XRISM status and challenges on galaxy clusters

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On behalf of the XRISM EGD working group (chairs : Fujita & Zhuravleva)

The XRISM revolution

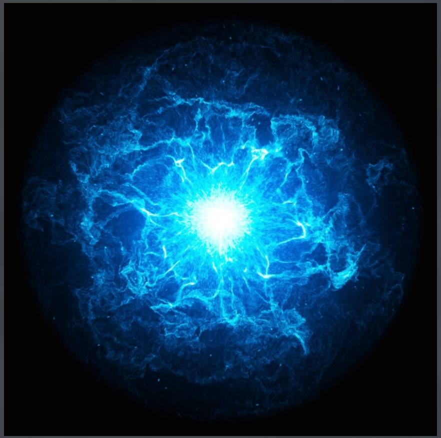
XRISM brings unique constraints on several fields of galaxy cluster science

Structure formation induced merger dynamics

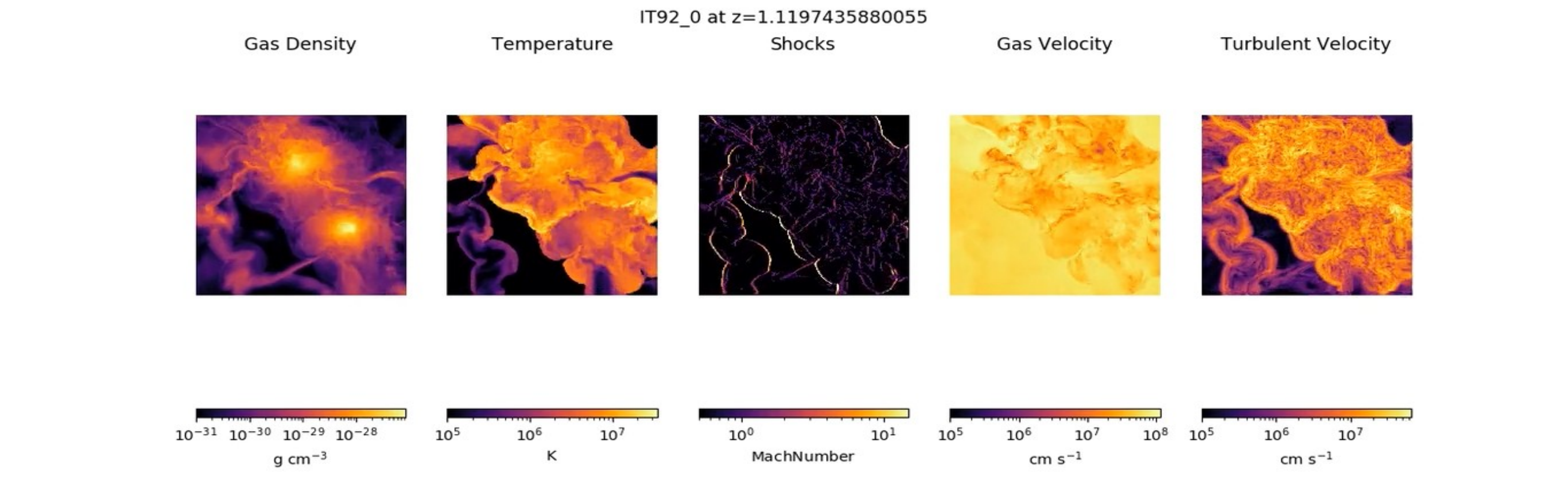
AGN feedback dynamics and thermalization

Chemical enrichment history and abundance of rare elements

Plasma diagnostics and temperature structure



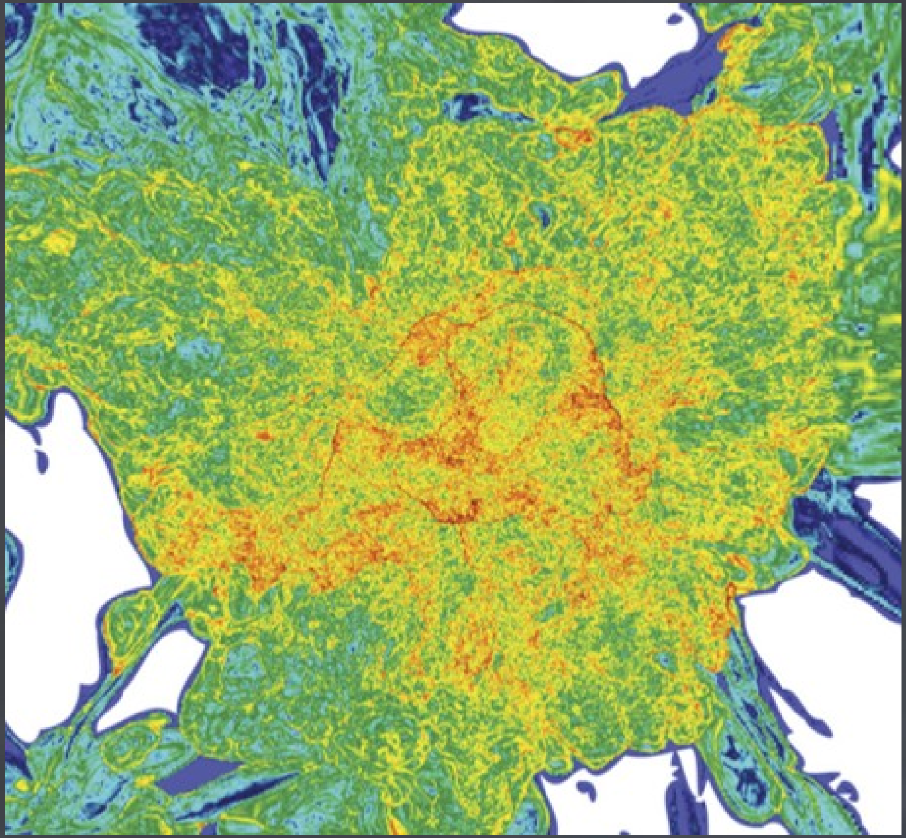
The velocity field of galaxy clusters



Vazza et al. 2018

Random gas motions in galaxy clusters

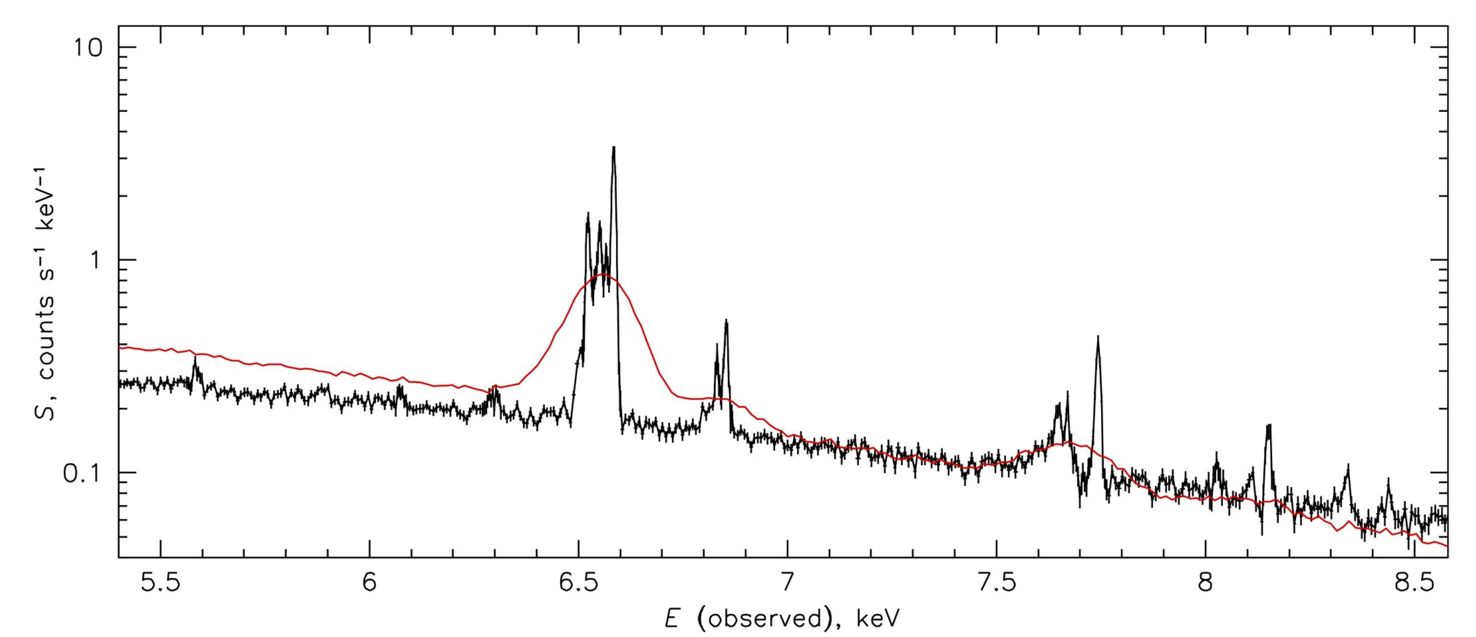
- A fraction of the energy injected by structure formation processes is *not thermalized*
- Simulations predict that the majority of the unvirialized energy should be in the form of random/turbulent motions
- High spectral resolution is required to study the velocity field !



