

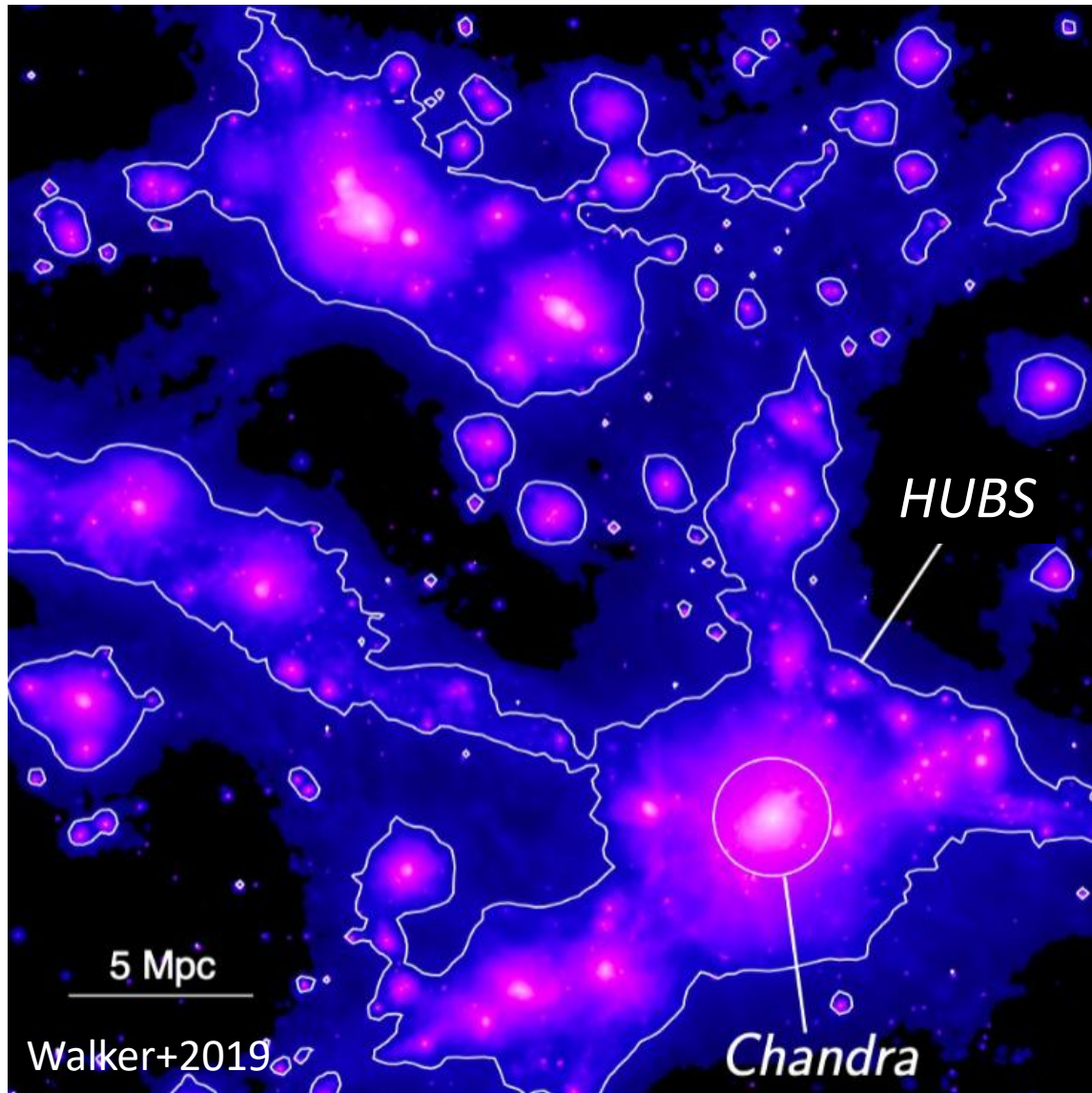
Mapping Hot Gas Kinematics in Galaxy Clusters: Recent Progress with XRISM

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XRISM collaboration

24/09/2025 @ Tatra

Why X-rays?



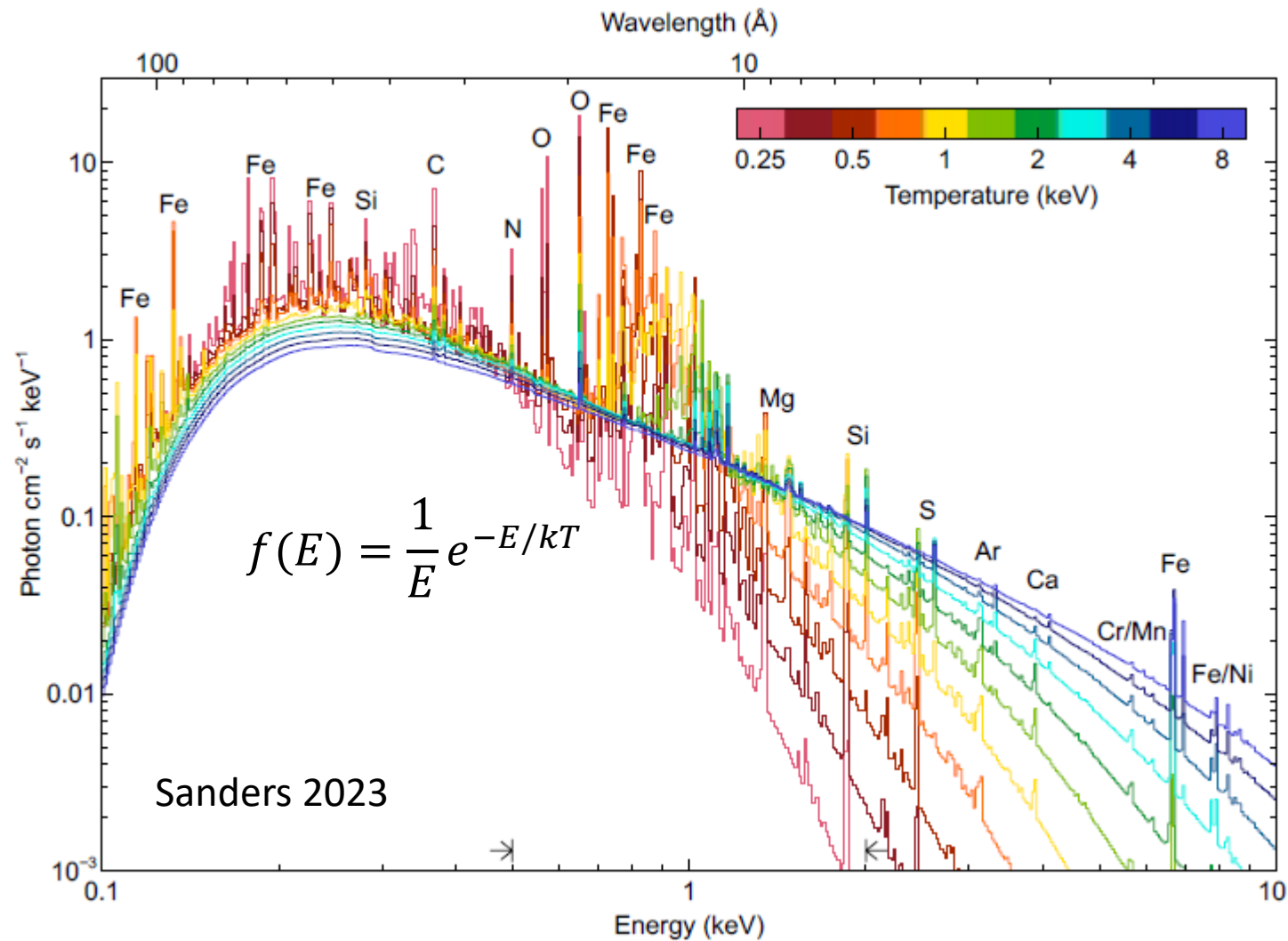
$$\frac{kT}{\mu m_p} \simeq \frac{GM}{R}$$
$$\simeq 5\text{keV} \left(\frac{M}{5 \times 10^{14} M_{\odot}} \right)^{2/3}$$

