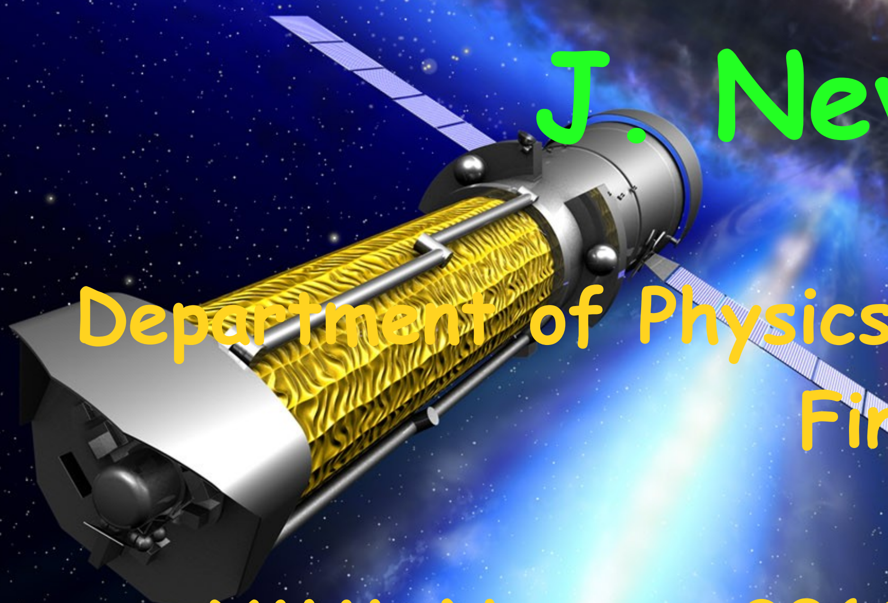
Bulk motion measurements in clusters of galaxies with ATHENA



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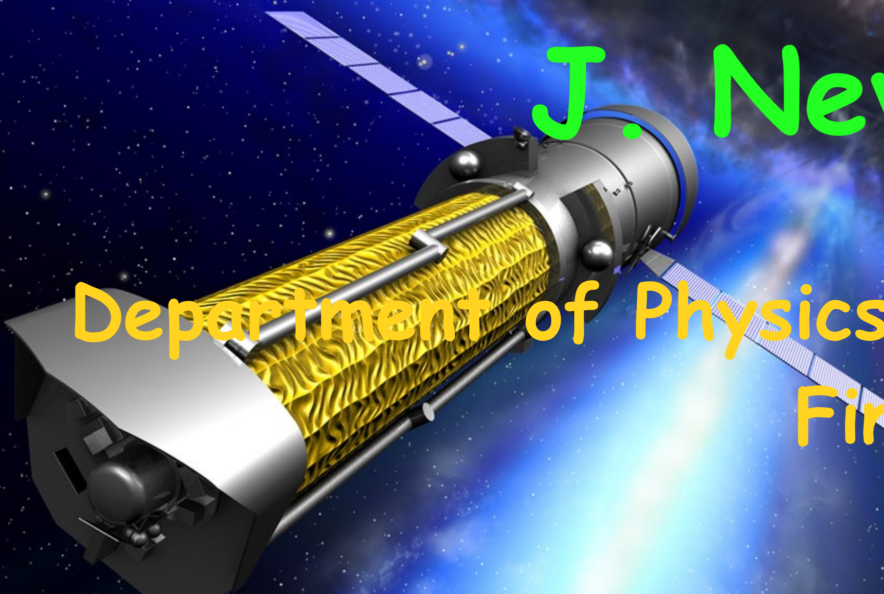
XMM-Newton 2012 Science Workshop
May 21-23, 2012

Bulk motion measurements in clusters of galaxies with ATHENA-like mission



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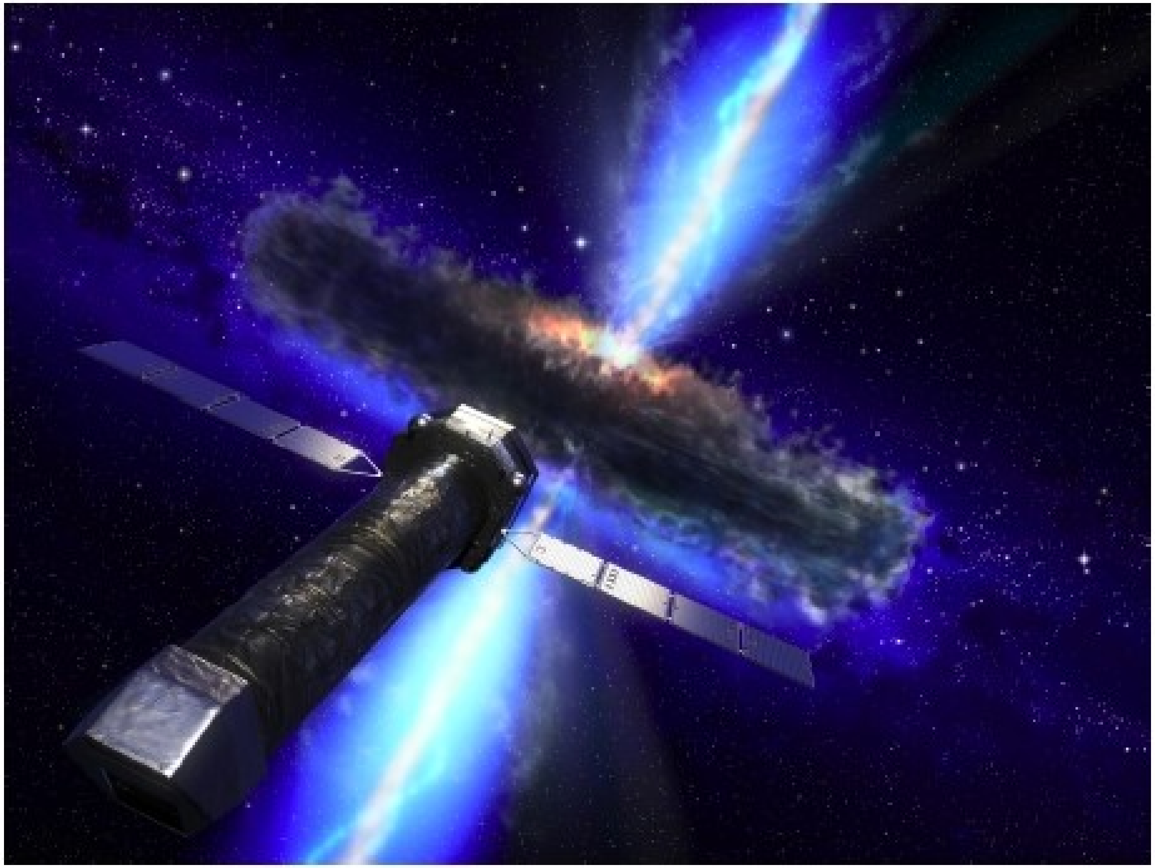
1) ATHENA