Miniati et al. 2014

The XRISM Revolution

- X-ray micro-calorimeters provide for the first time sufficient energy resolution to detect gas motions in the ICM

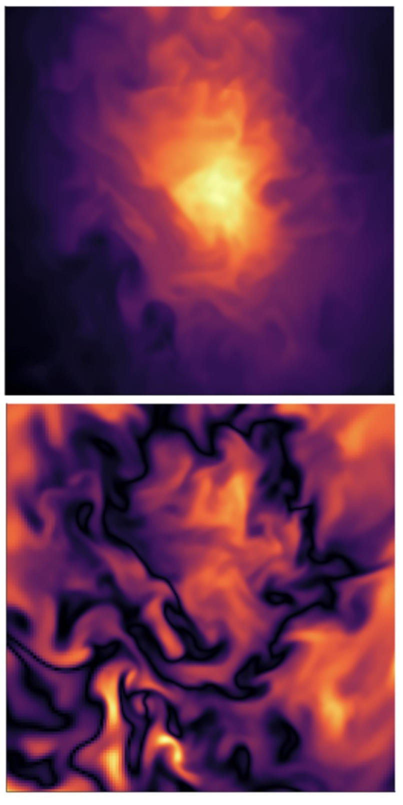


Hitomi Collaboration 2016

What are we really measuring ?

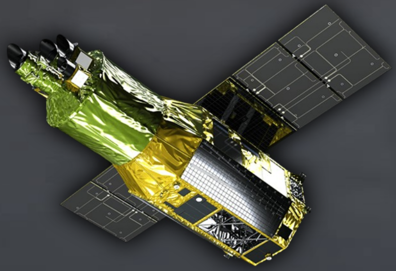
- The measured line widths and line shifts are weighted by the gas emissivity along the line of sight

Emissivity



Velocity

$$v_{bulk} = \frac{\int EM_{3D} v_{1D} dV}{\int EM_{3D} dV}$$



$$\sigma_{1D} = \left(\frac{\int EM_{3D} (v_{1D} - v_{bulk})^2 dV}{\int EM_{3D} dV} \right)^{1/2}$$

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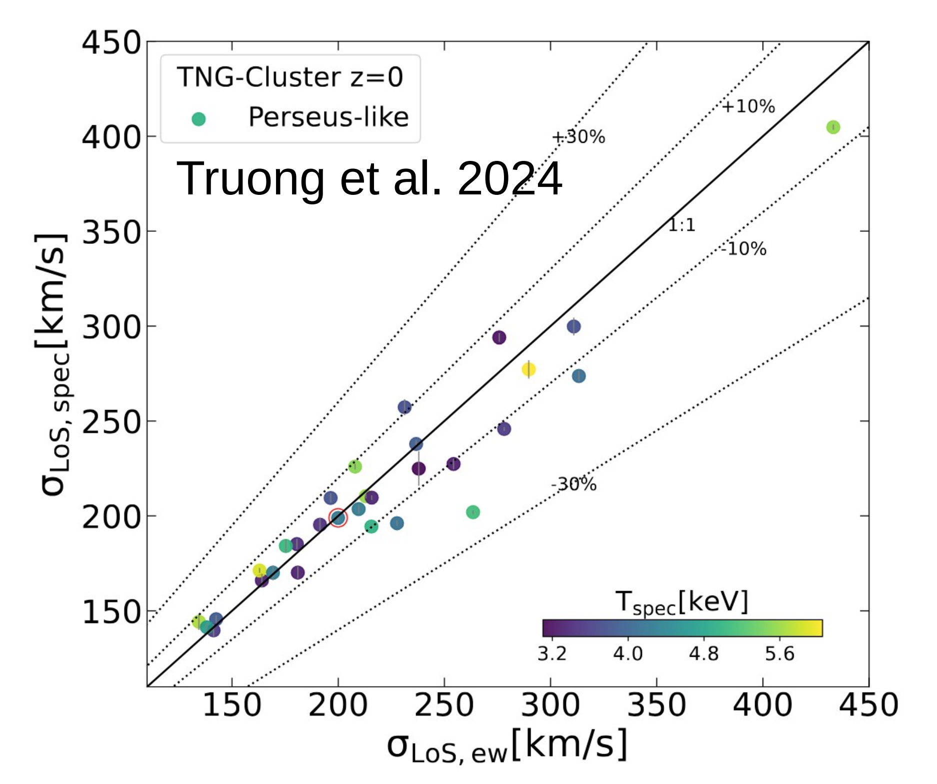
- The measured line widths and line shifts are weighted by the gas emissivity along the line of sight



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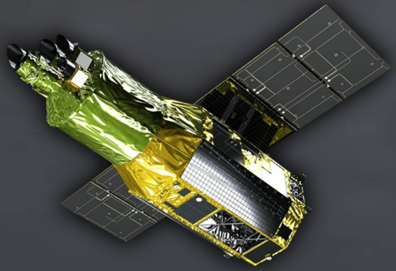

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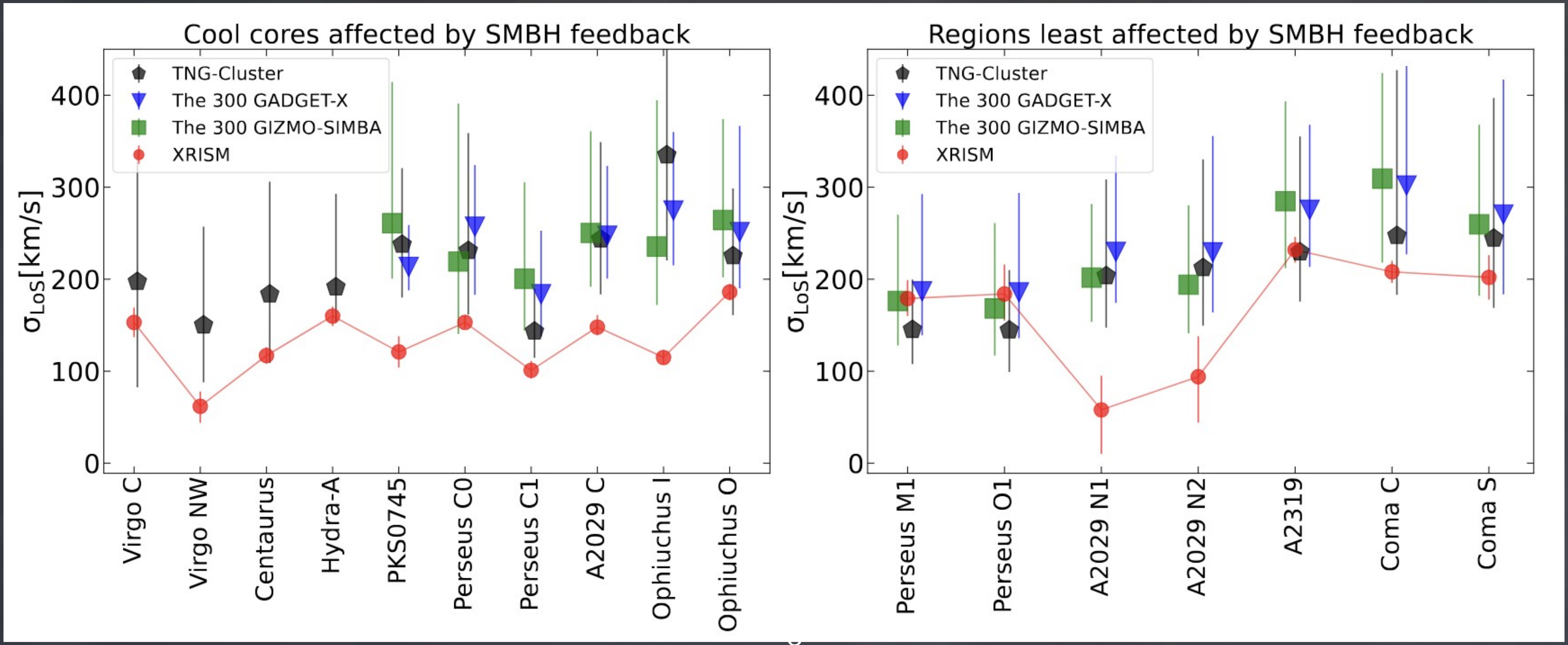
Velocity dispersions are low !

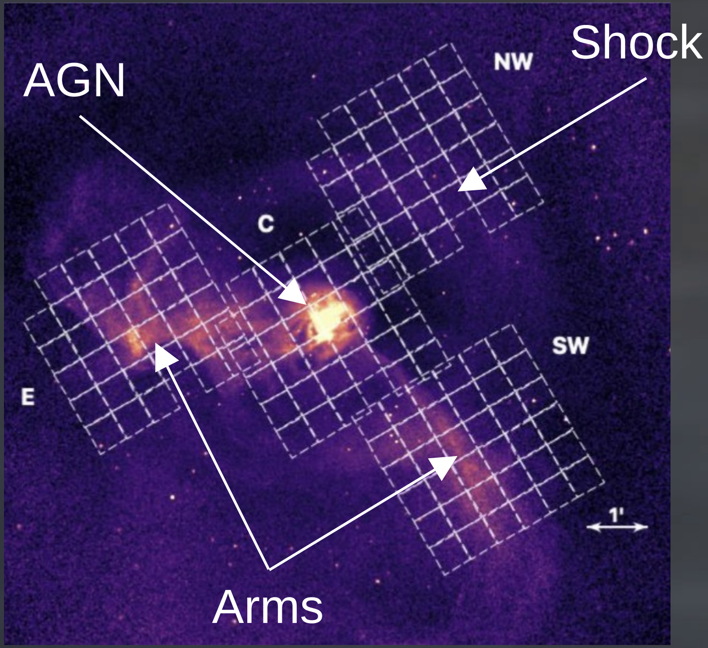
- Velocity dispersions in the range 100-200 km/s are **lower** than predictions from hydrodynamical simulations !



