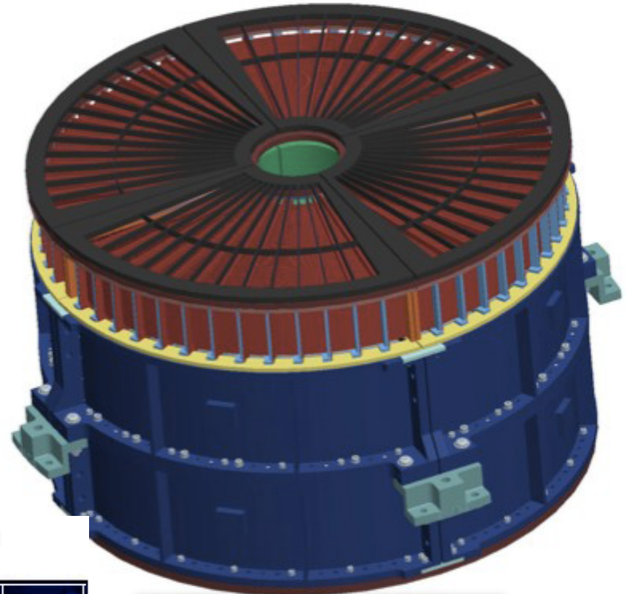
Clusters with ASTRO-H

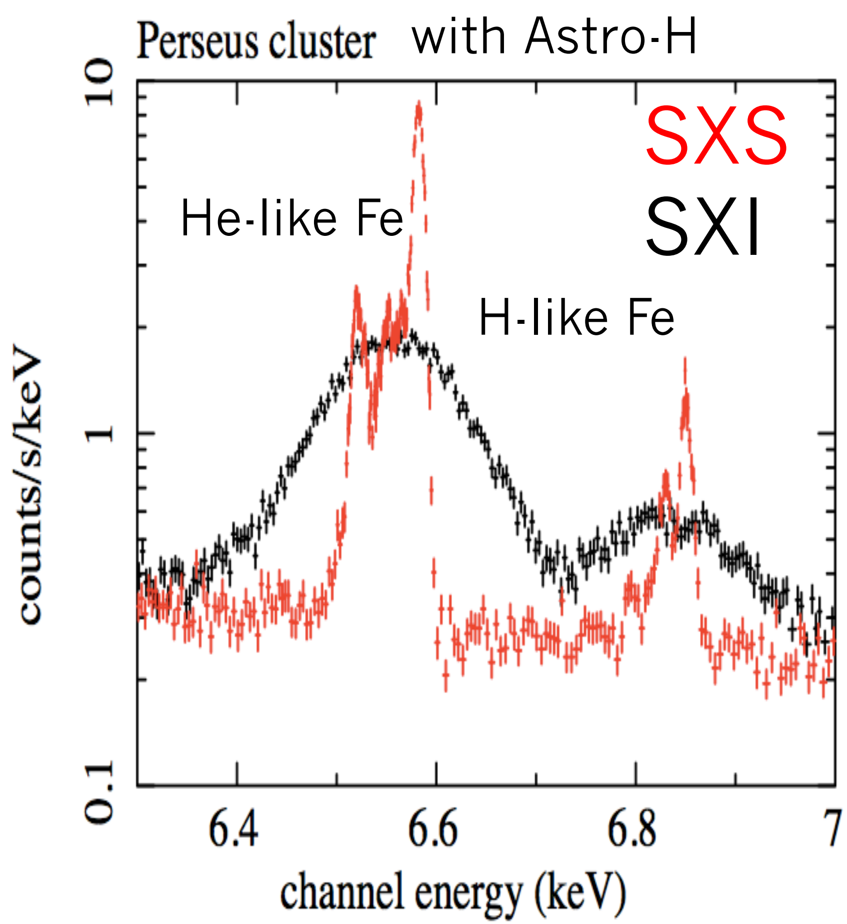
- The Perseus cluster
  - (N. Werner, S.W.Allen, T. Tamura et al.)
- M 87 in the Virgo cluster
  - (A. Simionescu, K. Matsushita et al.)
- Mapping Gas Flows and Turbulence in Merging Galaxy clusters
  - (M. Markevitch, H. Akamatsu et al.)
- Measuring Non-Thermal Pressure and Mass
  - (N. Ota, M. Bautz et al.)
- Chemical Composition and Evolution
  - (J. de Plaa, K. Sato et al.)
- Detecting and Characterizing the Warm-Hot Intergalactic Medium
  - (M. Galeazzi, T. Kitayama et al.)

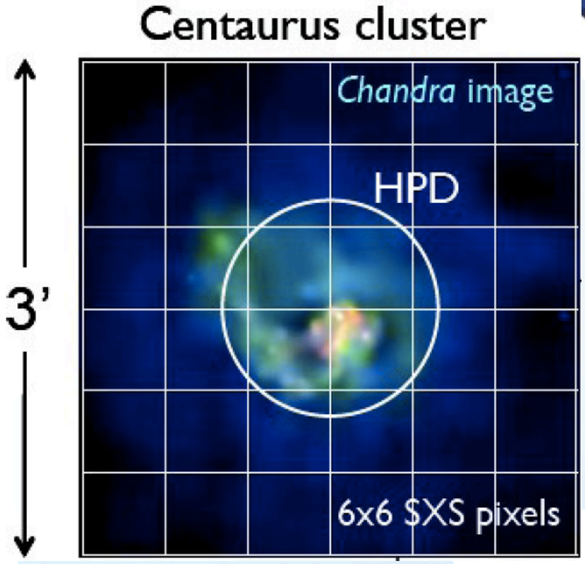
From ASTRO-H white papers

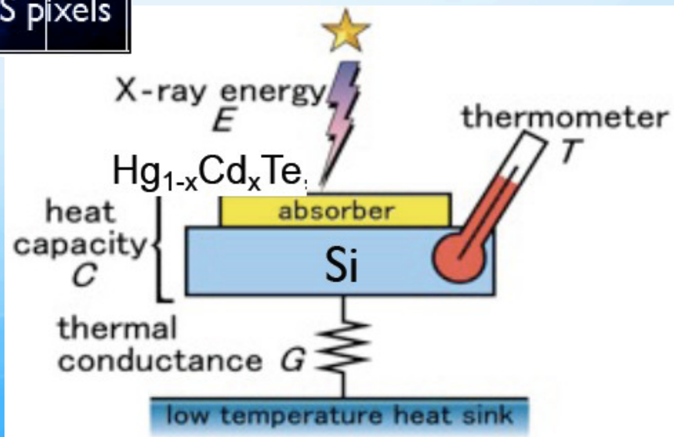
SXT＋SXS(calorimeter)

エネルギー帯域:0.3-12keV
エネルギー分解能:5eV
空間分解能 (HPD):1.3’
視野:3’x3’

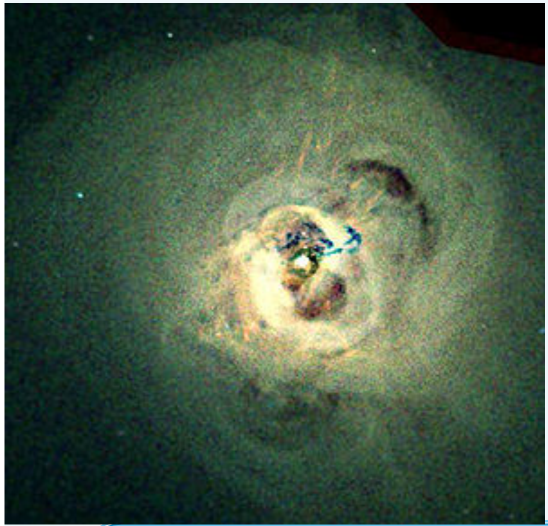








Feedbacks in cool cores



Heating mechanism

- AGN activity?
- Galaxies?

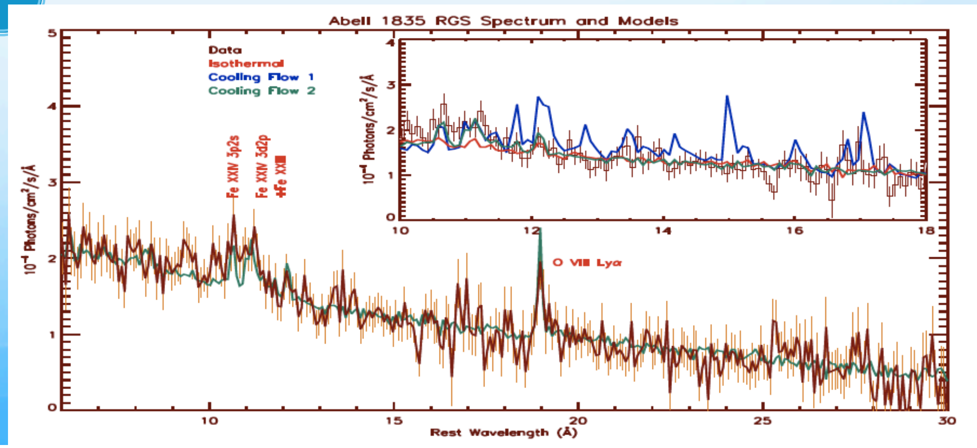
Viscosity?
Magnetic field?

Gas dynamics

- Velocity broadneng
- Metal distribution?
- Resonant line scattering

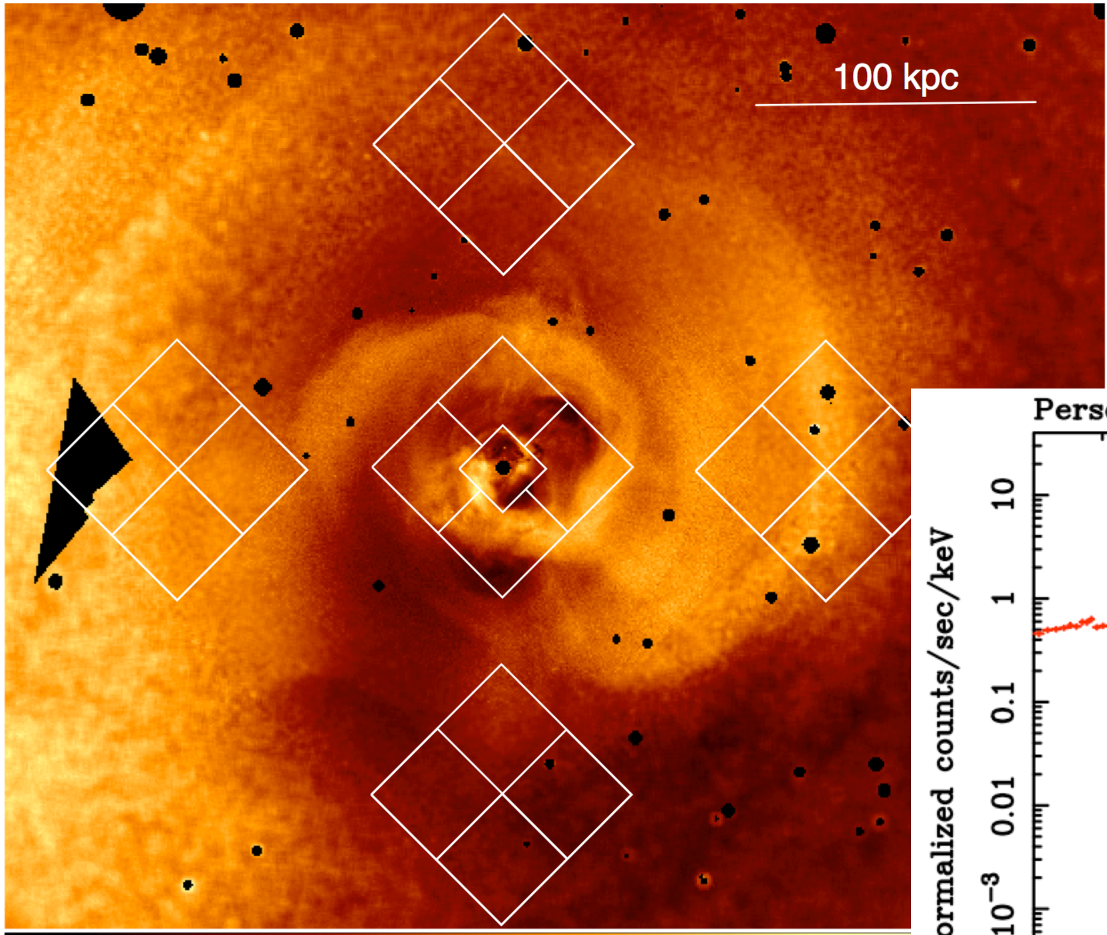
Temperature structure

With SXS, we can map brightest cools cores (several arcmin)