- ATHENA (Advanced Telescope for High ENergy Astrophysics), (ex-XEUS, ex-IXO) was one of three L-class (large) missions being considered by European Space Agency in the Cosmic Vision 2015-2025 plan.
- In May 2012 the Jupiter mission Jupiter Icy Moons Explorer (JUICE), (formerly Laplace) was chosen
- The technology development of ATHENA will continue
- I will present here some expected bulk motion measurements of clusters of galaxies with a future satellite approximating the capabilities of ATHENA
- The instrument responses used are from the ATHENA Yellow Book

ESA/SRE(2011)17
December 2011

Athena

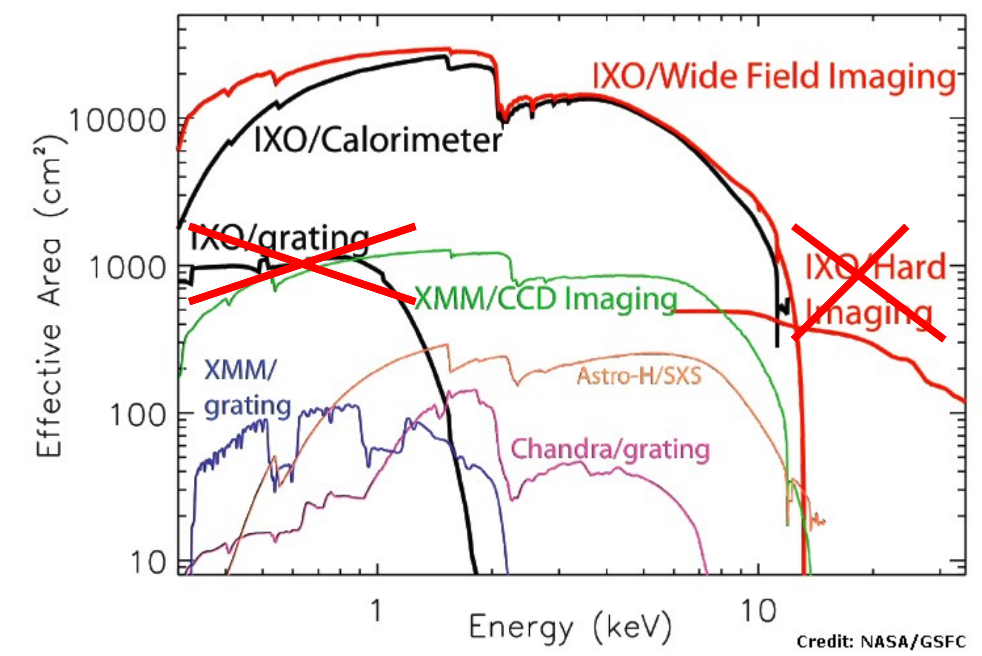
The extremes of the Universe: from black holes to large-scale structure



Assessment Study Report

Focal instruments

- Wide Field Imager
- dE = 150 eV @6 keV
- FOV: 25x25 arcmin

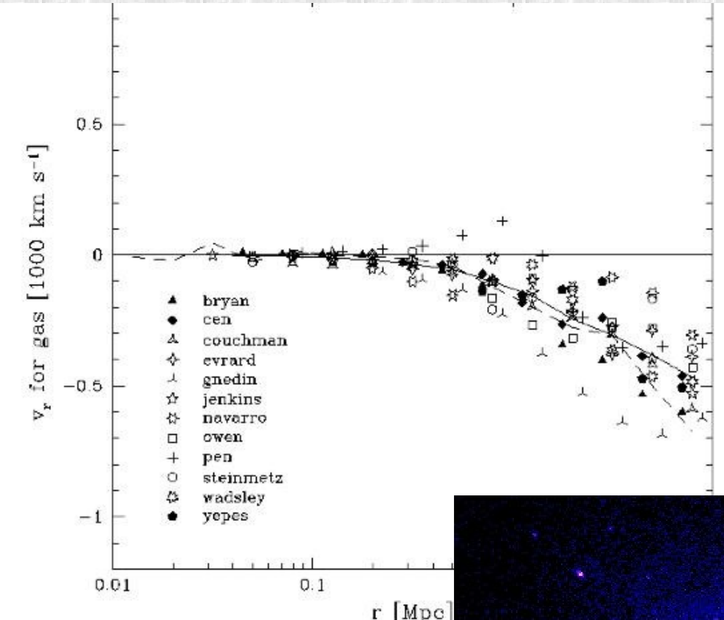


- X-ray Microcalorimeter spectrometer XMS
- dE = 3 eV @6 keV
- Similar energy resolution as in current Chandra and XMM high resolution spectrometers, but ~100-1000 times the effective area at 0.5 keV
- Extends to 10 keV (Fe XXV Kα !)
- FOV: 2x2 arcmin, spatial resolution 10"
- Spatially resolved high spectral resolution X-ray spectroscopy

