Suzaku Measurements of Gas Bulk Motions in a Galaxy Cluster

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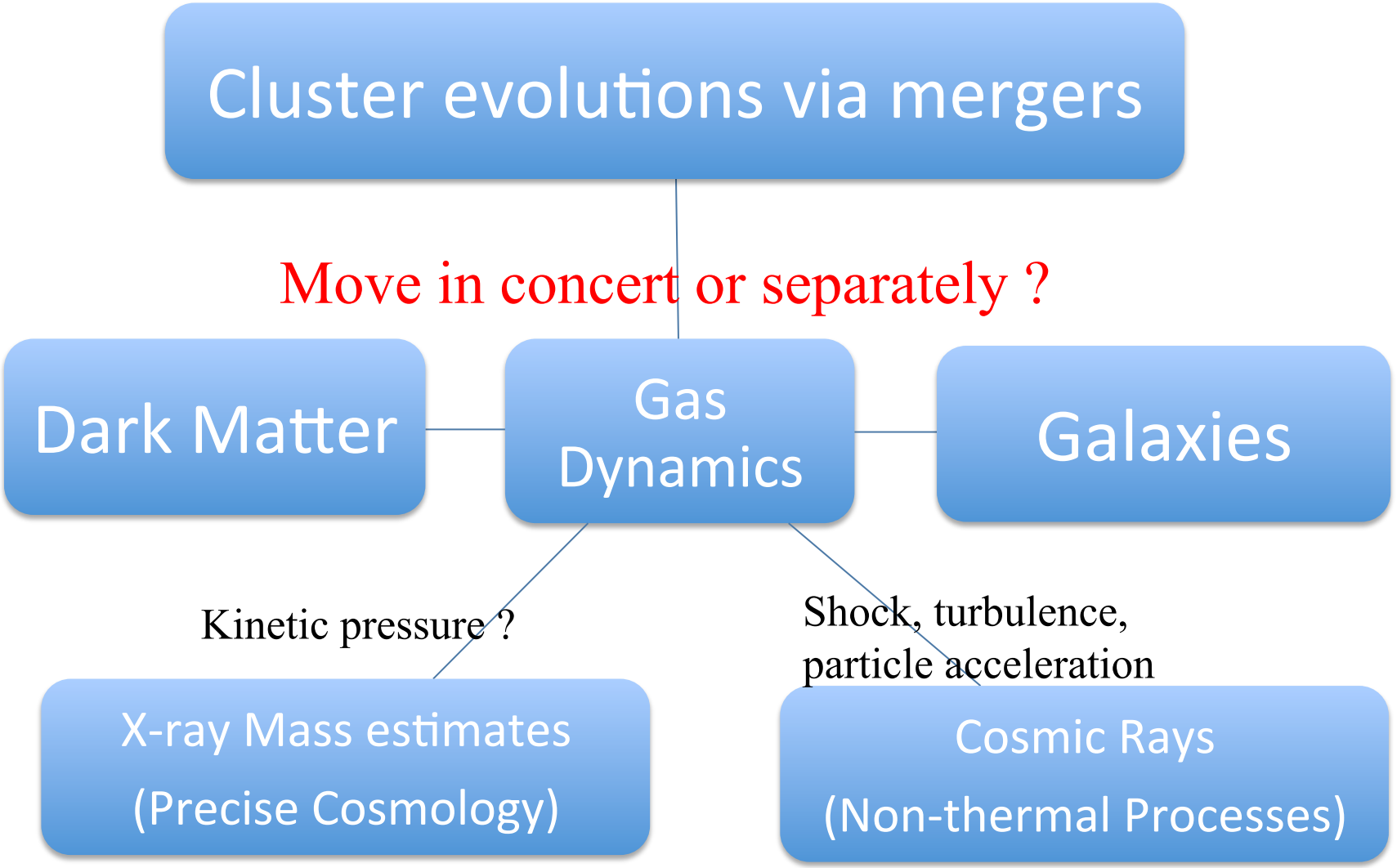
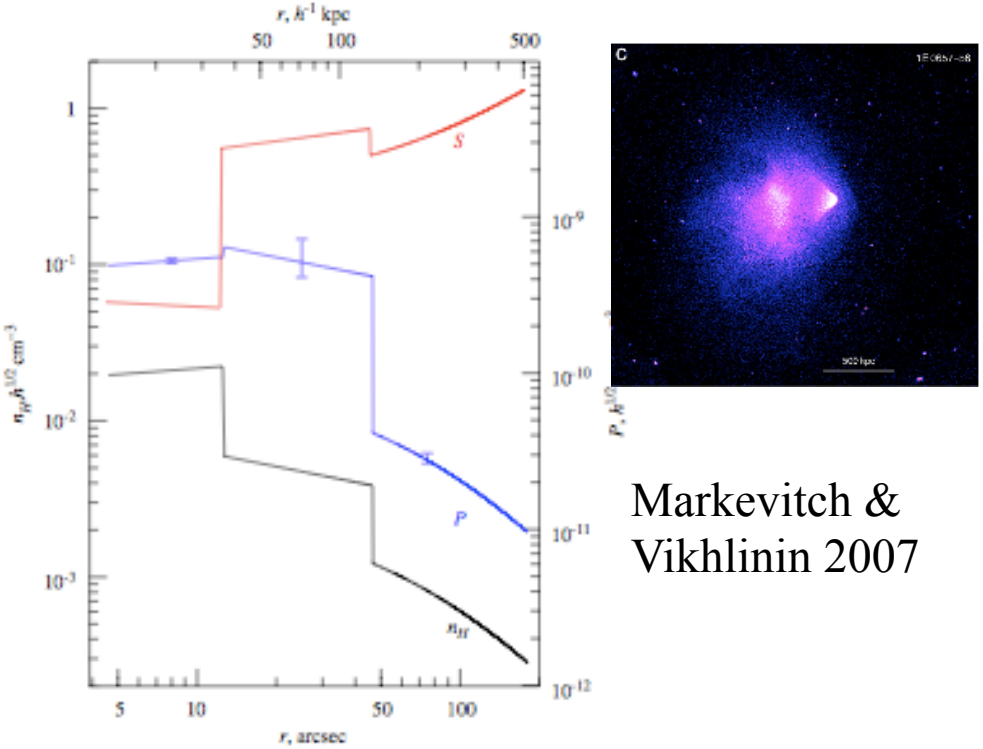
Motivations



How to measure Dynamical motion

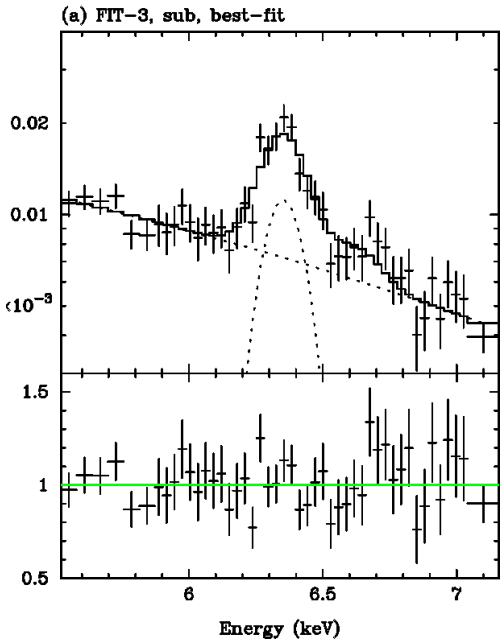
(1) X-ray imaging have shown cluster dynamics in the plane of the sky.