X-ray: 0.1 – 10 keV

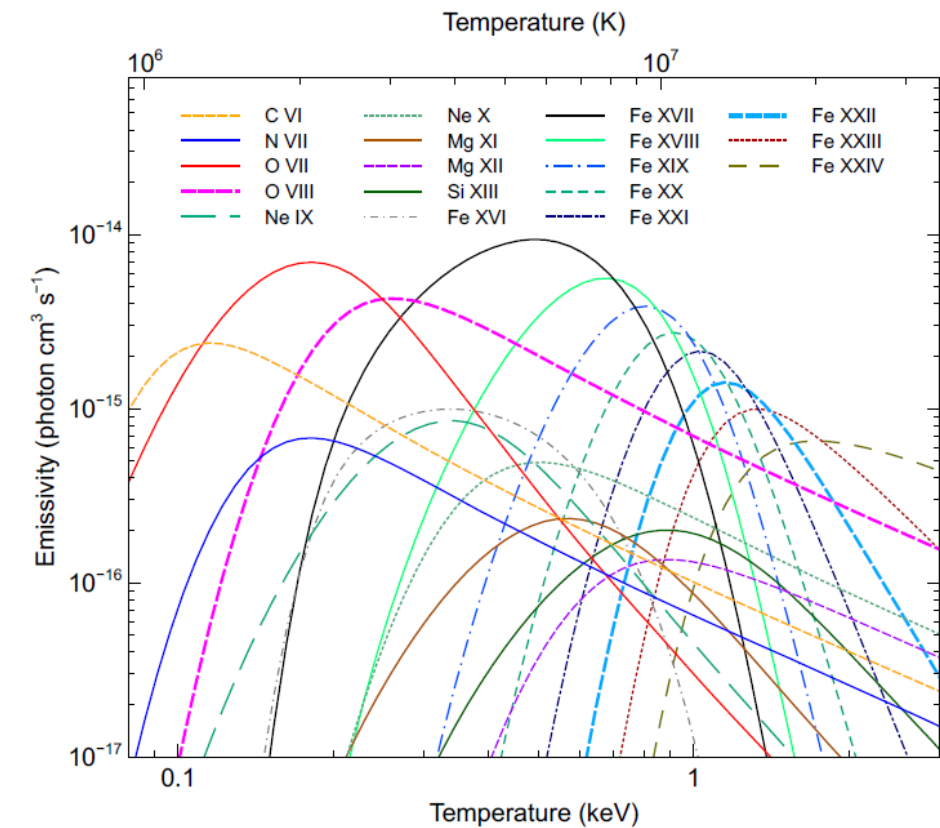
$\sim 10^6 - 10^8$ K

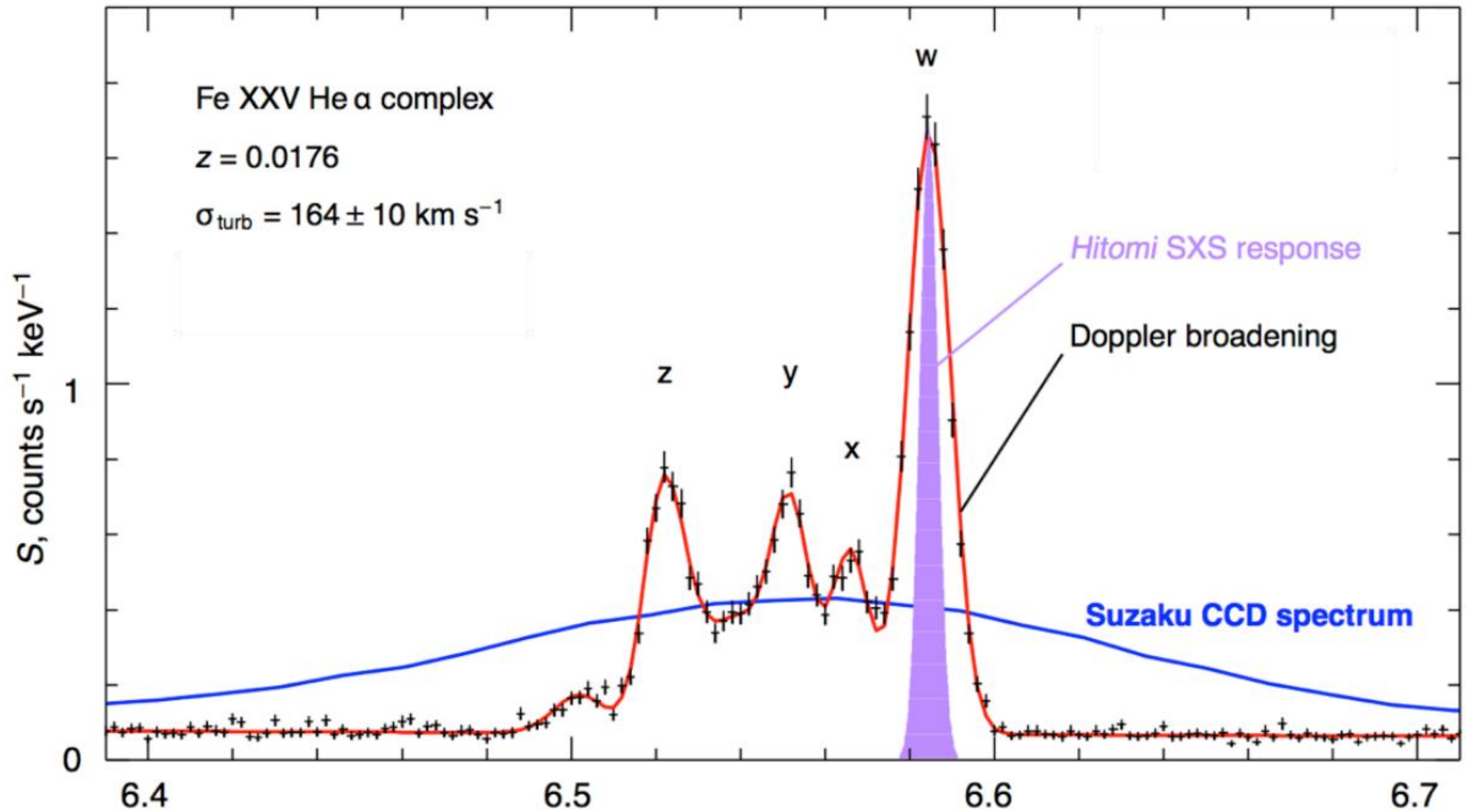
ICM, CGM, IGM

How does an X-ray spectrum look like?



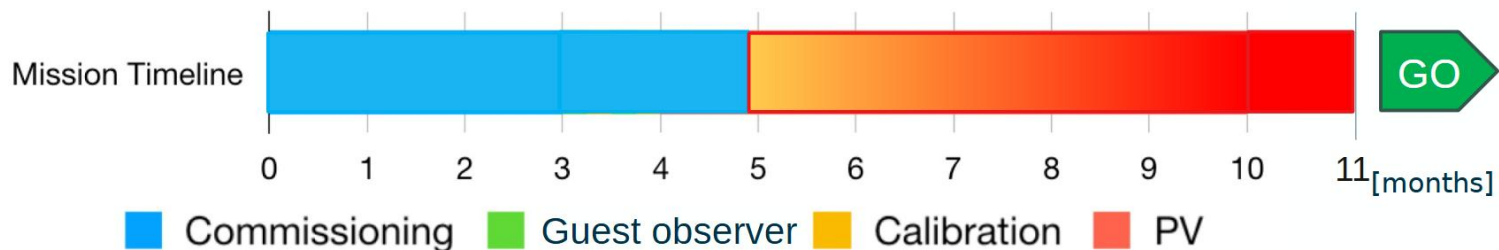
Bremsstrahlung + collisional excitation





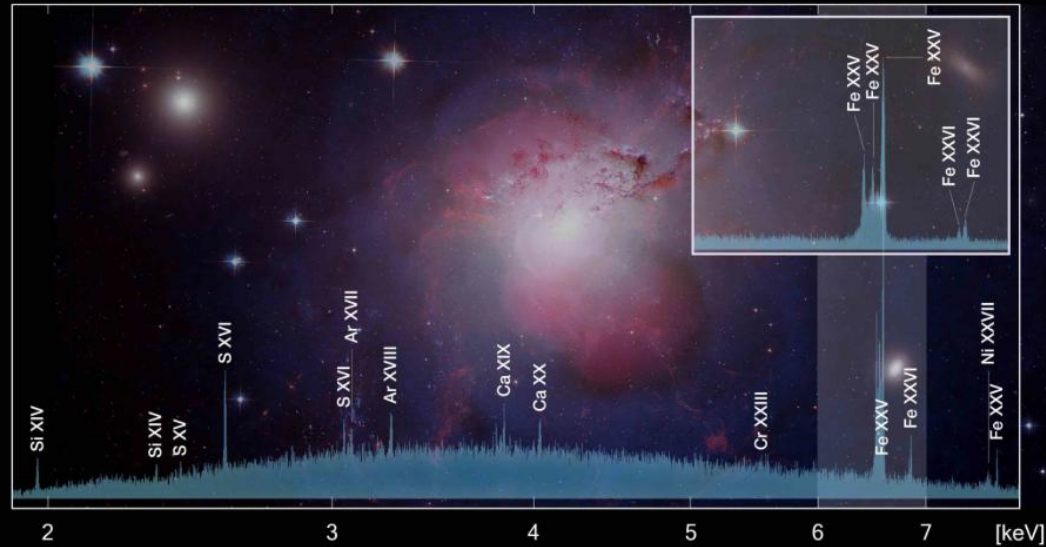
X-ray Imaging and Spectroscopy Mission (XRISM)

- Launch: Sep 7, 2023
- Commissioning: Sep 2023 – Feb 2024
- First light observations (Nov/Dec 2023)
- Feb 2024 – Aug 2024: In-flight calibration and Performance Verification (PV) phases
- Aug 2024: General Observer (GO) program



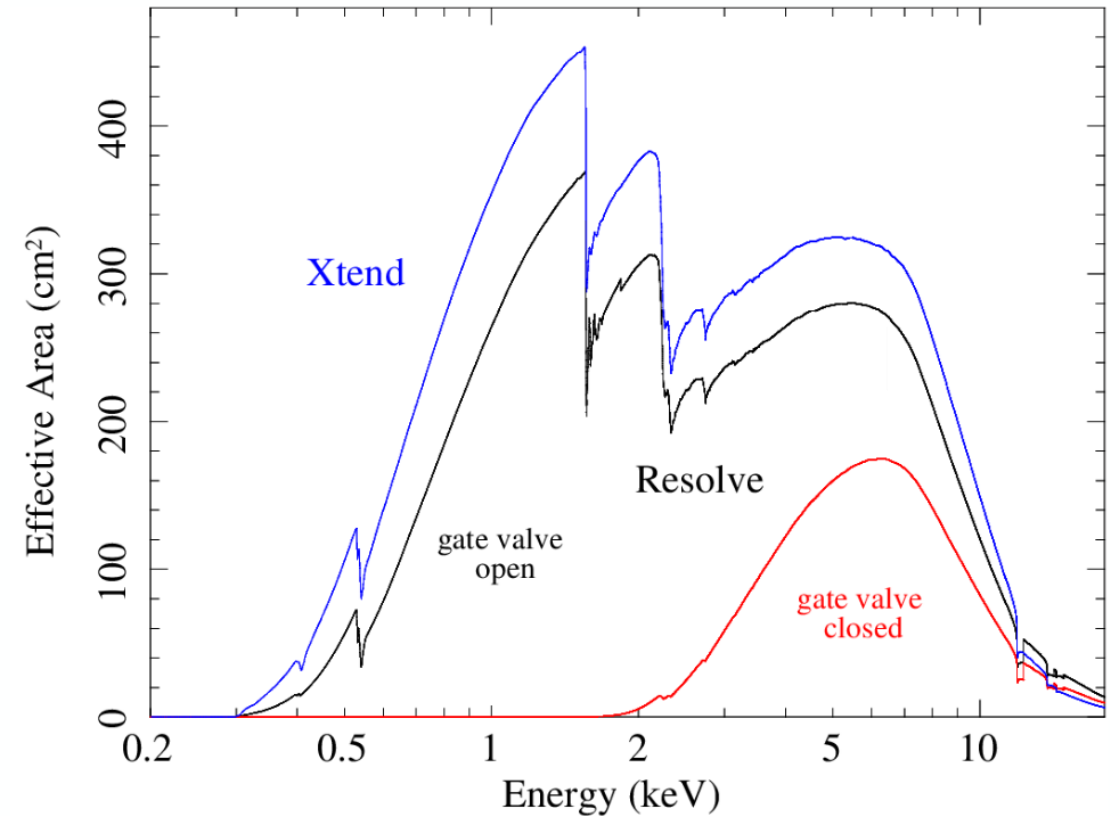
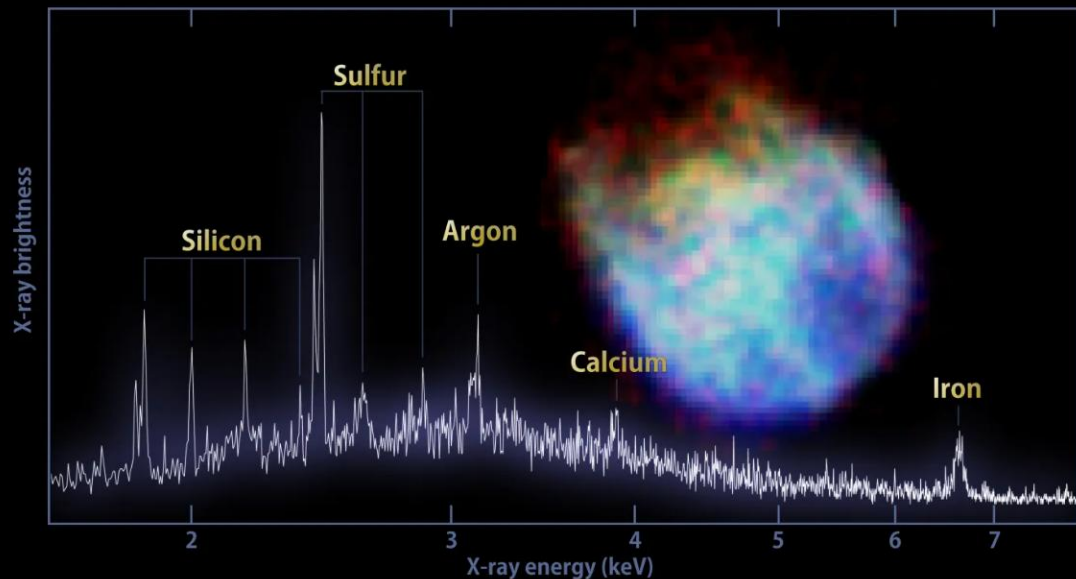