2) Bulk motions in clusters of galaxies

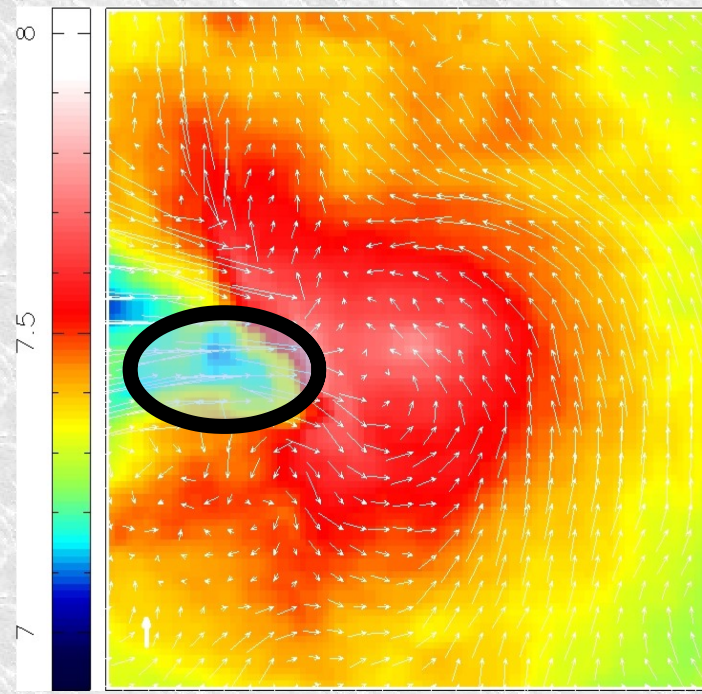
ACCRETION FLOWS ~1000 km s^{-1}

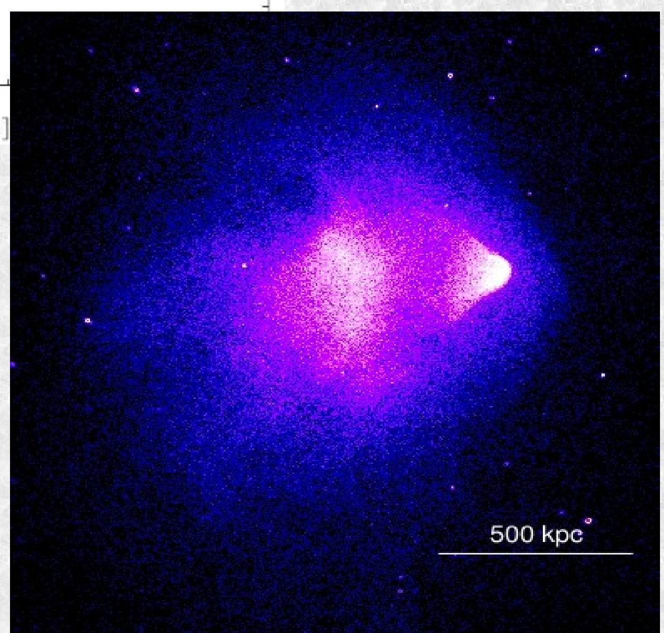
Frenk et al., 1999, ApJ, 525, 554



MINOR MERGERS ~ 1000 km s^{-1}

Nagai et al., 2003, ApJ, 587, 524





RESIDUAL ~ 100 km s^{-1}

MAJOR MERGERS several 1000 km s^{-1}

Markevitch et al., 2002, ApJ, 567, L27

Doppler shift

- Mergers happen in all directions
- Most sharp shock features are hidden due to projection
- Most of the lines-of-sight towards merging subunits contain a significant radial velocity component
- This can potentially be measured with the doppler shift of the X-ray emission lines

Doppler shift

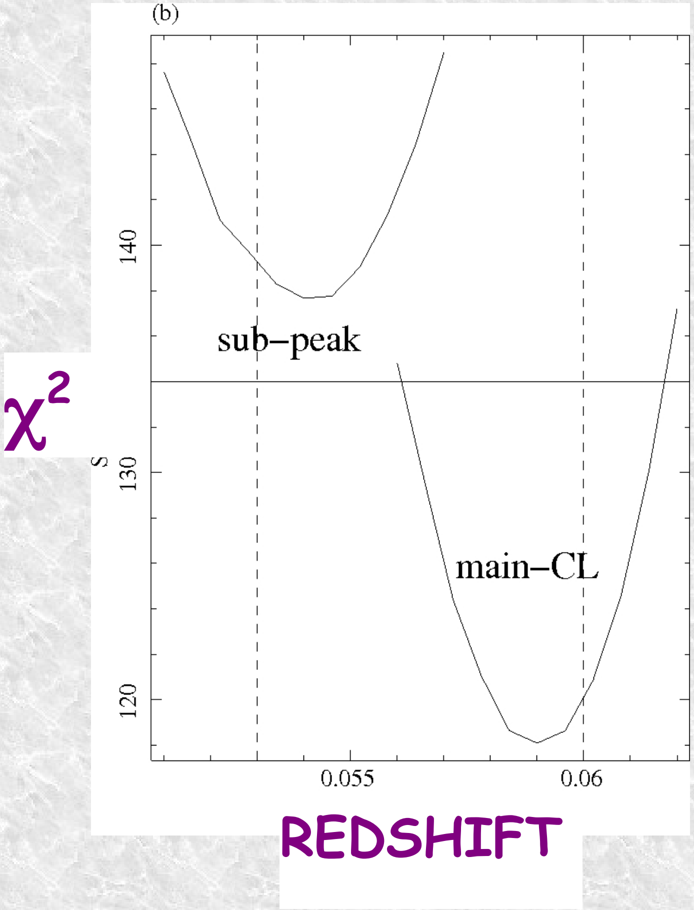
- LOS velocity of 100 - 1000 km s^{-1} means 2-20 eV shift in the emission line centroid energy at 6 keV (Fe XXV and XXVI Kα line)
- The currently most powerful X-ray instruments at 6 keV (XMM-Newton/EPIC, Chandra/ACIS and SUZAKU/XIS CCDs) have relatively low energy resolution ~100 eV
- Gaussian centroid can still be determined better than within 100 eV, depending on the gain calibration accuracy
- EPIC/MOS gain accuracy ~ 5 eV = 250 km s^{-1}
- Relative motions can be measured to better accuracy

Observational constraints

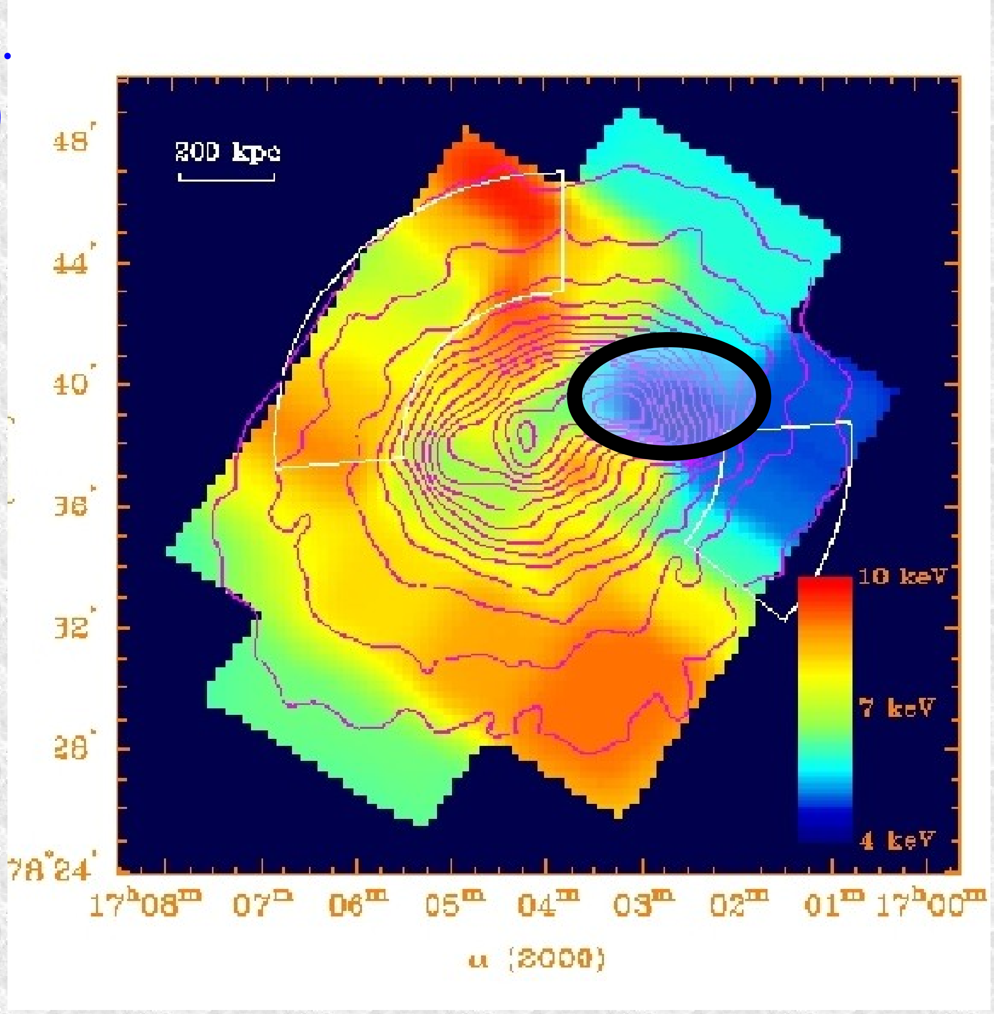
- Suzaku has been used to place upper limits for the bulk motion velocities at ~1000 km s^{-1} level in several clusters:
  - A2319 (Sugawara et al., 2009, PASJ, 61, 1293)
  - Centaurus (Ota et al., PASJ, 59, 351)
  - AWM7 (Sato et al., 2008, PASJ, 60, 333)