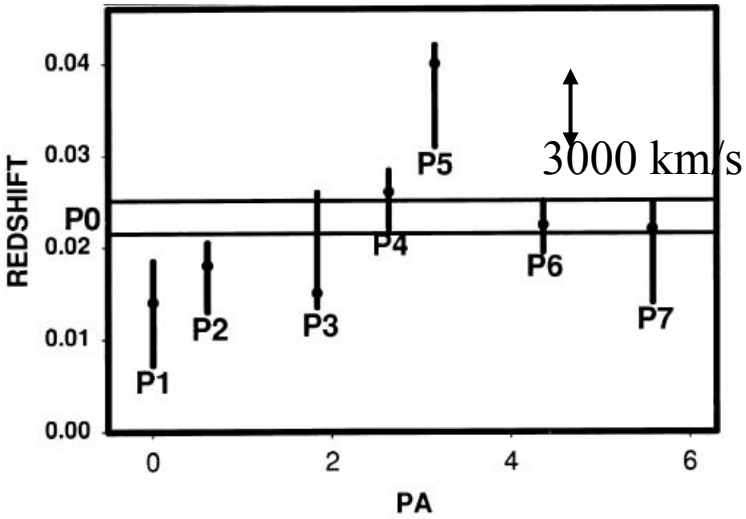
Markevitch & Vikhlinin 2007

(2) Doppler Mapping of X-ray lines

- Goals for future missions



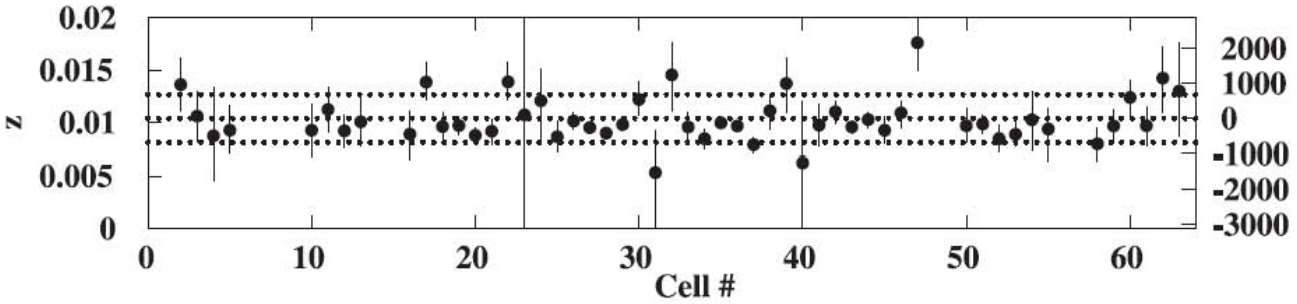
Previous Attempts

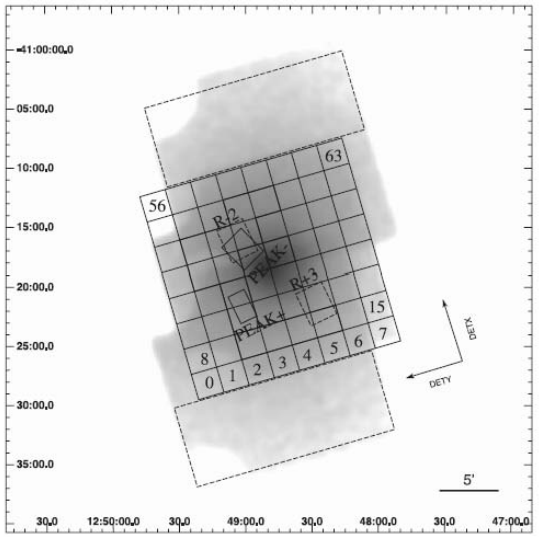


ASCA

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





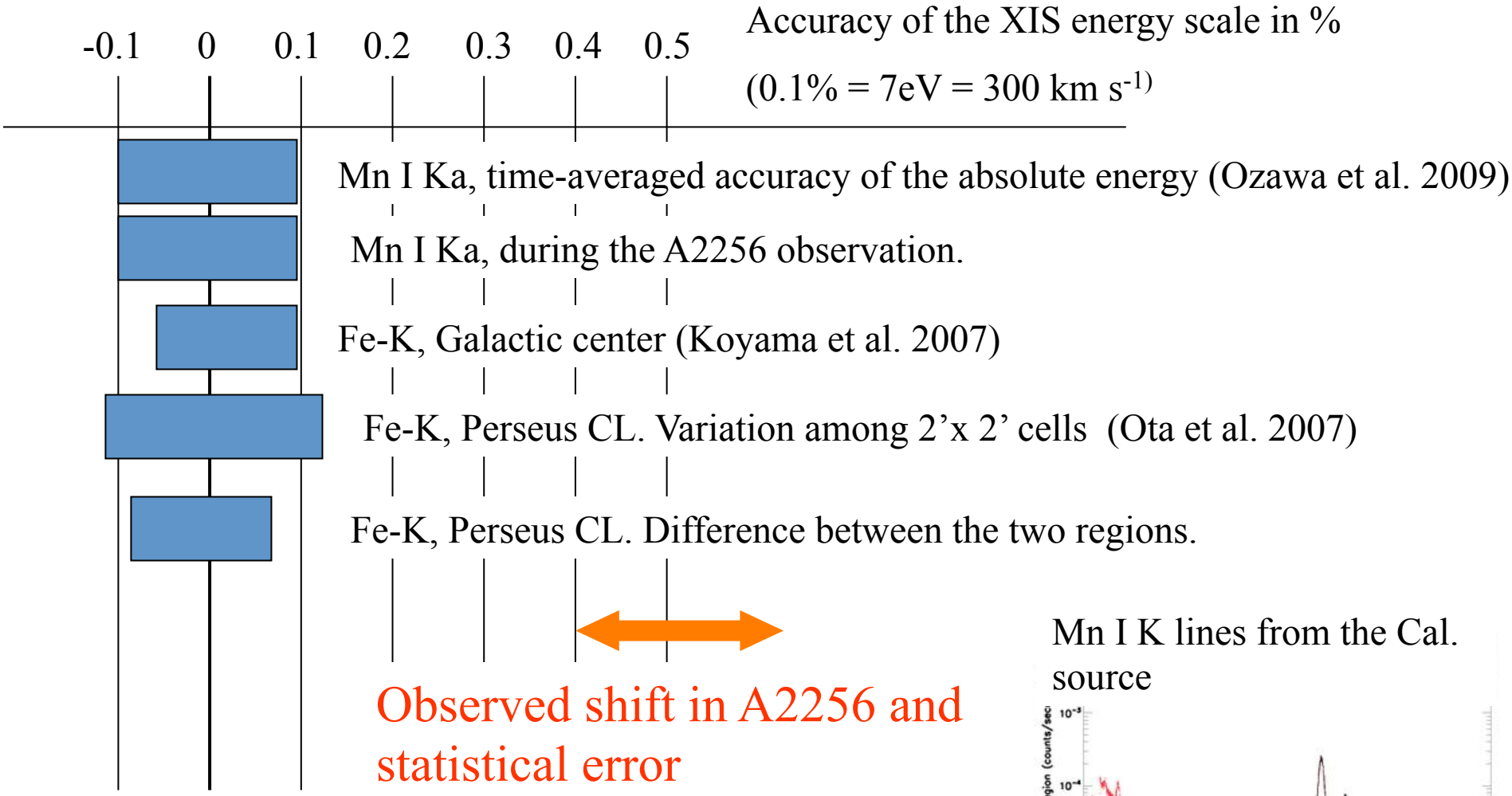
Suzaku Limits

- Centaurus: $\Delta v < 1400$ km/s (Ota et al. 2007)

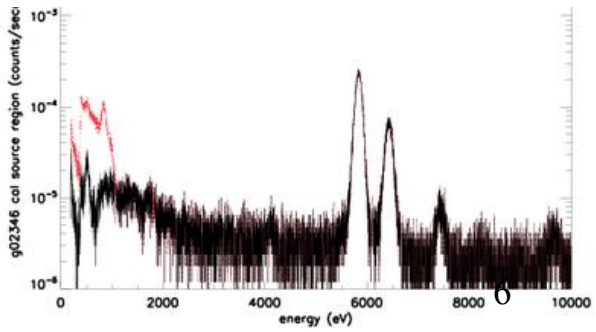
Velocity shift vs. Energy Resolution

Velocity (km/s)	E/ΔE	Shift @ Fe-K line
300	1000	0.1 % = 7 eV
1000	300	0.3 % = 20 eV
CCD energy resolution (FWHM)	60	120 eV

