X-ray study of Gas* Bulk Motions in Galaxy Clusters

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Gas = X-ray emitting intracluster medium

Talk Plan

Motivation and Past Observations

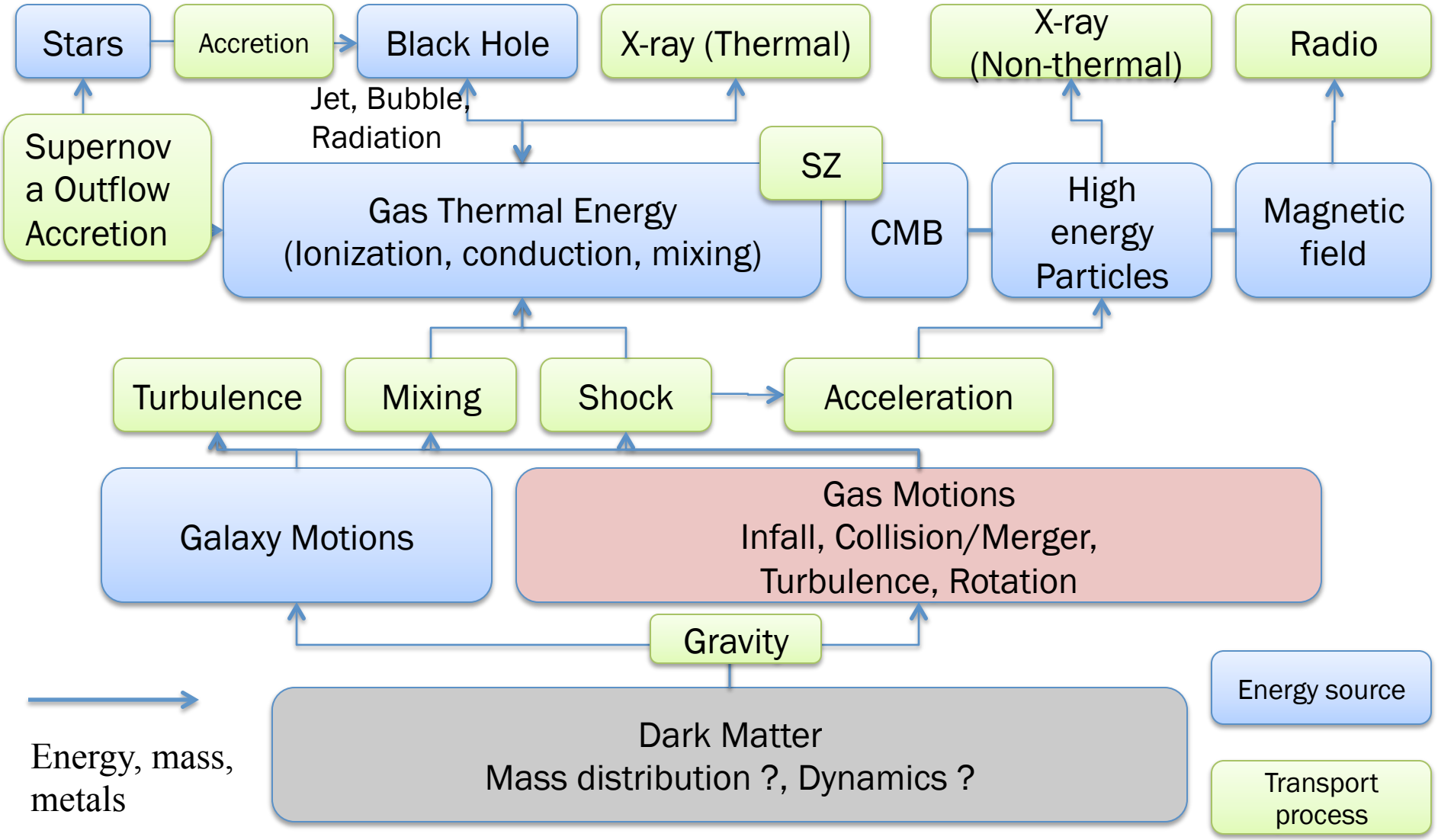
Discovery of Gas Bulk Motion in a merging cluster, A2256,

with Suzaku, an X-ray observatory

Future:

ASTRO-H high energy resolution spectroscopy

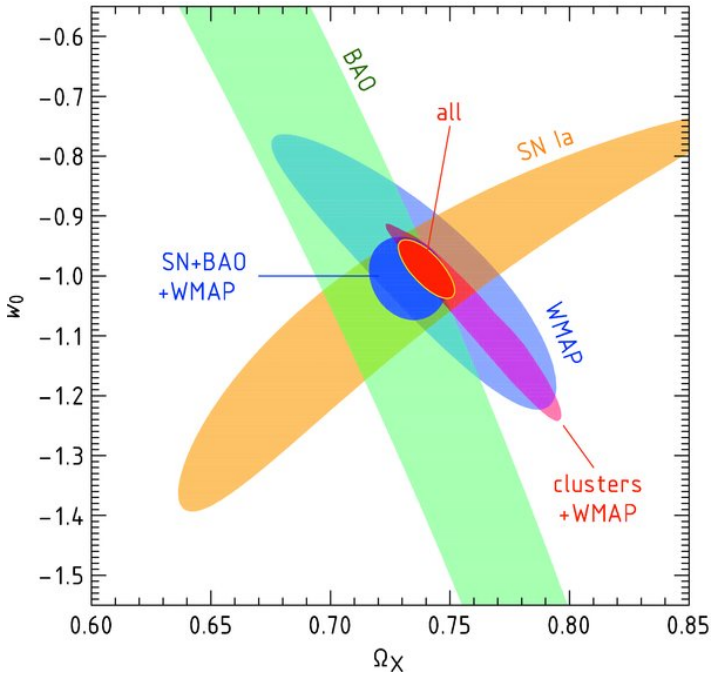
Energy flows through cluster hot gas



Reduce systematic error on the total mass estimates

$$\frac{d}{dr}[P_{thermal} + P_{kinetic} + \cdots] = -\rho_{gas}\frac{GM_{total}}{r^2}$$

$P_{kinetic}$ includes random, turbulent, rotational motions

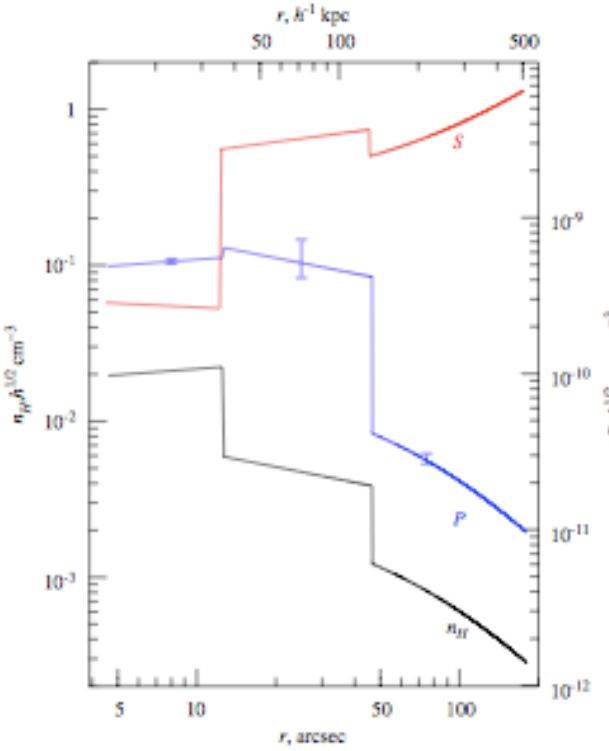


Ω_X : the present dark energy density
W0 ≡ pX/ρX a constant dark energy equation of state
(Vikhlinin et al. 2009)

How to measure Dynamical motion

(1) X-ray imaging:

→ cluster dynamics in the plane of the sky.