Nearby minor merger A2256

- First significant detection in A2256: Suzaku radial velocity difference btw. main cluster and secondary peak of 1500∓300 ∓300 km s^{-1} (Tamura et al. 2011, PASJ in press, arXiv:1104.2667)

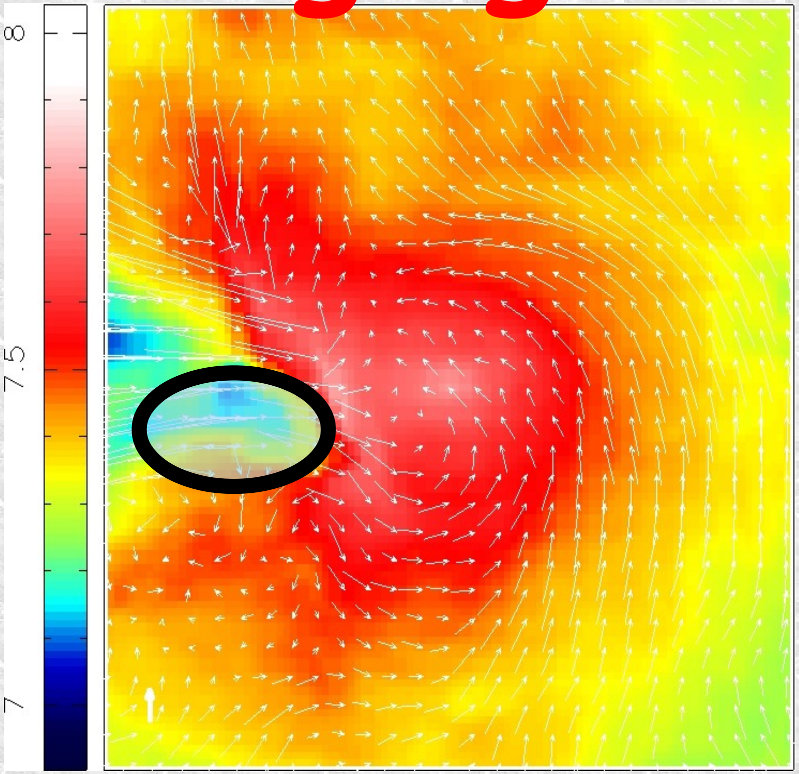


- Chandra T map shows the colder subclump (Sun et al., 2002, ApJ 565, 867)



How could ATHENA-like mission improve the situation?

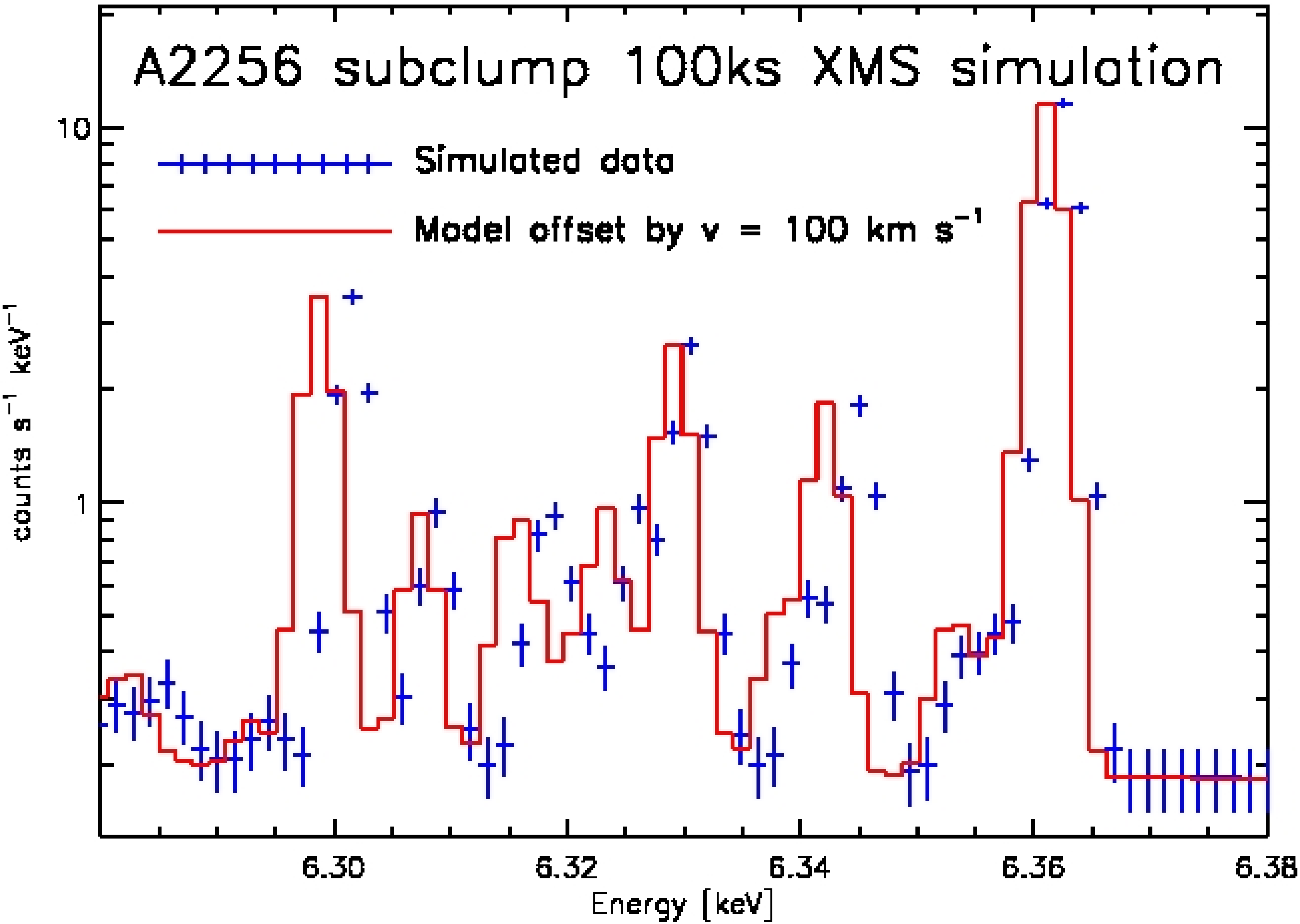
Can ATHENA make a breakthrough by <u>mapping</u> the velocity field in the merging subclumps in nearby minor mergers?