Suzaku XIS energy gain calibration

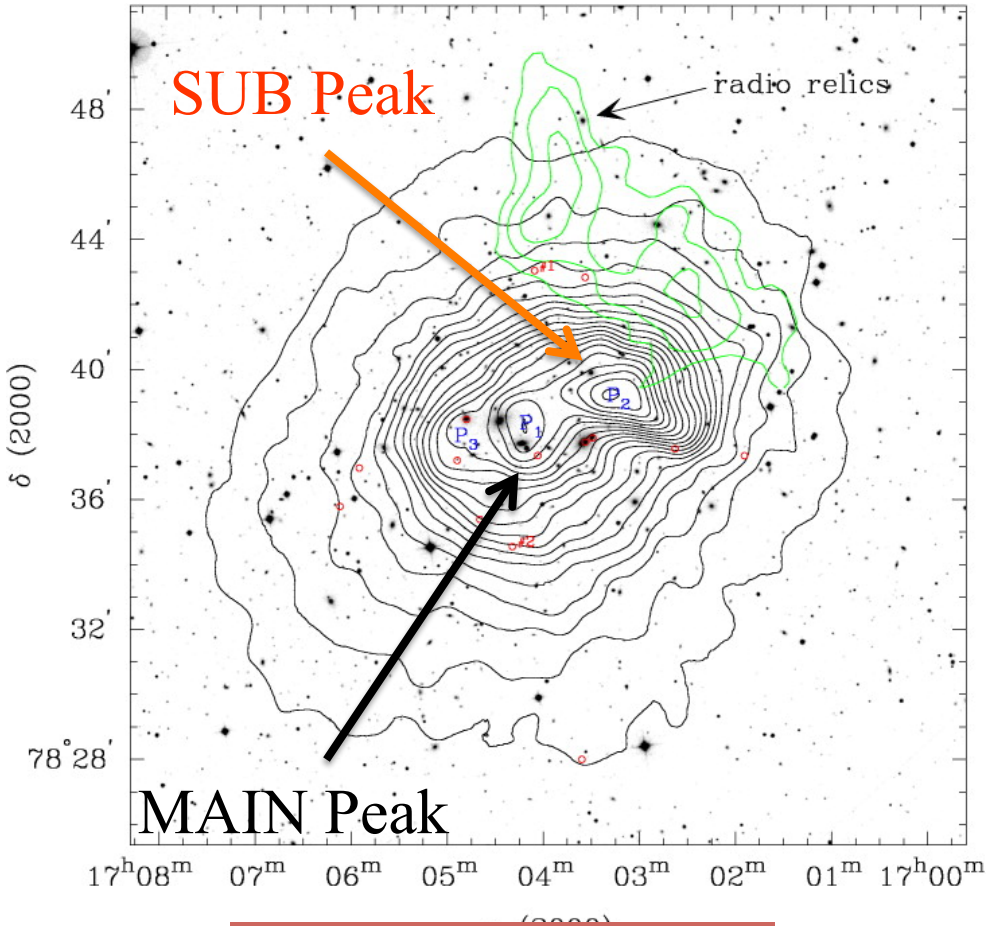


Mn I K lines from the Cal. source

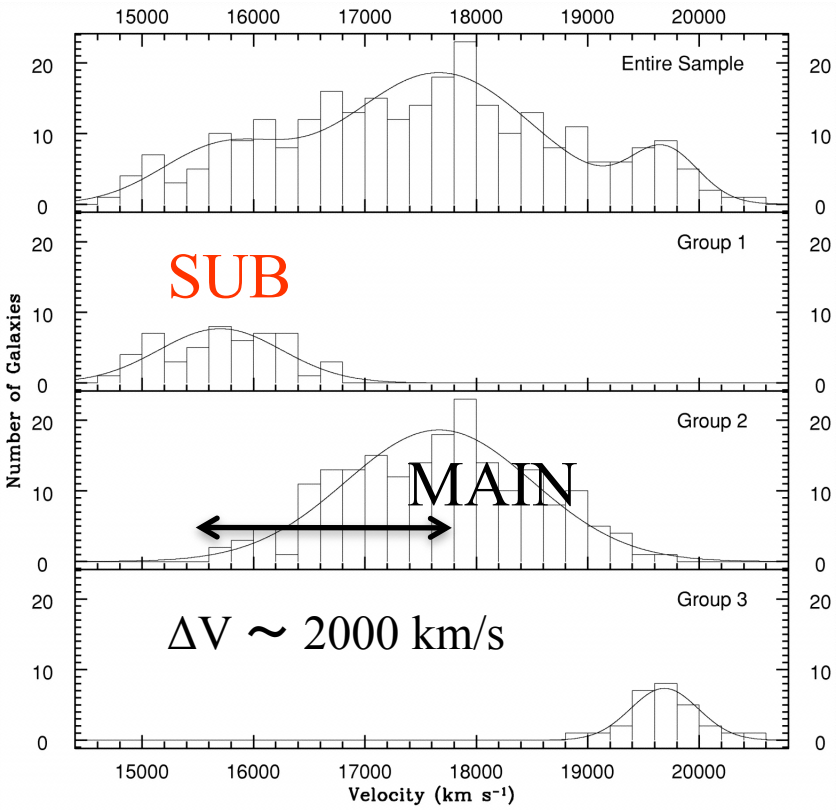


Good calibration is a key

A2256, X-ray bright, double peaked merging cluster



Sun et al. 2002 (Chandra)

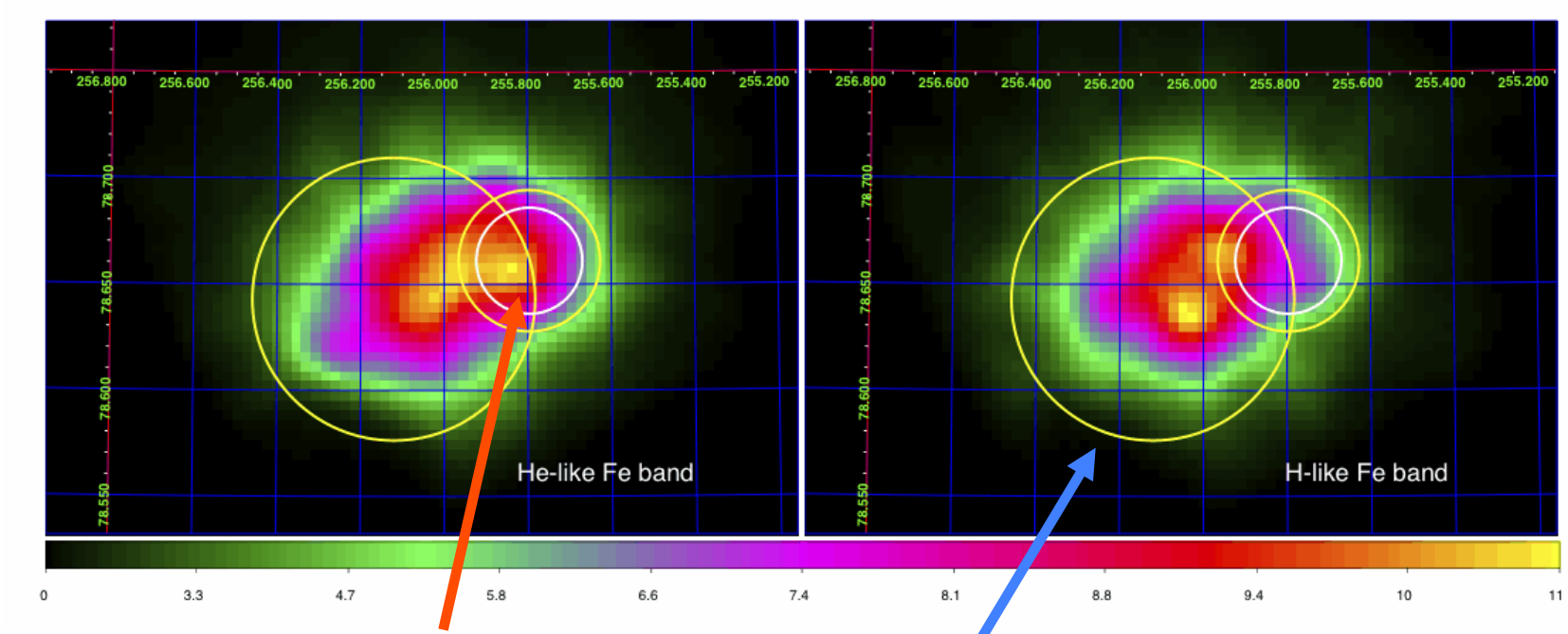


Berrington et al. 2002
(galaxy radial velocities)