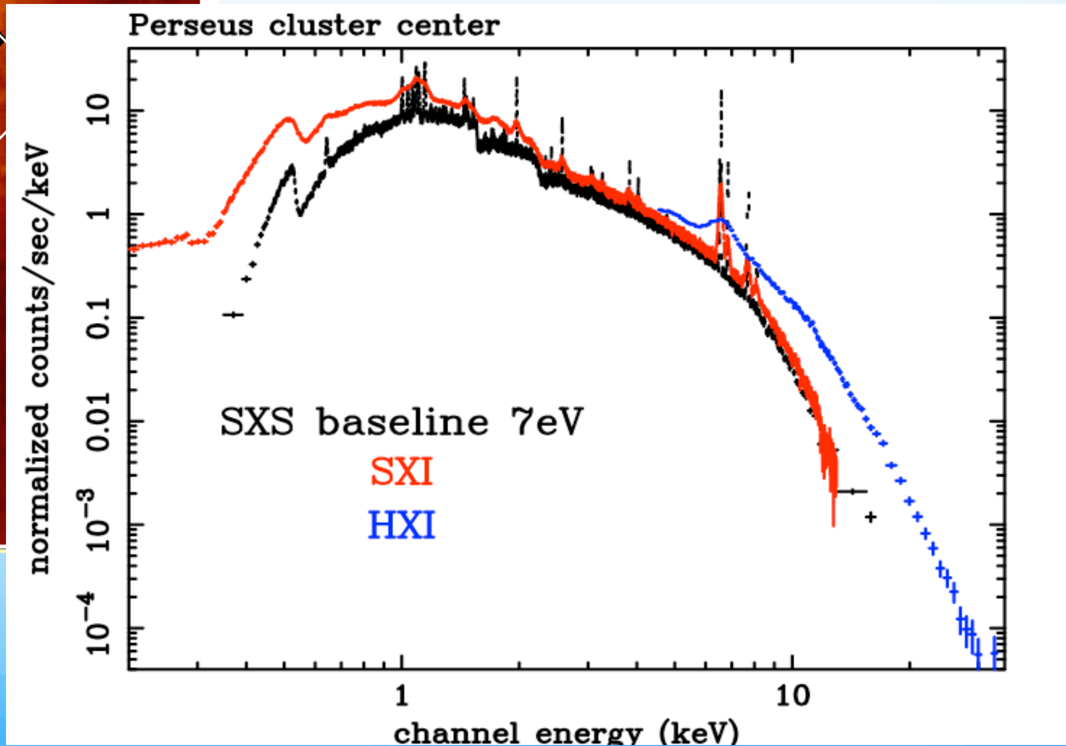
The Perseus cluster with ASTRO-H

The residual Chandra image of the
Perseus cluster with proposed SXS FOVs(3'x3')