A2256 with ATHENA/XMS

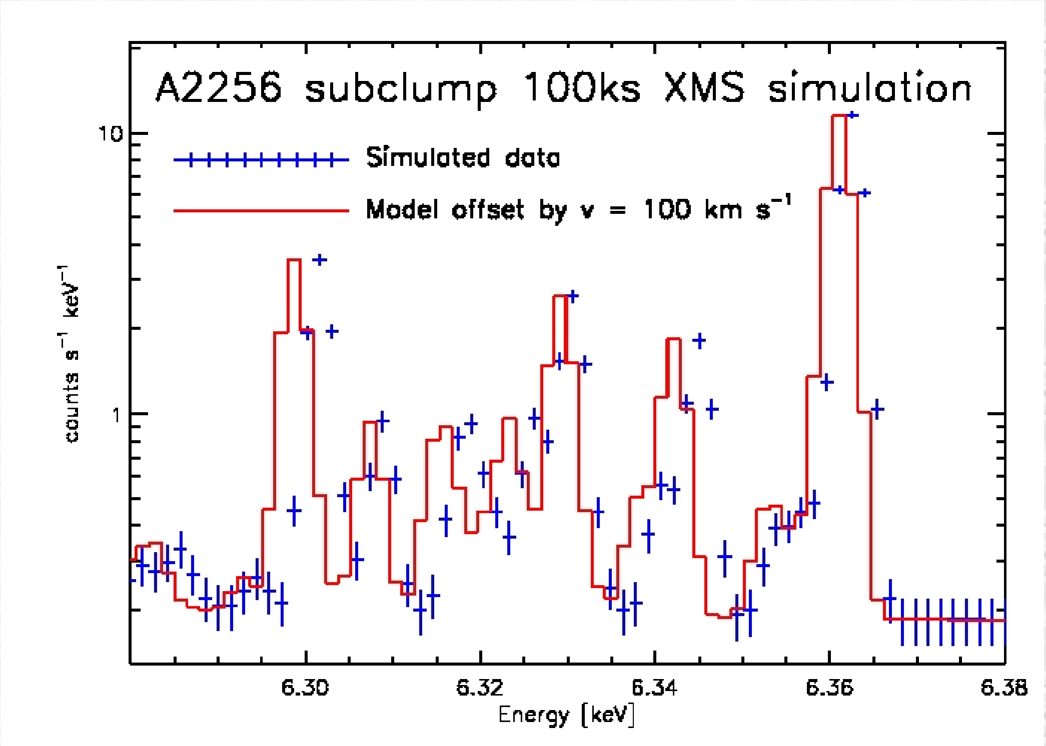
- ATHENA/XMS 100 ks simulation for A2256 main cluster and subclump with the owl response
- Emission model (bremsstrahlung continuum + collisional excitation lines) parameters from Tamura et al, 2011, PASJ in press, arXiv:1104.2667
- Background included (90% resolved CXB)

→


A2256 subclump 100ks XMS simulation
Simulated data
Model offset by v = 100 km s⁻¹
counts s⁻¹ keV⁻¹
10
1
6.30
6.32
6.34
6.36
6.38
Energy [keV]

A2256 with ATHENA/XMS

- Fit the simulated data with the input model →
- The statistical uncertainty of the redshift ($\sigma_z \sim 10^{-6}$) corresponds to a velocity precision of v = ∓3 km s^{-1}, yielding a 500σ detection for the clump motion



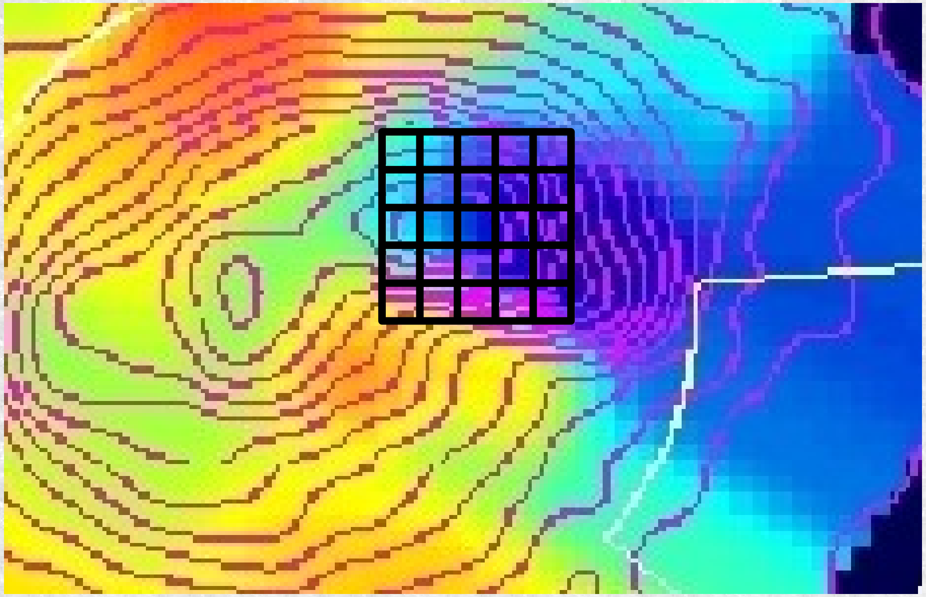
- Measurement is very precise because many line features are resolved. Each centroid gives weight to χ^2
- The gain needs to be accurate to dE/E = 0.1eV/6keV = 1e-5 for absolute velocity measurement. Differential measurement between the subclump and main cluster less demanding

Velocity mapping

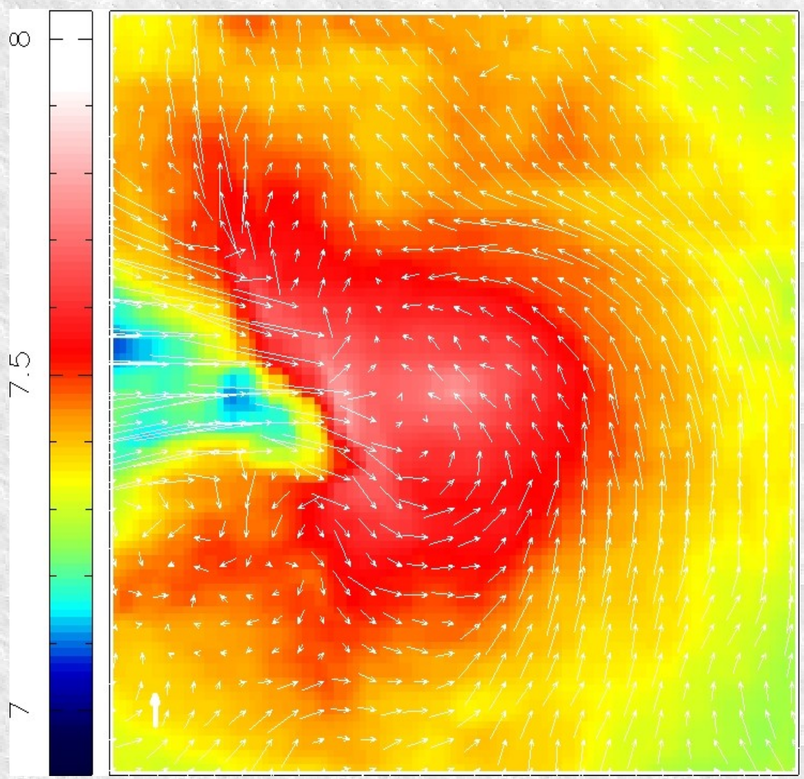
- Dividing the emission into (0.5 arcmin)^2 boxes (i.e. 5x5 map for the full XMS FOV) yields statictical precision level of ~10 km s^{-1} for A2256 subclump ➔

BREAKTHROUGH!