Suzaku Fe-line Image of A2256 (1)

He-like Fe band

H-like Fe band

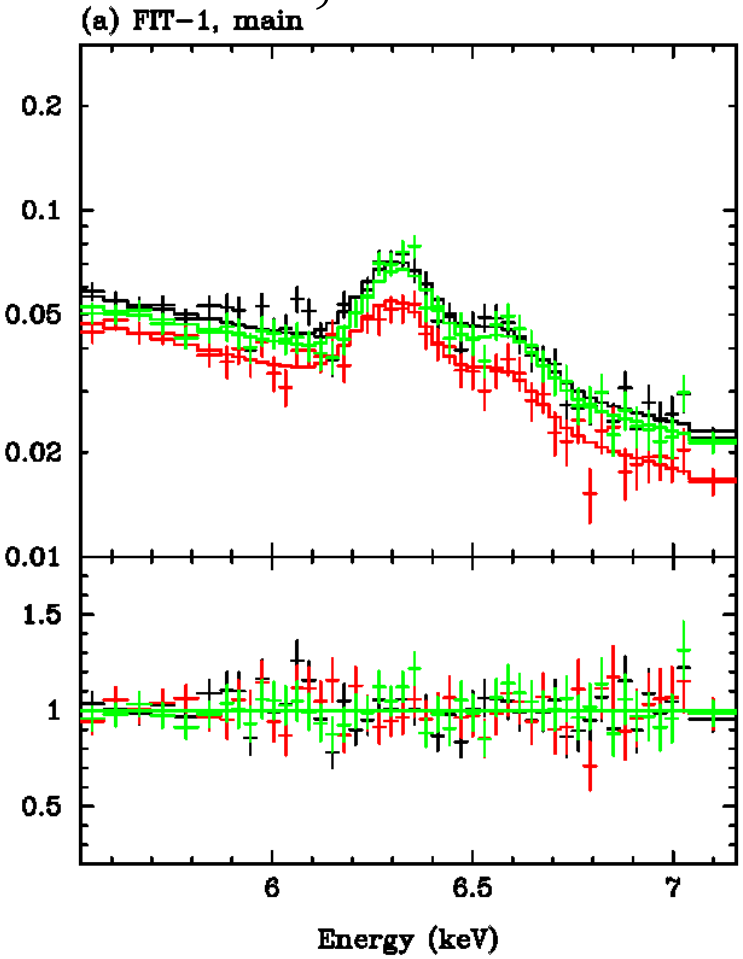


Sub, cooler

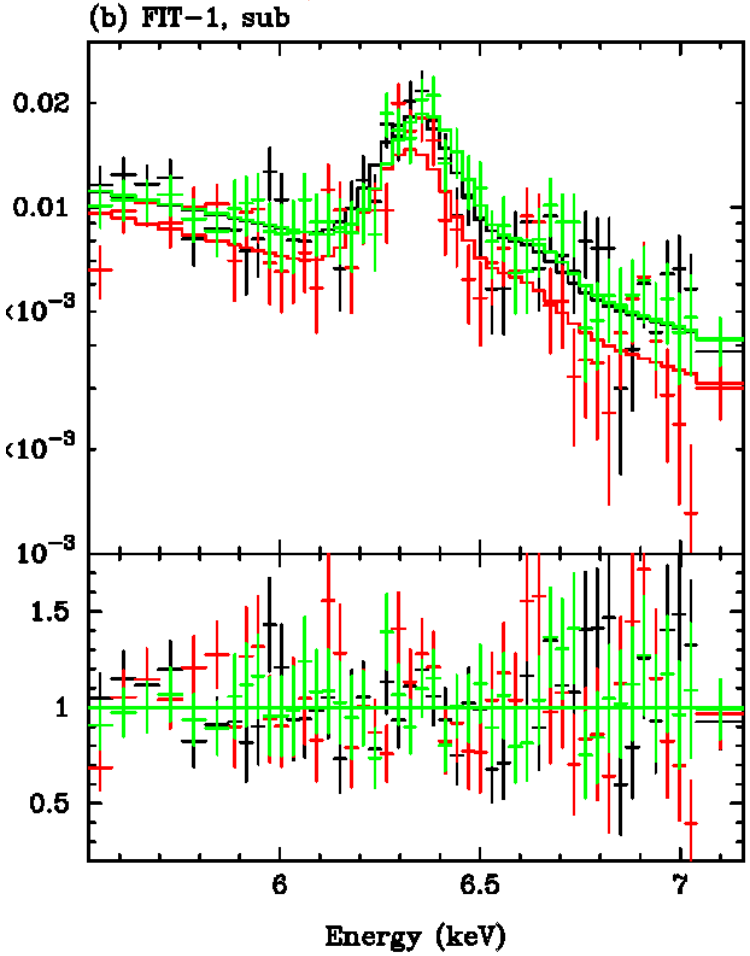
Main

Suzaku Results on A2256 (2)