X-ray Spectrum of Perseus Galaxy Cluster Measured by XRISM Resolve



~~2000 Astro-E~~
~~2005 Suzaku~~
~~2016 Hitomi~~
2023 XRISM

XRISM Resolve's Recipe for Supernova Remnant N132D

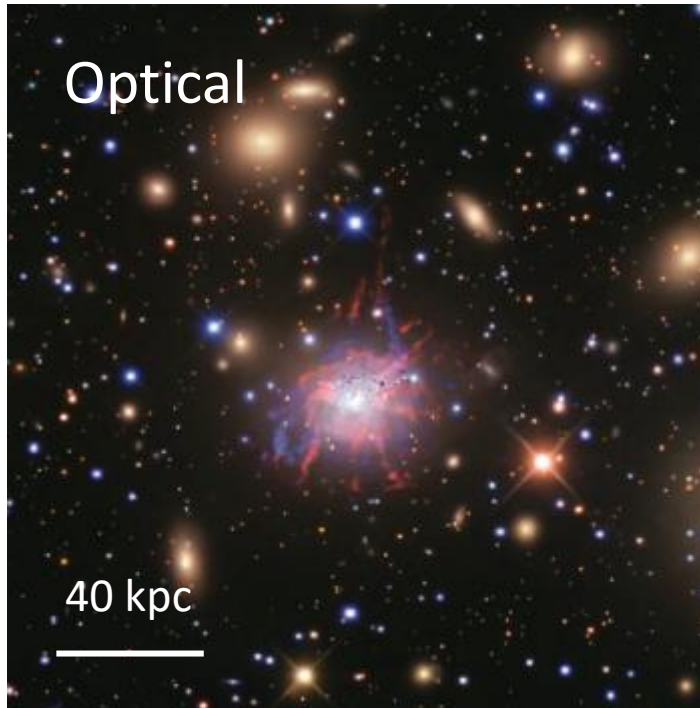


The brightest clusters in the sky

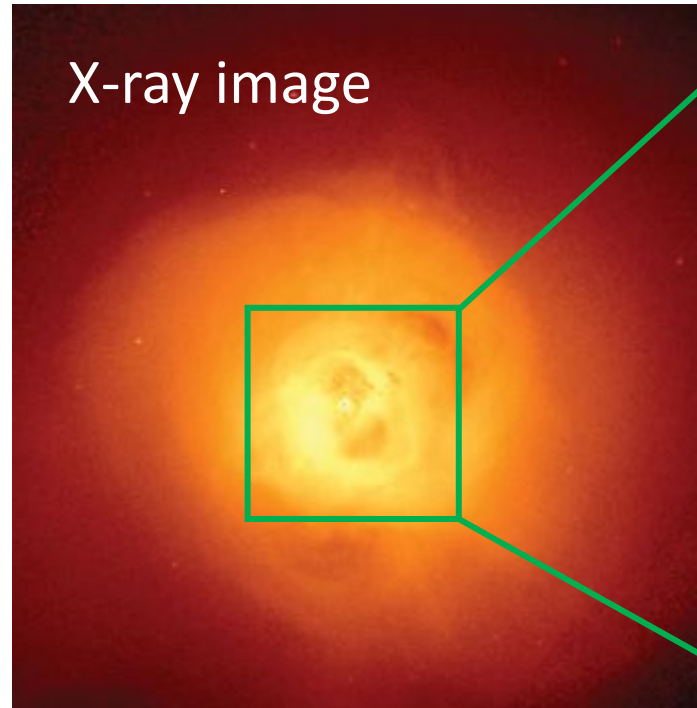
Cluster	Redshift	2-10 keV Flux (10^{-11} erg cm $^{-2}$ s $^{-1}$)	2-10 keV Luminosity (h_{50}^{-2} erg s $^{-1}$)	Temperature (keV)	Survey Detection
A426*	0.0183	75.0 [1]	1.10×10^{45}	5.5 ± 0.5	UWA
Ophiuchus*	0.028	44.5 [1]	1.52×10^{45}	9.0 ± 0.8	UA
Virgo	18 Mpc	30.0 [1]	1.16×10^{43}	2.4 ± 0.3	UPWA
Coma	0.0232	25.4 [1]	5.95×10^{44}	8.0 ± 0.3	UPWA
A2319*	0.0564	12.1 [2]	1.70×10^{45}	$9.2^{+1.8}_{-1.7}$	UPWA
A3571	0.0391	11.5 [1]	7.67×10^{44}	$7.6^{+1.2}_{-0.9}$	UPWA
Centaurus	0.0109	11.2 [1]	5.75×10^{43}	3.6 ± 0.4	UPWA
Triang. Aust.*	0.051	11.0 [1]	1.26×10^{45}	8.0 ± 1.4	UWA
3C129*	0.022	9.59 [1]	2.02×10^{44}	$5.6^{+0.7}_{-0.6}$	UWA
AWM7*	0.0172	9.14 [1]	1.17×10^{44}	3.6 ± 0.2	UWA
A754	0.0528	8.53 [1]	1.05×10^{45}	$8.7^{+1.8}_{-1.6}$	UPWA
A2029	0.0767	7.52 [2]	1.97×10^{45}	$7.1^{+2.0}_{-1.4}$	PWA
A2142	0.0899	7.50 [1]	2.72×10^{45}	$11.0^{+2.0}_{-1.7}$	UPWA
A2199	0.0309	7.12 [1]	2.97×10^{44}	4.7 ± 0.4	UPWA
A3667	0.0530	6.68 [2]	8.28×10^{44}	$6.5^{+1.5}_{-1.6}$	PWA
A478	0.09	6.63 [1]	2.41×10^{45}	6.8 ± 1.0	UPWA
A85	0.0518	6.37 [2]	7.54×10^{44}	$6.6^{+1.8}_{-1.4}$	UPWA
A3266	0.0594	5.90 [2]	9.21×10^{44}	$7.4^{+1.6}_{-1.2}$	UPWA
A401	0.0748	5.88 [2]	1.47×10^{45}	$8.6^{+1.4}_{-1.6}$	UPWA
0745-19*	0.1028	5.87 [1]	2.80×10^{45}	$8.5^{+1.9}_{-1.4}$	UWA
A496	0.0320	5.67 [1]	2.54×10^{44}	$4.8^{+0.9}_{-0.8}$	UPWA
A1795	0.0616	5.30 [1]	8.91×10^{44}	$5.1^{+0.4}_{-0.5}$	UPWA
A2256	0.0601	5.20 [2]	8.32×10^{44}	$7.4^{+1.8}_{-1.5}$	UPWA