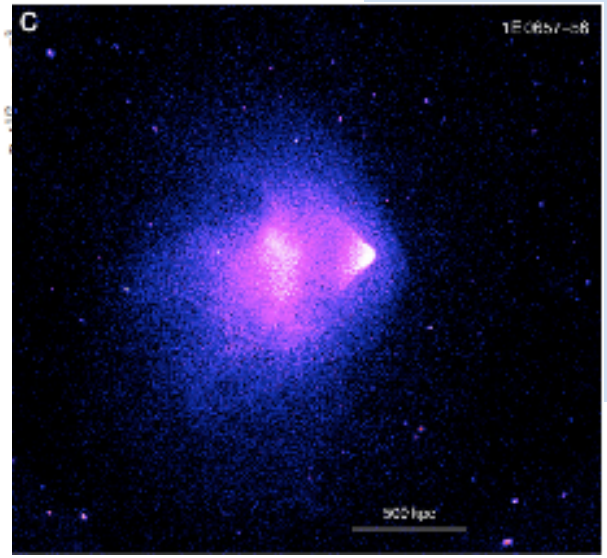


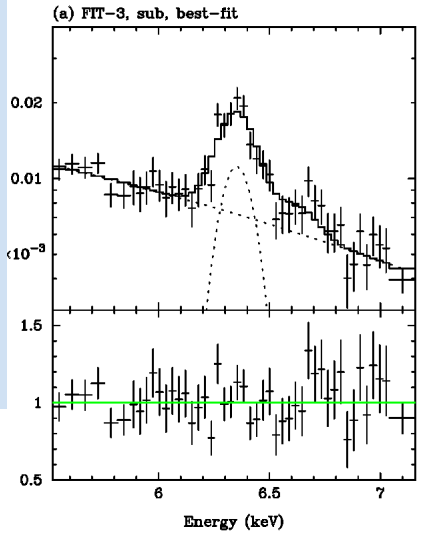
Markevitch & Vikhlinin 2007

(2) Doppler Mapping of X-ray lines

→ line of sight velocity

→ Goals for future X-ray missions





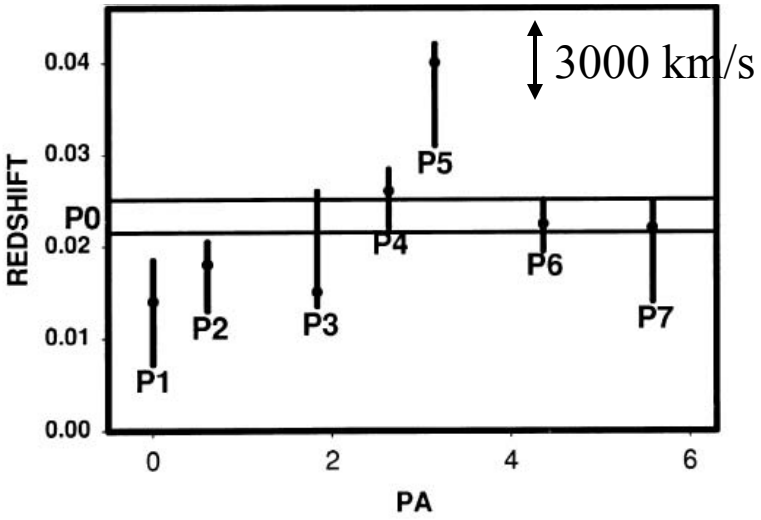
Previous Attempts

ASCA, Perseus: Dupke and Bregman (2001) claimed 4100 (+2200, -3100) km/s, but not confirmed by later study (Ezawa et al. 2001)

Centaurs: Dupke and Bregman (2001) claimed 1600 ± 320 km/s, but not confirmed by Suzaku

See also Chandra results (Dupke et al. 2006)

Previous results by Dupke and Bregman suggest bulk motions in some clusters but with large uncertainties.

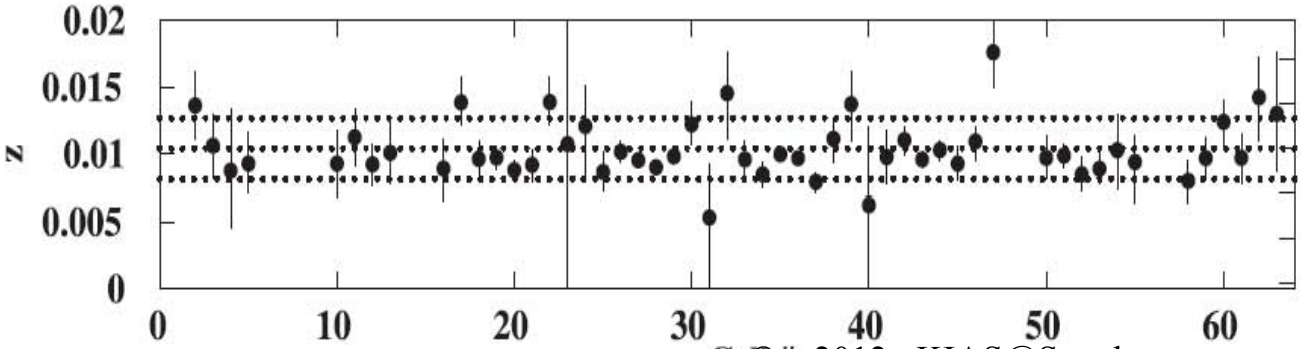


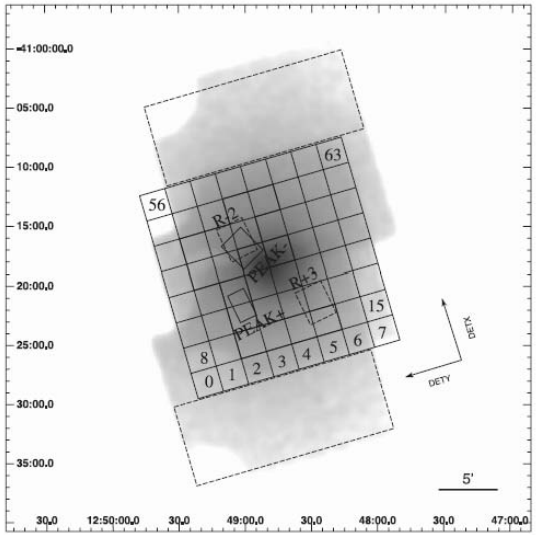
Velocity (km/s)	E/ΔE	Shift @ Fe-K line, 6.7 keV
300	1000	0.1% = 7 eV
CCD energy resolution	60	120 eV