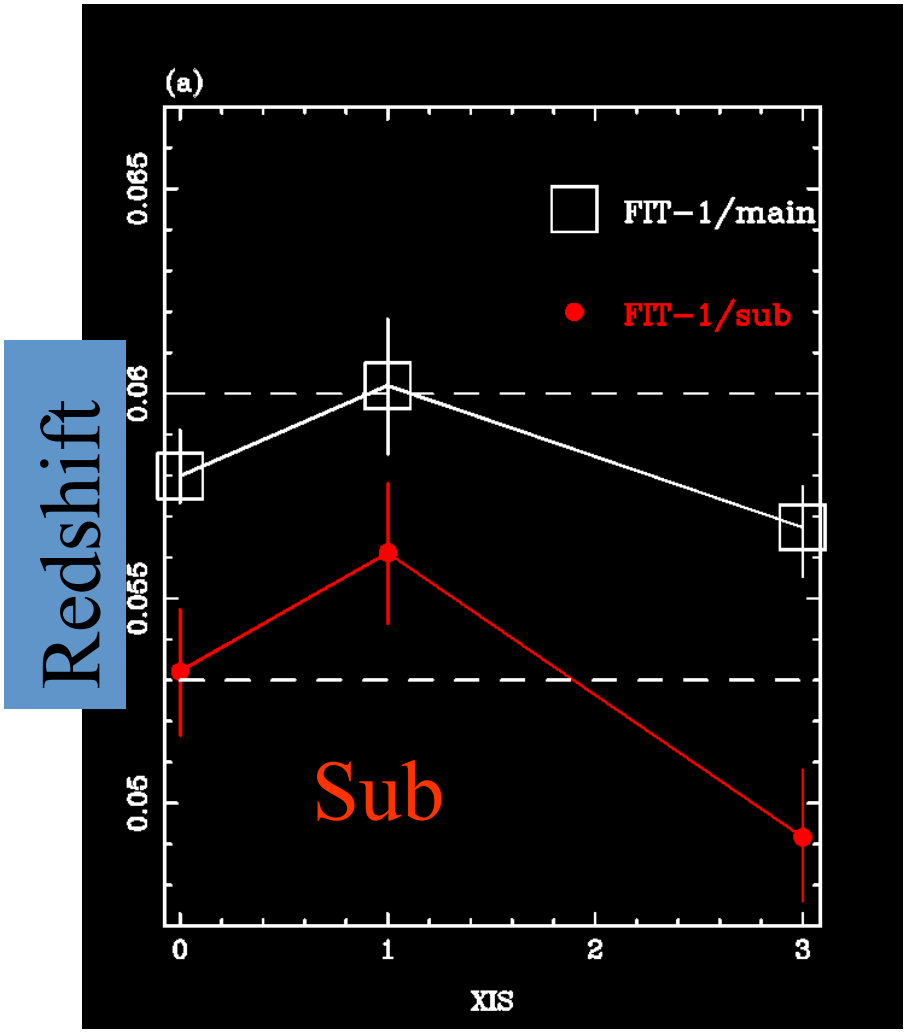
Main, 7.1 keV

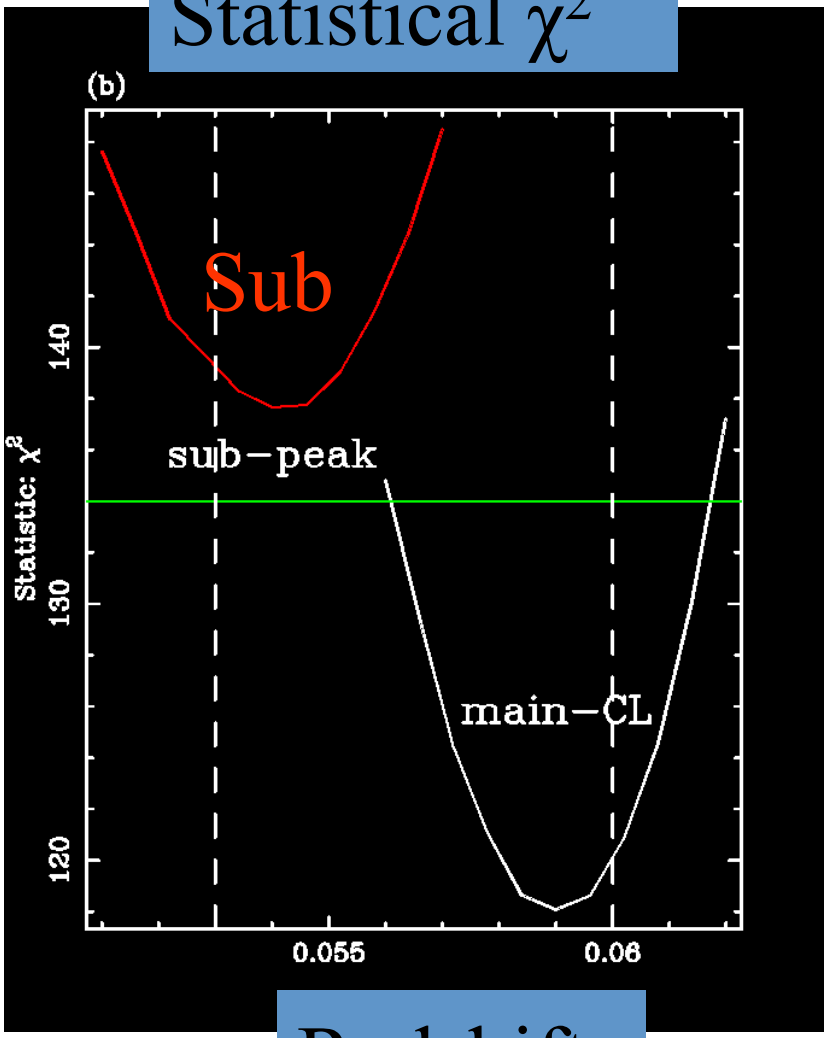


Sub, 5.0 keV



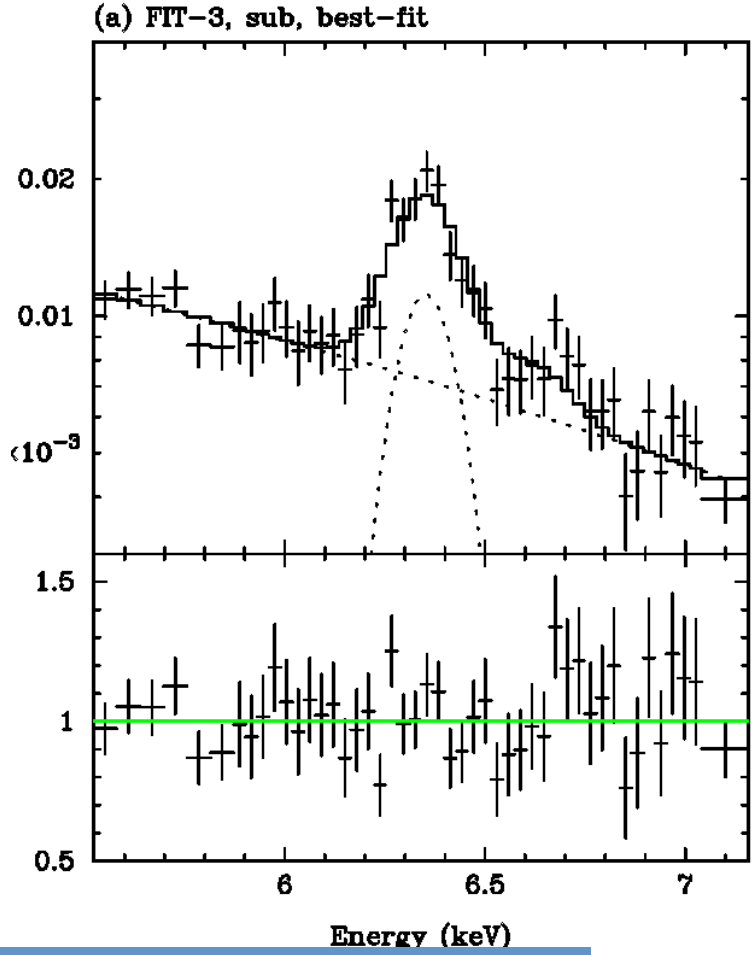
Redshifts from X-ray and Optical





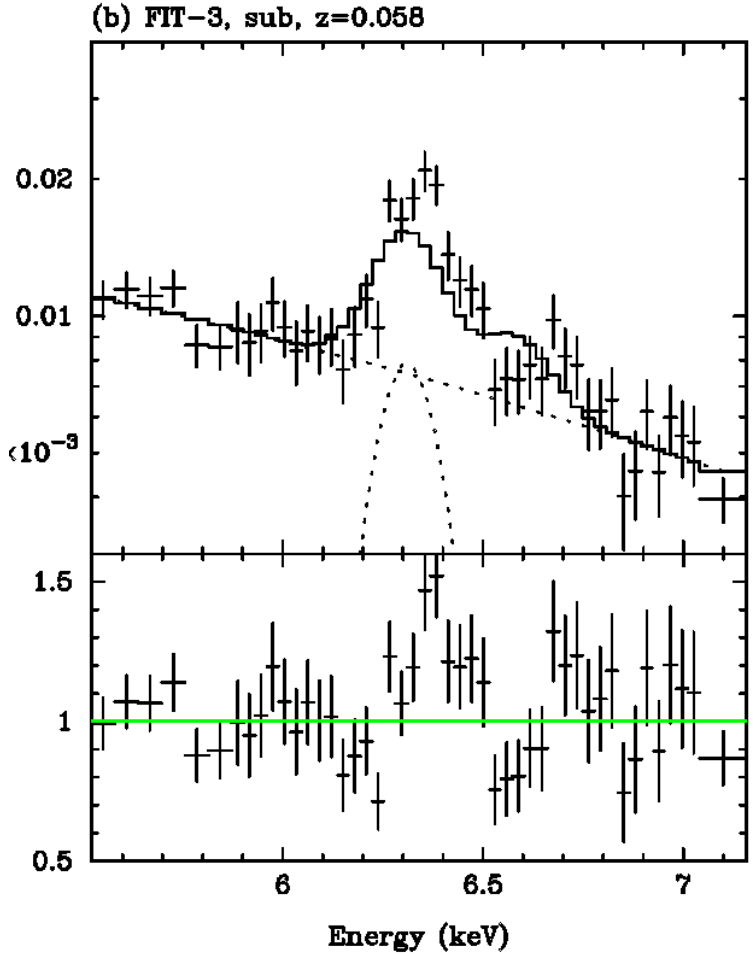
Sub Region Spectra

Best fit redshift



X^2/d.o.f. = 40.4/42

Δv fixed to 0



X^2/d.o.f. = 80.8/43

Interpretations

(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

Discussion : Dynamics of A2256
(1) The X-ray mass estimation

* The determined radial velocity, Vr ~1500 km/s, gives an lower limit of V = Vr/sinα, this velocity corresponds to a Mach number $M > 1.4$. α(the angle between the motion and the plane of the sky)

* Around the sub component, the gas kinematic pressure (or energy) can be $1.4^2 \sim 2$ x larger than the thermal one.