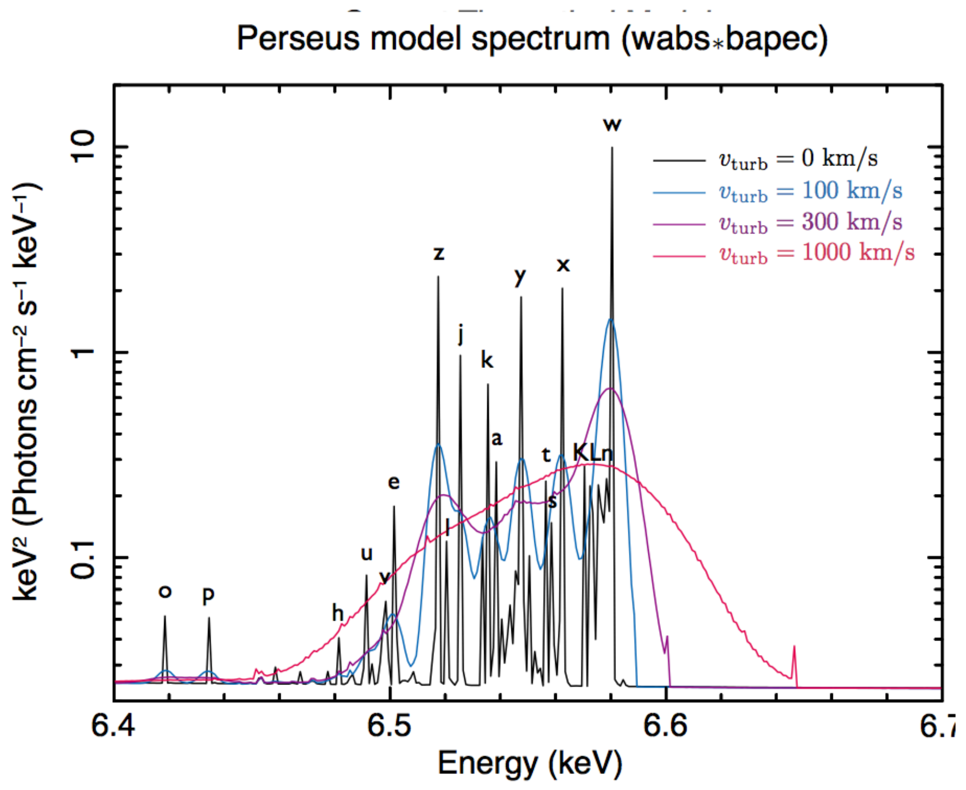


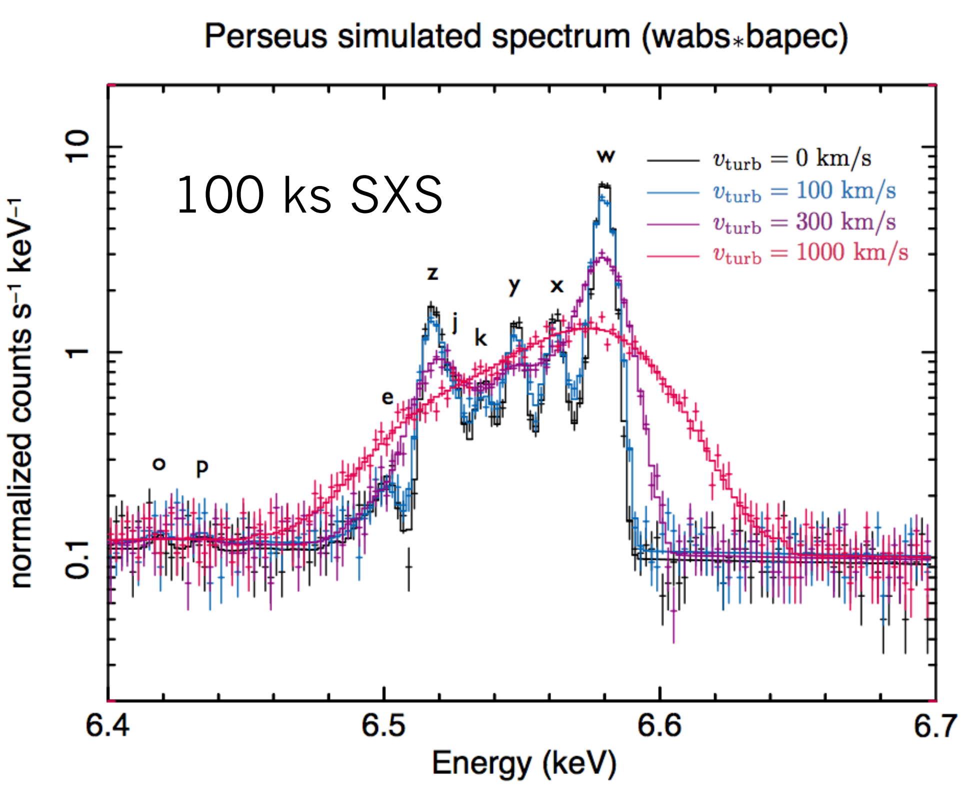
The brightest cool core

Predicted ASTRO-H spectra
for the center



He-like Fe from the Perseus core with SXS

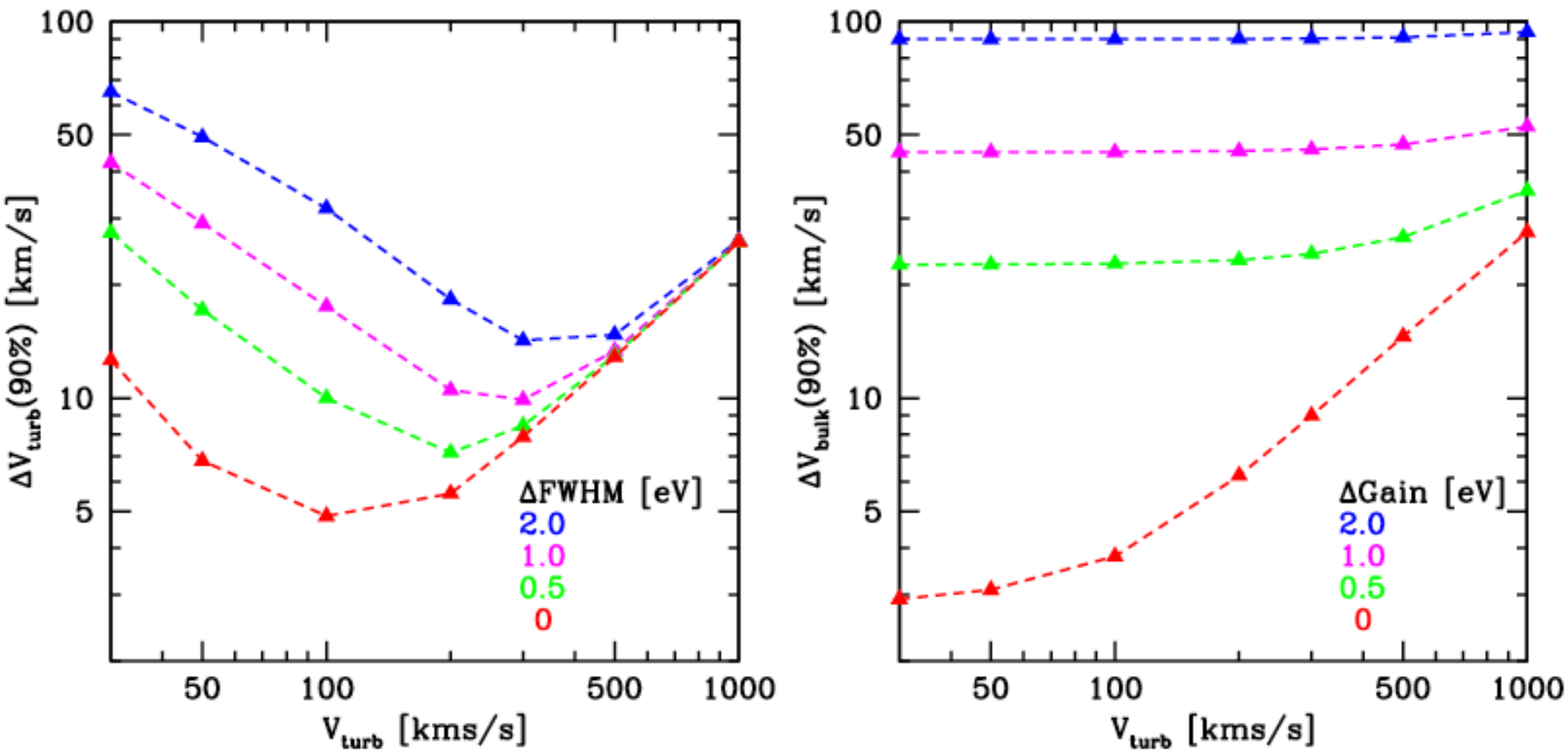




- Statistical uncertainties in bulk and turbulent velocities < 10 km/s
- Systematic uncertainties caused by uncertainties in the line spread function and gain of SXS ~ several times km/s

The brightest Fe-K lines

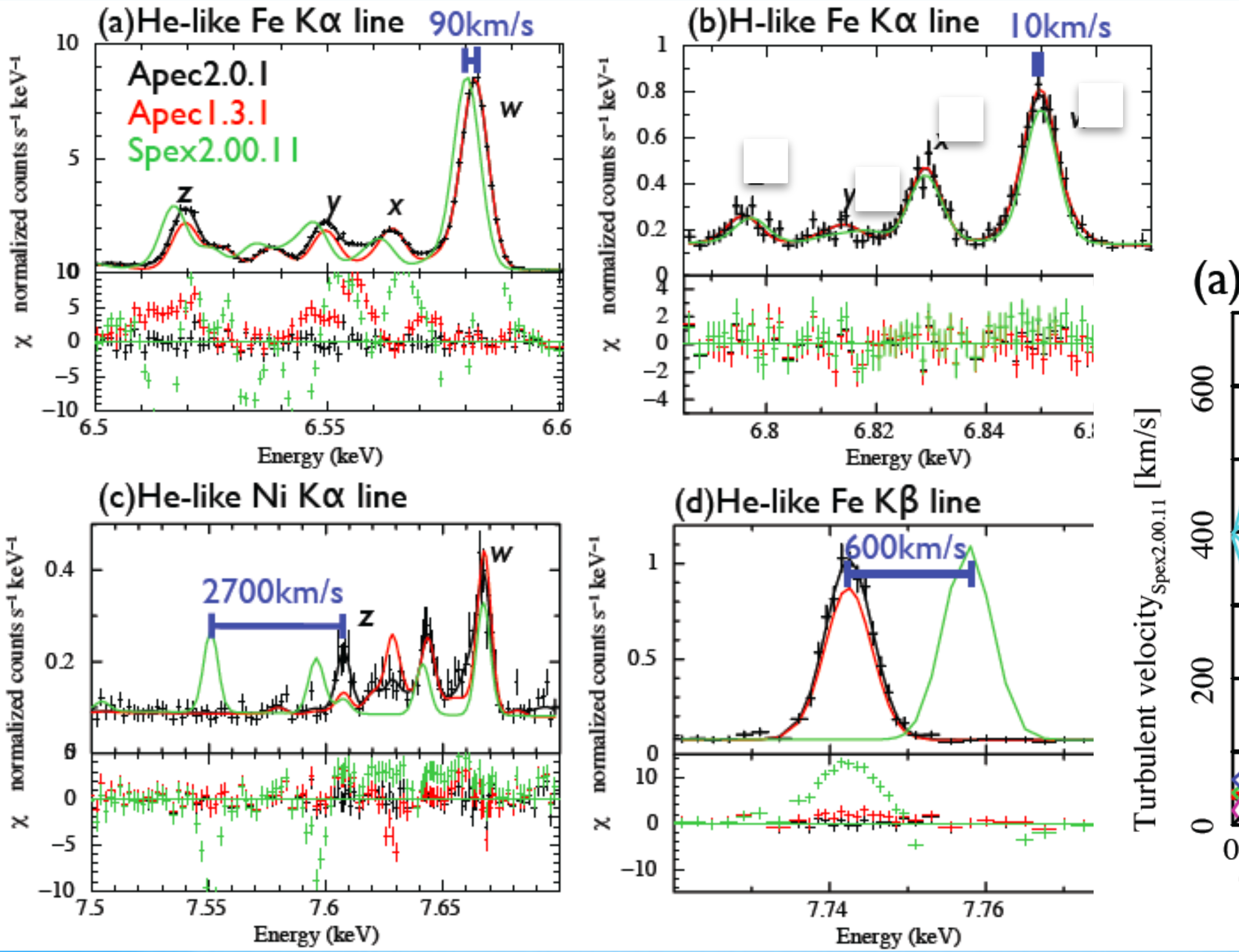
Systematic uncertainties caused by uncertainties in detector responses

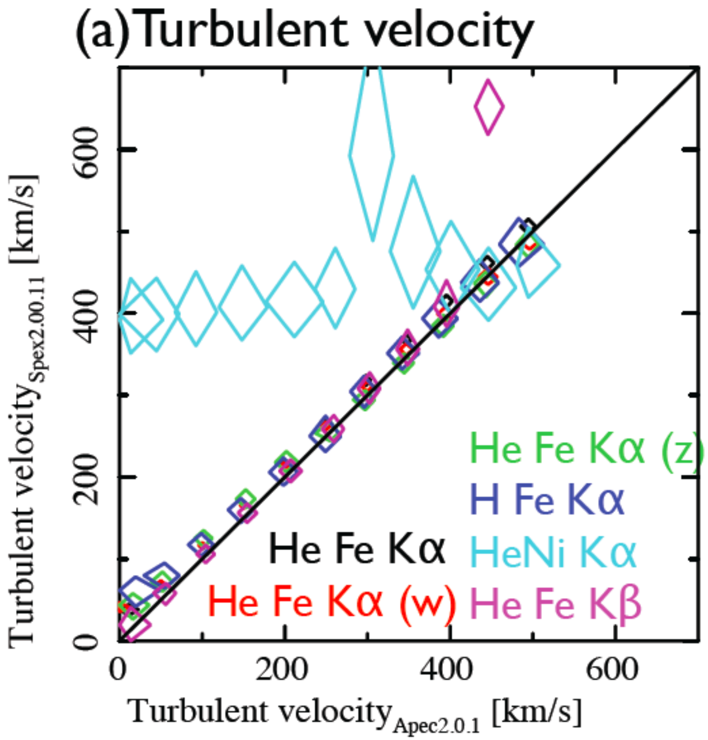


- Systematic uncertainties caused by uncertainties in the line spread function and gain of SXS ∼ several times km/s

Systematic uncertainties in the plasma codes

(by Sasaki)





APEC, SPEX – plasma codes

We need some calibrations using SXS cluster data (3’ offset of the Perseus cluster?)