SMBHs and AGN feedback

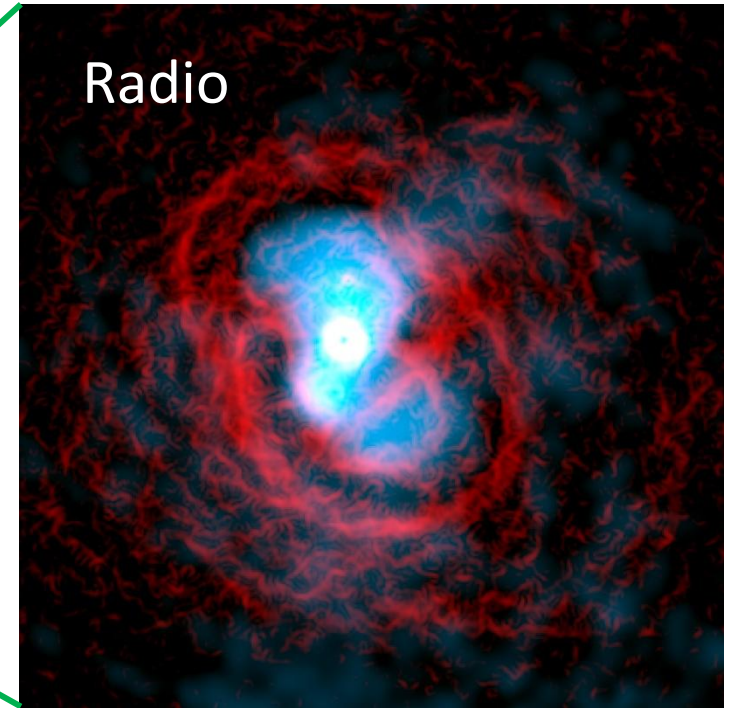
Feedback heating vs. radiative cooling



H α filaments

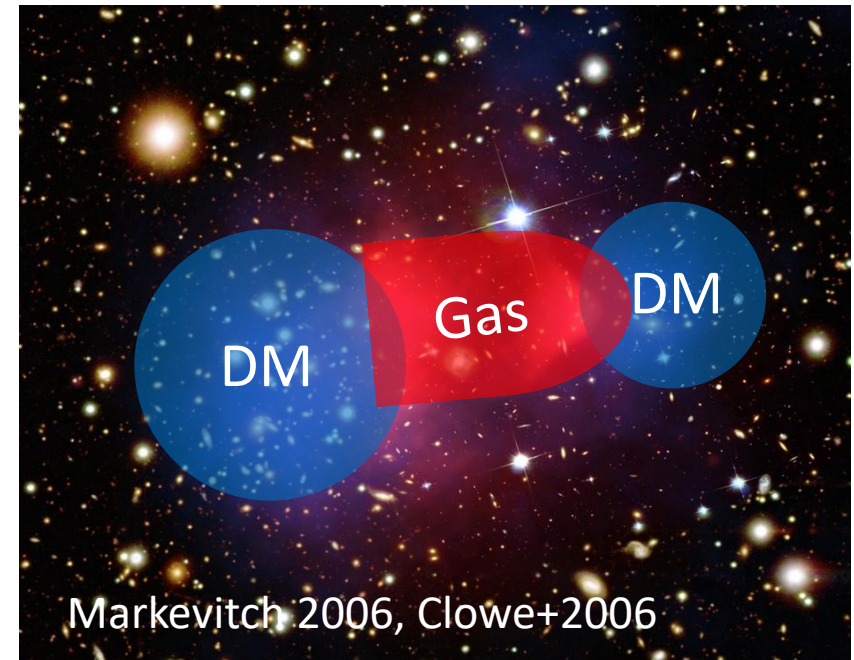
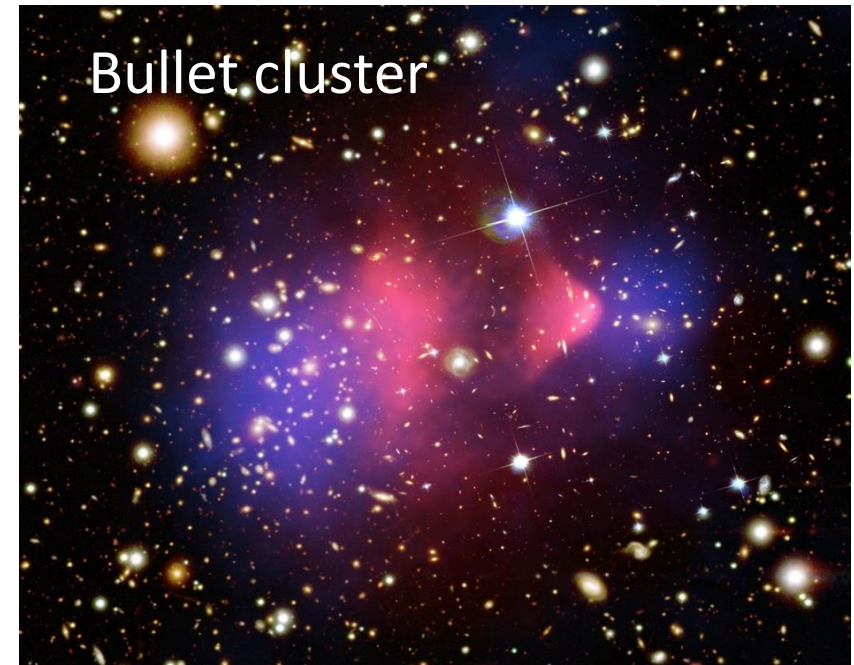
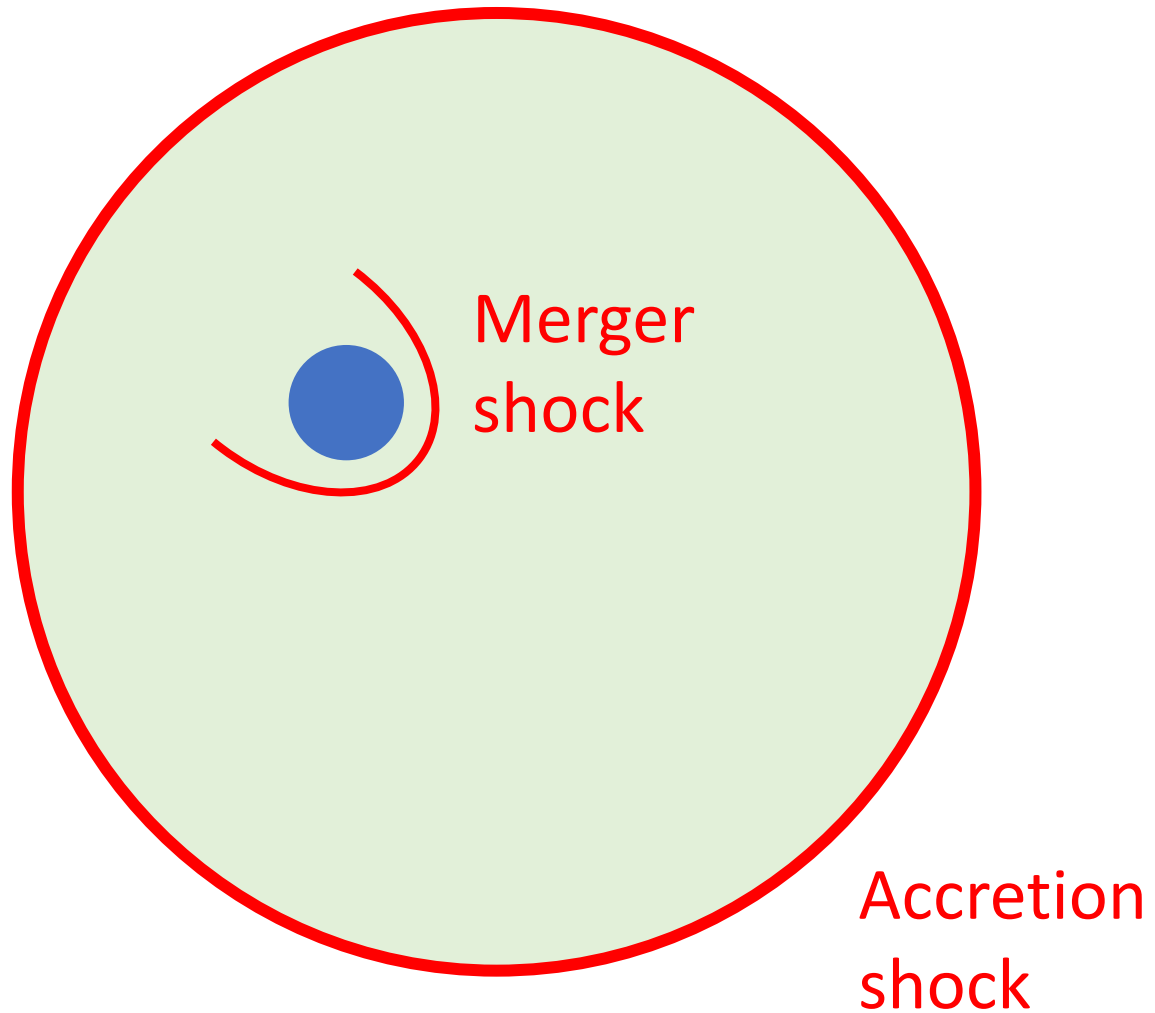


X-ray bubbles

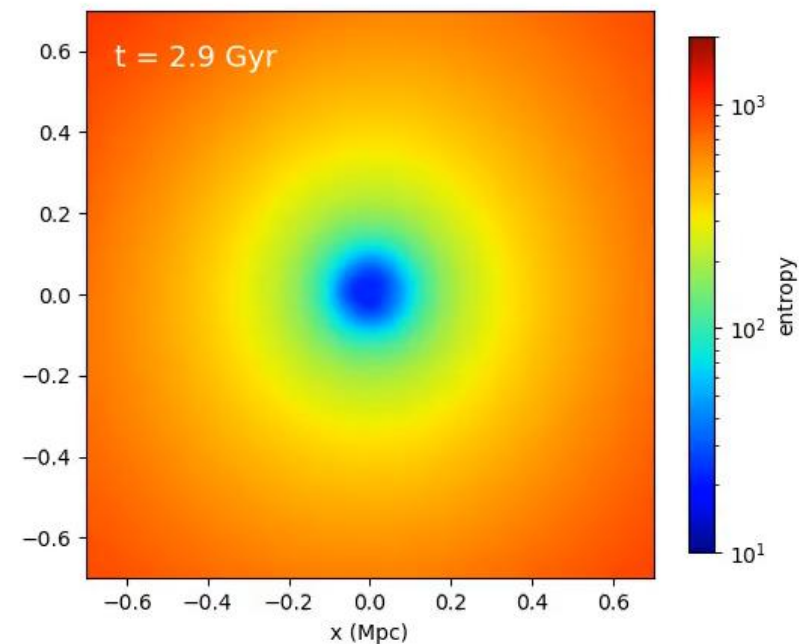
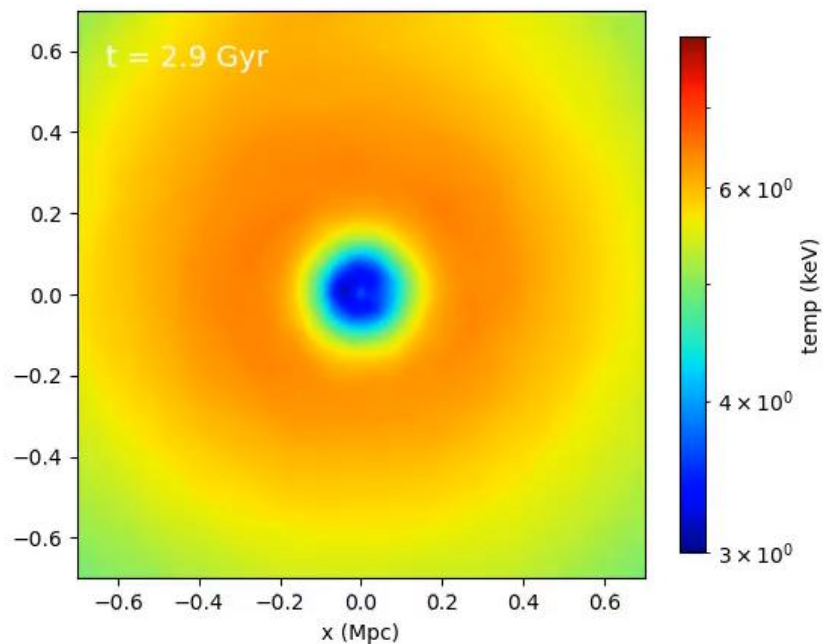
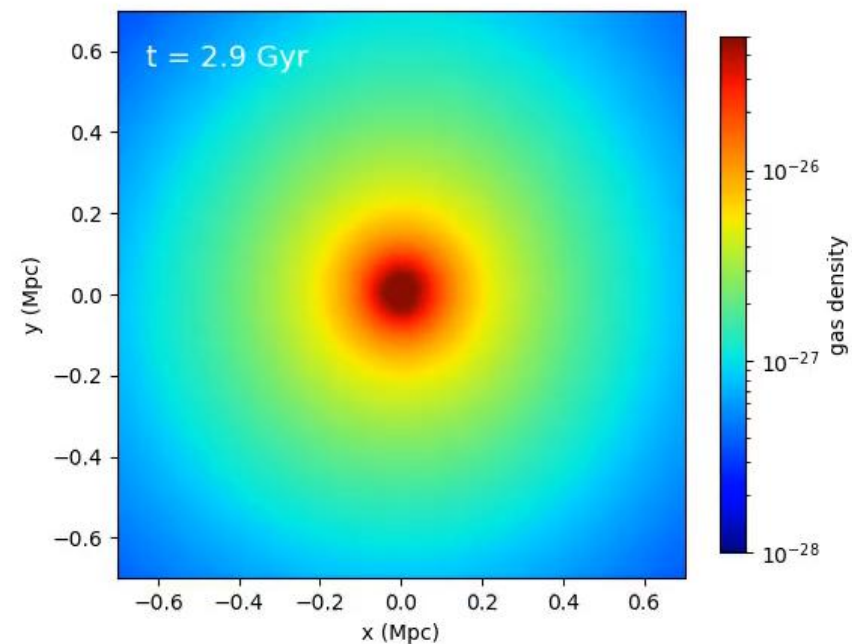
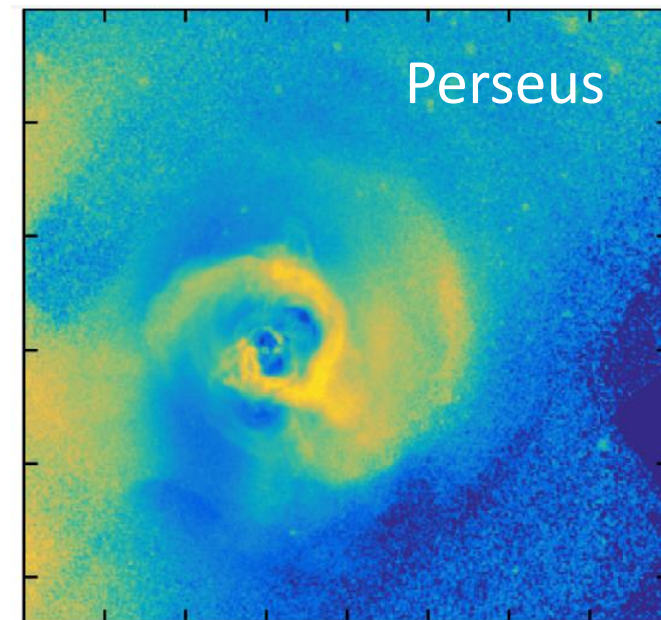
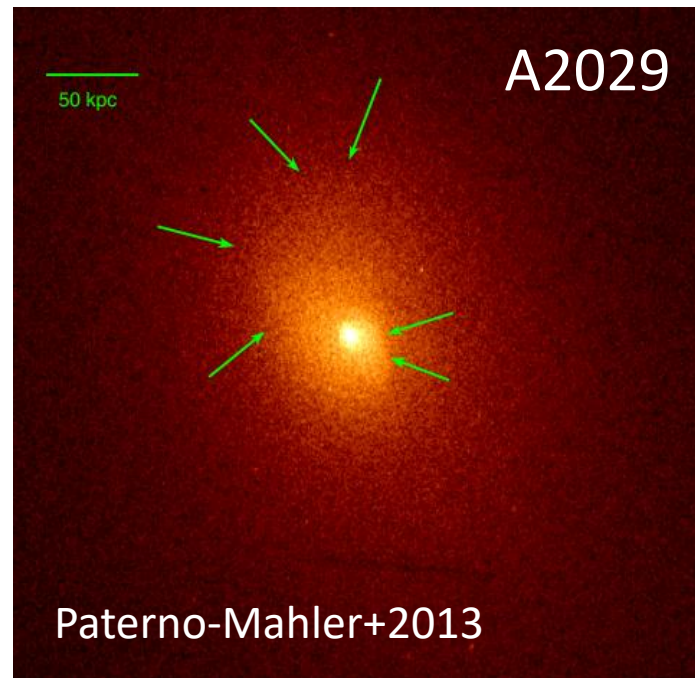