Suzaku Limits

Centaurus	Ota et al. 2007	ΔV < 1400 km/s, 2' x 2' grids
Ophiuchus	Fujita et al. 2008	ΔV < 3000 km/s, center vs. offset regions
AMW7	Sato et al. 2008	ΔV < 2000 km/s, a hint ΔV between east/ west
A 2319	Sugawara et al. 2009	ΔV < 2000 km/s, variation within the core
Coma	Sato et al. 2011	ΔV < 2000 km/s, center vs. offset regions
A3627	Nishino et al. 2012	ΔV < 800 km/s, sub cluster shift

Centaurus (Ota et al. 2007)





Motivation and Past Observations

Discovery of Gas Bulk Motion in a merging cluster, A2256,

with Suzaku, an X-ray observatory

Future:

ASTRO-H high energy resolution spectroscopy

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Discovery of Gas Bulk Motion in the Galaxy Cluster Abell 2256 with Suzaku

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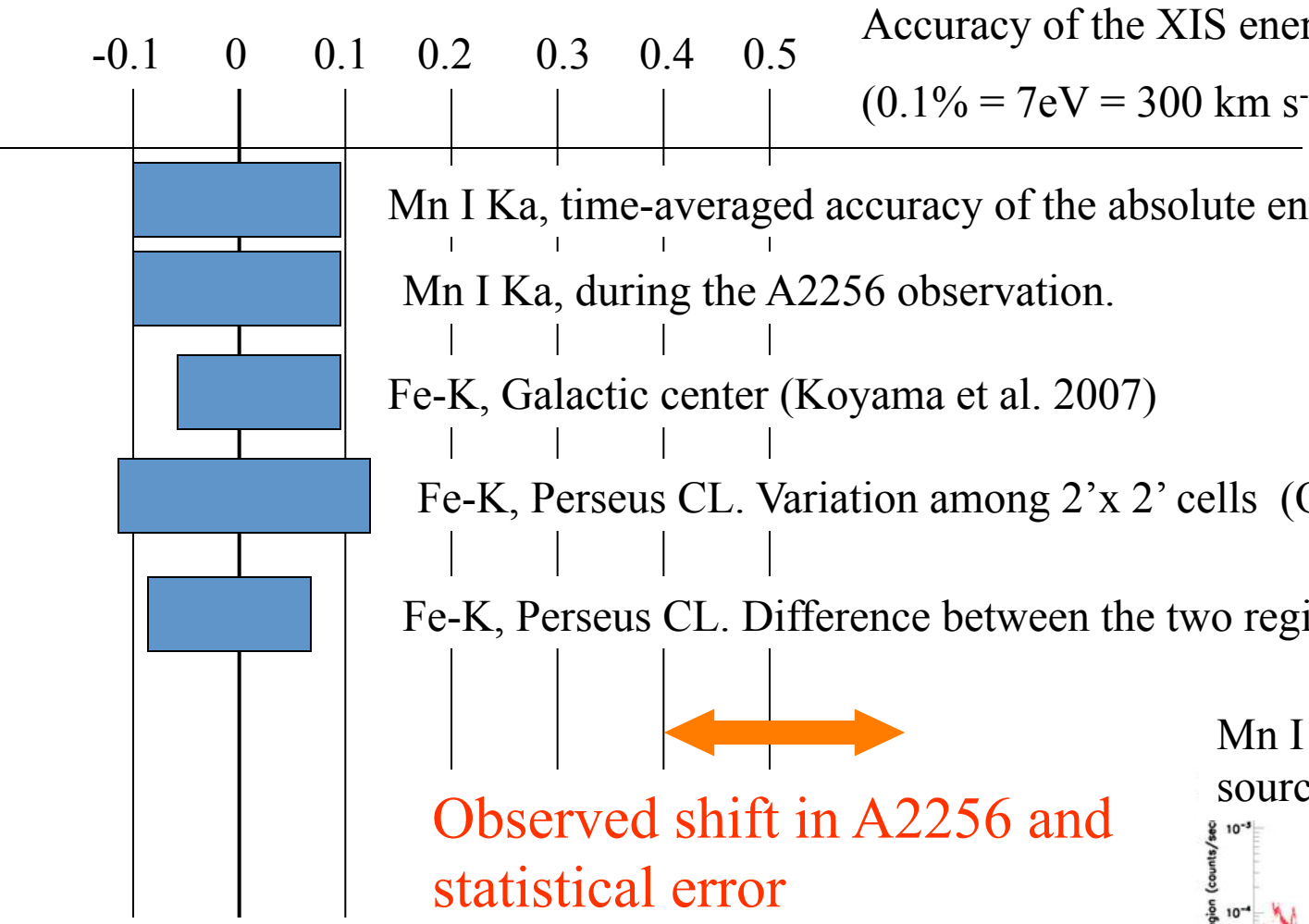
Abstract

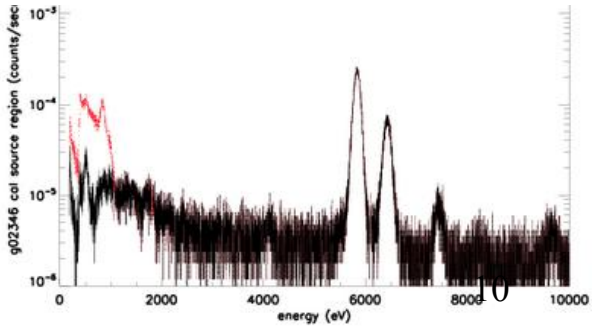
The results from Suzaku observations of the galaxy cluster Abell 2256 are presented. This cluster is a prototypical and well-studied merging system, exhibiting substructures both in the X-ray surface brightness and in the radial velocity distribution of member galaxies. There are main and sub components separated by $3'.5$ in the sky and by about $2000\,\mathrm{km\,s^{-1}}$ in radial-velocity peaks of the member galaxies. In order to measure the Doppler shifts of iron K-shell lines from the two gas components by the Suzaku XIS, the energy scale of the instrument was carefully evaluated and found to be calibrated well. A significant shift of the radial velocity of the sub component gas with respect to that of the main cluster was detected. All three XIS sensors show the shift independently and consistently among the three. The difference is found to be 1500 ± 300 (statistical) ± 300 (systematic) $\mathrm{km\,s^{-1}}$. The X-ray determined absolute redshifts of, and hence the difference between, the main and sub components are consistent with those of member galaxies in the optical band. The observation indicates robustly that the X-ray emitting gas is moving together with galaxies as a substructure within the cluster. These results along with other X-ray observations of gas bulk motions in merging clusters are discussed.