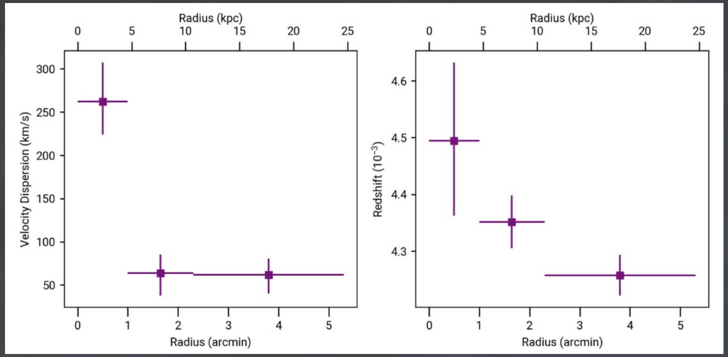
XRISM Collaboration 2025a, CA : Truong

AGN-induced gas motions

- XRISM revealed large l.o.s. dispersion close to the AGN but steeply decreasing with radius

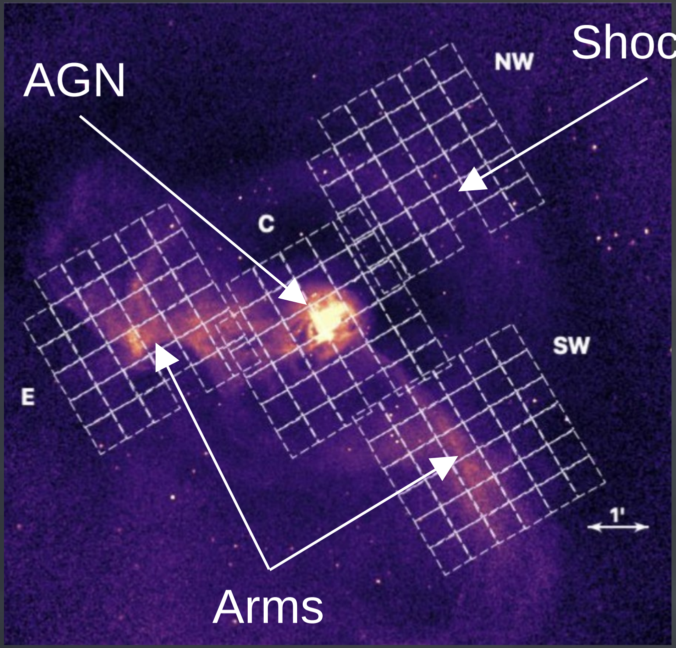


XRISM Collab. 2025b,
CA : McCall

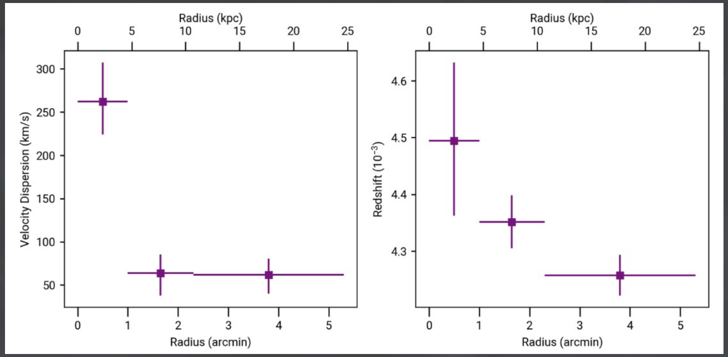


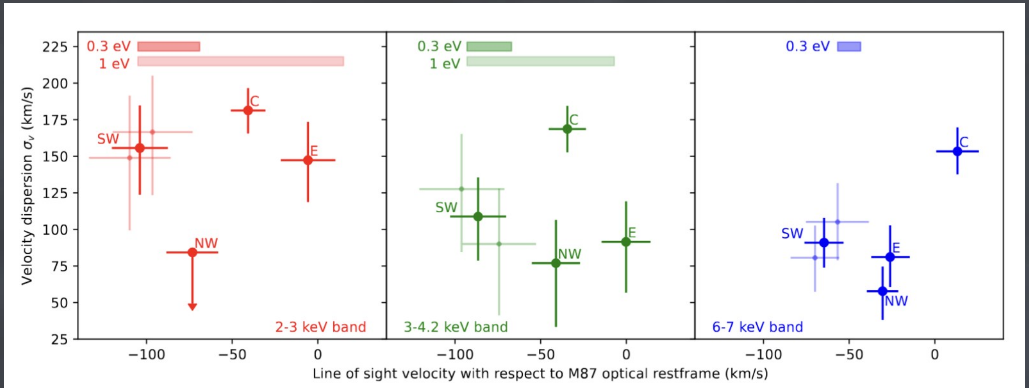
AGN-induced gas motions

- The SW arm seems to be moving towards us, whereas the E is receding… but beware of energy gain calibration !



XRISM Collab. 2025b,
CA : McCall

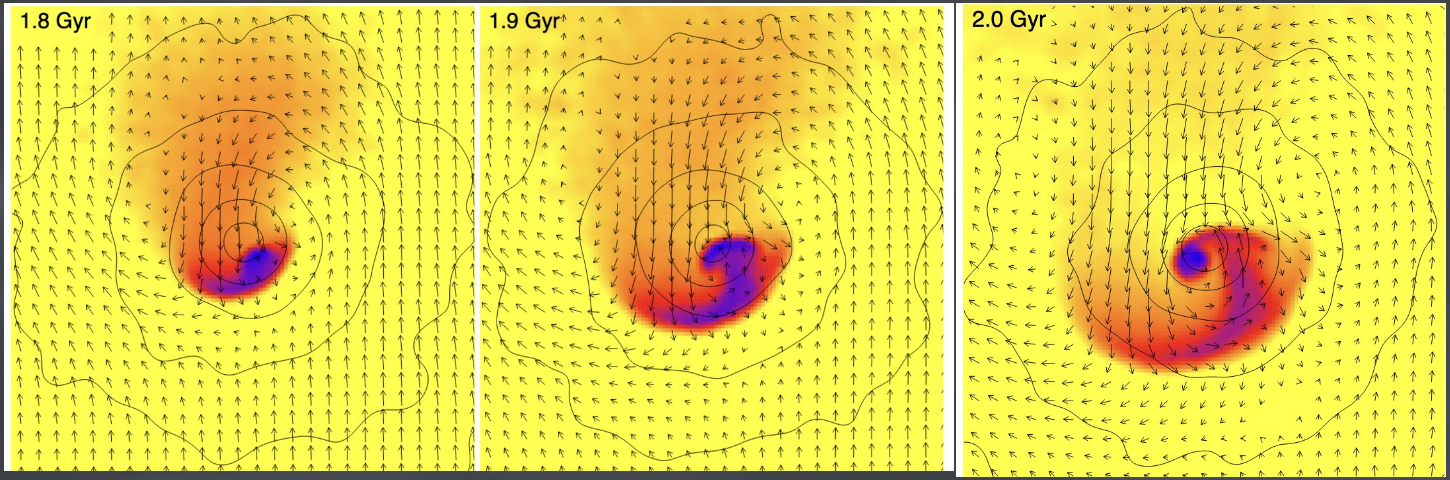




Simionescu et al. subm.

Gas sloshing

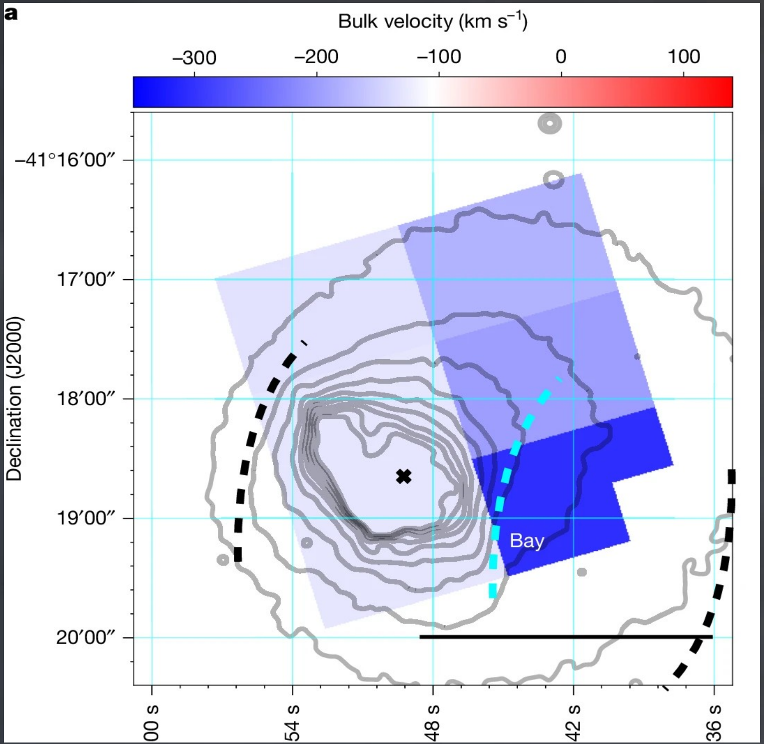
- In the presence of an off-axis perturber the gas will oscillate (*slosh*) at the bottom of the potential well