Radio bubbles

Hierarchical formation (mergers, accretion)



Sloshing: oscillations in the stratified atmosphere



Perseus: a direct probe of the AGN feedback kinematics

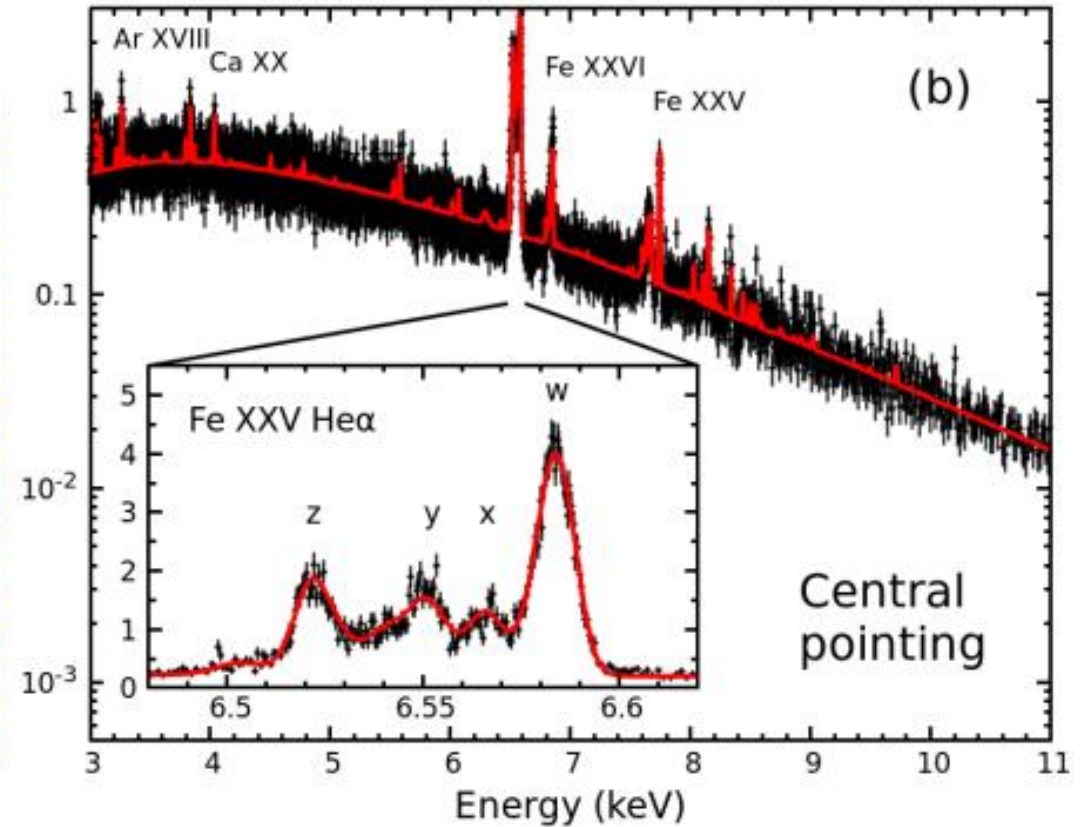
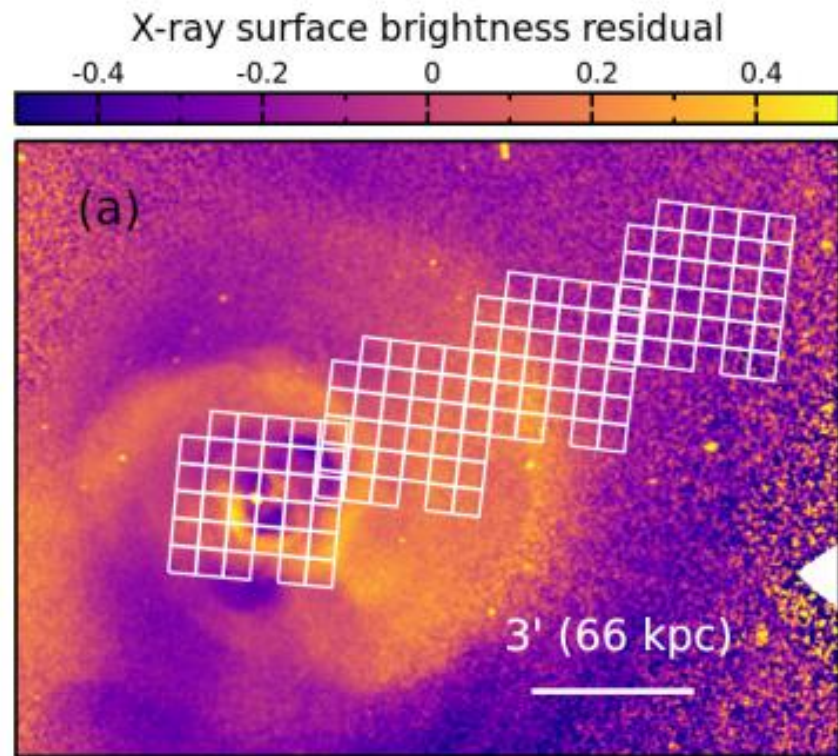
A2029: lower nonthermal pressure than expected?

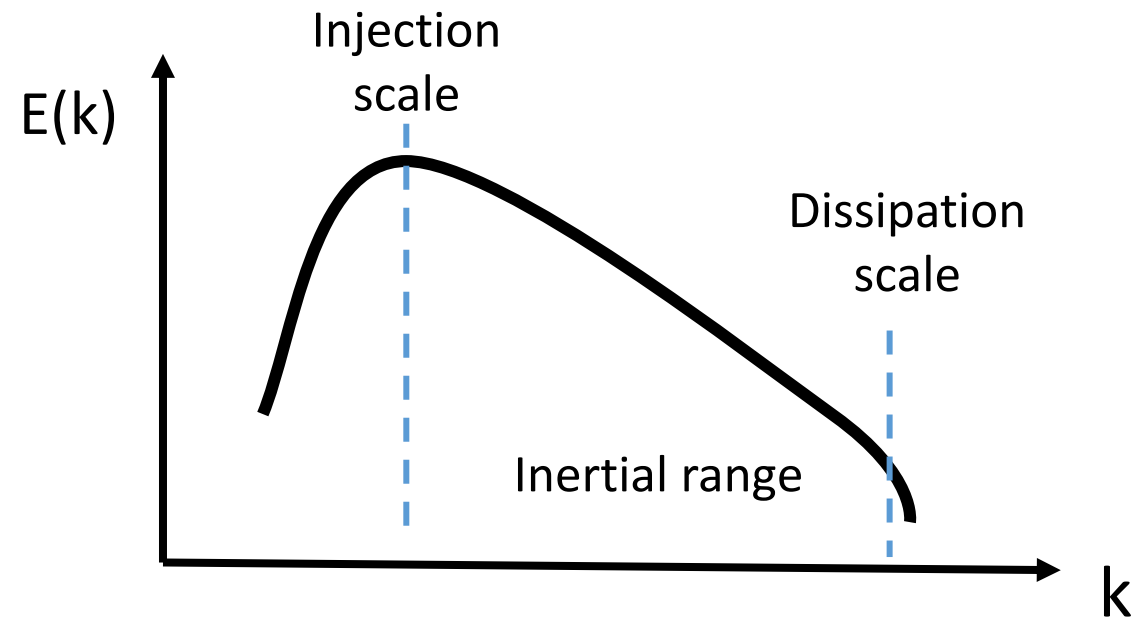
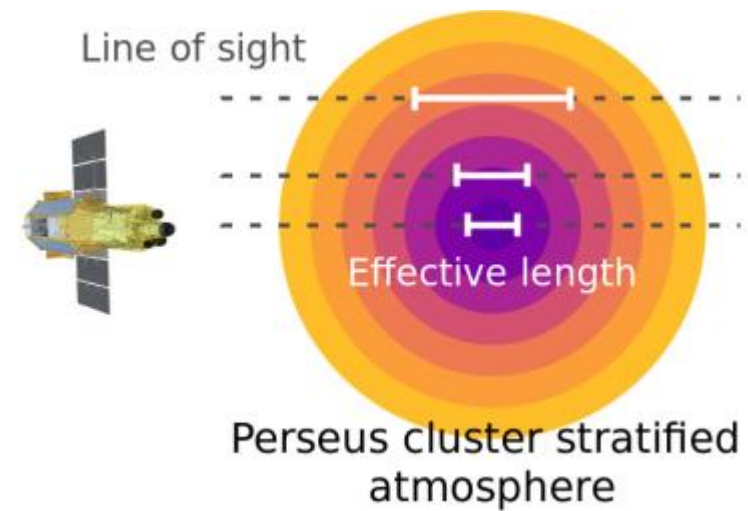
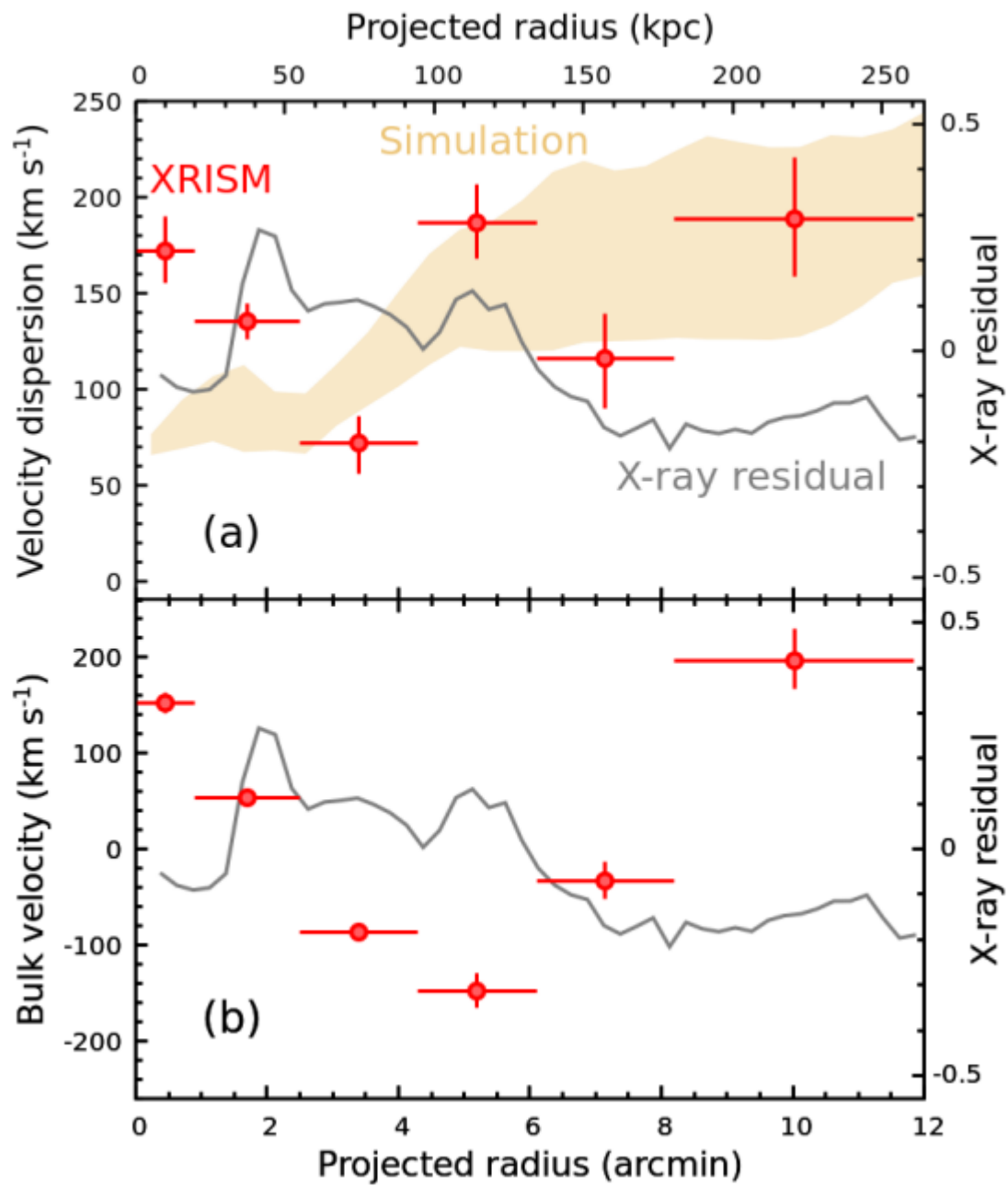
A1914: a line-of-sight merging cluster