Key words: cosmology: large-scale structure — galaxies: clusters: individual (Abell 2256) — galaxies: intergalactic medium — X-rays: diffuse background

Suzaku XIS energy scale calibration

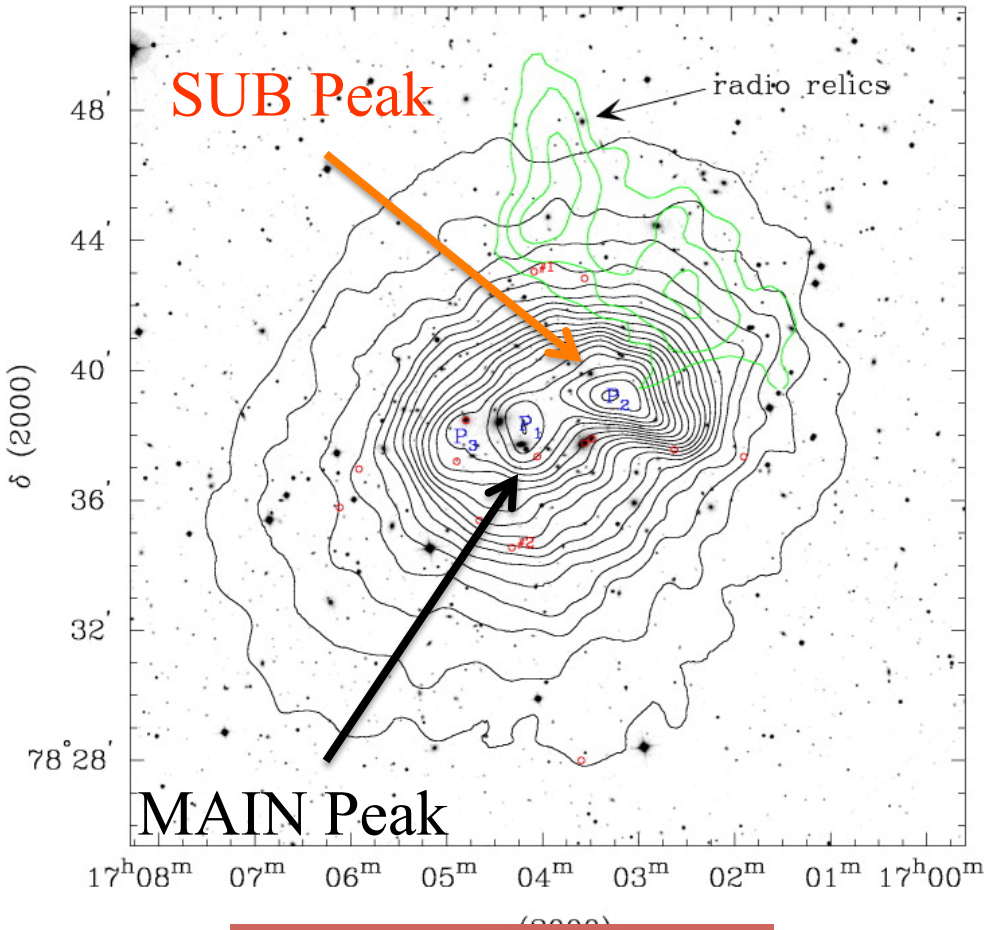


Mn I K lines from the Cal. source

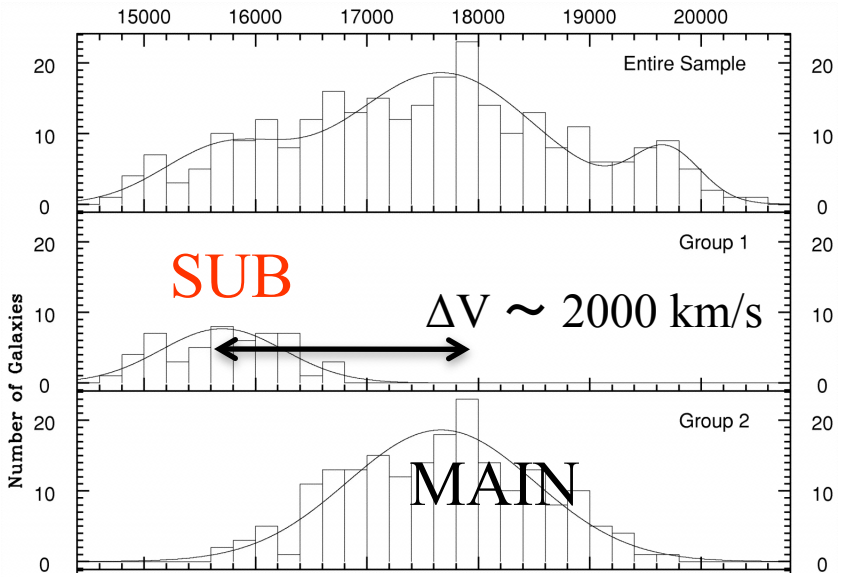