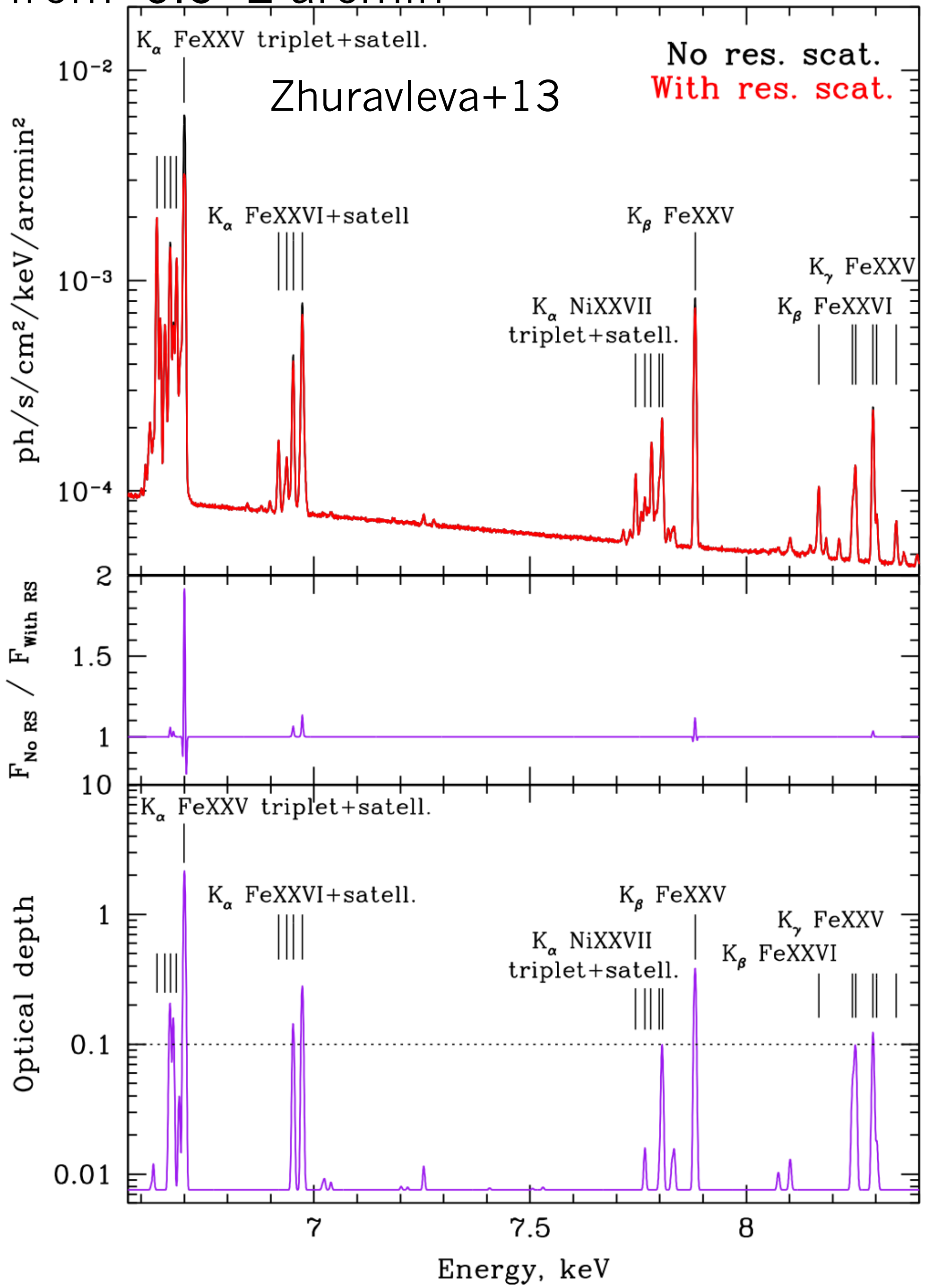
Resonant line scattering vs turbulence

Turbulent motions of gas -- suppress the effect of the resonant line scattering

A different sensitivity from the line broadening effect

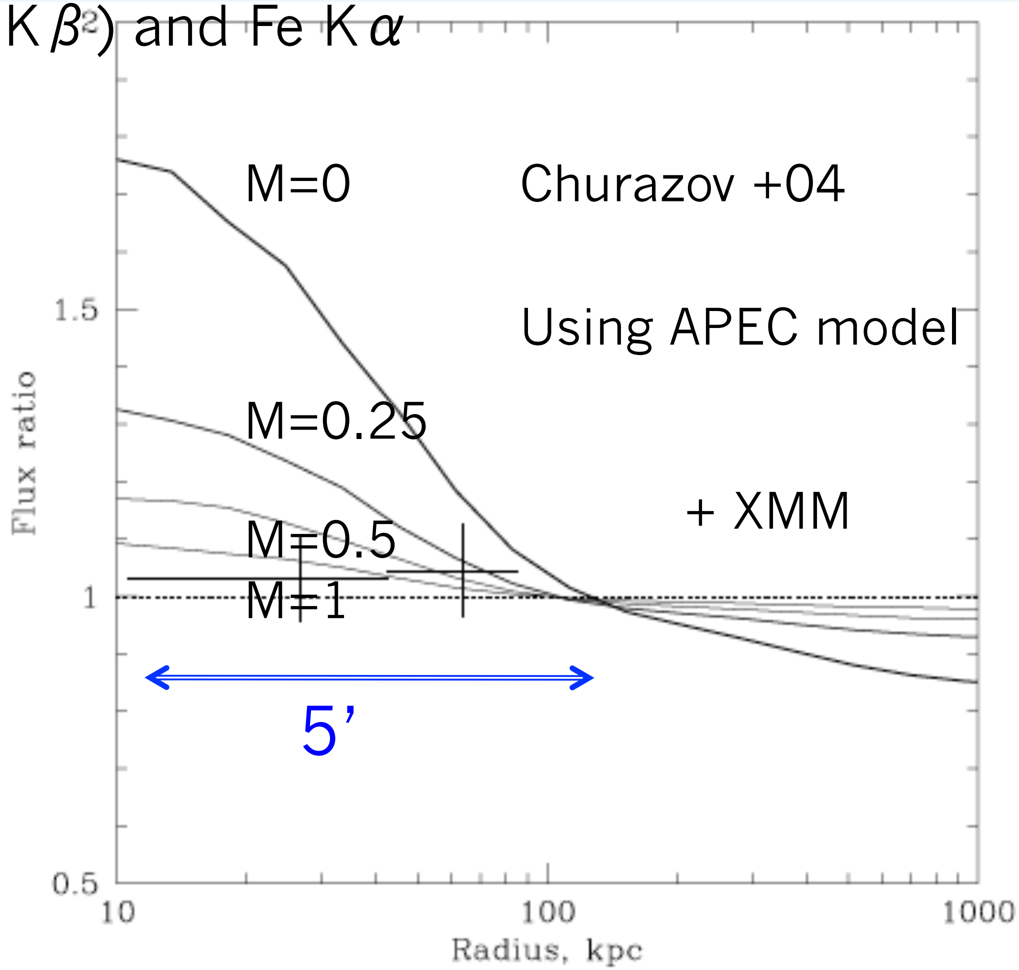
Measurements of flux ratios of optically thick and thin lines

Predicted spectrum of the Perseus cluster from 0.5 -2 arcmin

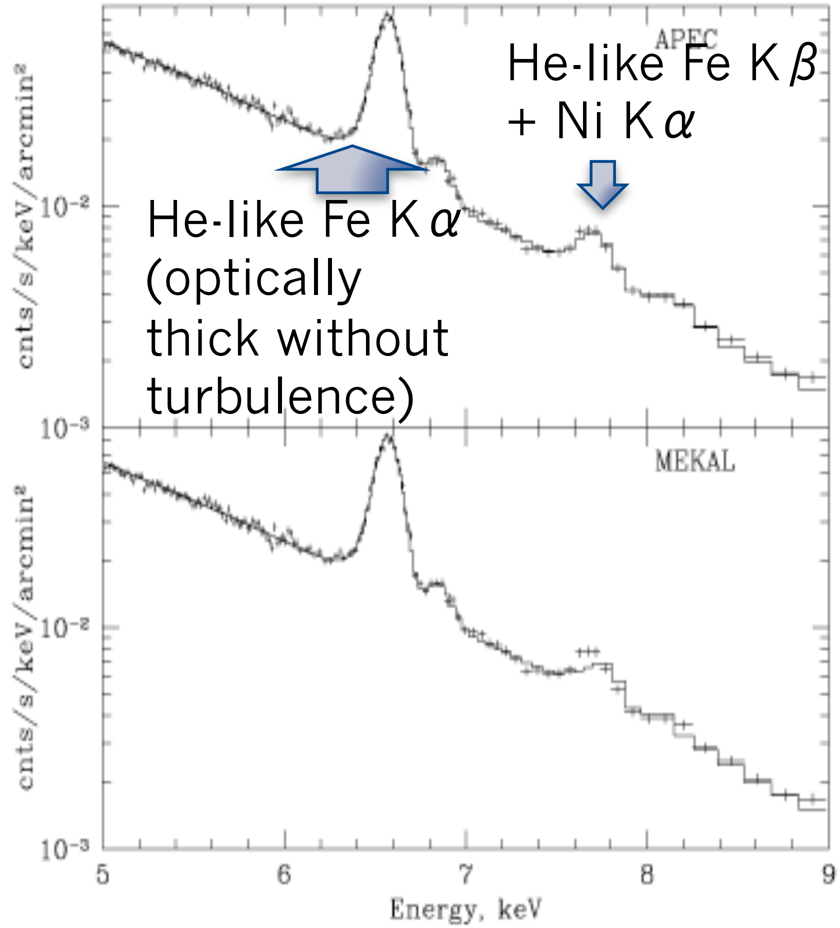


Resonant line scattering with XMM

Lack of the effect of resonant line scattering for the Perseus cluster. Abundance ratio of 7.8 keV (Ni Kα+Fe Kβ) and Fe Kα



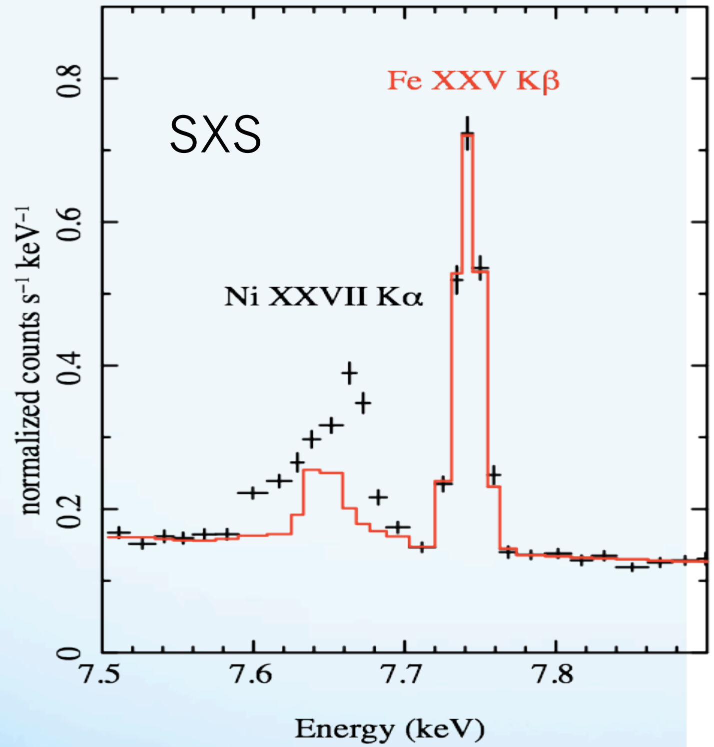
MOS spectrum of the Perseus cluster at 0.5'—2'

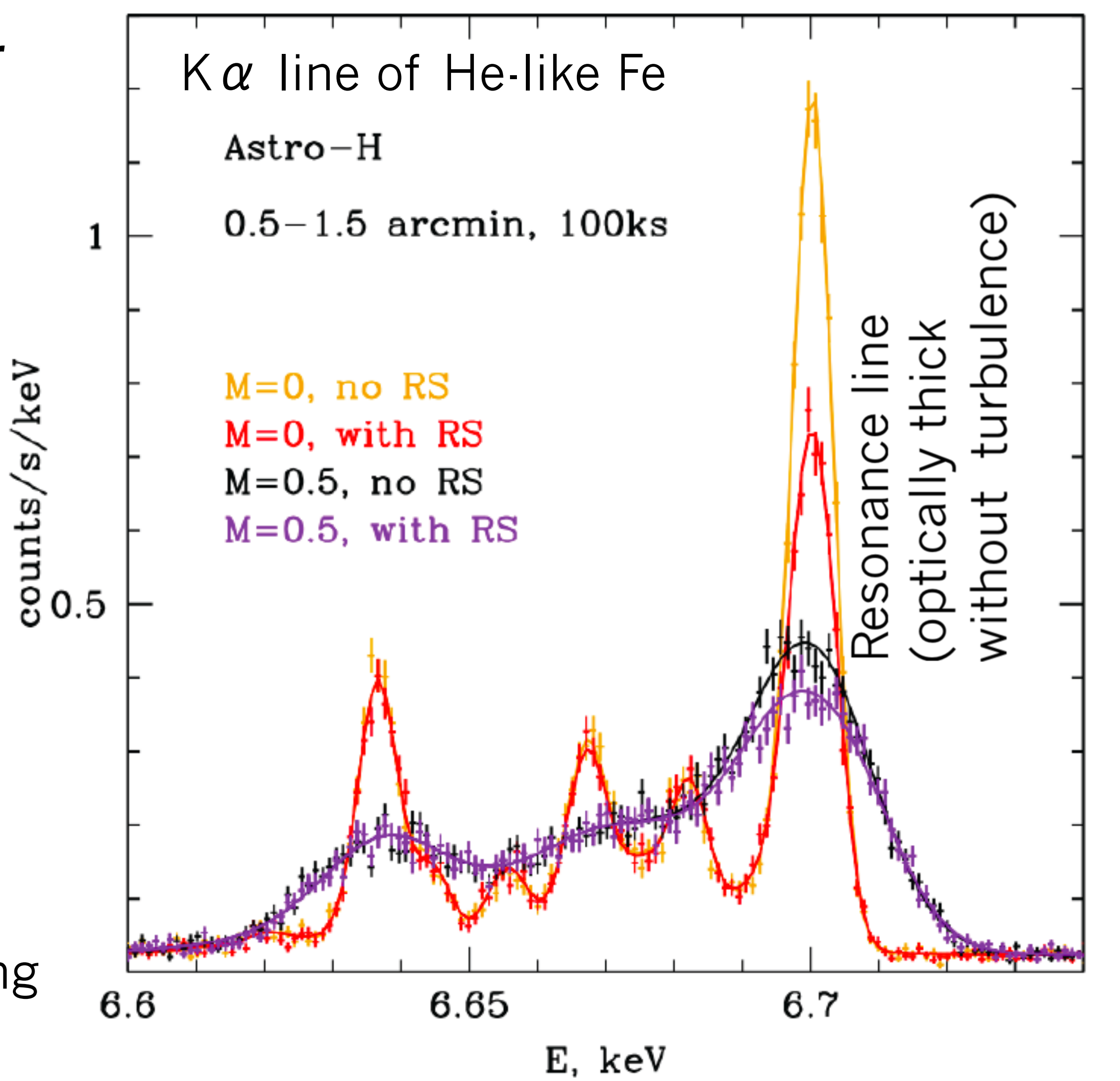


Turbulences in the cool cores of the Perseus cluster?