Coma: very steep energy power spectrum?

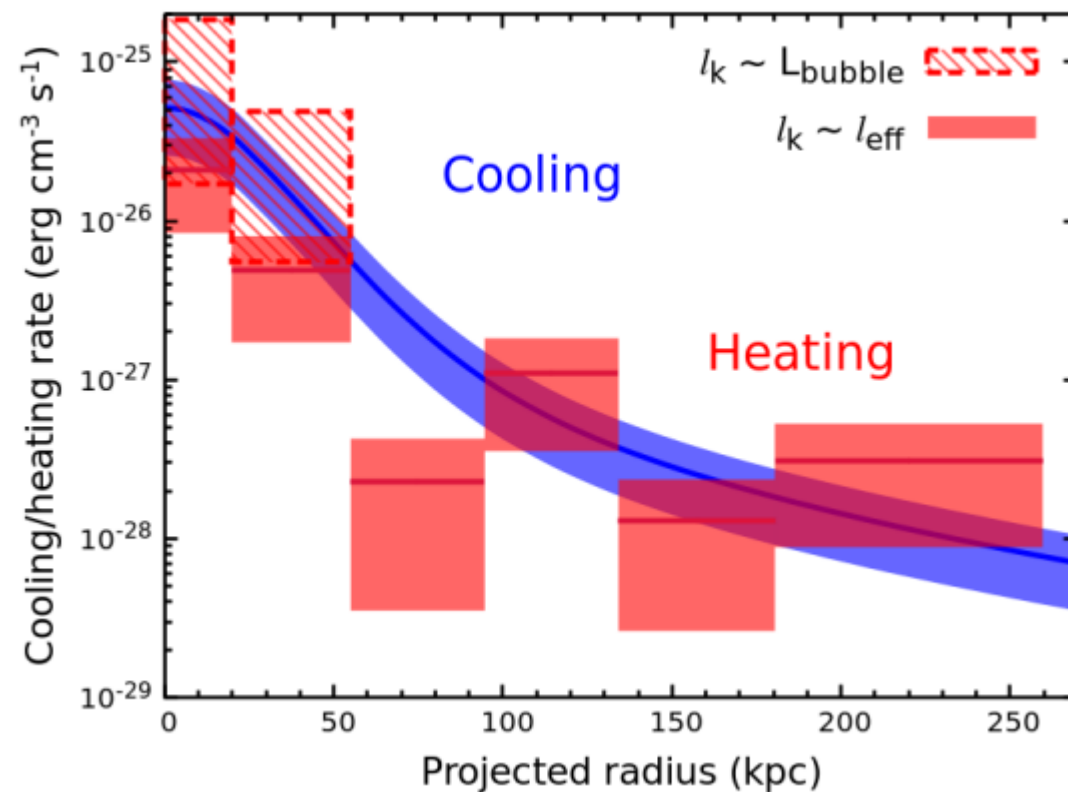
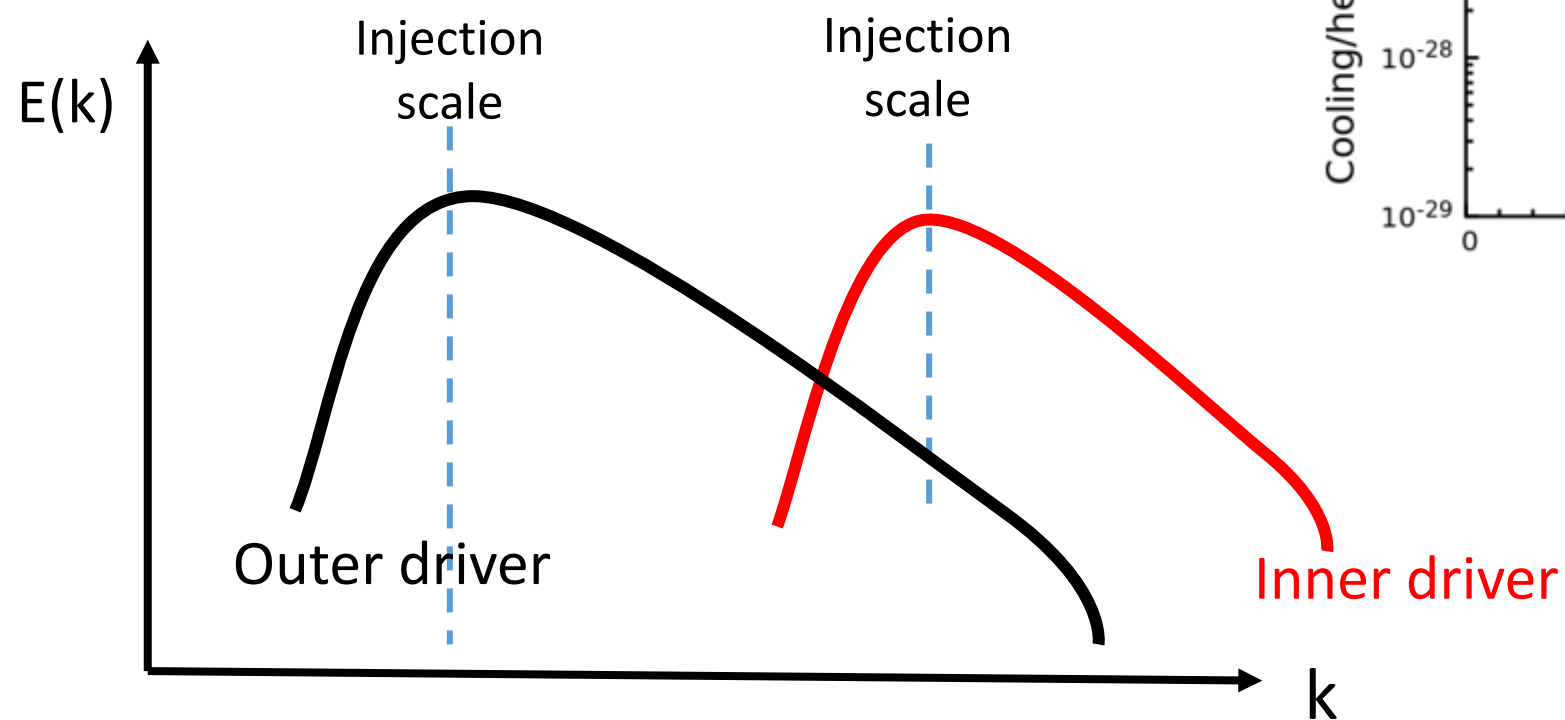
And many more ...