Good calibration is a key

A2256, X-ray bright, double peaked merging cluster

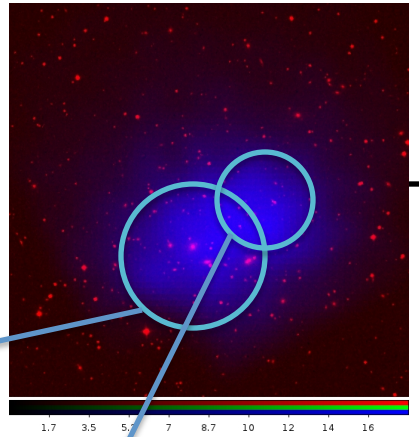


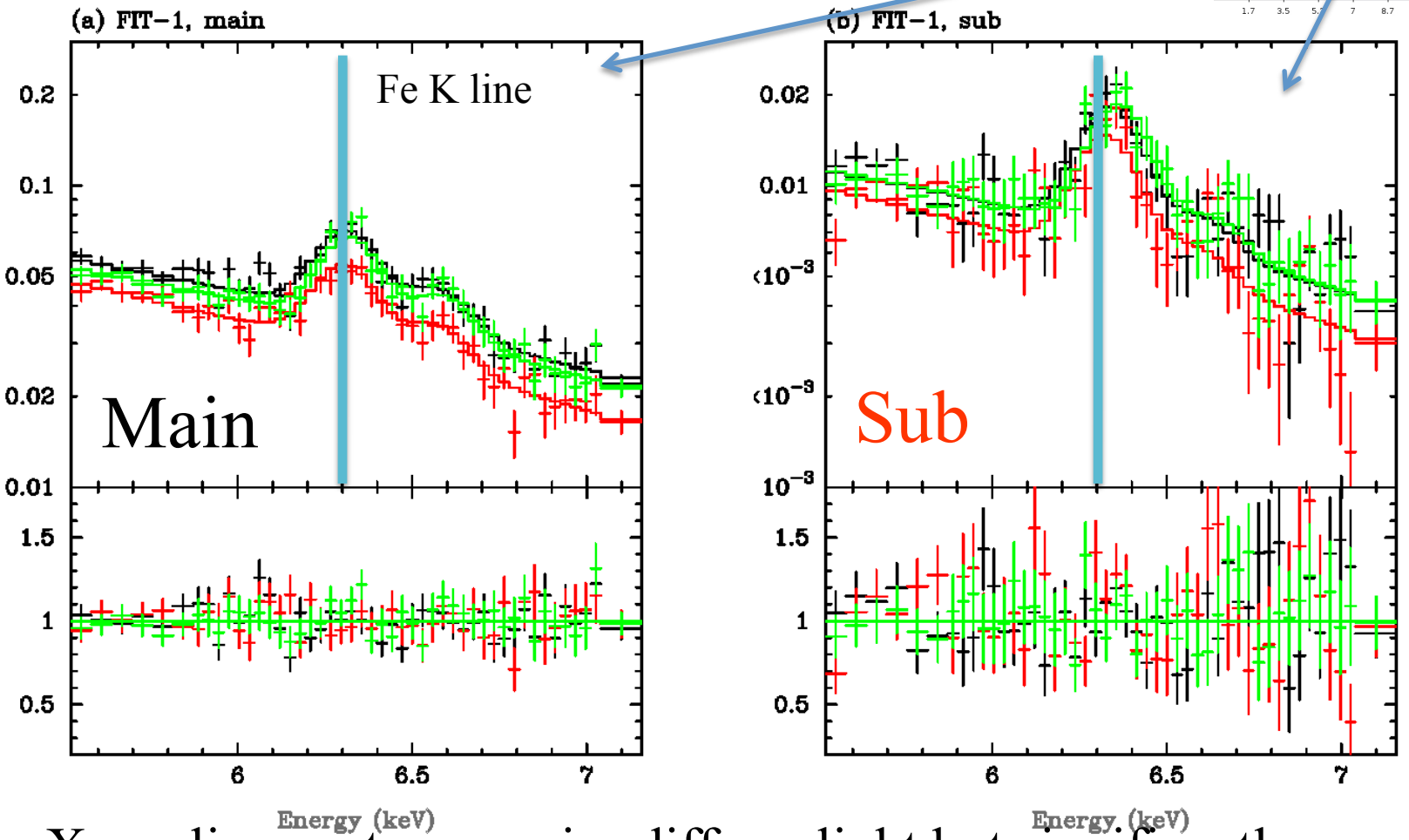
Sun et al. 2002 (Chandra)



Galaxy Radial Velocity (km/s)
Berrington et al. 2002

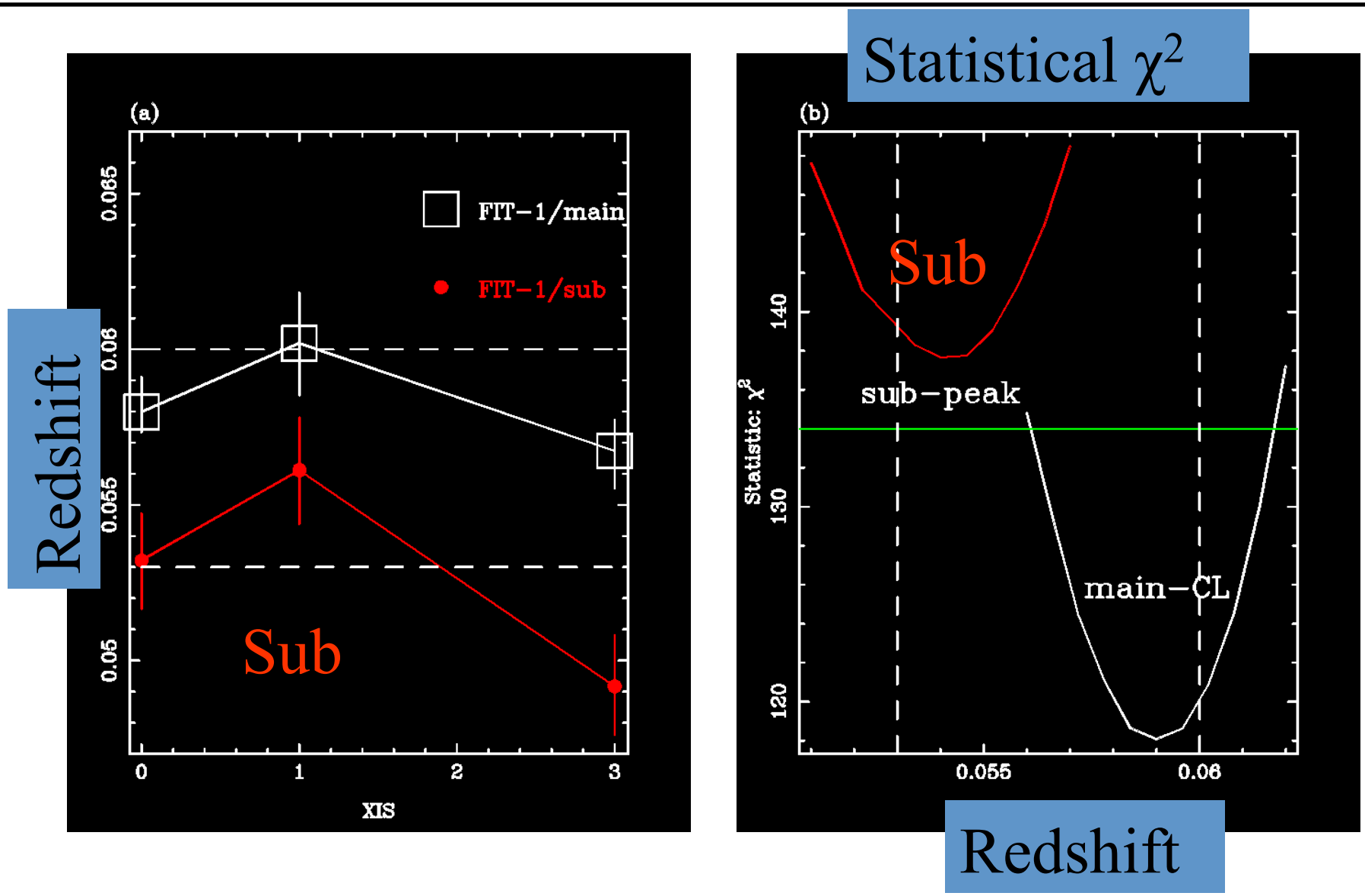
X-ray Spectra from main and sub components