Resonant line scattering with SXS

The Perseus cluster



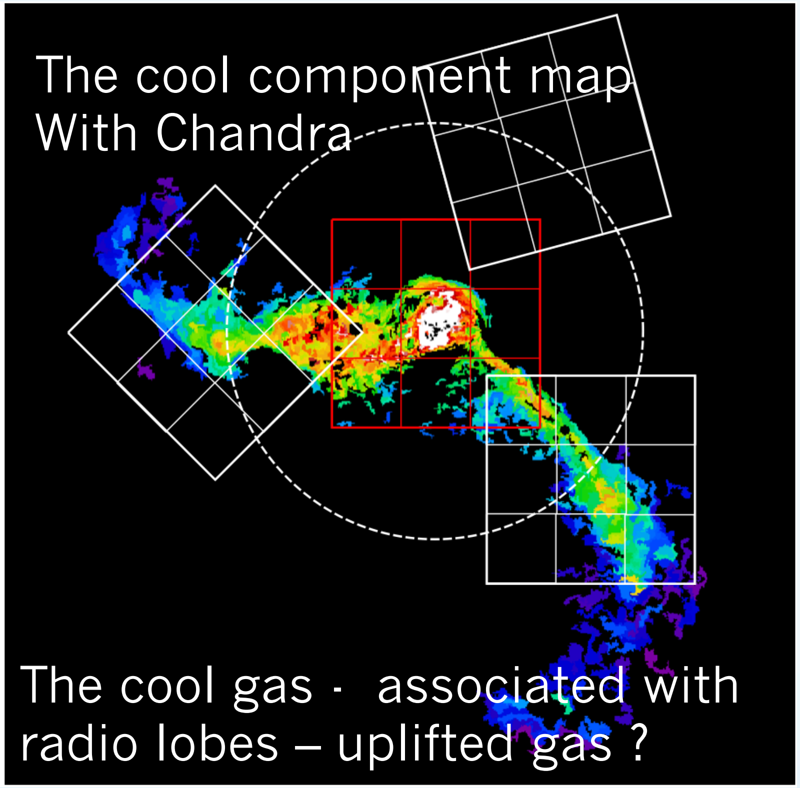


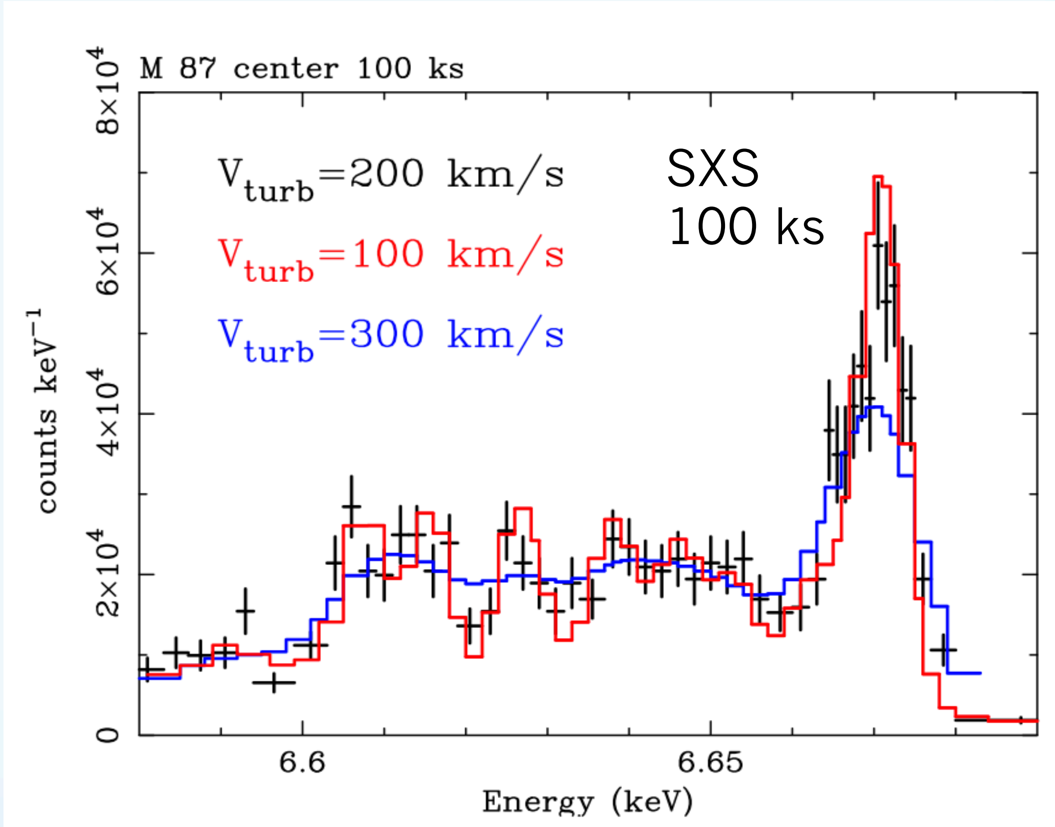
Kβ/Kα → resonant line scattering

CCDs can not resolve
He-like Ni Kα and He-like Fe Kβ

Turbulence, resonant line scattering

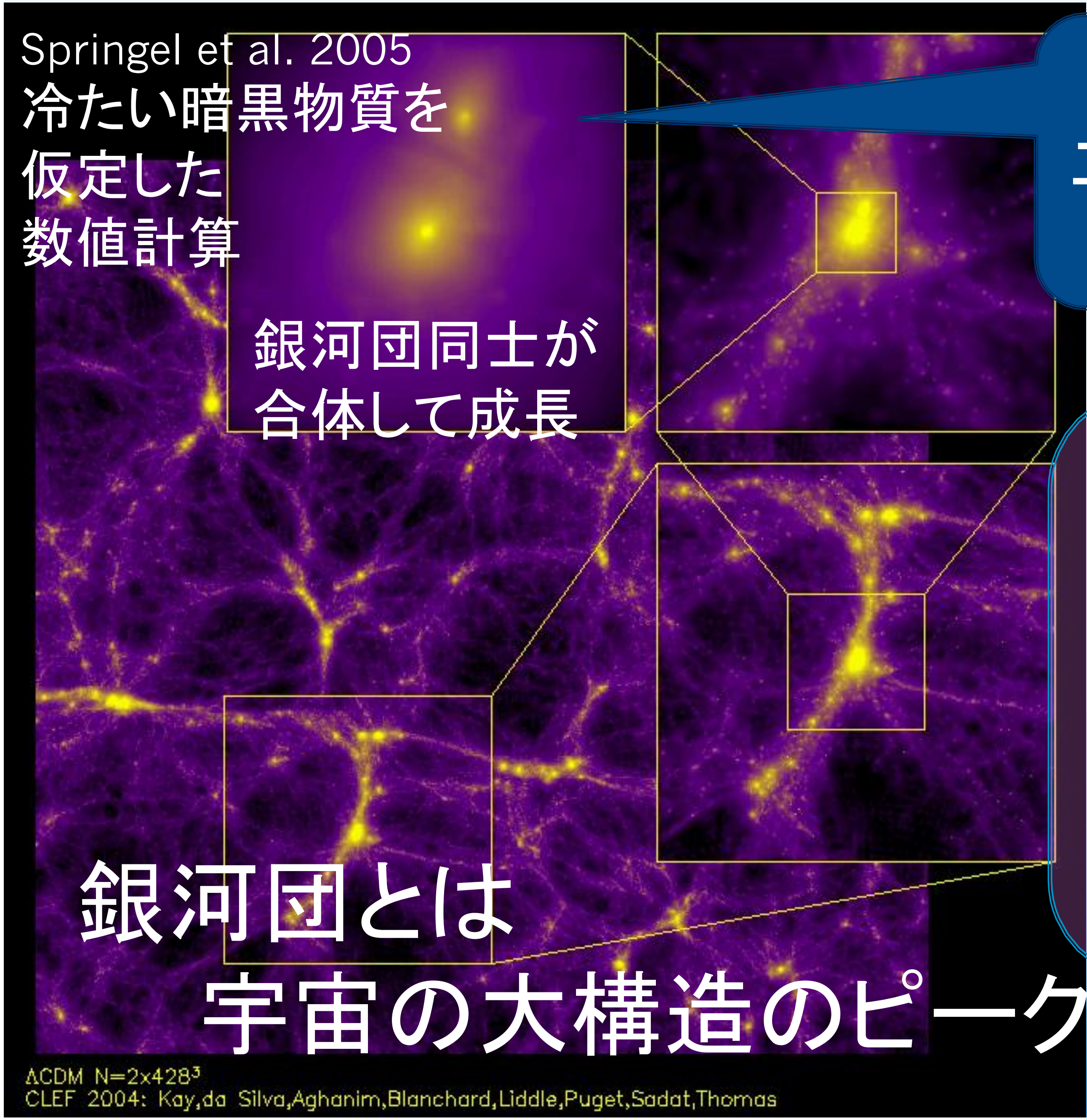
M 87 (the Virgo cD) with SXS





The gas dynamics in the center and uplifted gas with radio lobes.
Turbulence induced by the radio bubble and shock fronts?
Metal uplift from the core?