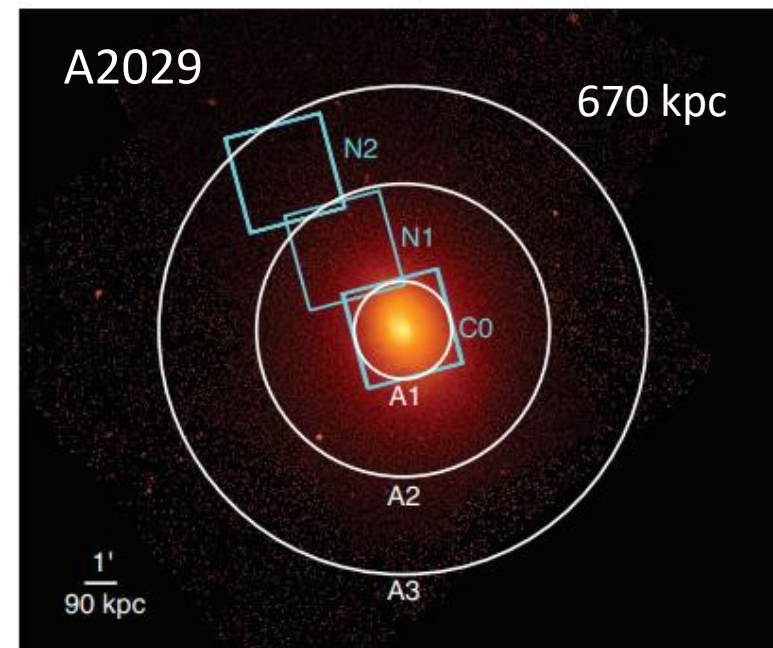
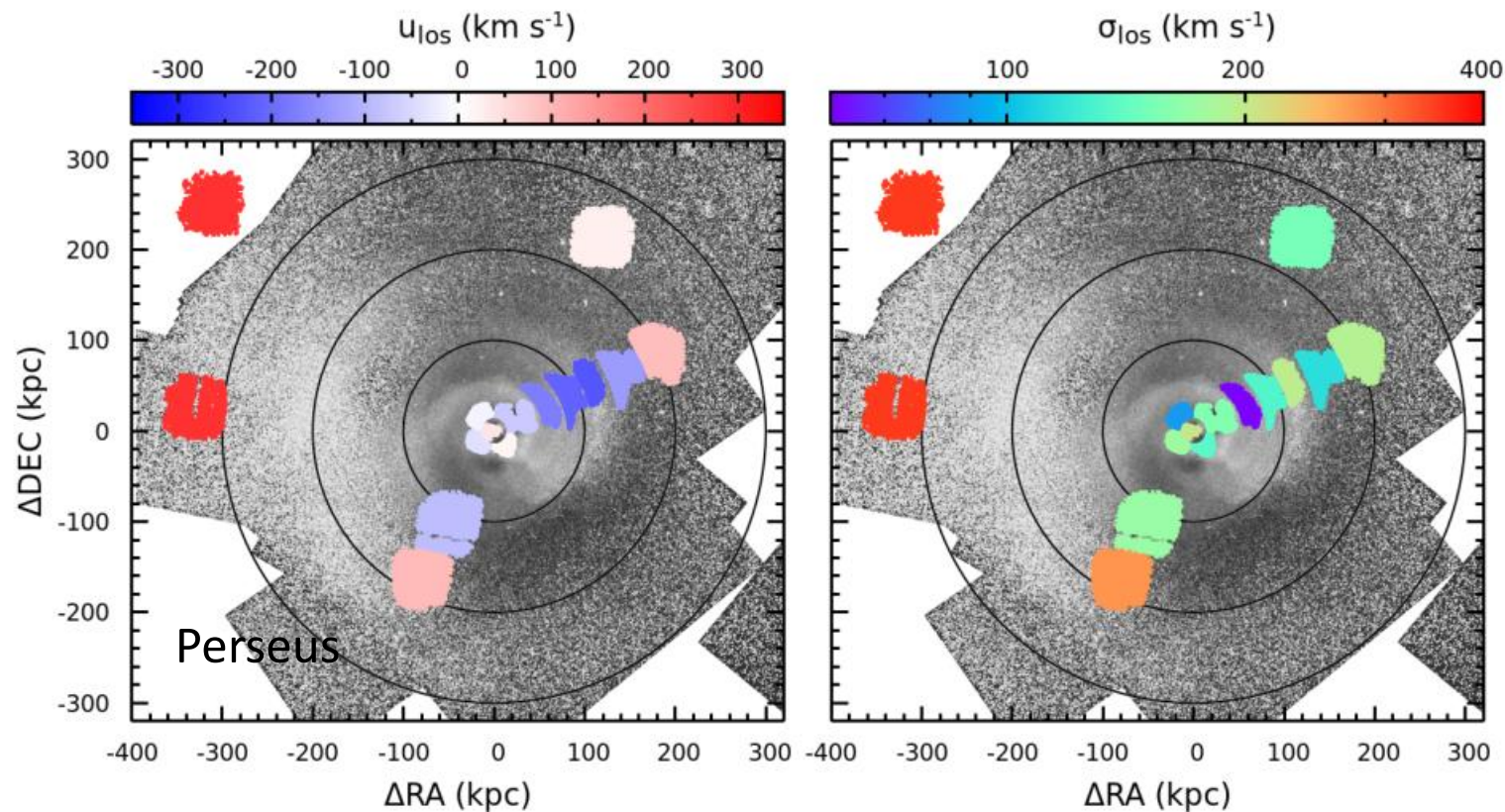
The Perseus cluster





A double-cascade scenario

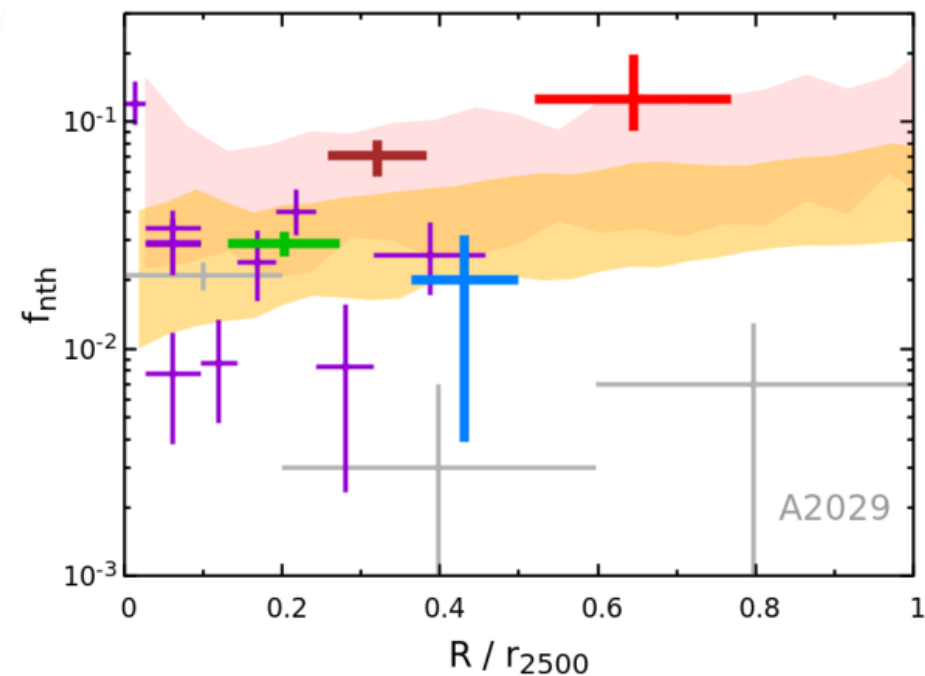




Nonthermal pressure

$$f_{\text{nth}}(r) = \frac{P_{\text{nth}}(r)}{P_{\text{gas}}(r) + P_{\text{nth}}(r)}$$

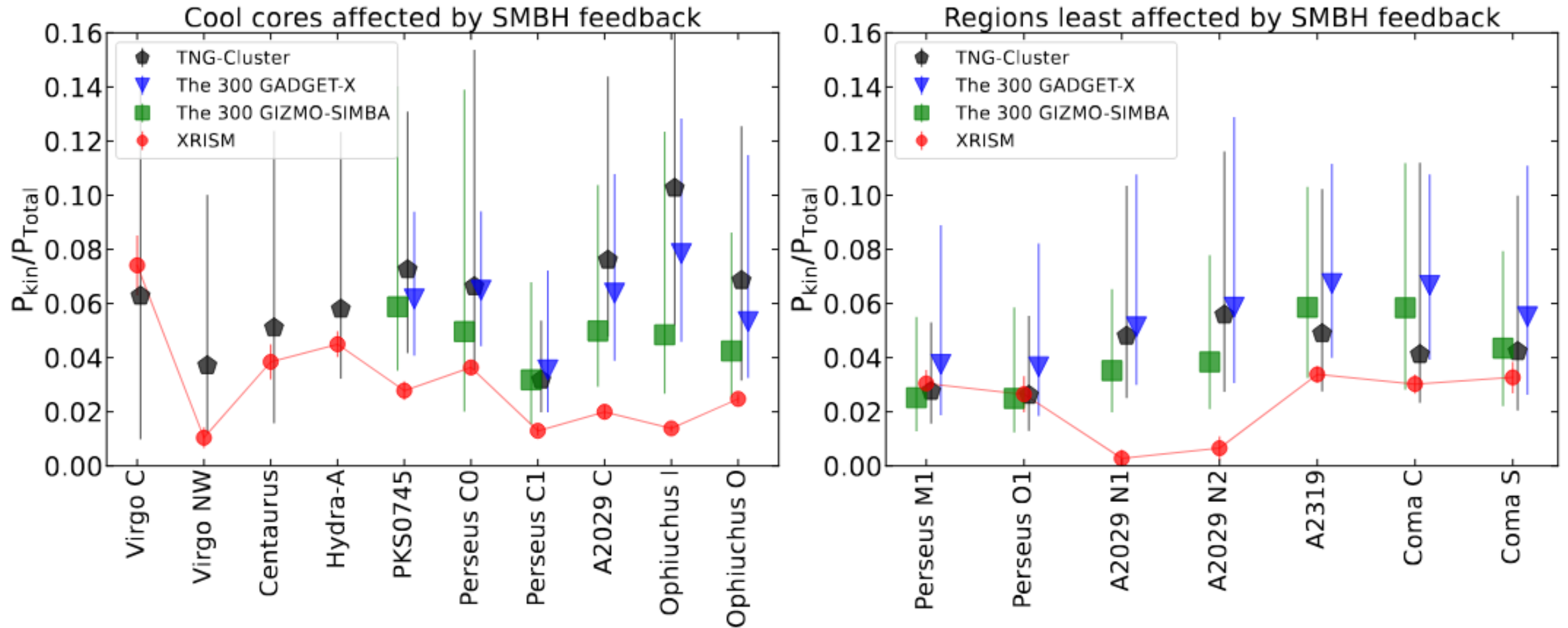
$$P_{\text{nth}}(r) \equiv \rho_{\text{gas}}(r) \sigma_{1D}(r)^2$$



XRISM collaboration 2025

C. Zhang, et al. in prep.

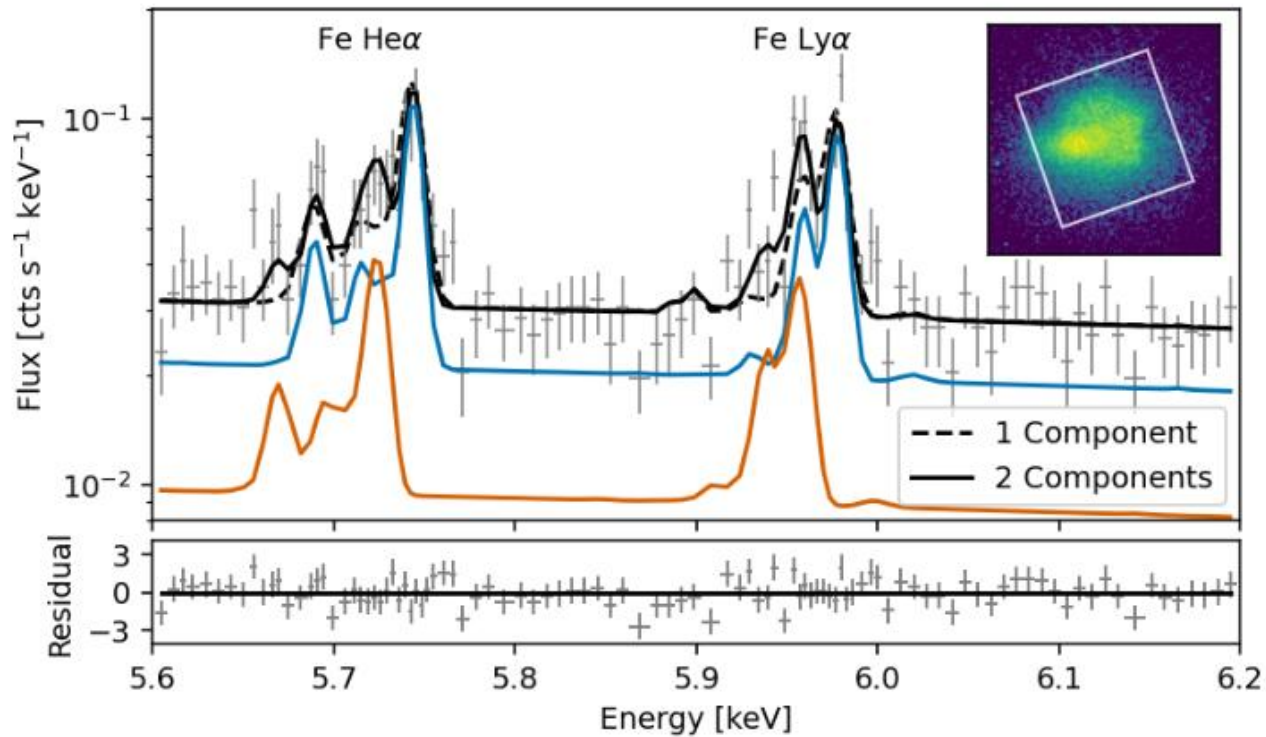
A comparison with cosmological simulations