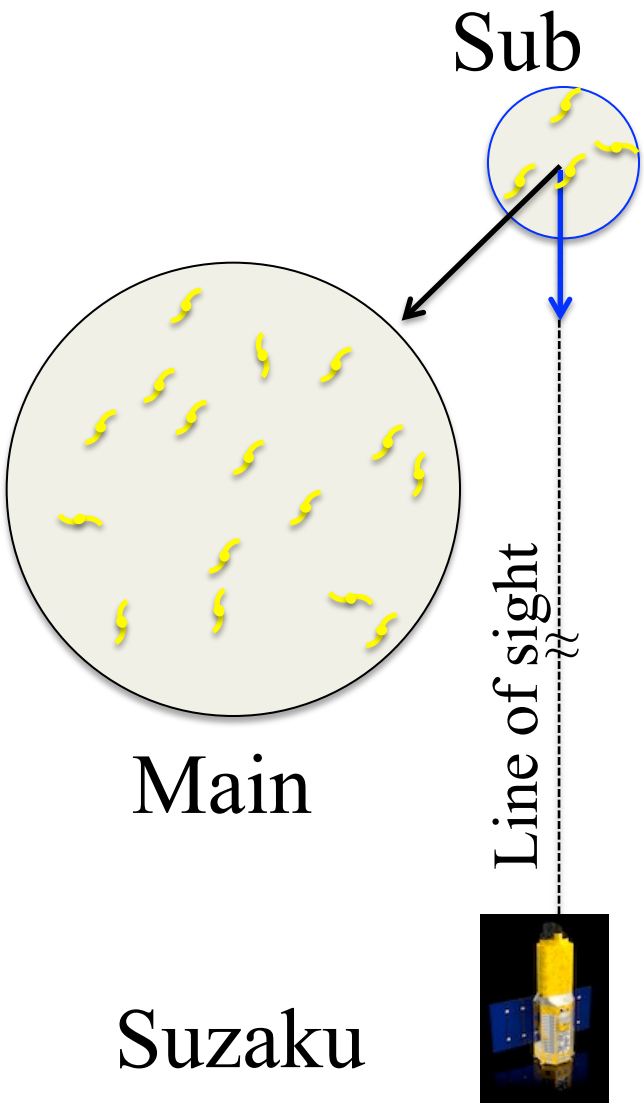
X-ray line center energies differs slight but significantly

Redshifts from X-ray and Optical



Summary of the A2256 Result

- Gas bulk motion of the sub component was found. The difference in the redshifts, and hence the radial velocities between the main and sub systems is 1500 ± 300 (sta.) ± 300 (sys.) km/s.
- This shift is only 0.5% in energy, but is well beyond the accuracy of the energy scale.
- The obtained X-ray redshifts are consistent with those in member galaxies.
- The most robust detection of the gas bulk motion.



Interpretations (see Tamura et al 2011 in detail)

(1) X-ray mass estimation

- Departs from hydrostatic equilibrium around the sub component.
- Need to consider to weight the total cluster mass. (No significant effect on the mas of the primary)

(2) A new method to study the gas dynamics.

- Complementary with X-ray imaging studies.

(3) Merger state in A2256

- Before the final collision

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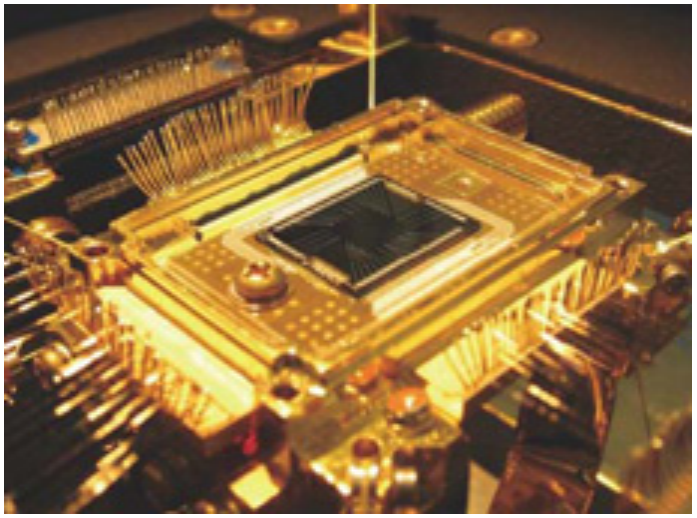
The ASTRO-H Team

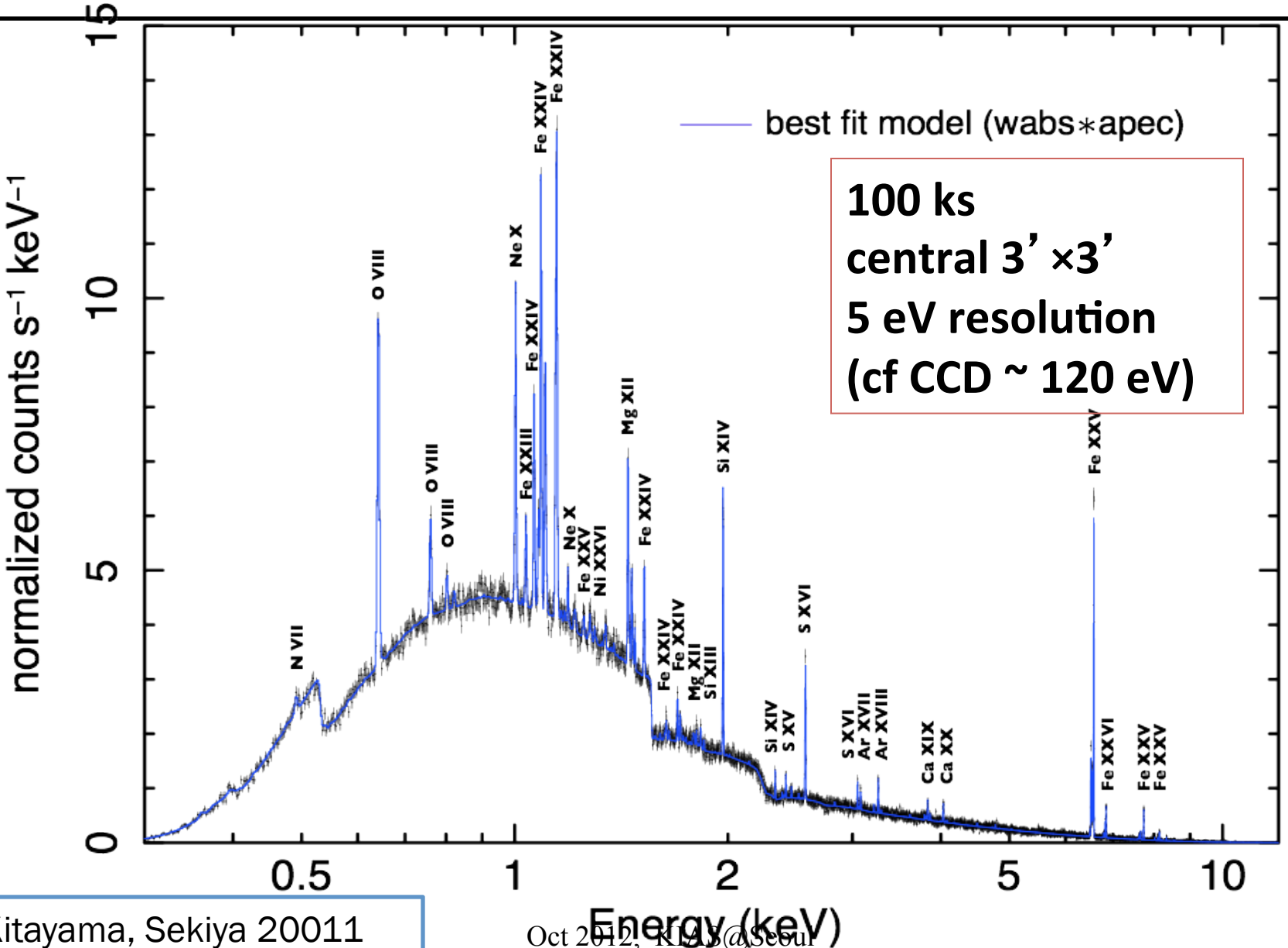
ASTRO-H, an International X-ray Observatory