→ the gas departs from hydrostatic equilibrium.

* does this motion affect the estimation of the mass of the primary cluster ?

→ depends on the physical separation between the two components.

* In the case of A2256, the two are not likely too closely connected to disturb the hydrostatic condition around the primary.

* However, to weight the total mass within the larger volume including the sub component we should consider not only the mass of the sub itself but also the dynamical pressure associated with the relative motion.

(2) Methods to measure ICM

◆ Shock/Cold front

Assumptions:

(1) adiabatic flow

(2) Velocity in the plane of the sky

→ rare case

Requires high spatial resolution

Shock in 1E~0657-56, M~3±0.4 (Markevitch et al. 2002).

Cold front in A3667, M~1±0.2 (Vikhlinin et al. 2001).

◆ X-ray Doppler shift

Direct measurement of the radial velocity

Require high energy spectral resolution

In A2256, M>1.4

Combination:

These two are complementary.

If applied to a merging system simultaneously,

→ a direct measurement of three dimensional motion

(3) Merger state in A2256

Suzaku Measurement: Vr = 1500 km/s

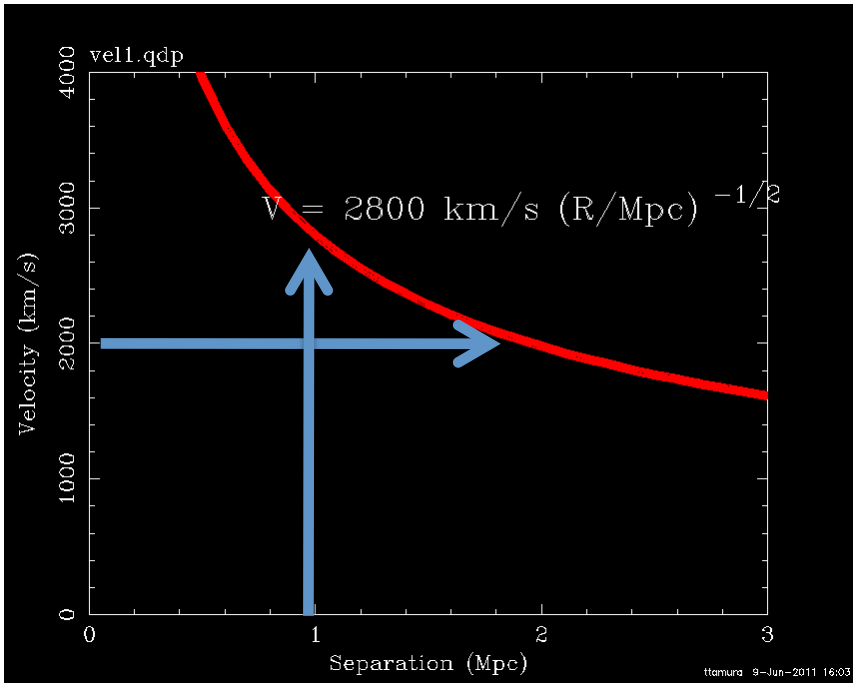
Cold front condition (Sun et al. 2002):

Vsky ~ 1500 km/s

→ V ~ 2000 km/s

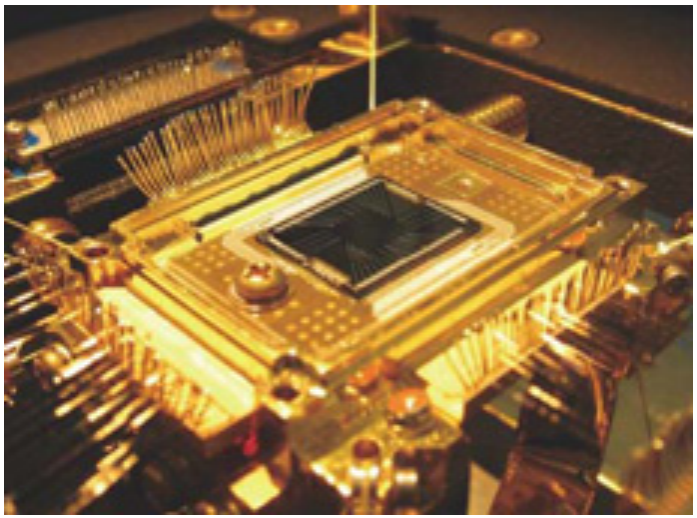
Assume the two system start from rest.

→ $V \sim (2GM_{tot}/R)^{1/2}$, $M_{tot} \sim 8x10_{14}\ M_{sun}$



Time to the collision at R=1 Mpc
→ (2-1 Mpc)/ V ~ 0.4 Gy
"Before the final collision",
Consistent with no strong disturbance in the X-ray structure

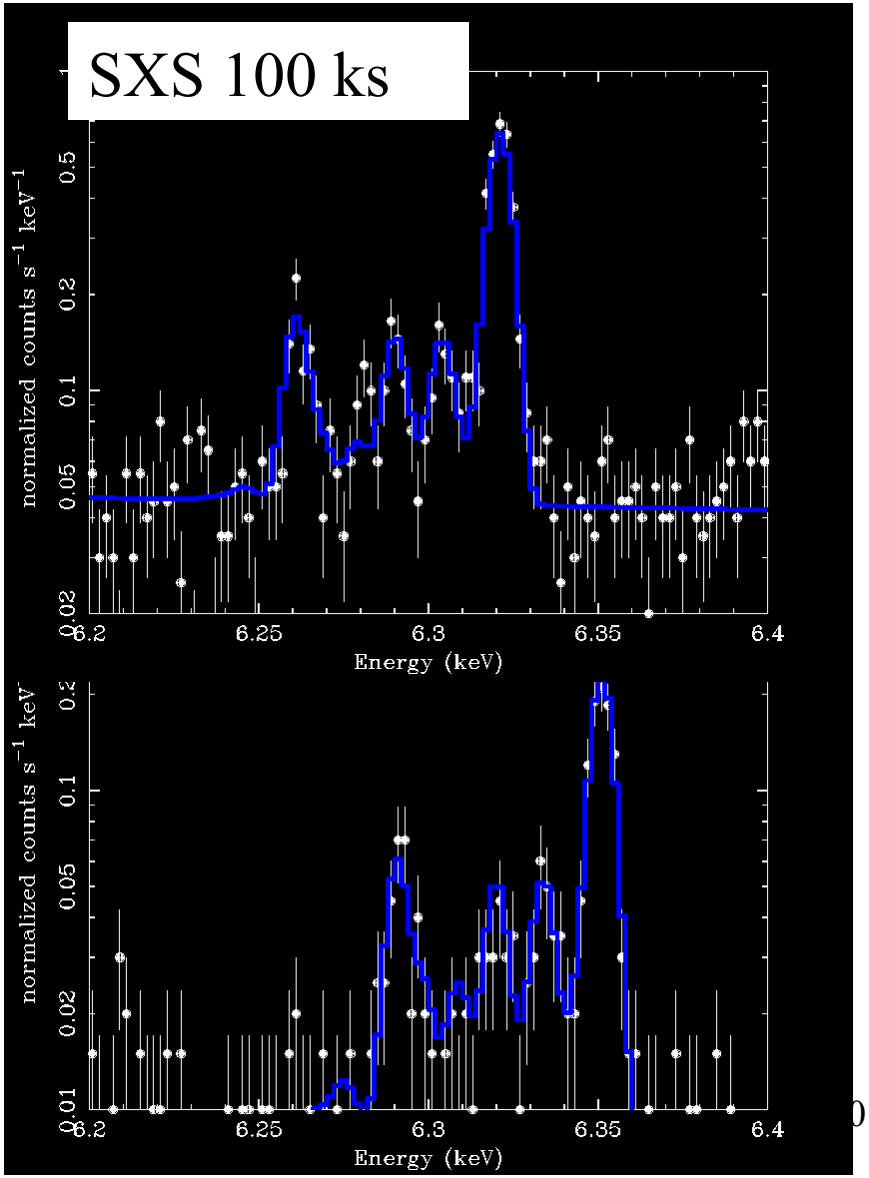
ASTRO-H, an International X-ray Observatory