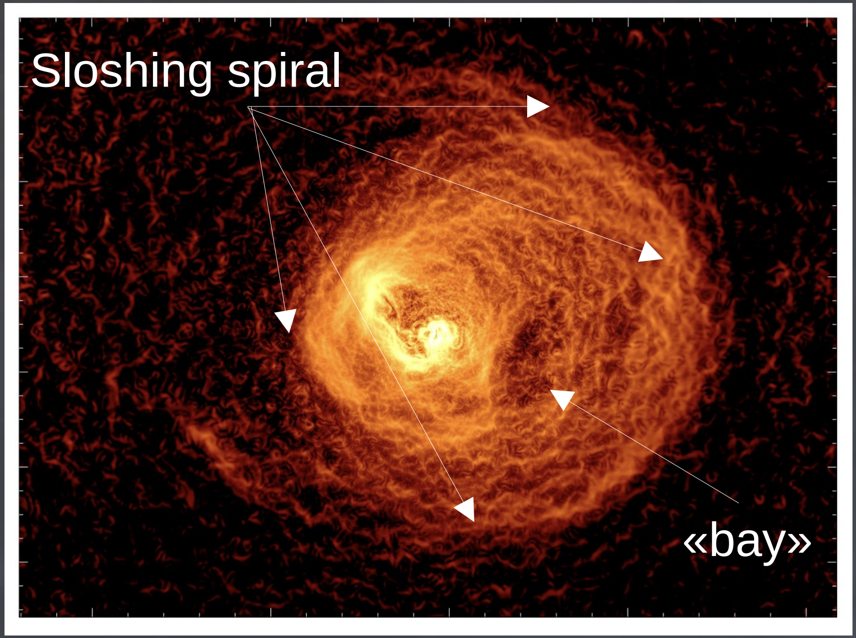


Ascasibar & Markevitch 2006

Bulk velocities in Centaurus

- XRISM detects large bulk velocities associated with sloshing features

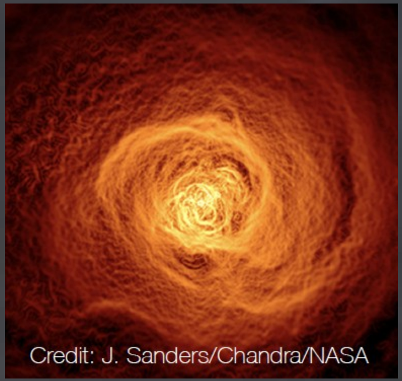


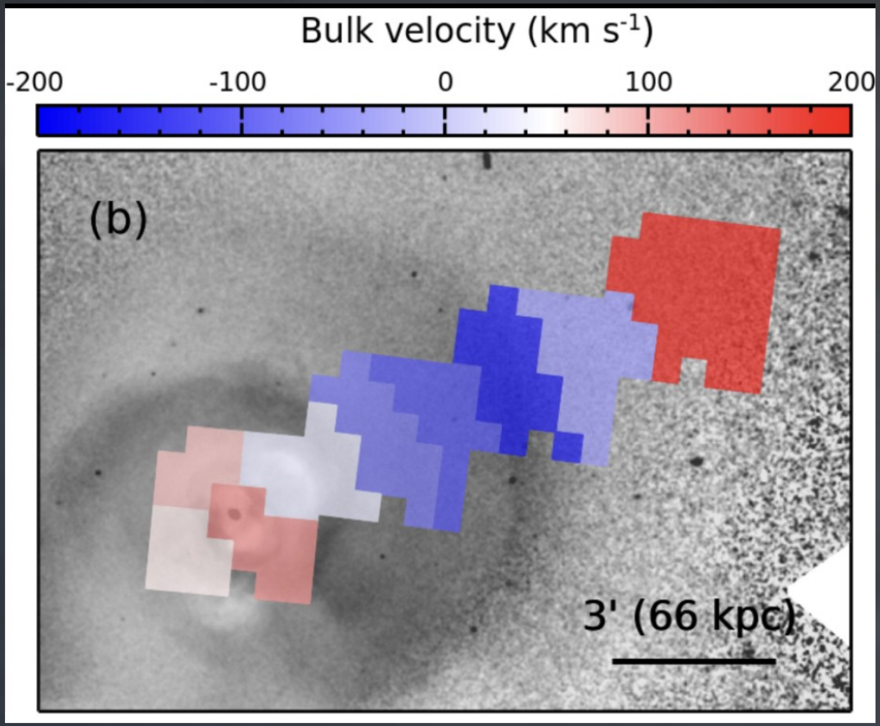


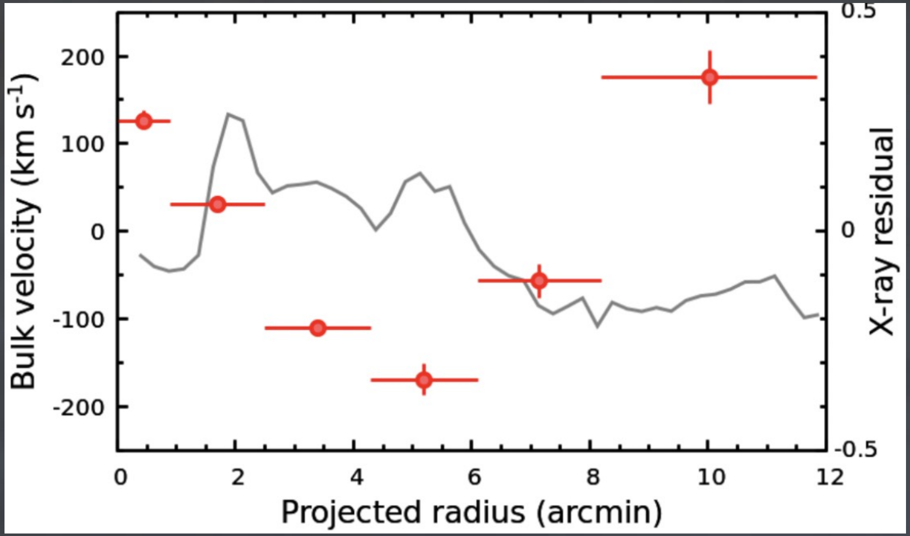
XRISM Collaboration 2025c, Nature
CA : Fujita

