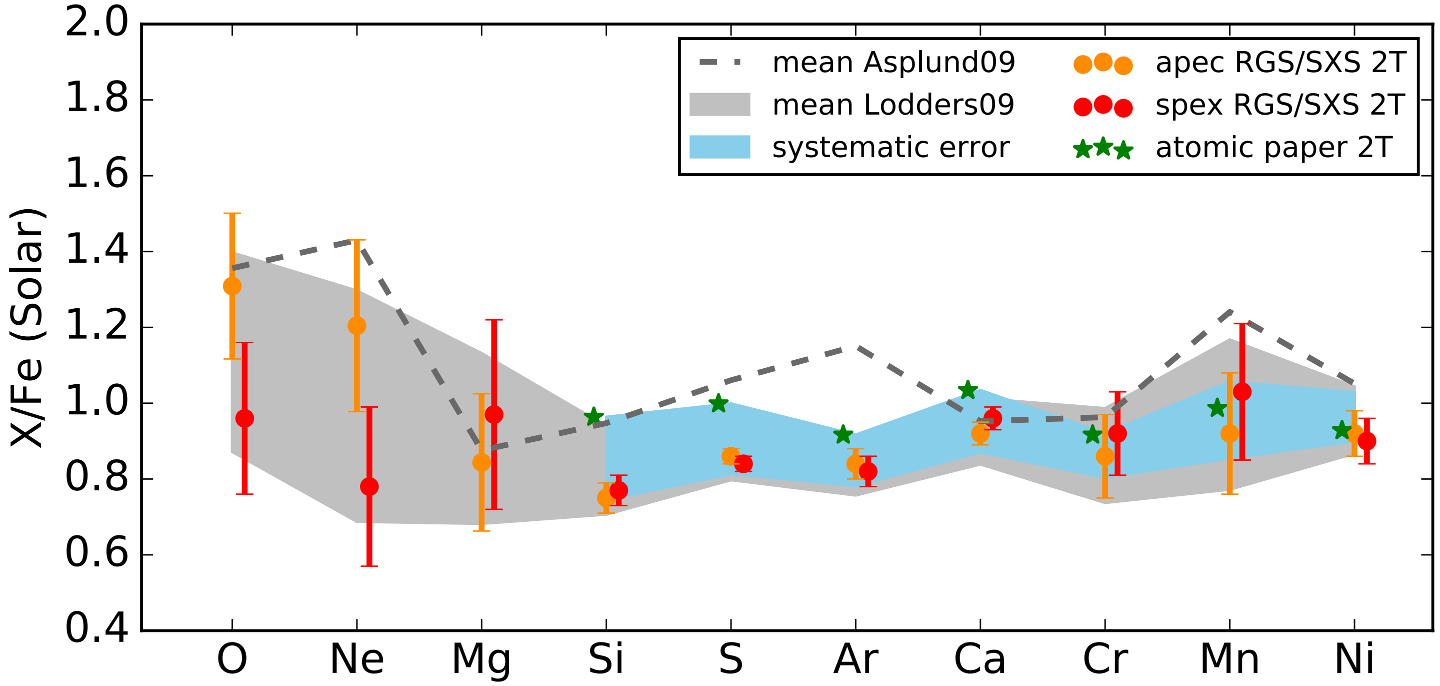


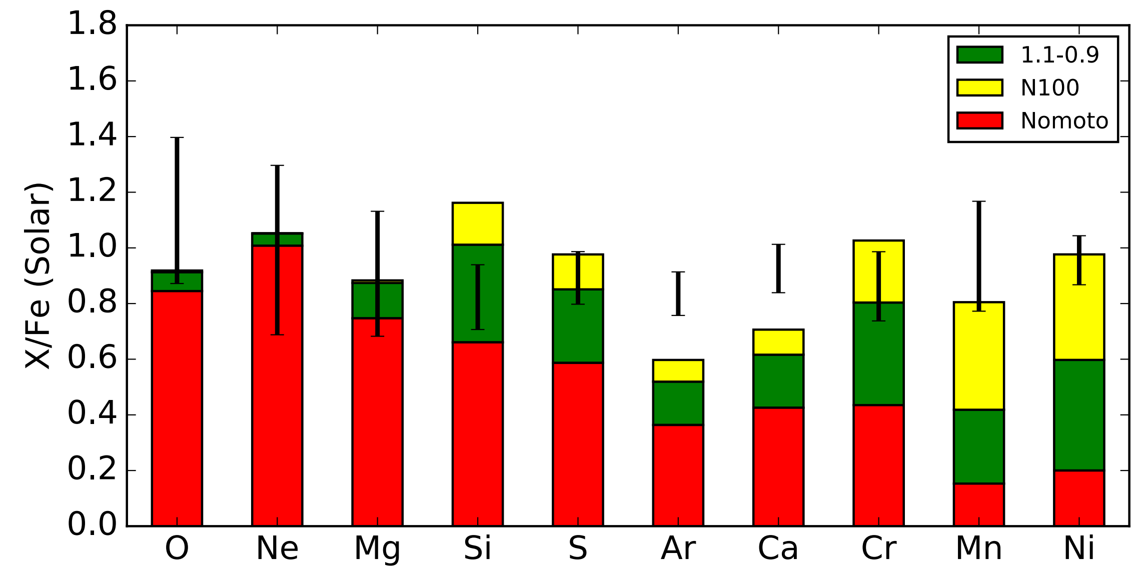




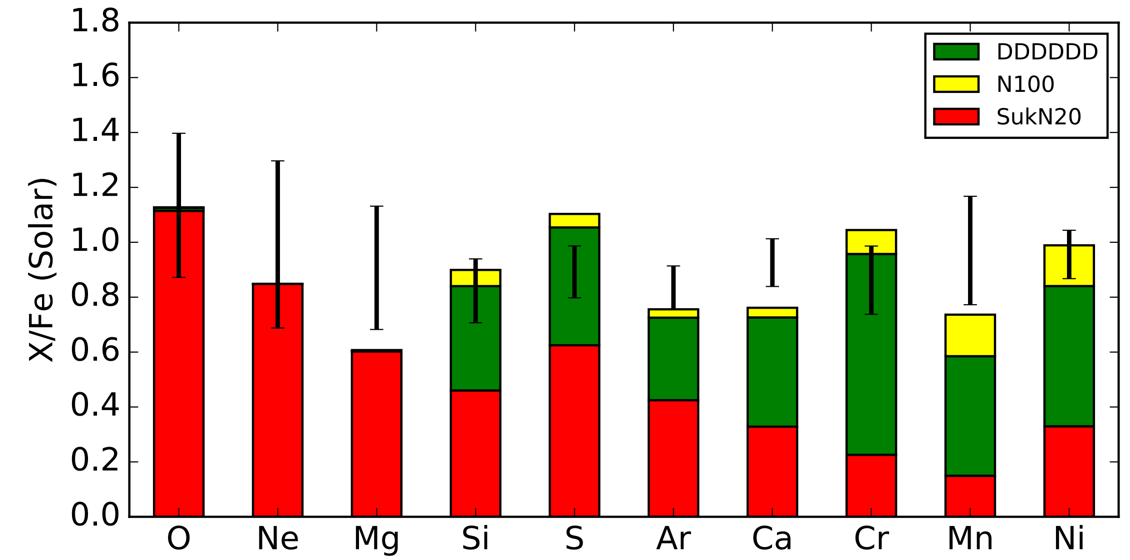