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)

ASTRO-H/SXS simulation (1)
the two components in A2256



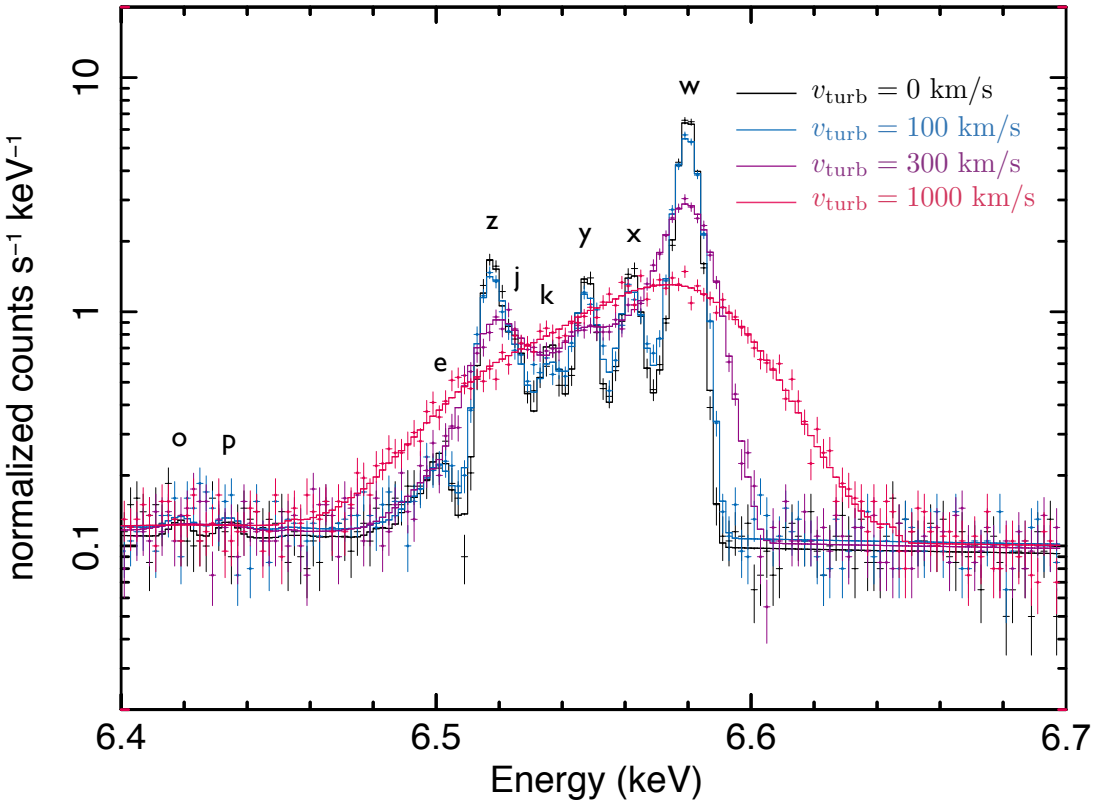
Using the SXS with an energy resolution better than 7eV, we could measure gas bulk motions in a fair number of X-ray bright clusters.

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

SXS simulation (2)
– The brightest cluster core: The Perseus –

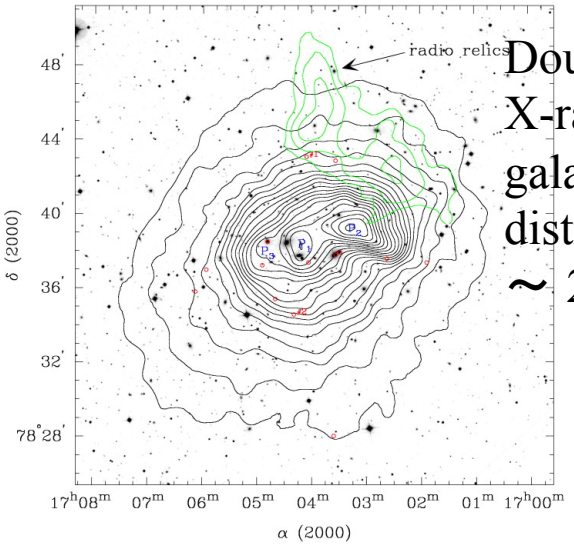
- Detect and locate the gas turbulence.
- Combined with hard X-ray imaging, gas dynamics, particle acceleration, shocks and non-thermal processes will be investigated.

Perseus simulated spectrum (wabs*bapec)

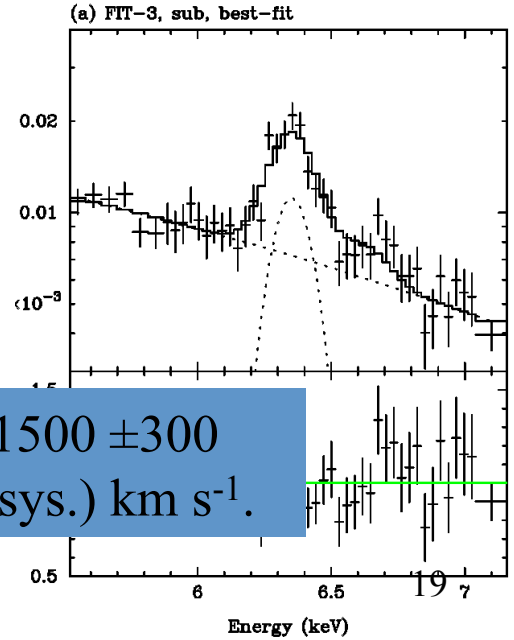


Summary

- 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.
- Bulk motions and turbulences will be measured by the ASTRO-H (SXS) more robustly and in a systematic way.