Perseus cluster

- Bulk velocity pattern in Perseus follows sloshing spiral



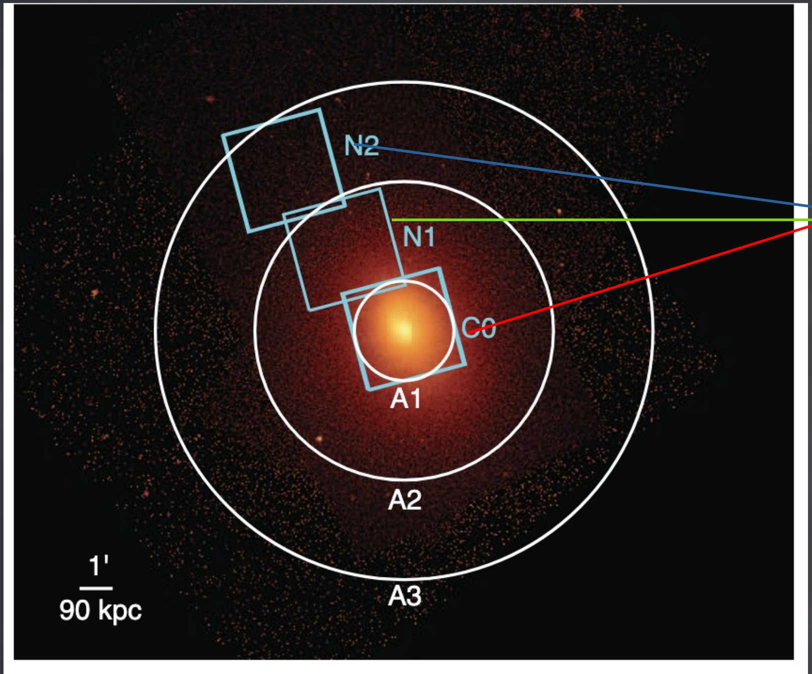


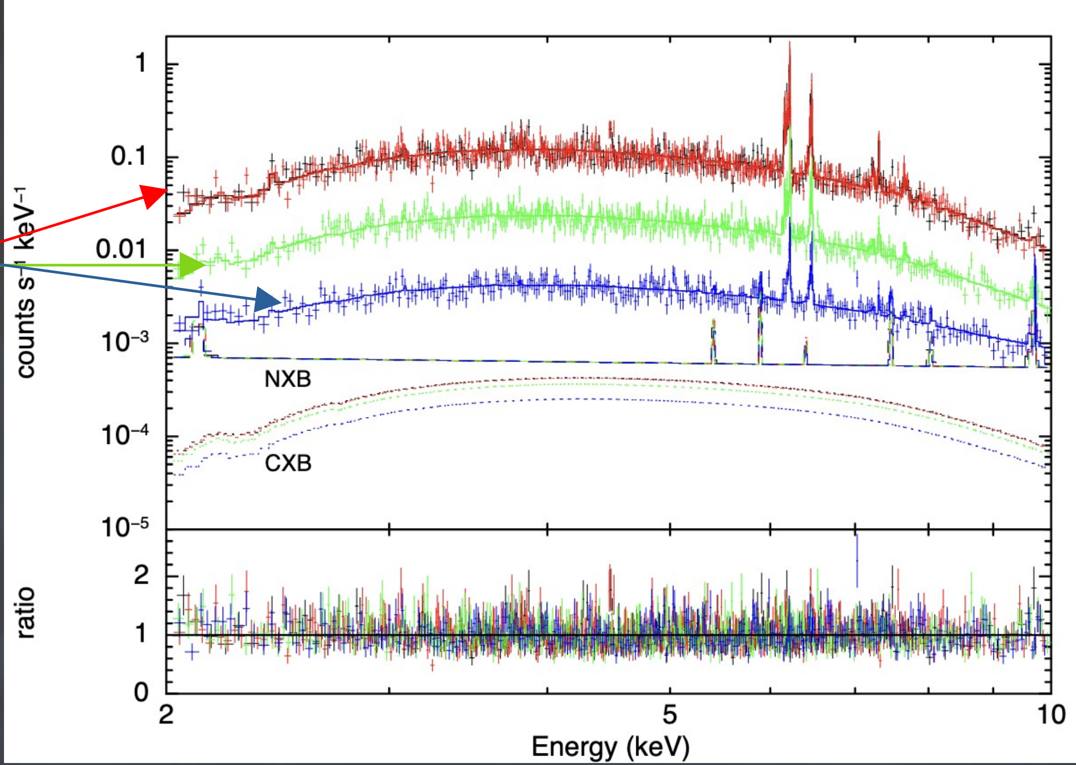


XRISM Collab. 2025d, Nature in press
CA : Zhuravleva

Radial velocity profile in A2029

- Velocity measurements out to ~650 kpc in A2029





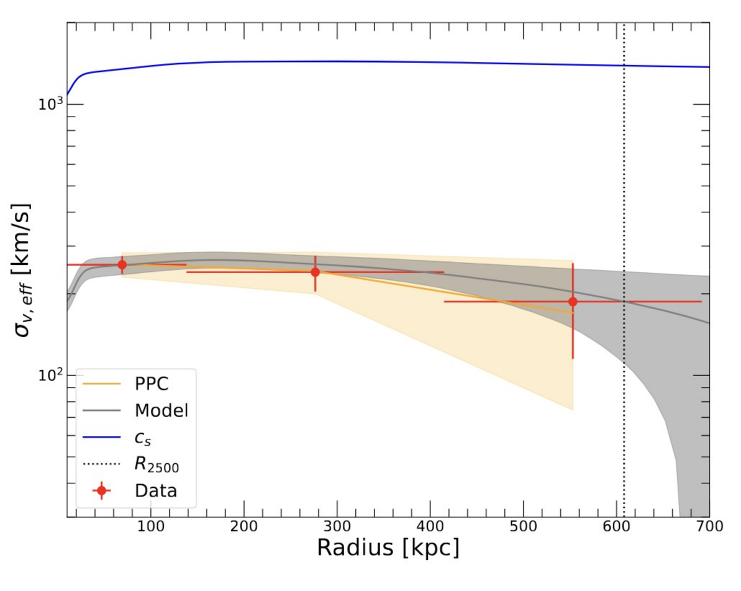
XRISM Collab. 2025e, CA : Miller
XRISM Collab. 2025f, CA : Ota

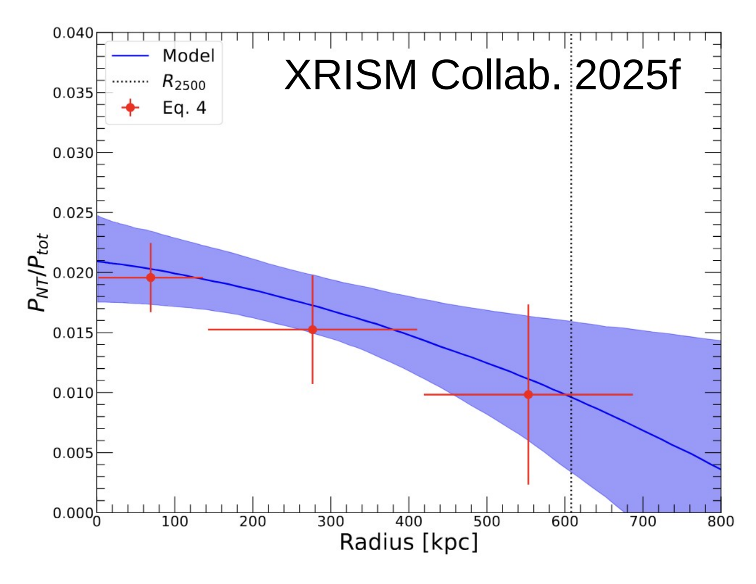
Abell 2029 non-thermal pressure

- Non-thermal energy in A2029 is low (<2 %) at least out to 650 kpc

$$\alpha = \frac{P_{\rm NT}}{P_{\rm tot}} = \frac{\mathcal{M}_{\rm 3D,eff}^2}{\mathcal{M}_{\rm 3D,eff}^2 + \frac{3}{\gamma}}$$

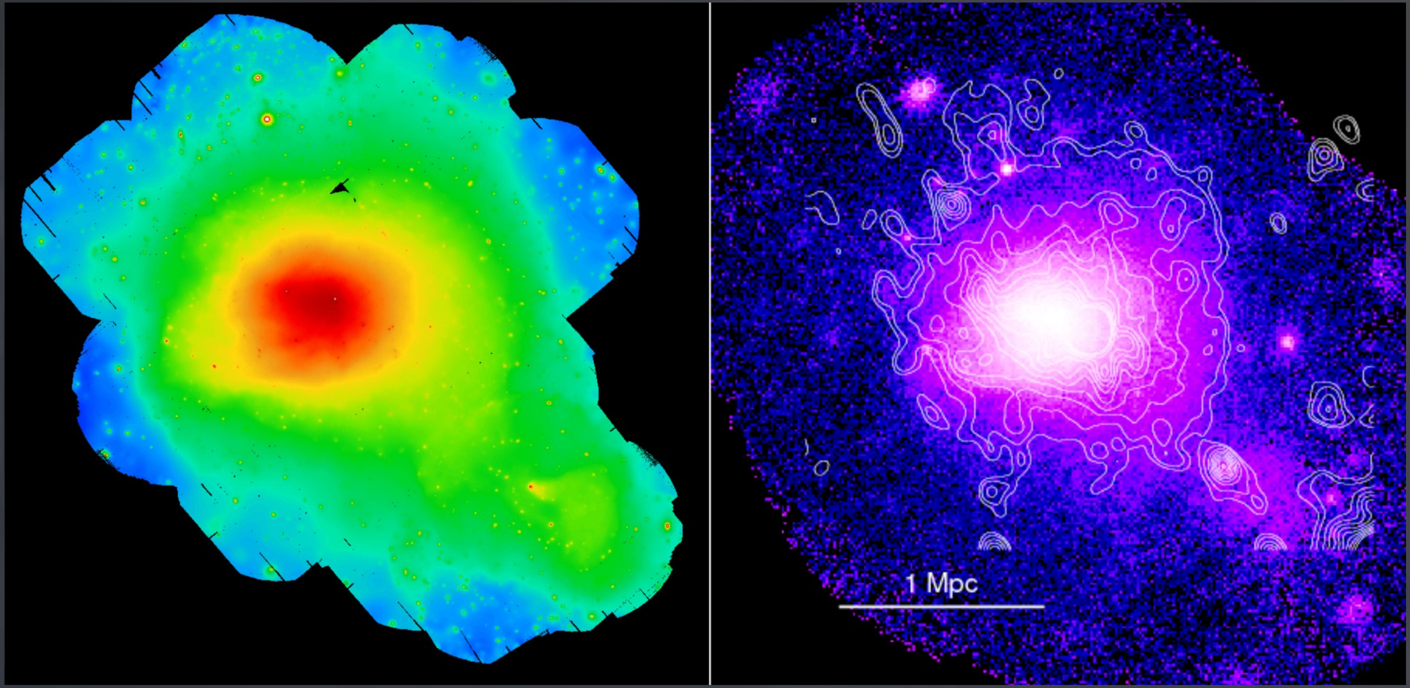
$$\mathcal{M}_{\rm 3D,eff} = \frac{\sigma_{v,\rm eff}}{c_s} = \frac{\sqrt{3\sigma_v^2 + v_{\rm bulk}^2}}{c_s}$$