Hitomi Collaboration 2017, Nature

SNCC NUCLEOSYNTHESIS CONSTRAINTS FROM HITOMI

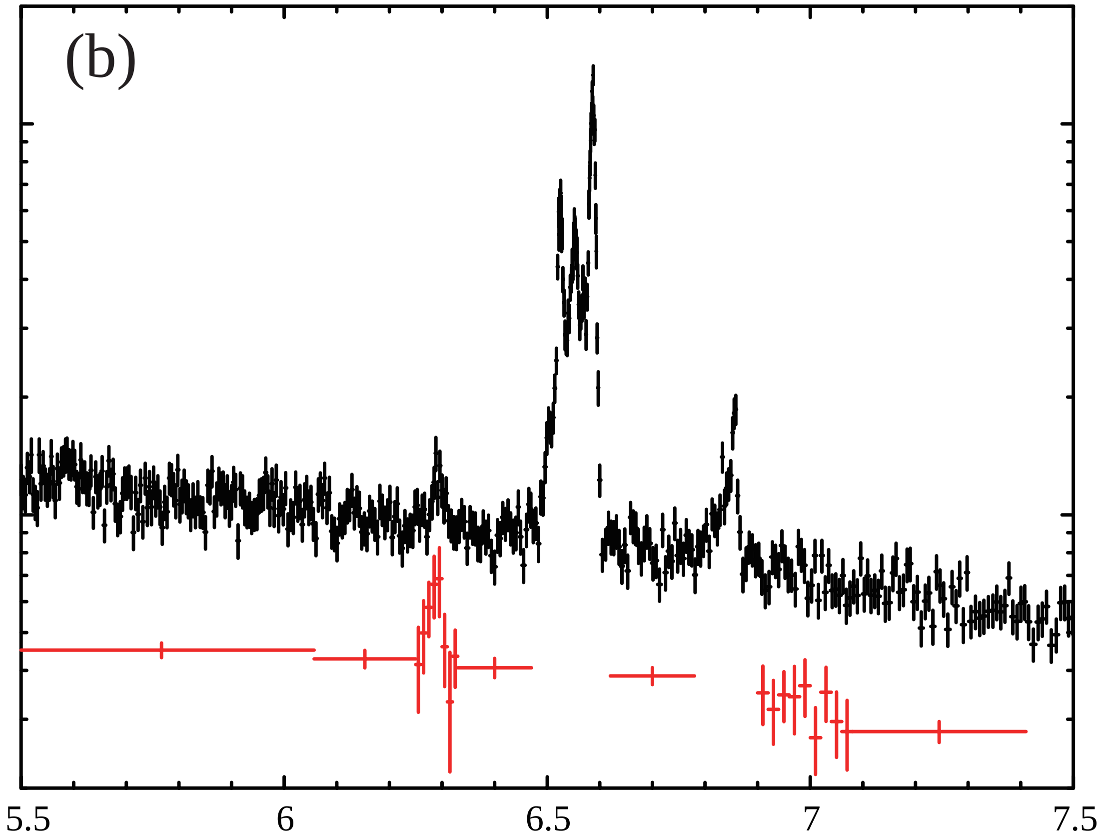




Hypothesis:
the "recipe" for chemical enrichment of the Perseus Cluster is the same as the Solar neighbourhood (Lodders+09 measurement)
chi2= 10.7 / 10 d.o.f