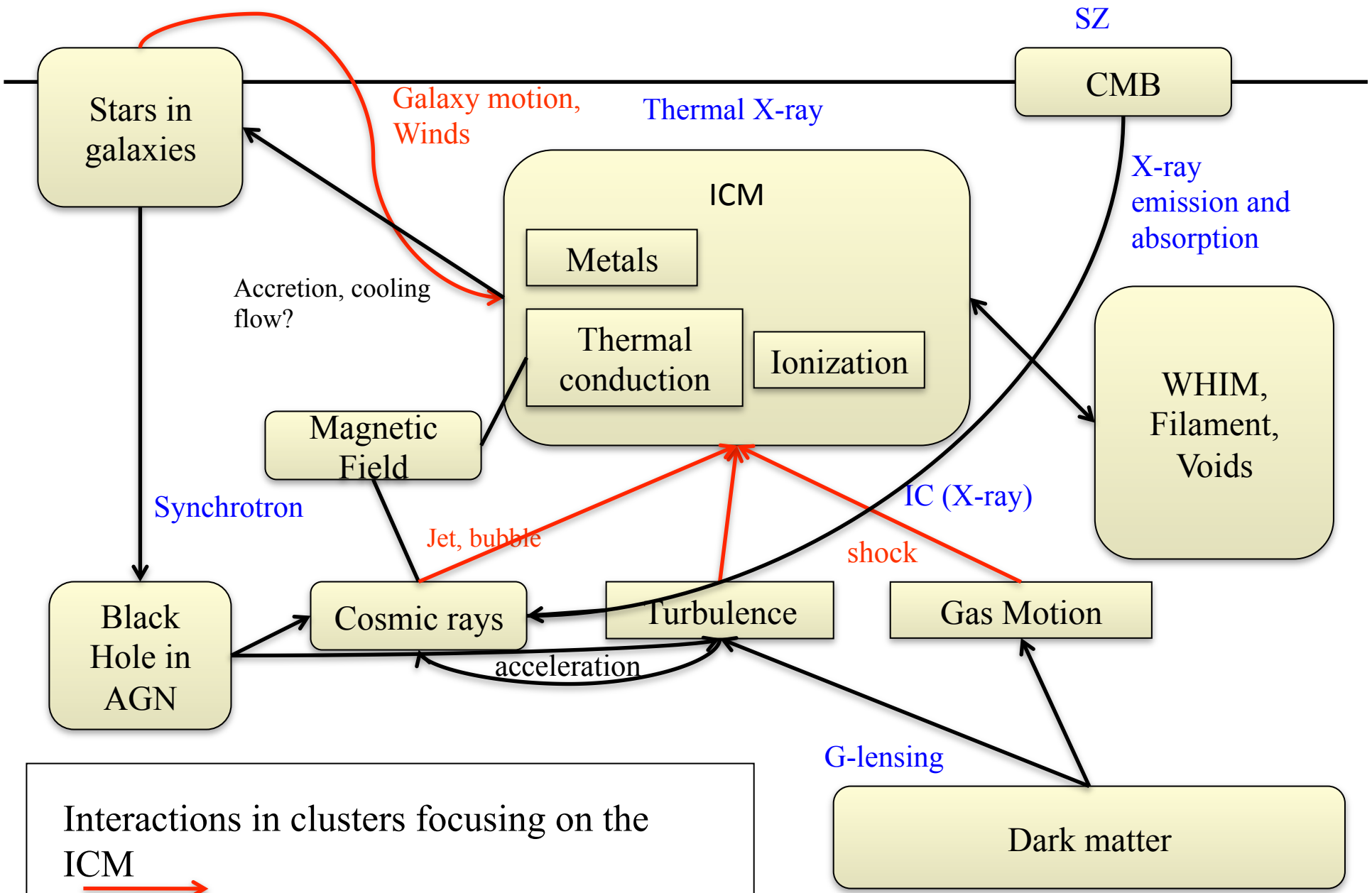
Double peaked in X-ray image and galaxy velocity distribution Δv is ~ 2000 km s^{-1}.



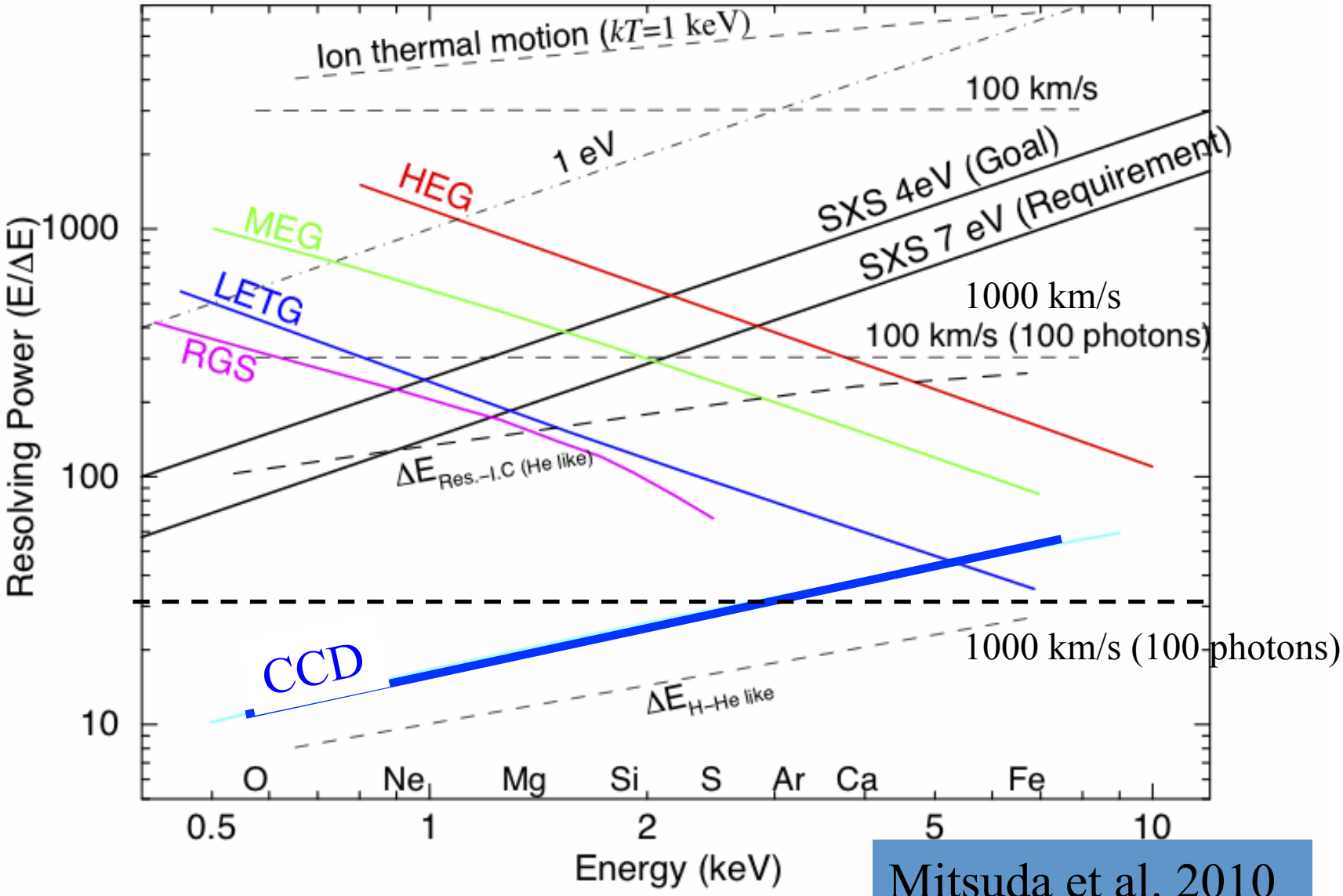
X-ray: Δv=1500 ±300 (sta.) ±300(sys.) km s^{-1}.

See Tamura et al. 2011, PASJ, arXiv:1104.2667

Supplements


SZ
CMB
Stars in galaxies
Galaxy motion, Winds
Thermal X-ray
X-ray emission and absorption
ICM
Metals
Thermal conduction
Ionization
Accretion, cooling flow?
Magnetic Field
WHIM, Filament, Voids
Synchrotron
Jet, bubble
IC (X-ray)
shock
Black Hole in AGN
Cosmic rays
Turbulence
Gas Motion
acceleration
G-lensing
Dark matter
Interactions in clusters focusing on the ICM
heating
Observation
Interaction

Spectral Resolution and Features



Mitsuda et al. 2010

Suzaku, ASTRO-H, and IXO Spectrometers

		Suzaku XIS	ASTRO-H SXS (best estimate)	IXO XMS
Effective Area	cm^2 @ 7 keV	460	220	6000
FOV		18' x 18'	3' x 3'	5' x 5 '
Spatial Resolution ,	HPD	120"	90"	5"
Energy Resolution	E/ΔE @ 7 keV	50	1000	3000