Merging clusters : the case of Coma

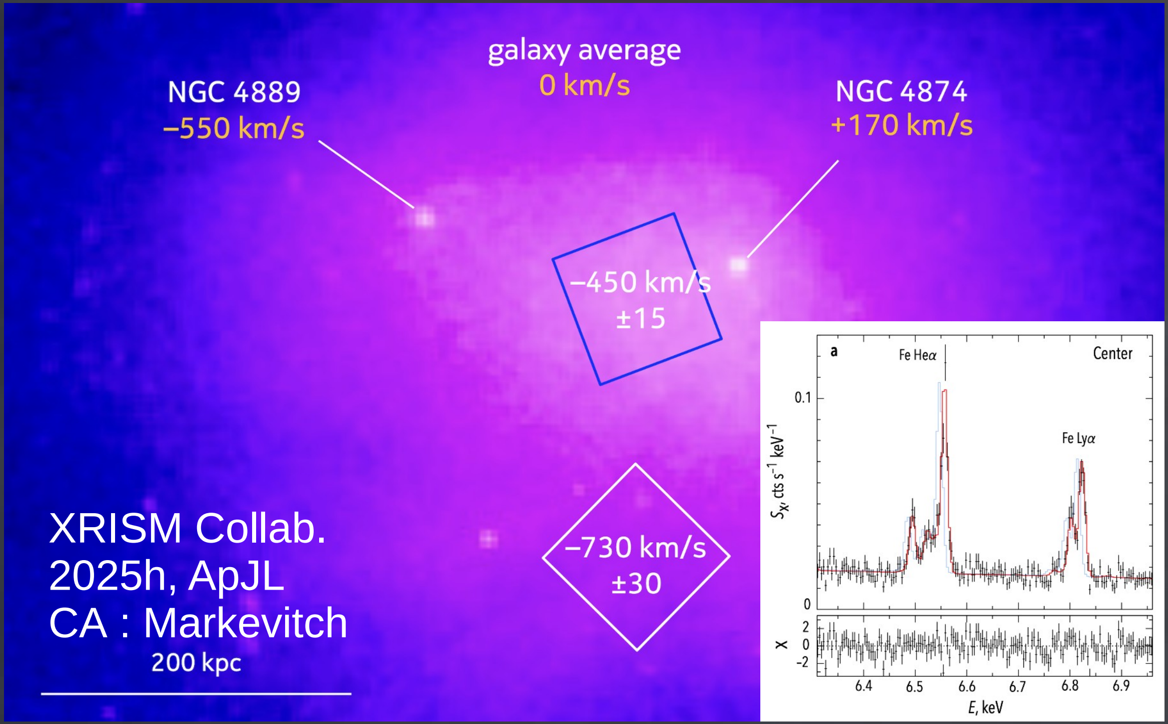
- One of the best studied clusters. Major merger at z=0.023. Prototypical giant radio halo

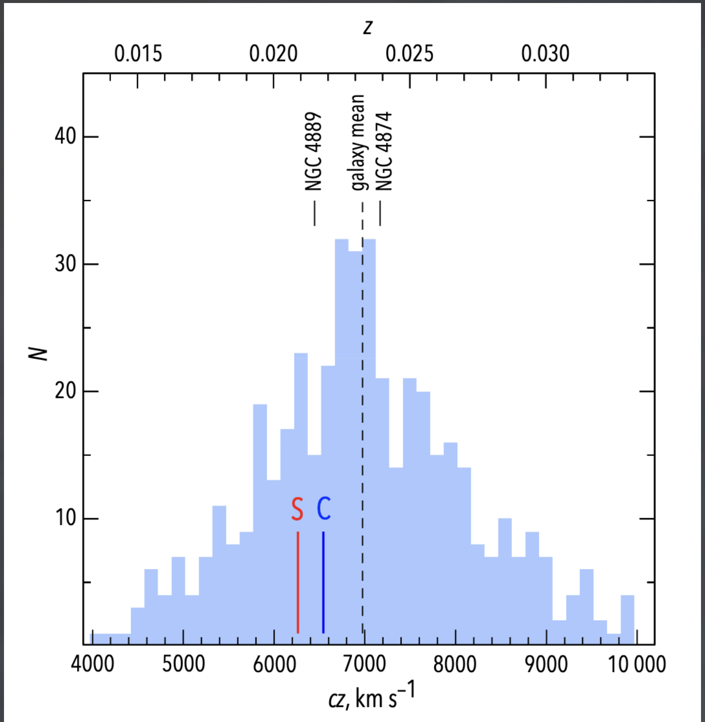


See also :
A2319, XRISM 2025g
CA : Nakazawa
A3667, Omiya+25

Large bulk velocities in Coma

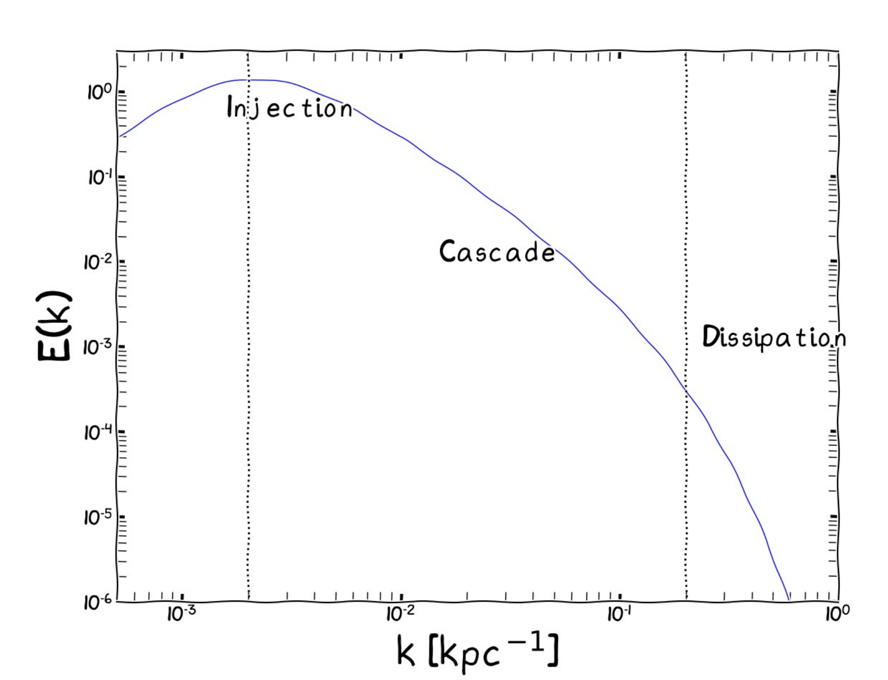
- The gas is blue-shifted by >700 km/s with respect to the galaxies !





Characterizing turbulence

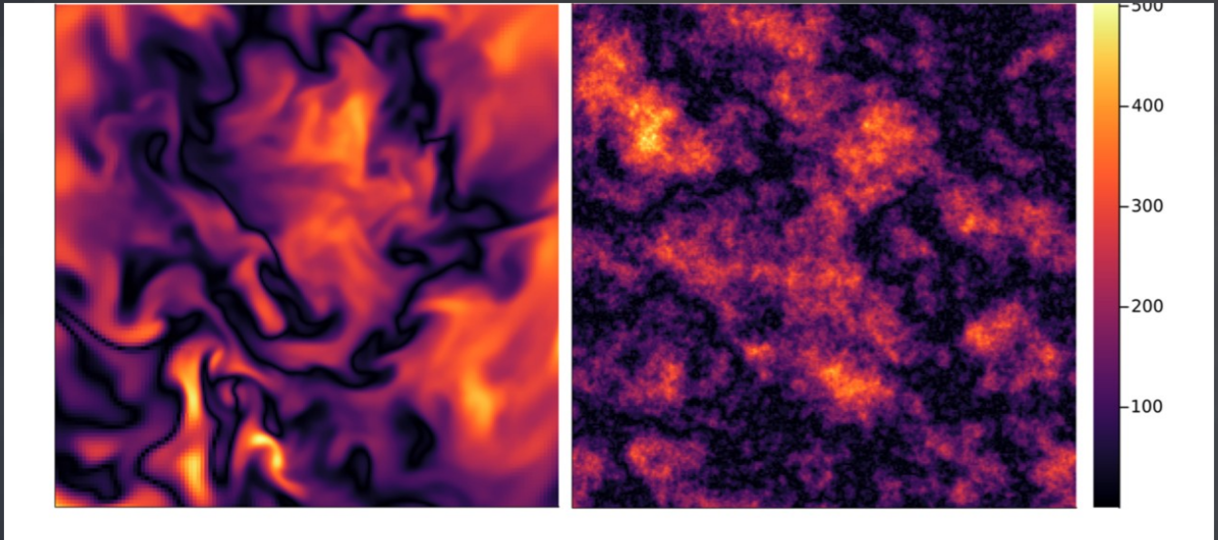
- The statistical properties of the velocity field are characterized by the fluctuation power spectrum P(k)

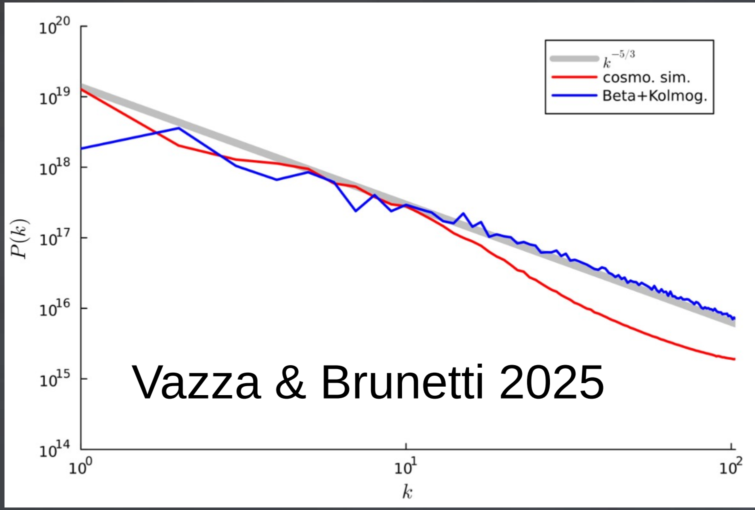


Kolmogorov spectrum:
Energy slope -5/3

Turning XRISM data into power spectrum constraints

- Challenge : the same power spectrum corresponds to very different looking velocity fields