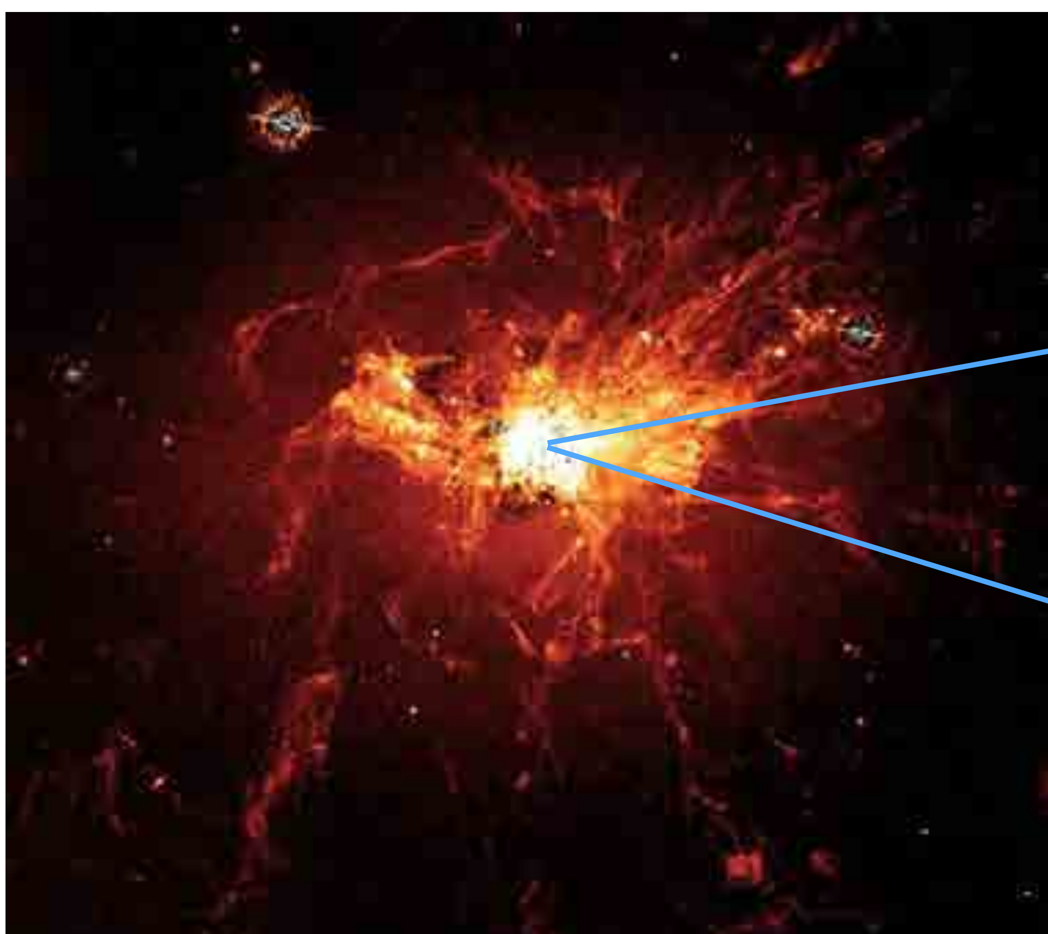


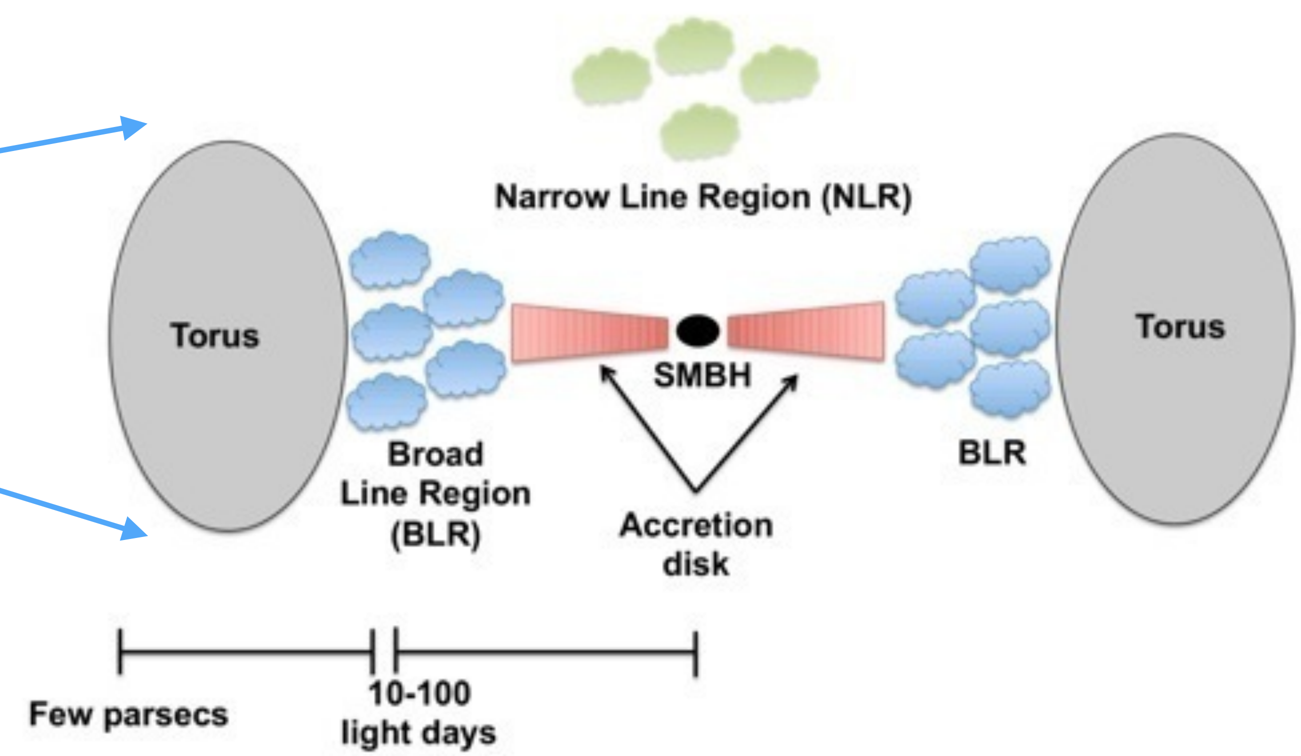
Simionescu et al., in prep



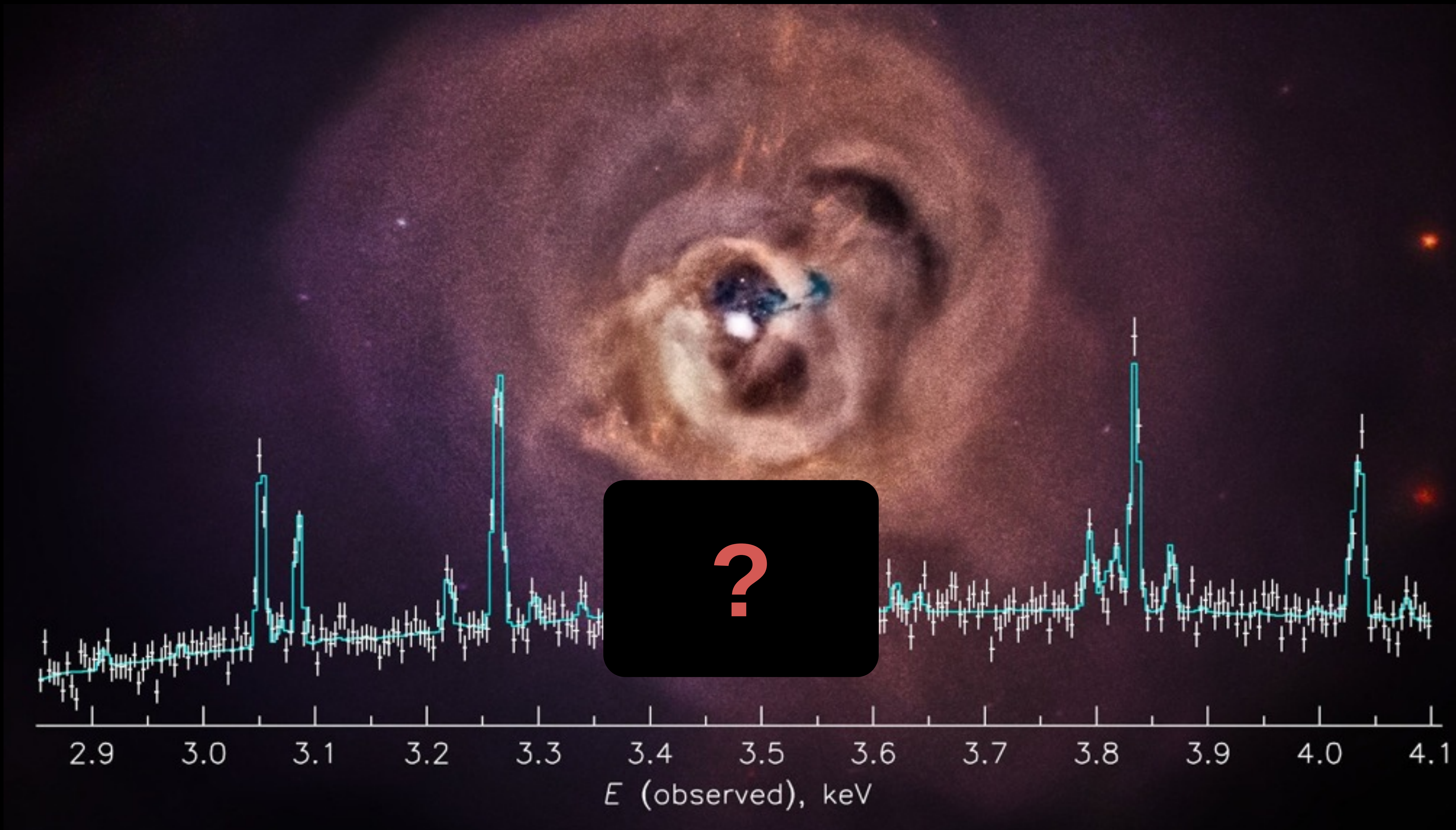
Origin of fluorescent Fe line

- too narrow to come from broad line region or accretion disk
- not spatially extended enough to come from interaction between ICM and cold gas in the nebula of NGC1275
- likely a molecular torus or rotating molecular disk on 1-100 pc scale