宇宙の大構造と銀河団の合体と成長



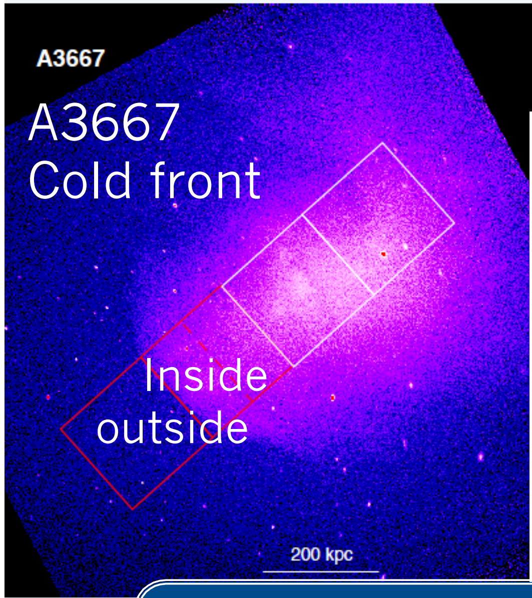
宇宙で最大の
エネルギーの現象
10^{57}J

宇宙最大の加熱源
（超高温成分）

ガスの運動
（速度分布）

宇宙最大の加速器
（硬X線放射）

Gas Dynamics in Merging Galaxy clusters

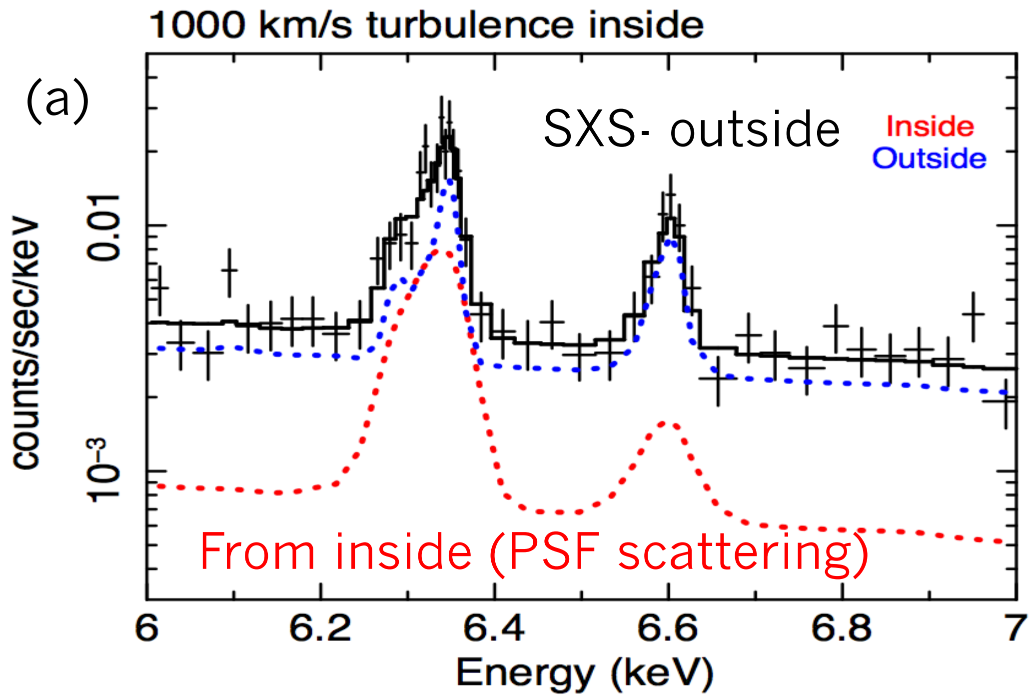


The generation and dissipation of turbulence depends on a microphysical properties of the ICM (viscosity, B)

Region 200ks	$v_{\rm bulk}$, km s^{-1}	σ_v, km s^{-1}
Constraints for gas inside:		
(a) $v_{\rm bulk} = 0$, $\sigma_v = 1000$ km s^{-1} inside		1005 ± 23
(b) $v_{\rm bulk} = 1000$ km s^{-1}	± 43	
Constraints for gas outside:		
(a) $v_{\rm bulk} = 0$, $\sigma_v = 1000$ km s^{-1} inside	± 100	420 ± 150
(b) $v_{\rm bulk} = 1000$ km s^{-1}	± 136	571 ± 143

Dissipated kinetic energy

- Turbulence?
- Bulk motions?
- Thermal energy?
- cosmic rays?



Measuring Non-thermal pressure and mass

Test the assumption that the ICM is in hydrostatic equilibrium

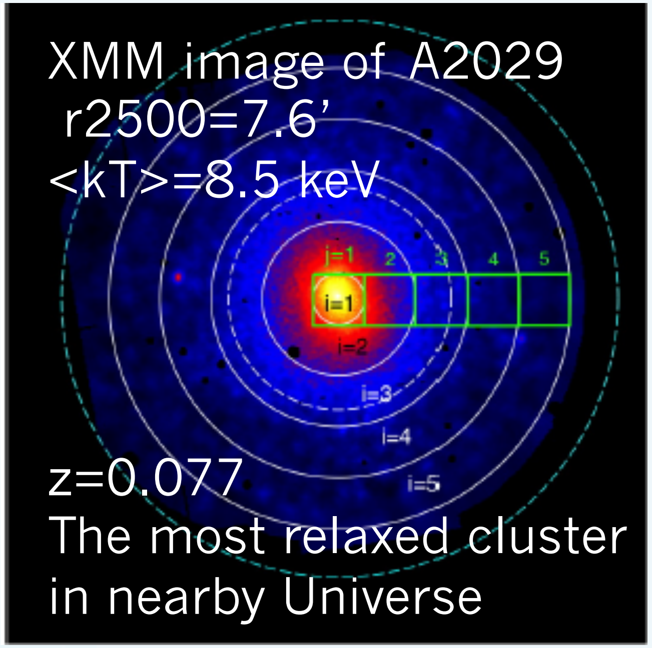
Accuracy of mass measurements of clusters

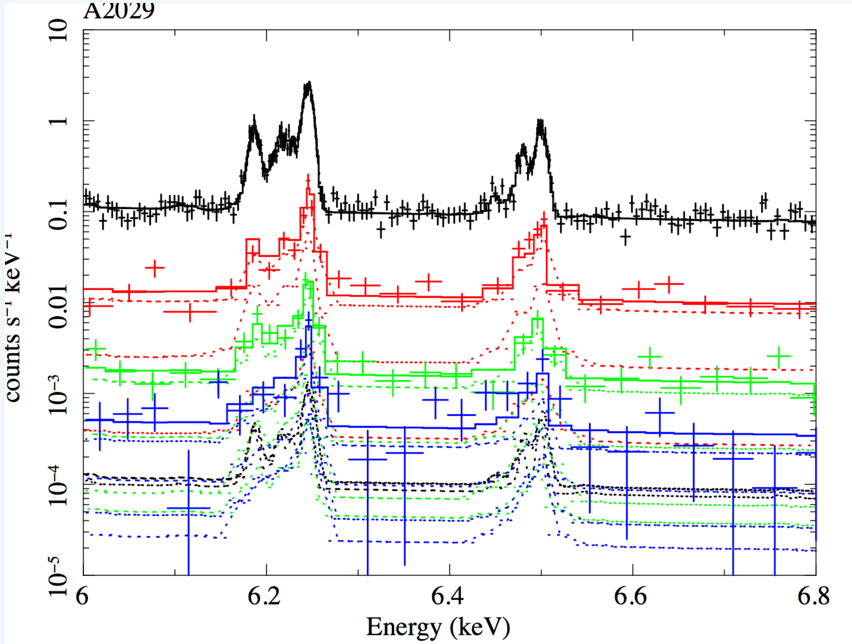
cosmology

$$\frac{p_{\rm turb}}{p_{\rm therm}} \simeq 1.2 \times 10^{-2} \left(\frac{\sigma_{\rm v}}{100\ {\rm km/s}}\right)^2 \left(\frac{\mu}{0.59}\right) \left(\frac{k_{\rm B} T_{\rm gas}}{5\ {\rm keV}}\right)^{-1}.$$

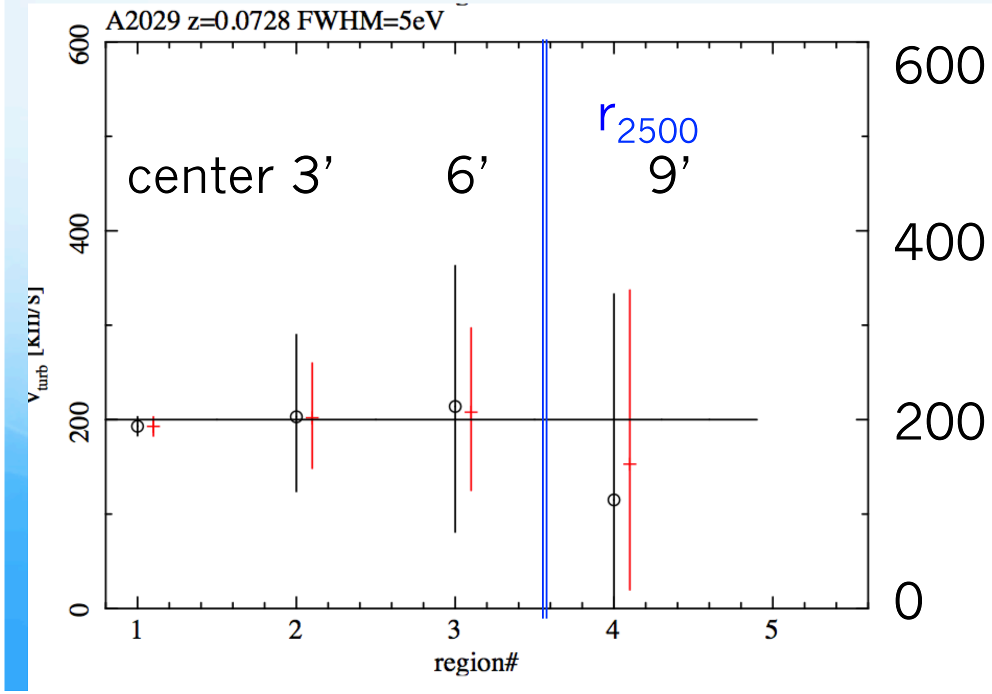
$$\frac{v_{\rm bulk}}{v_{\rm sound}} = 0.11 \left(\frac{v_{\rm bulk}}{100\ {\rm km/s}}\right) \left(\frac{k_{\rm B} T_{\rm gas}}{5\ {\rm keV}}\right)^{-1/2},$$

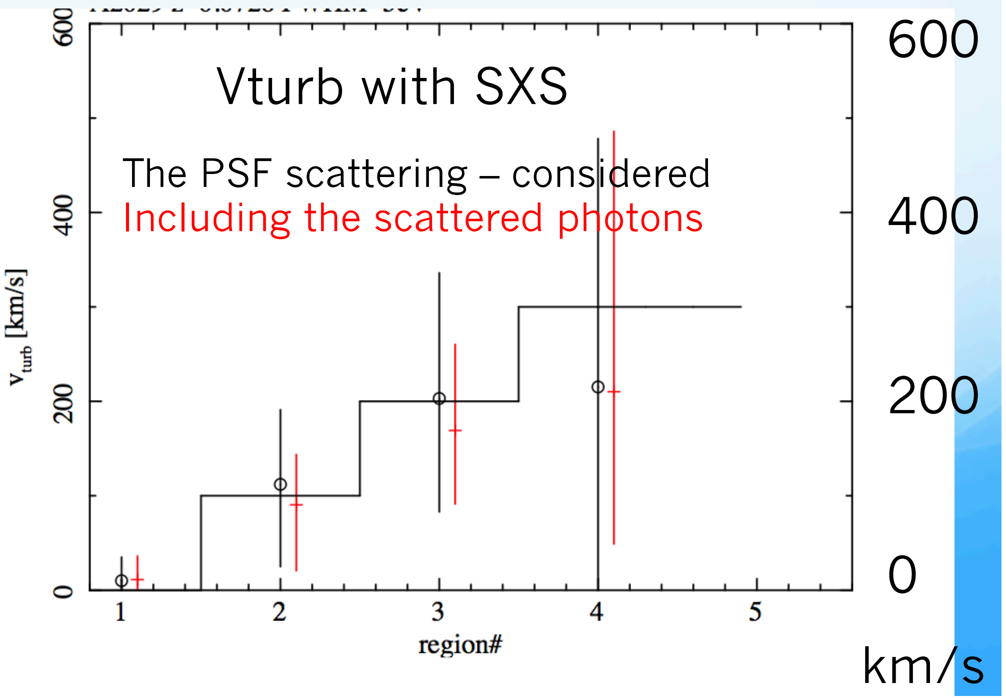
Gas dynamics of relaxed clusters out to r_{2500}