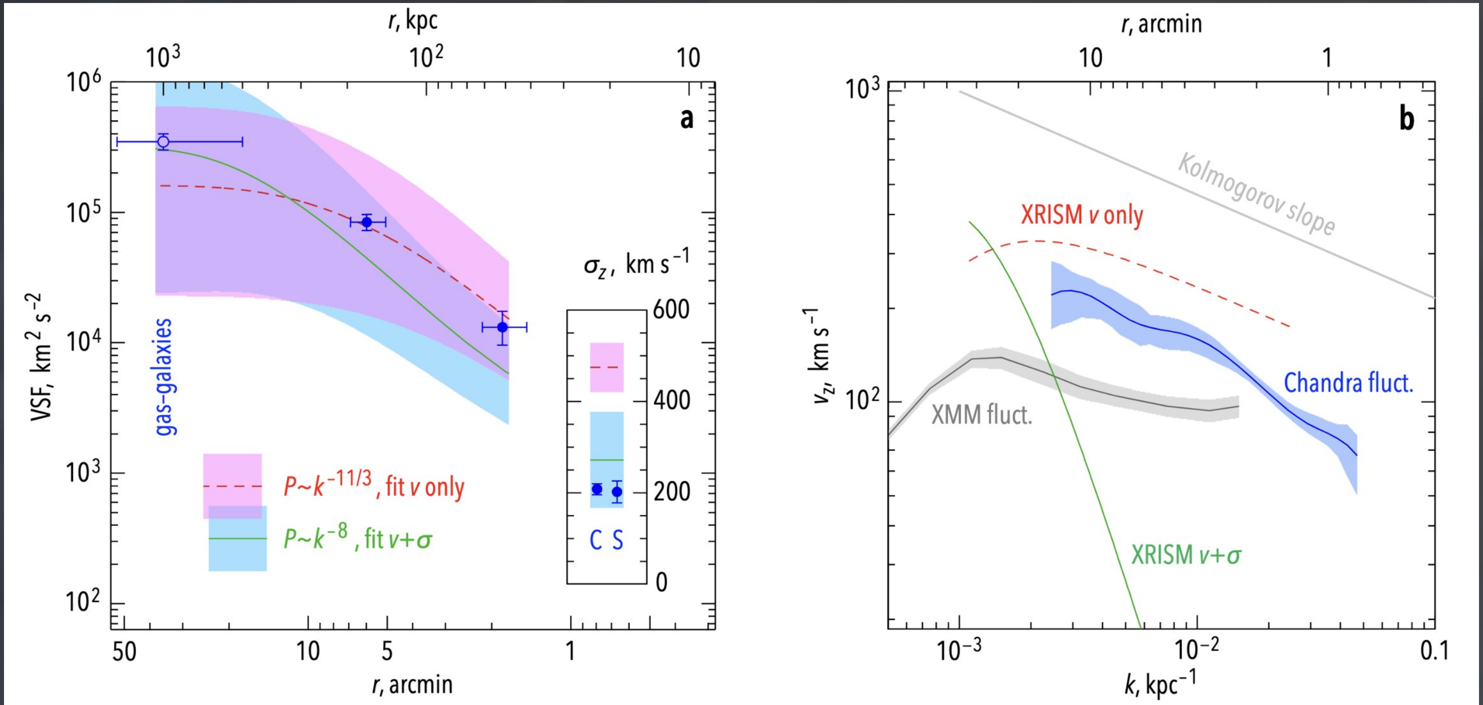




- We can i) fit for a summary statistic, e.g. the velocity structure function ; ii) forward model the measurements given a model power spectrum

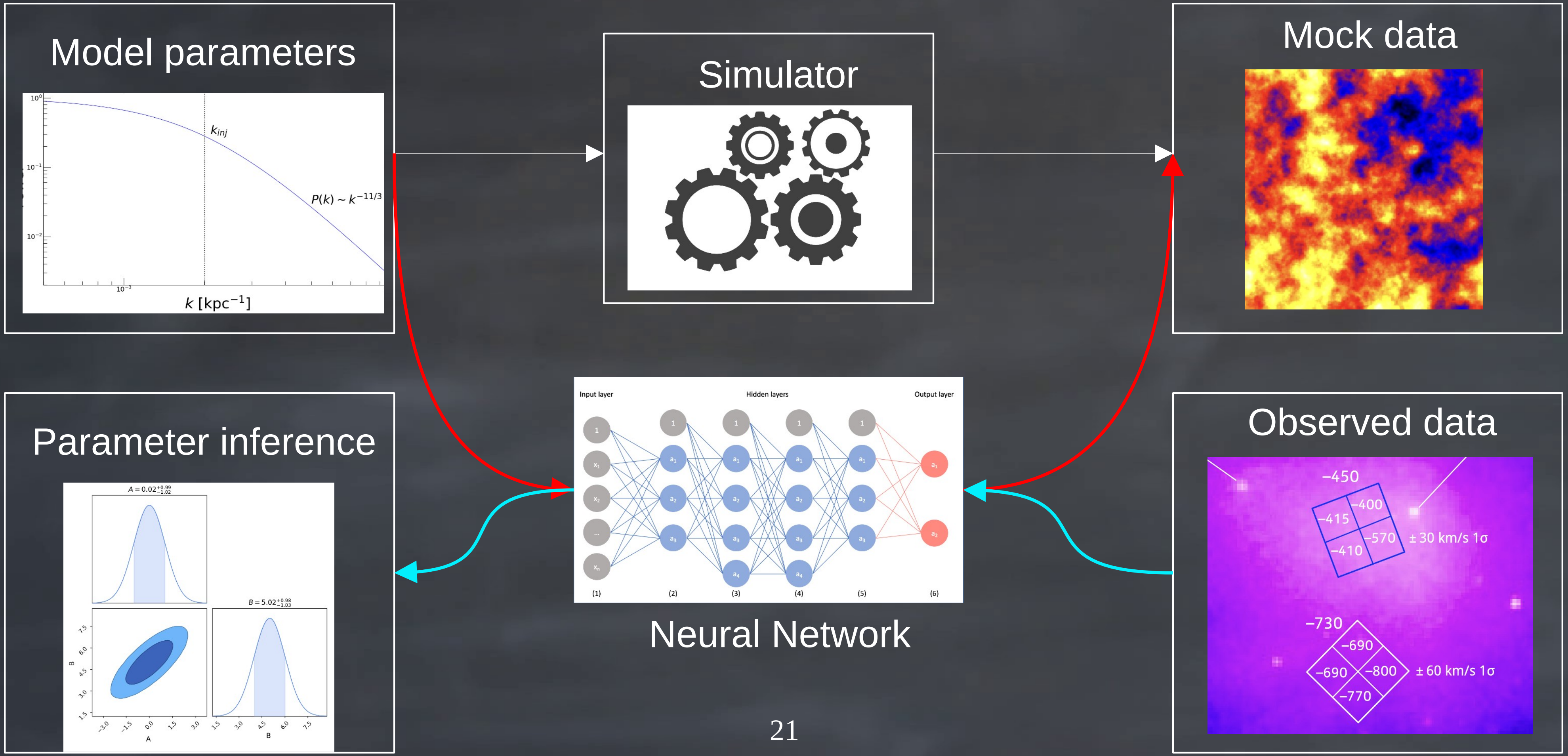
Implications for the velocity power spectrum

- We observe high bulk velocities, but low dispersions… how can this be ?



- Large-scale motions must dominate, i.e. the PS must be steep !

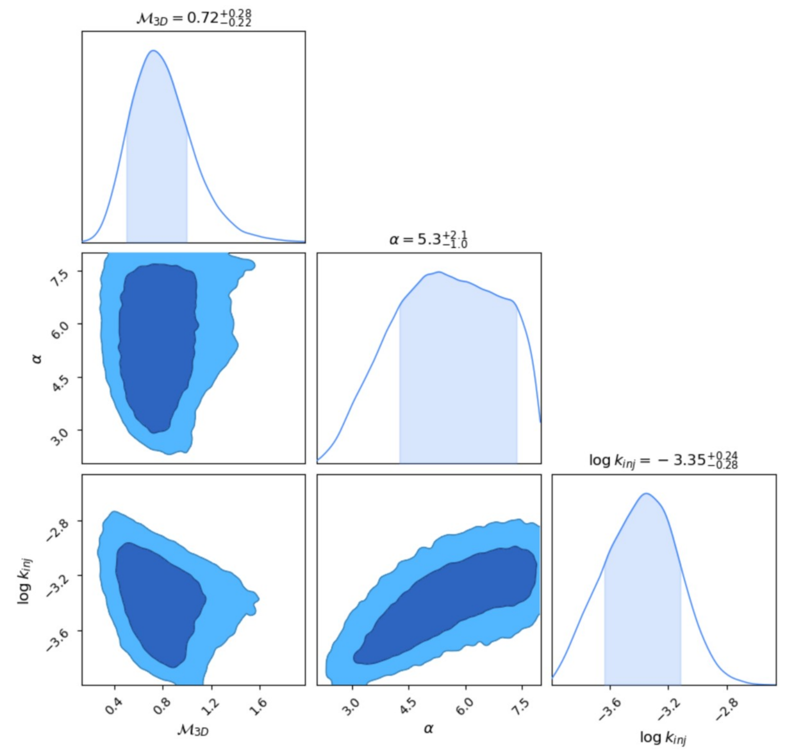
Simulation based inference (SBI)