Soft X-ray Spectrometer (SXS; microcalorimeter)

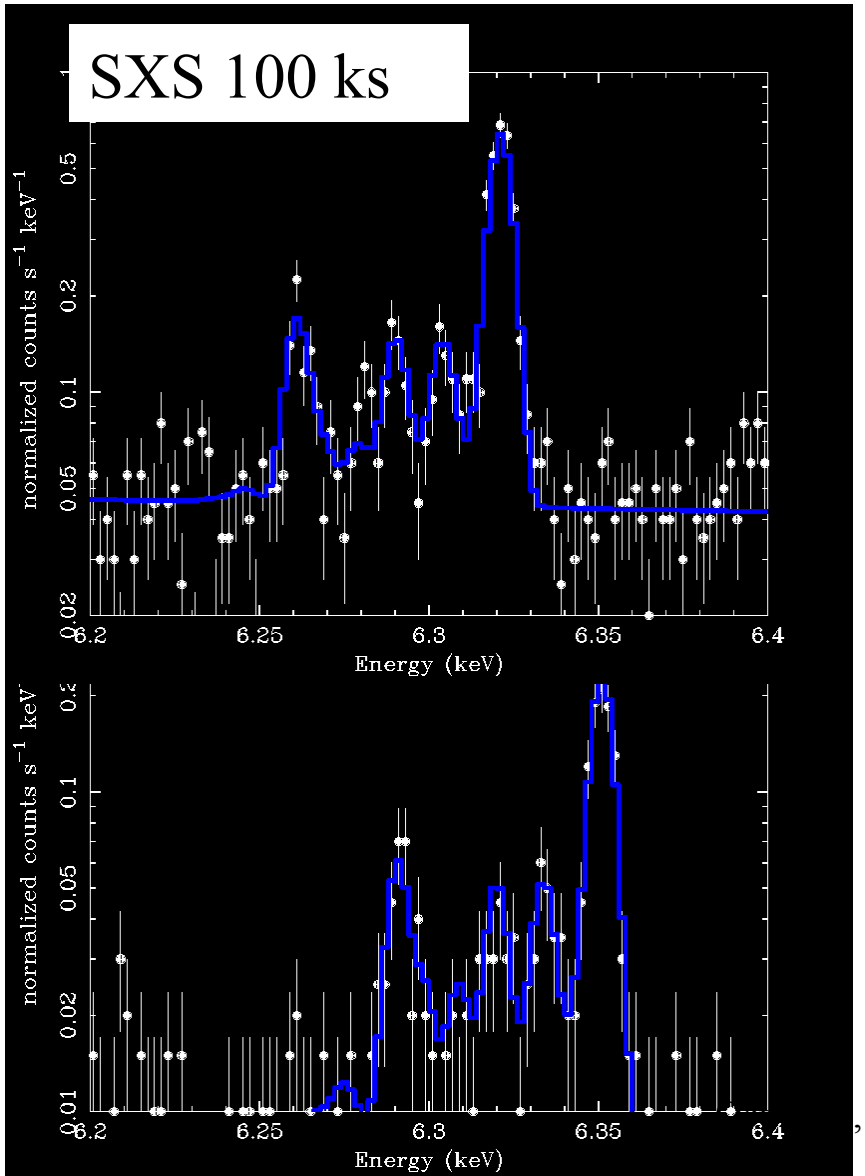
- To be launched in 2014 from Japan.
- SXS is a key instrument to reveal the large scale structure and its evolution of the Universe.
(check astro-h.isas.jaxa.jp)

Perseus simulated spectrum (wabs∗apec)



Kitayama, Sekiya 20011

ASTRO-H/SXS simulation the two components in A2256

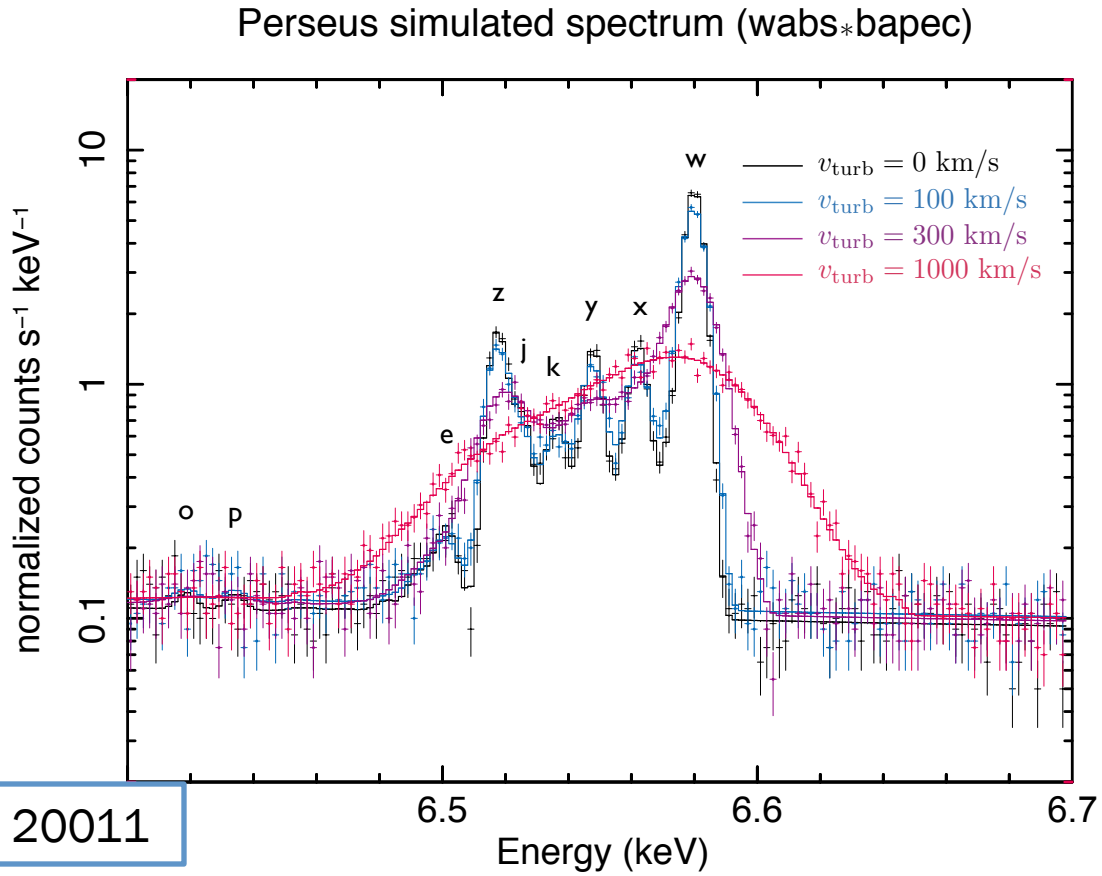


Using the SXS with an energy resolution better than 7eV, we could measure gas bulk motions in a fair number of X-ray bright clusters.