- The major mergers have bigger velocities an thus are easier to map



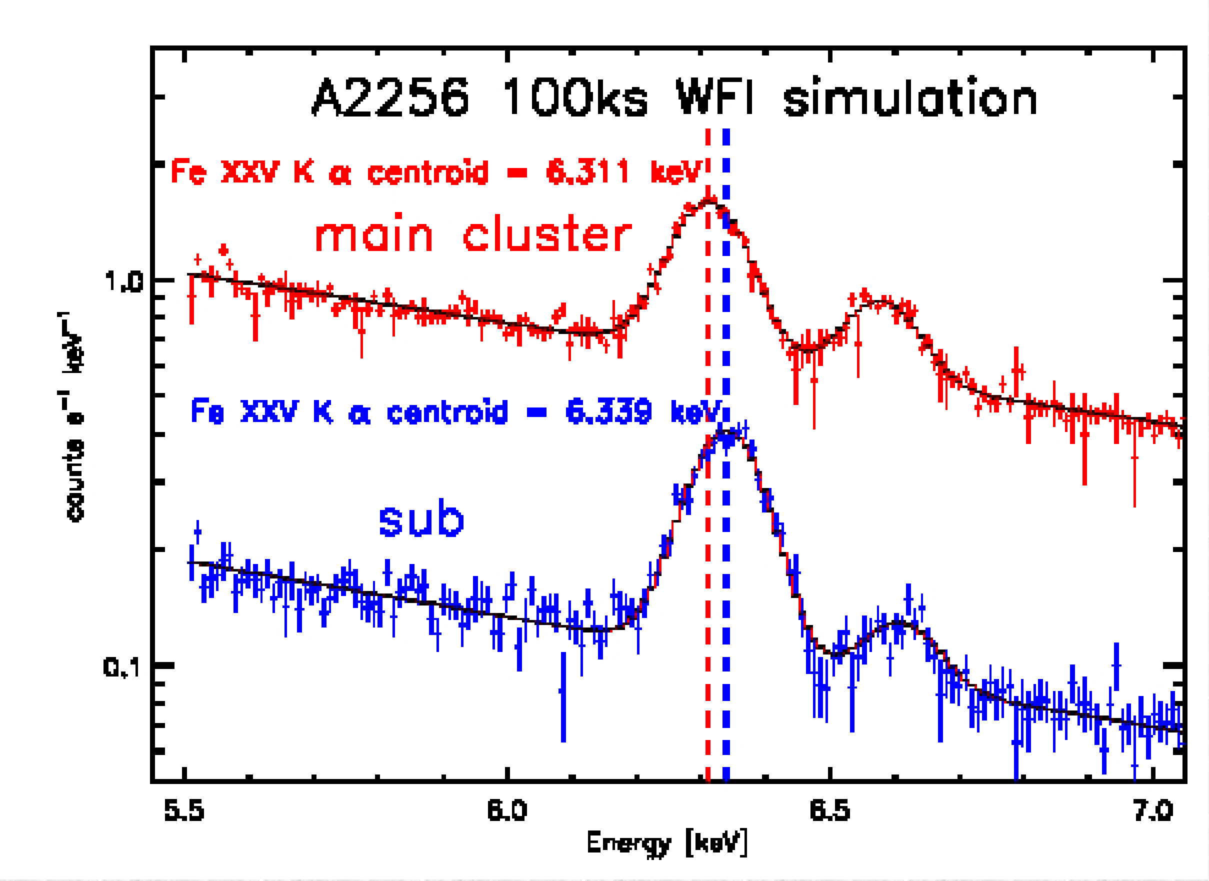
Can ATHENA make a breakthrough by mapping the omnipresent 100 km s^{-1} level of residual bulk motions?



- Single XMS pointing only covers a small angle.
- Wide Field Imager can complement the mapping by covering a larger region with sub-arcmin spatial resolution and ~ 100 eV energy resolution

- 100ks WFI simulation of A2256 main cluster and subclump ➔

Fe XXV Kα shift detected at ~25 σ level



- WFI simulations using:
  - KT = 5 keV cluster at z=0.1
  - $L_{bol}(r_{500})$ = 7 x 10^{44} erg s^{-1} (from Pratt et al. 2009 L-T relation)
  - r_{500} = 10 arcmin (using r_{500} - T relation of Vikhlinin et al. 2006)
  - β - profile with β = 2/3 and r_{core} = 0.1 r_{500} for surface brightness distribution
  - detection box size 0.1 r_{500} (= 100 kpc) in the center, increasing outwards
  - background assuming 90% resolved CXB
  - 100 ks exposure

Results

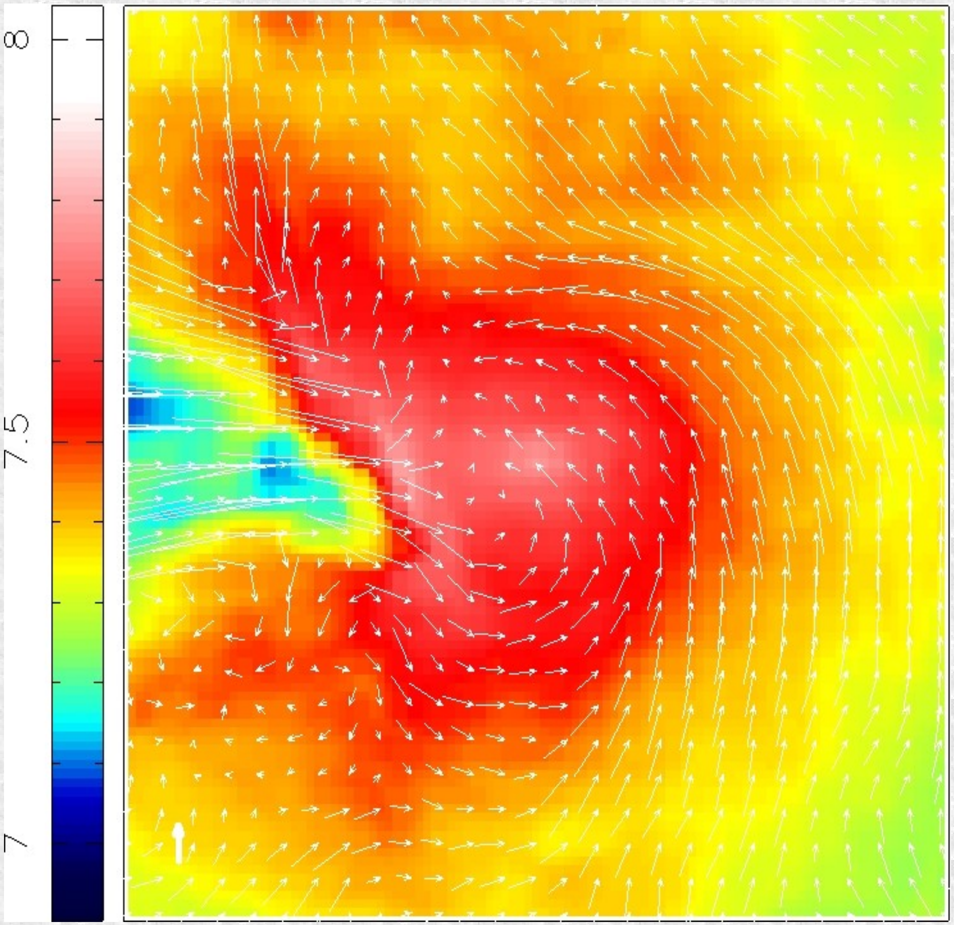
- In the center, the bulk velocity can be mapped with angular resolution of 0.1 r_{500} and v = 100 km s^{-1} for a kT = 5 keV cluster with 100 ks exposure
- At a distance of 0.5 r_{500} from the center, the background reaches the cluster emission level at E> 6 keV which degrades the precision to ~1000 km s^{-1} level
- The hottest clusters can still be mapped with spatial resolution of 0.3 r_{500} at 400 km s^{-1} level at 0.5 r_{500} using 100 ks exposure