The Hunt for Dark Matter

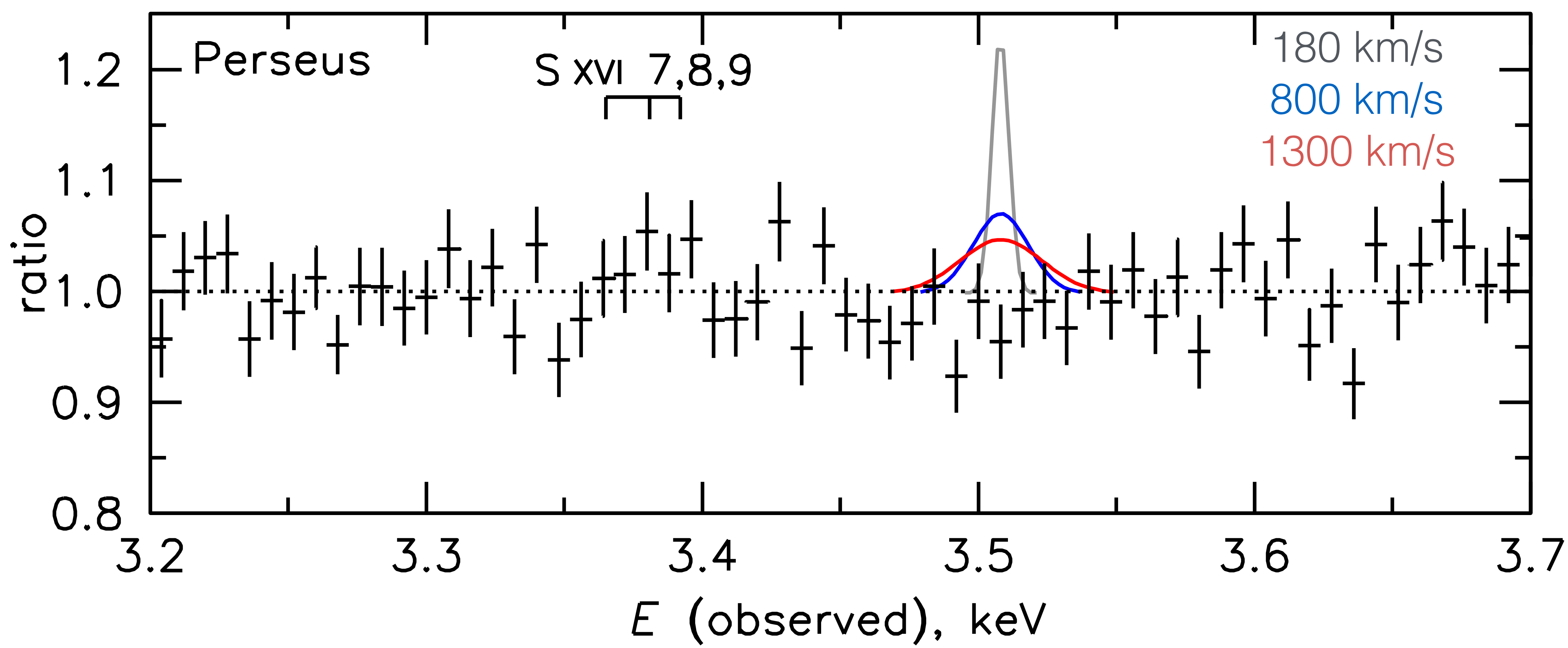


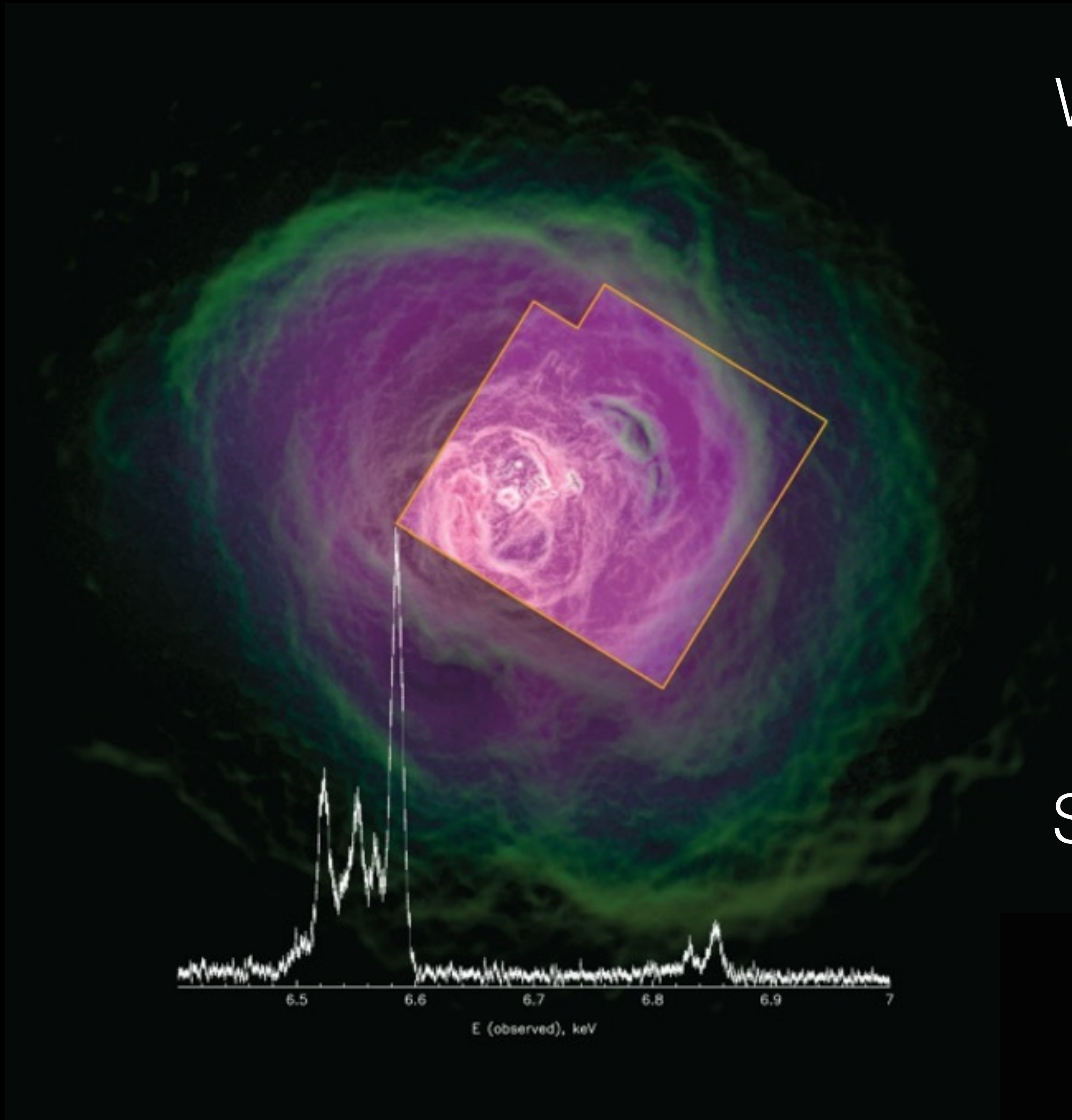
Aharonian et al. 2017

For the flux measured with CCD spectra in the core of the Perseus Cluster,

- a broad line (σ~DM velocity dispersion) is excluded at 99% confidence
- a narrow line (σ~ICM velocity dispersion) is excluded at 99.7% confidence

The signal from the stacked cluster sample was much lower than Perseus and is too weak to be excluded.





We have a lot to learn from X-ray spectroscopy!

Stay tuned for XARM, 2020!