Note the Suzaku-observed energy shift is about 30 eV ~ 1500 km/s.

SXS simulation
The brightest cluster core: The Perseus

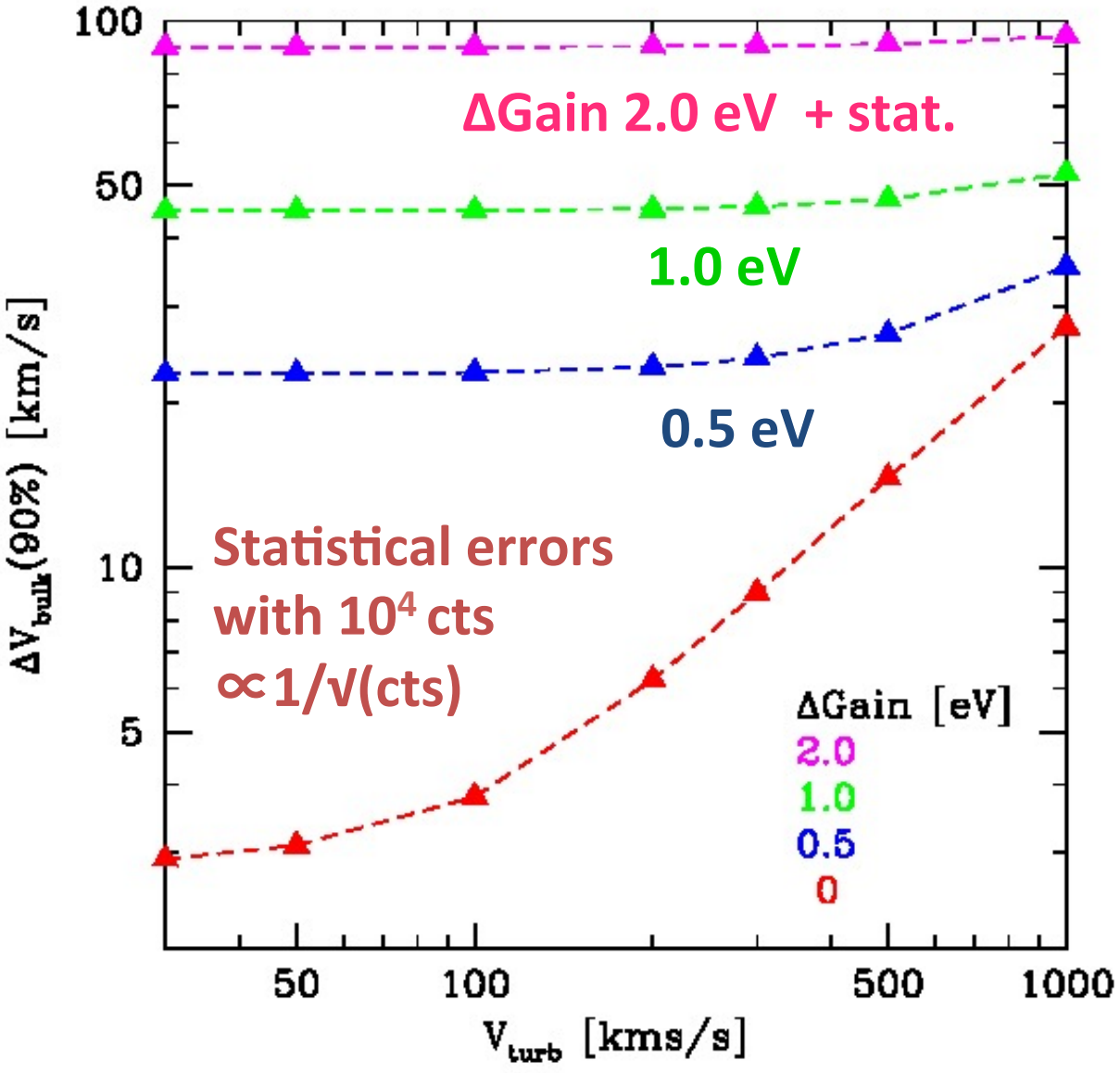
- Detect and locate the gas turbulence.
- Combined with hard X-ray imaging, gas dynamics, particle acceleration, shocks and non-thermal processes will be inves



Turbulent Velocity:
0 km/s
100 km/s
300 km/s
1000 km/s

Sekiya 20011

Perseus: Line shift & gain



Perseus
100ks, 3' ×3'
11,000 cts in He-like Fe

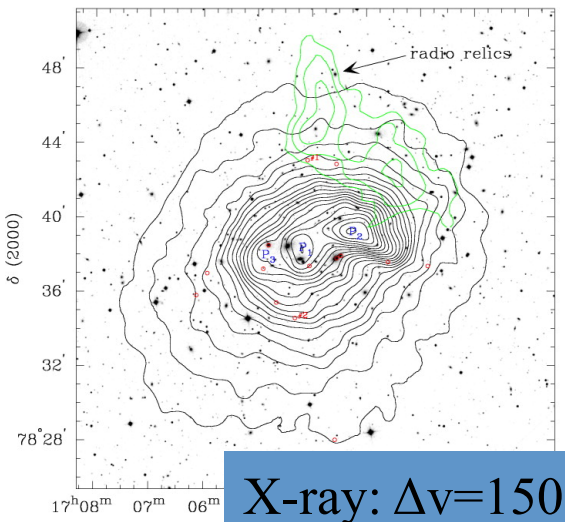
Gain errors (2.0 eV) dominate if cts >100 & V_{turb} < 300 km/s

1 eV= 45km/s @ 6.7keV

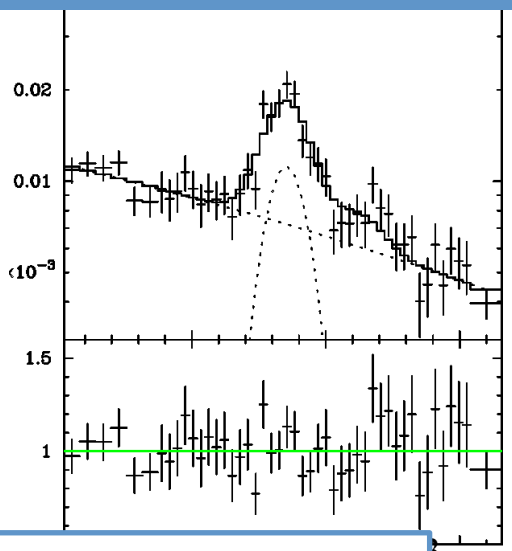
Kitayama, Sekiya, TT 2011

Summary

- X-ray Doppler mapping of the ICM is a next major step to study the cluster dynamics.
- Suzaku observation of the merging system A2256 demonstrated this.
- A significant shift of the redshift of the sub component was detected. The gas moves is pair with galaxies.
- We are searching for bulk motions in other Suzaku clusters.
- Bulk motions and turbulences will be measured by the ASTRO-H (SXS) more robustly and in a systematic way.



X-ray: $\Delta v = 1500 \pm 300$ (sta.) ± 300(sys.) km s^{-1}.



See Tamura et al. 2011, PASJ