Distance [r_{500}]	Spatial resol. Δr [r_{500}]	Velocity precision Δv [km s^{-1}]	
		kT 5 keV	kT 8 keV
0.00	0.1	100	
0.25	0.2	200	
0.50	0.3	800	400

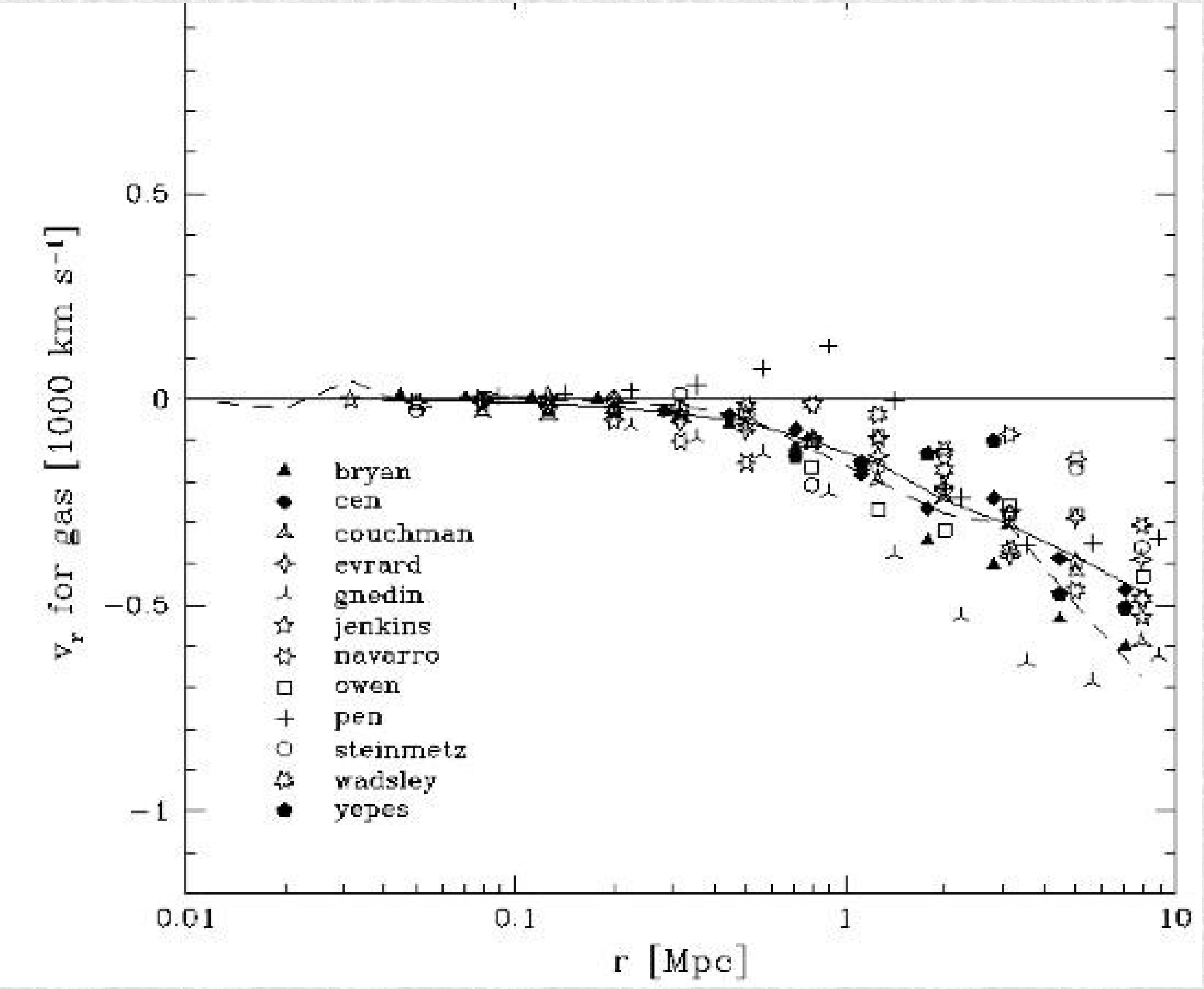
Results

- At least for the hottest clusters the $r \leq 0.5\ r_{500}$ area can be mapped into ~20 regions at a few 100 km s^{-1} level by WFI 100 ks exposure ➔