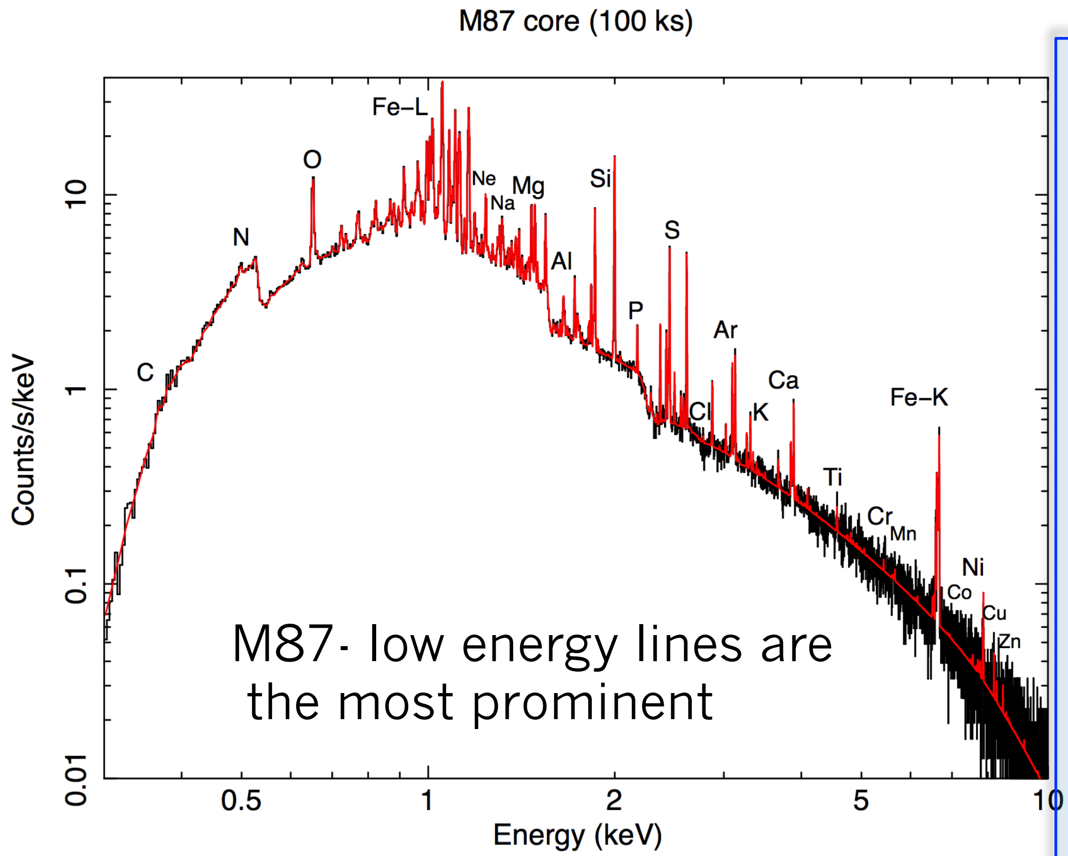


center (50ks)
3' offset(50ks)
6' offset(300ks)
9' offset(600ks)





Rare metals with Astro-H



M87- low energy lines are the most prominent

Expected errors in solar units in the SXS Perseus core pointing

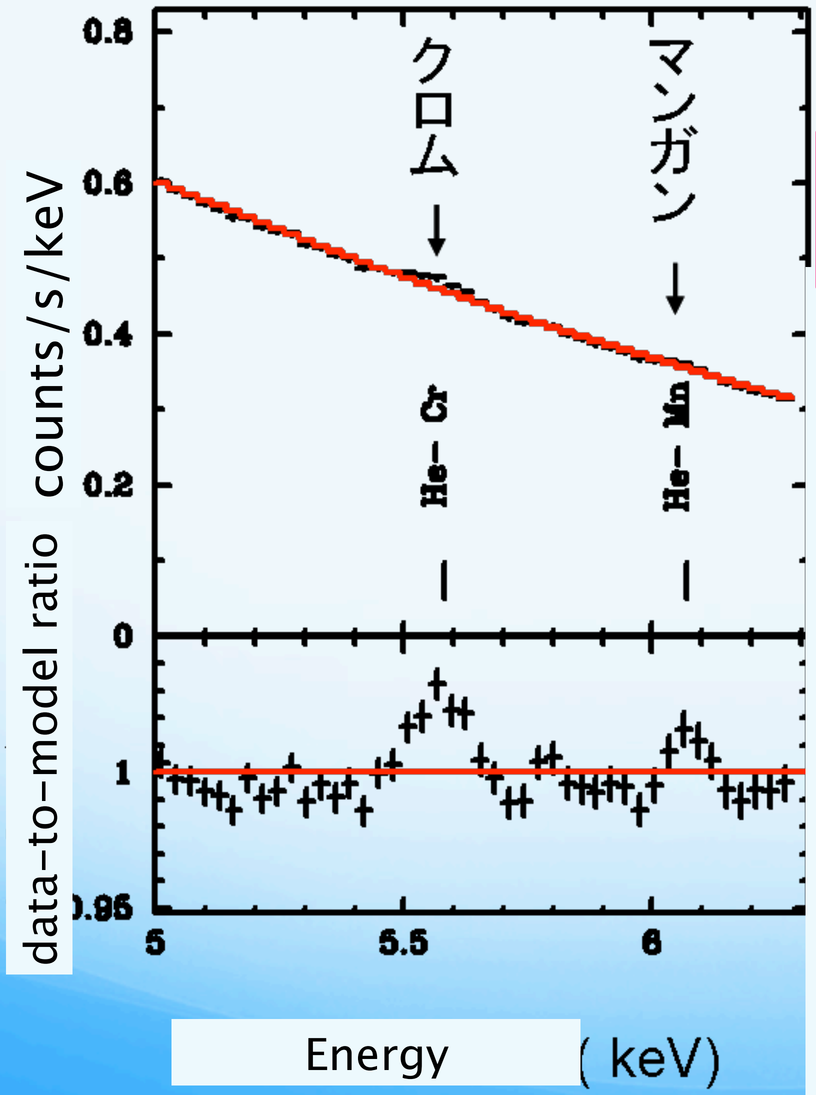
Assuming that the abundance is 1 solar

Element	Exposure 50 ks	Exposure 100 ks	Exposure needed for detection $>5\sigma$
F	83	59	-
Na	0.35	0.25	$\gtrsim$ 150 ks
Al	0.14	0.10	$\gtrsim$ 25 ks
P	0.7	0.5	$\gtrsim$ 625 ks
Cl	0.4	0.3	$\gtrsim$ 225 ks
K	0.7	0.5	$\gtrsim$ 625 ks
Sc	55	39	-
Ti	0.7	0.5	$\gtrsim$ 625 ks
V	6.0	4.3	-
Cr	0.14	0.10	$\gtrsim$ 25 ks
Mn	0.27	0.19	$\gtrsim$ 90 ks
Co	0.7	0.5	$\gtrsim$ 625 ks
Cu	4.0	2.8	-
Zn	1.6	1.1	-

Rare metals are different indicators for SN Ia/SNcc contributions, Progenetor metallicity

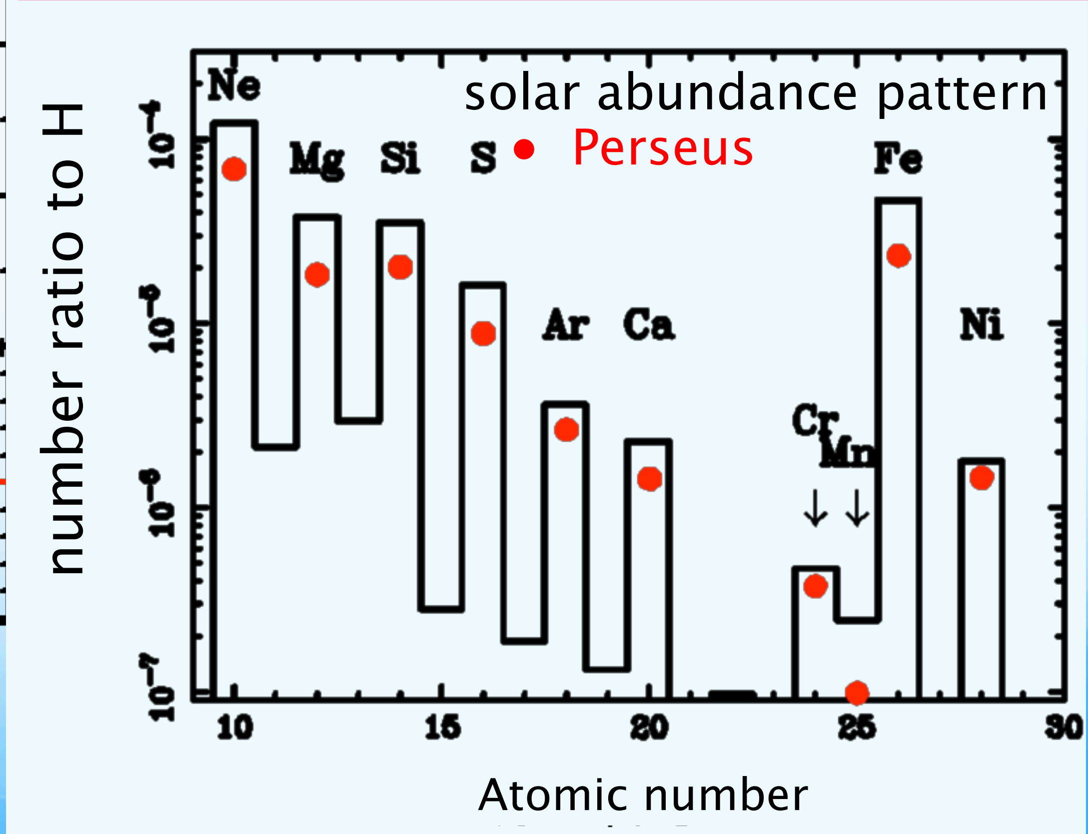
Cr and Mn detection from the Perseus cluster with Suzaku