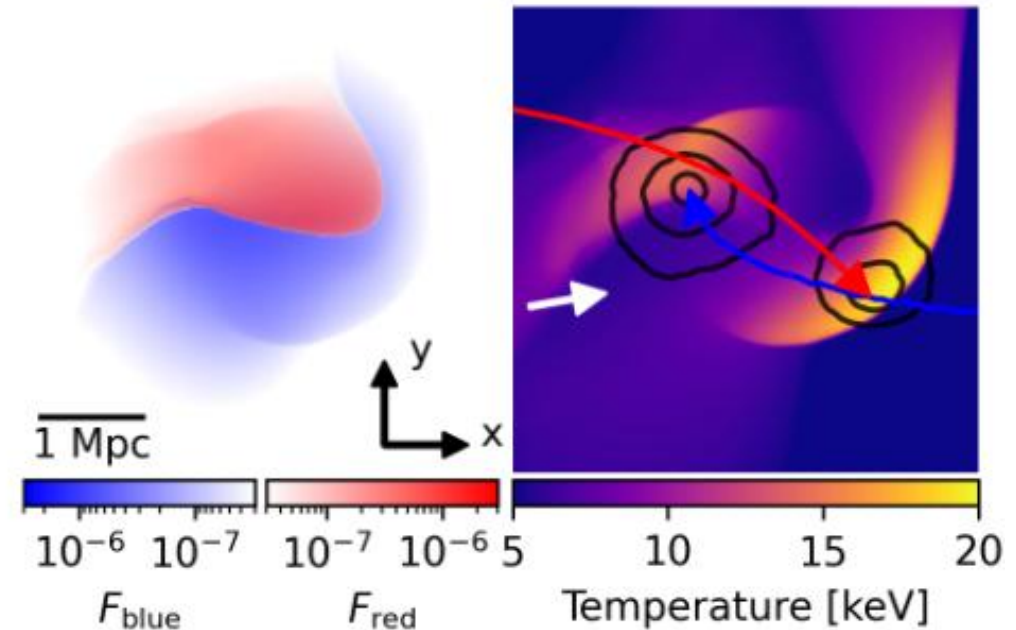
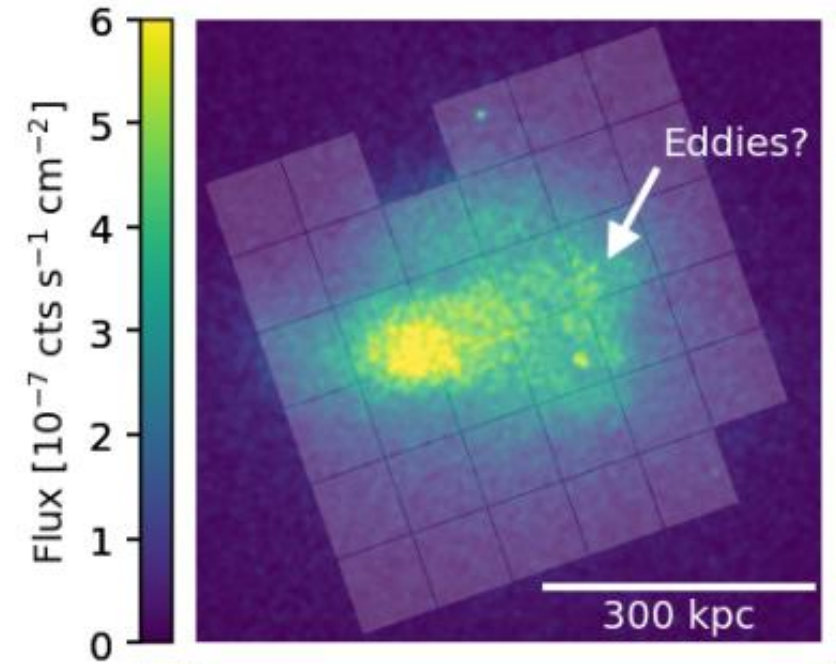
A1914 – a merging cluster along the LOS

A Ying-Yang configuration

~1100 km/s pairwise velocity

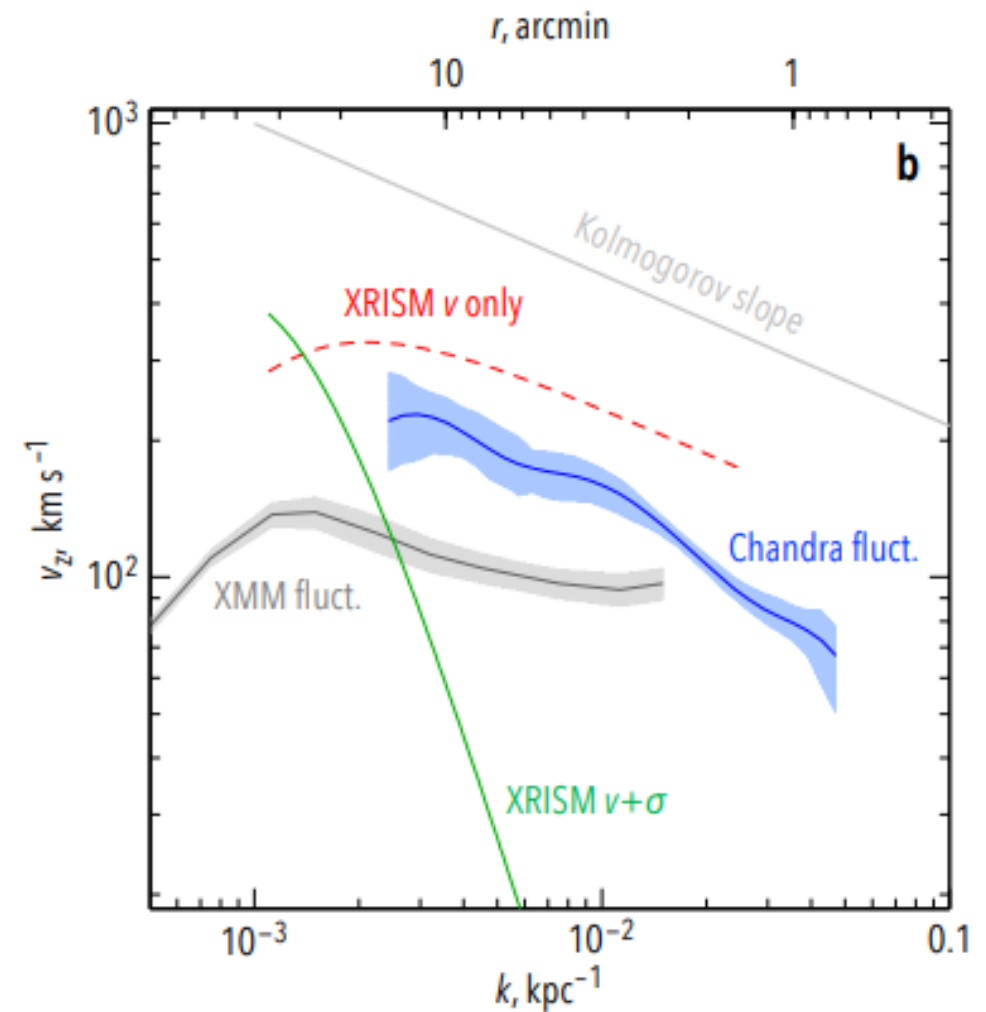
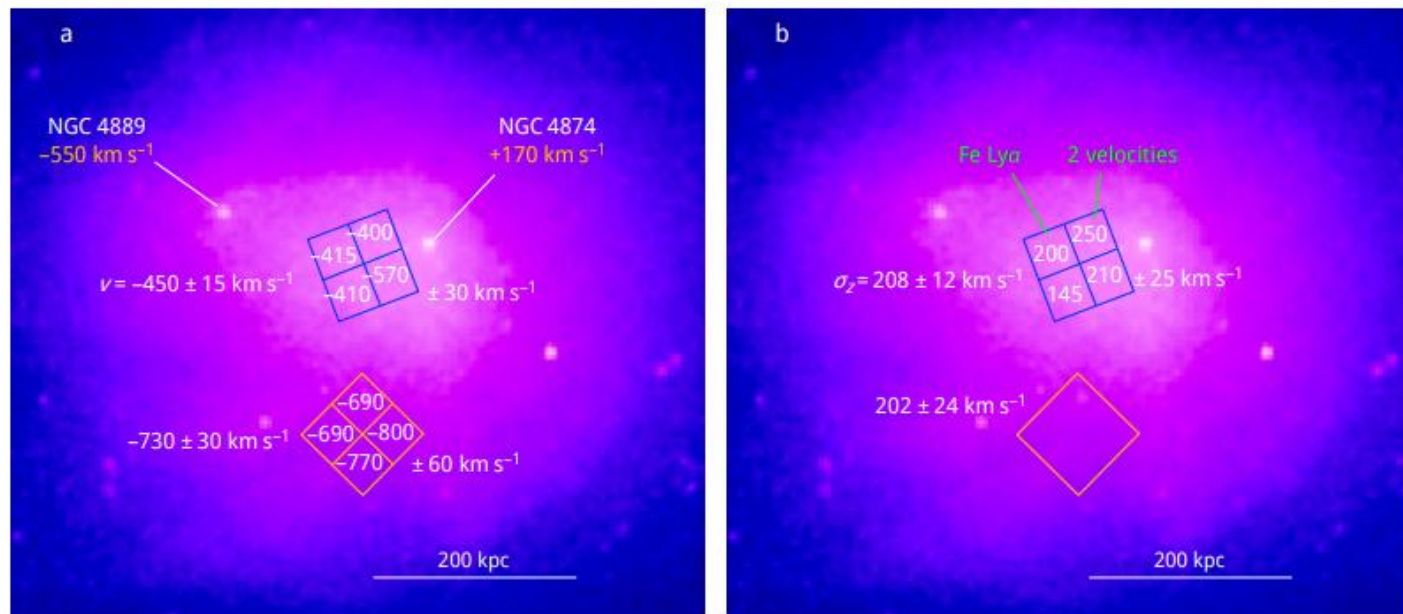


A. Heinrich et al. submitted



Coma cluster

A steep power spectrum – unexpected dissipation scale?



Take home messages

- The era of high-resolution X-ray spectroscopy has already arrived.
- XRISM has delivered exciting results on cluster mergers, AGN feedback, turbulence, etc.
- All PV data have been released since September.