BREAKTHROUGH

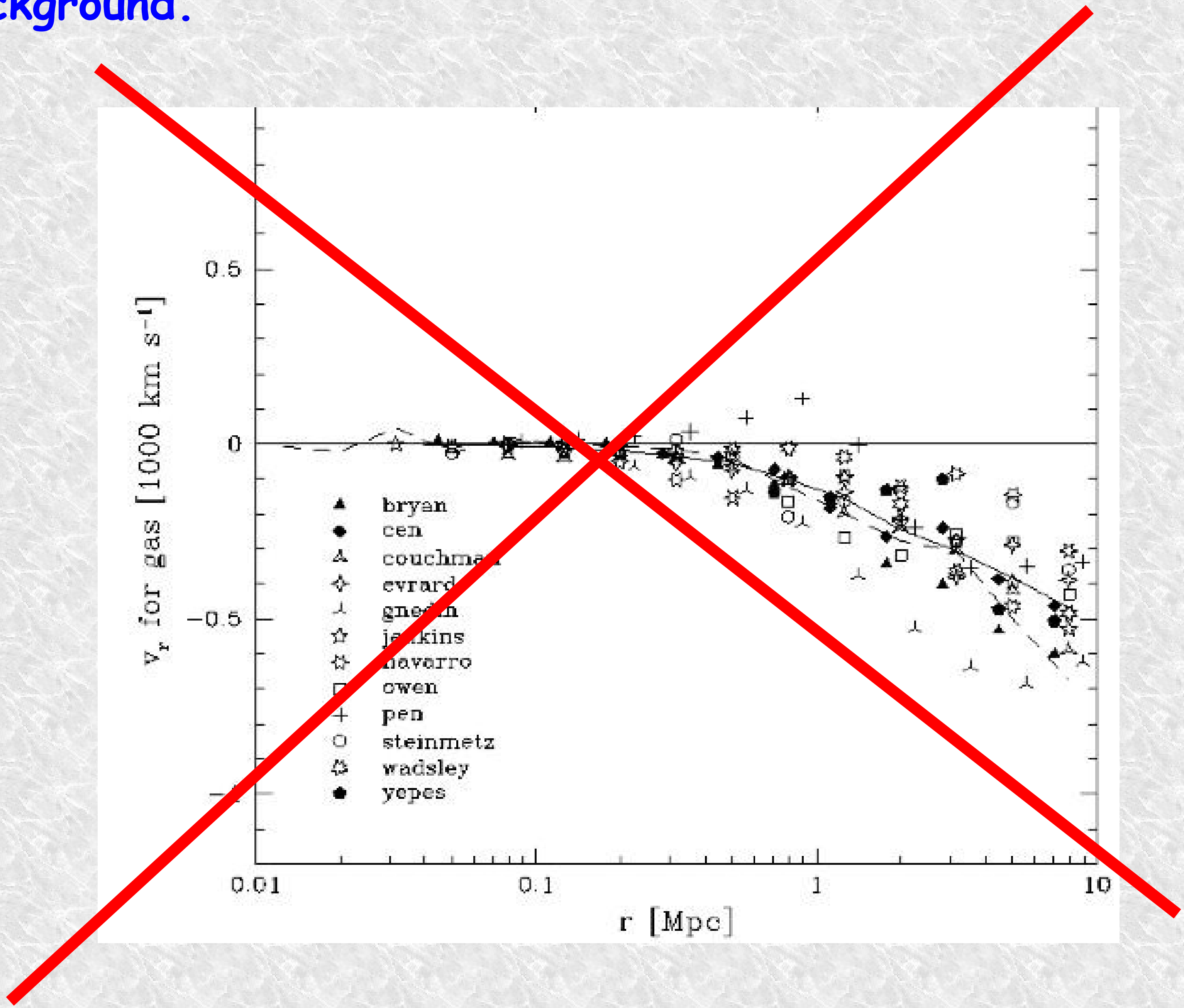


Can ATHENA make a breakthrough by mapping the accretion velocities at virial radius?

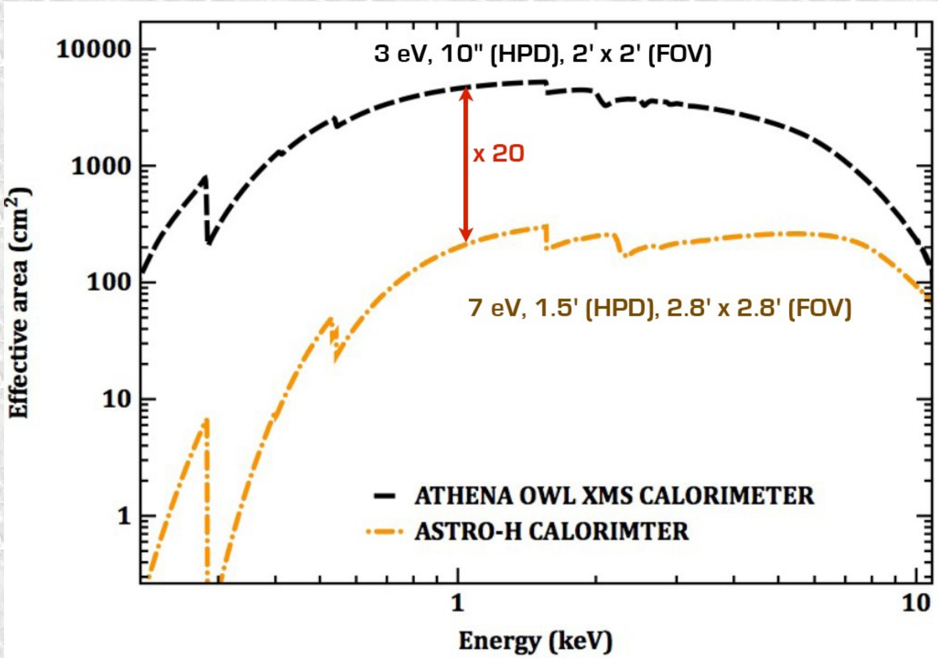


0.5
0
−0.5
−1
v_r for gas [1000 km s^{-1}]
0.01
0.1
1
10
r [Mpc]
bryan
cen
couchman
evrard
gnedin
jenkins
navarro
owen
pen
steinmetz
wadsley
yepes

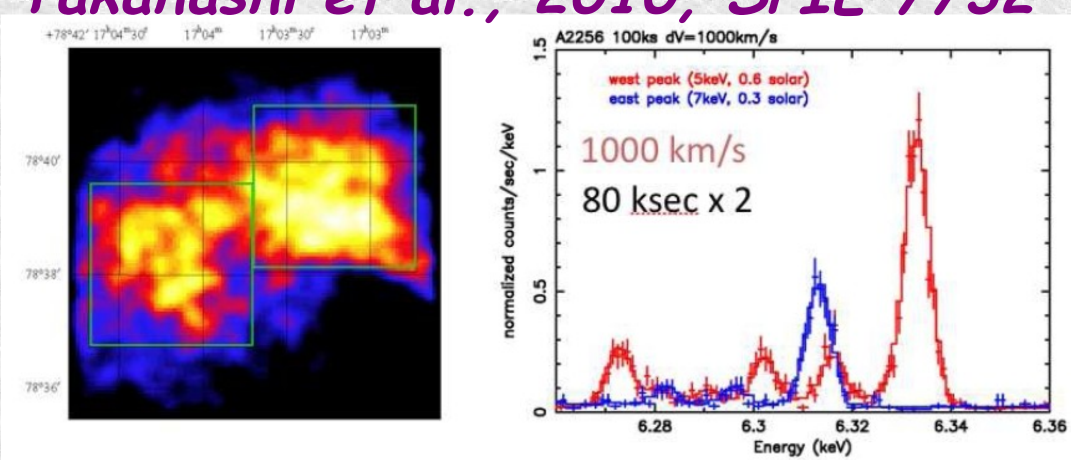
- No, the data are too noisy at r_{500} with the current estimate of the background.



ASTRO-H



A2256 ASTRO-H simulation
Takahashi et al., 2010, SPIE 7732



- Soft X-ray Spectrometer SXS onboard Astro-H has potential for detecting the bulk motions in the brightest nearby mergers
  - + energy resolution ~ half of that of XMS
  - - effective area ~ 1/10 of that of XMS at 6 keV
- Soft X-ray Imager SXI of Astro-H for mapping the 100 km s^{-1} motions?
  - + energy resolution 150eV at 6 keV
  - + FOV 38'
  - - effective area ~ 1/5 of that of ATHENA/WFI ➔ Need ~500ks per cluster

Summary

- ATHENA-like mission could measure
  - Bulk motions in major mergers: Piece of cake, as long as movement not close to the plane of the sky
  - Bulk motions in nearby minor mergers: Spatial mapping at ~ arcmin scale with very high velocity precision ~ 10 km s^{-1} feasible with 100 ks observations using XMS and 100 km s^{-1} with WFI to larger radii
  - Omnipresent residual velocities: Nearby ($z \leq 0.1$) clusters mapped into ~20 regions with WFI up to $r \leq 0.5\ r_{500}$ at a few 100 km s^{-1} level with a single 100-500 ks pointing