Tamura et al. 2009

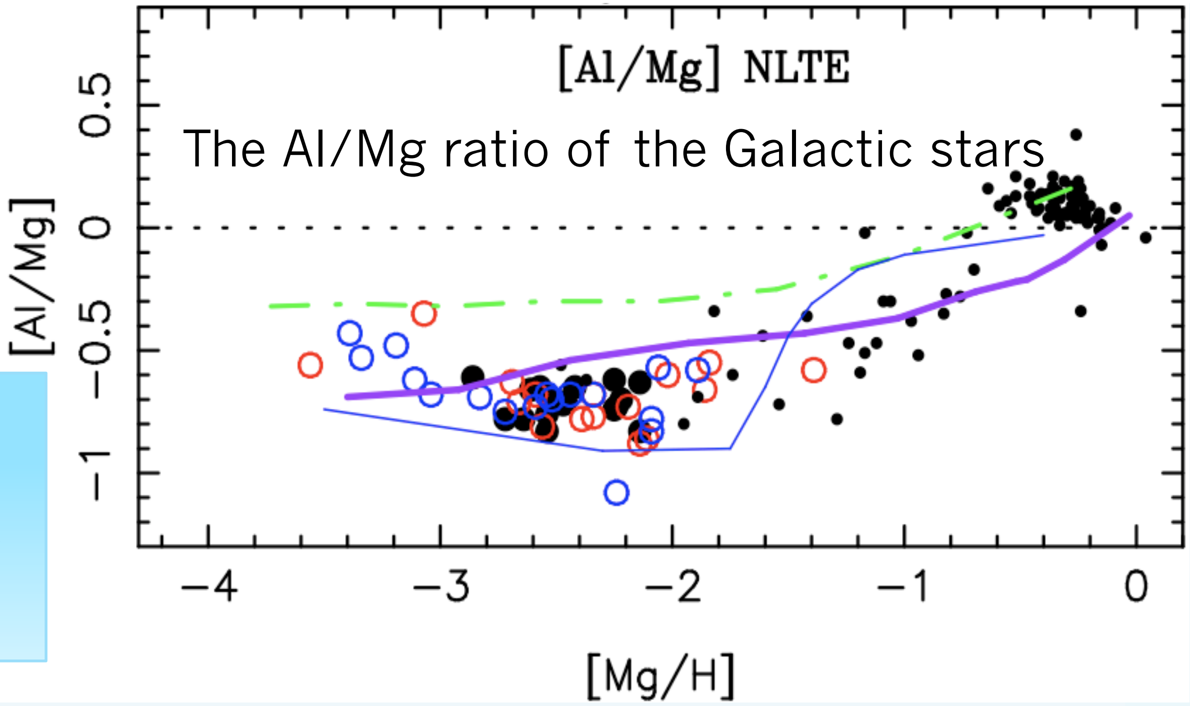


also XMM detectinon from
2A 0335+096
by Werner et al. (2006)

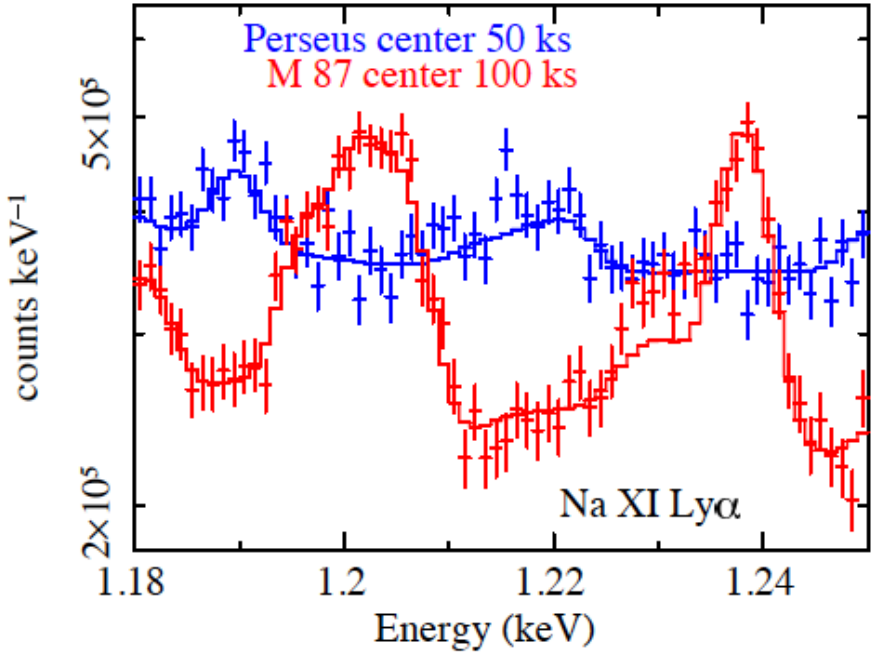
Mn is an indicator of SN Ia, since SN II do not produce Mn very much

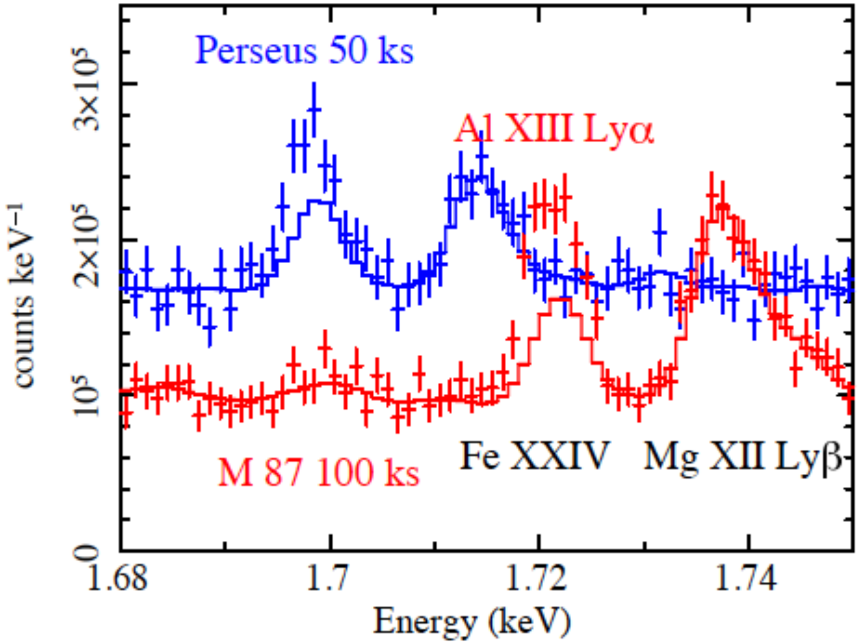


Al and Na with SXS

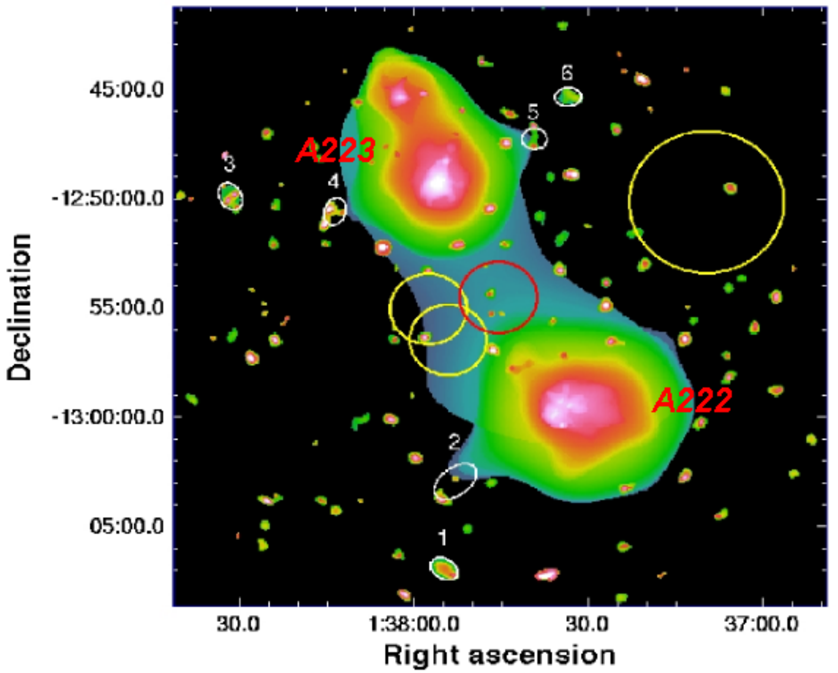


Increase of the Al/Mg ratio should reflect dependence of metallicity of progenitor of SN II

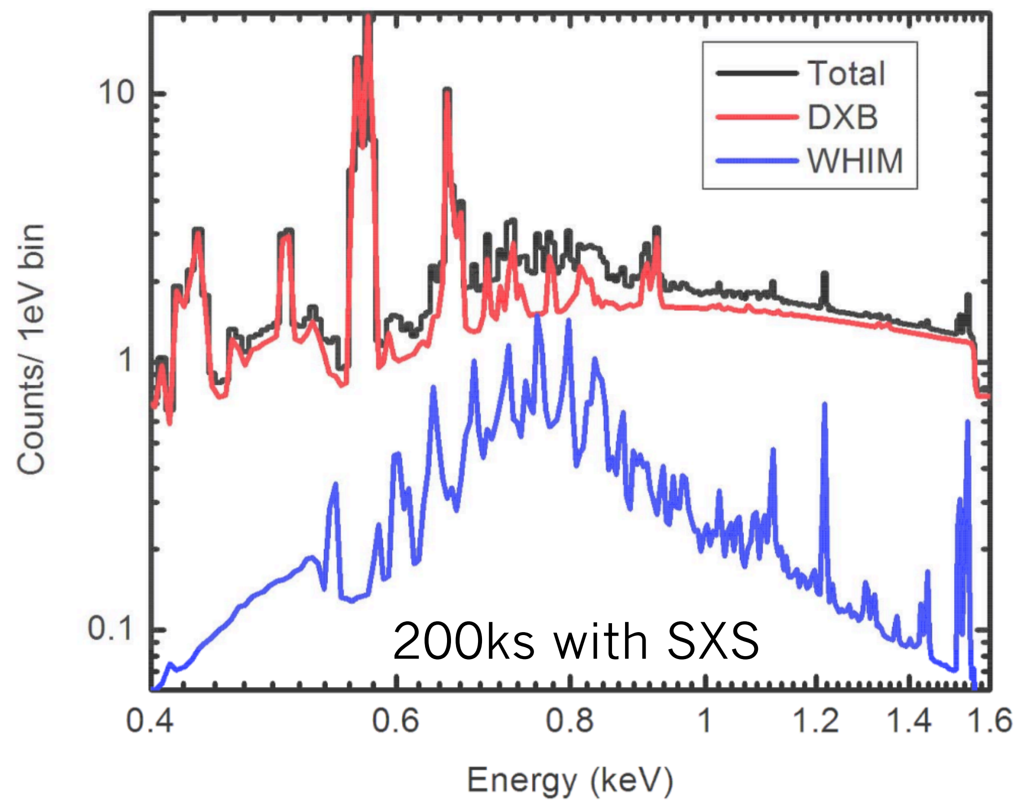




Detecting and Characterizing the Warm-Hot Intergalactic Medium



Wavelet decomposed 0.5–2.0 keV image of Abell 222 and Abell 223 (from Werner et al. 2008). The filament connecting the two massive clusters is clearly visible in the image.



- **z=0.21**
- **Excess emission detected at kT=(0.91±0.25) keV**
- **Extrapolated Overdensity ~ 150**

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