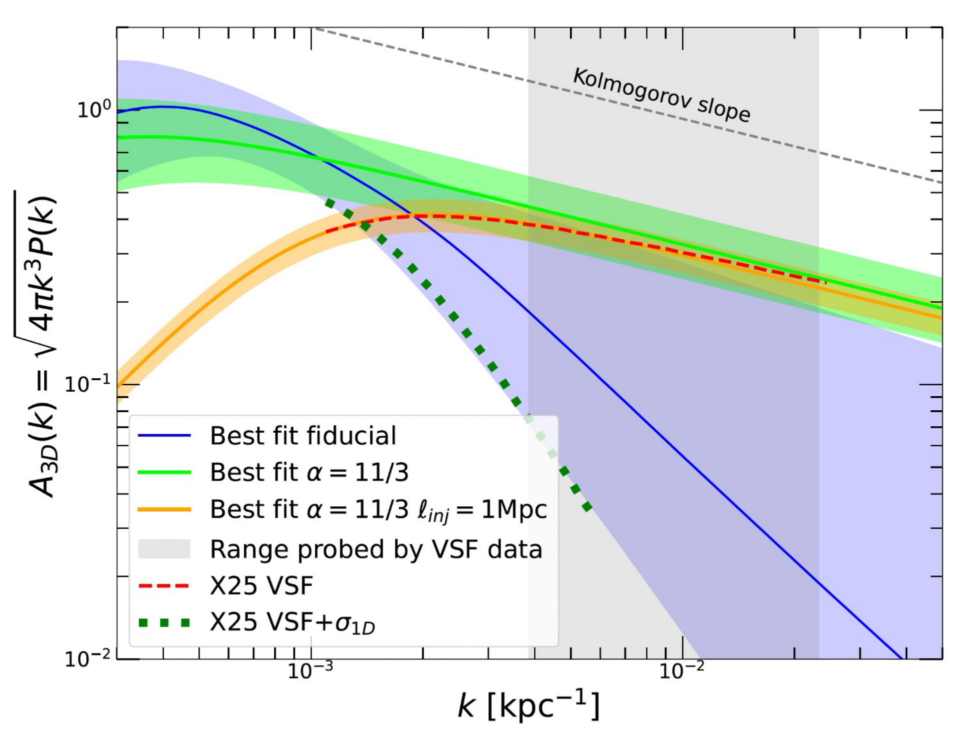


See also talks by Molin, Barret, Buchner

Power spectrum constraints from SBI

- To fit the data we require very large injection scales (>2 Mpc)

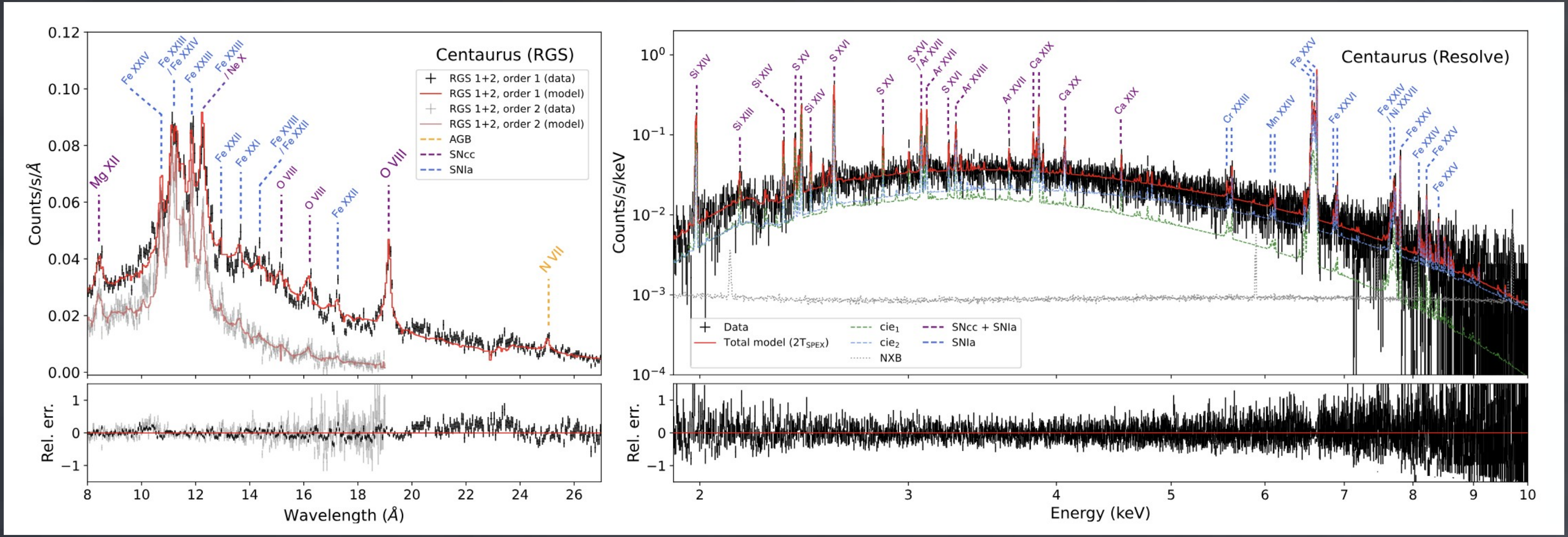




Eckert et al. 2025

Chemical enrichment

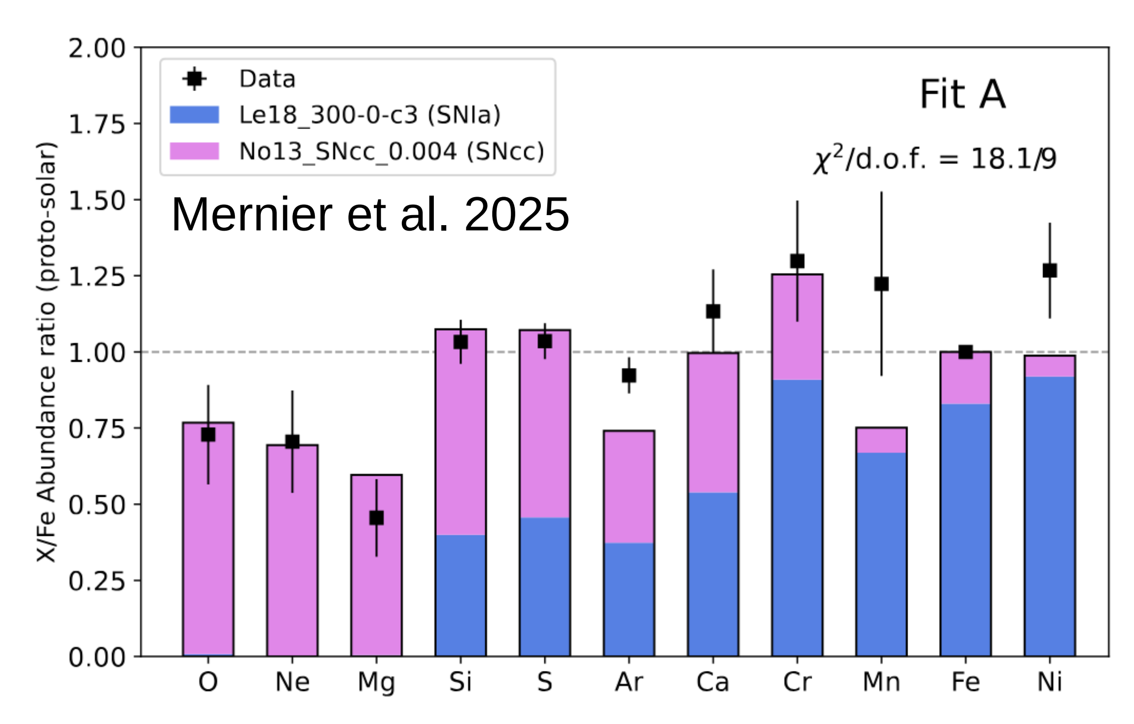
- High spectral resolution data constrain the metallicity of rare elements



Centaurus cluster XRISM+RGS, Mernier et al. 2025

Metal enrichment pattern

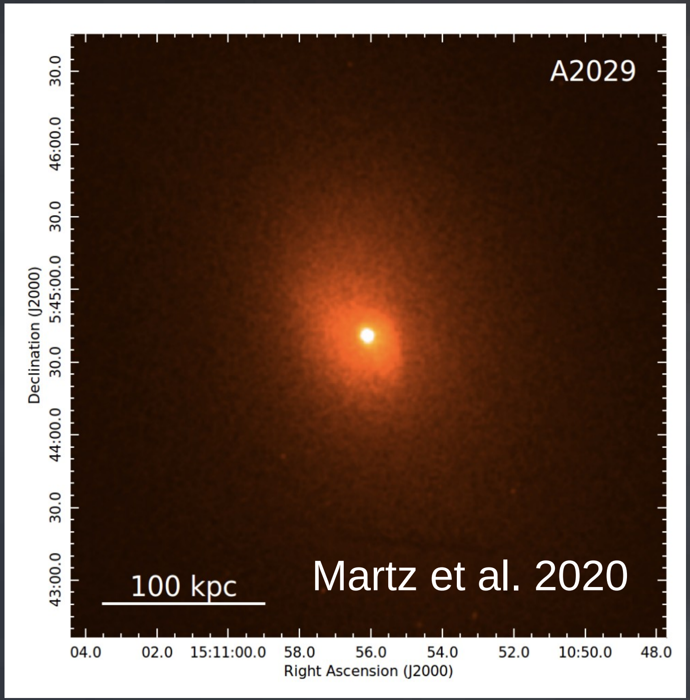
- Metal abundance pattern constrains the total contribution of SN Ia and SN cc to chemical enrichment… but beware of uncertainties on SN yields !

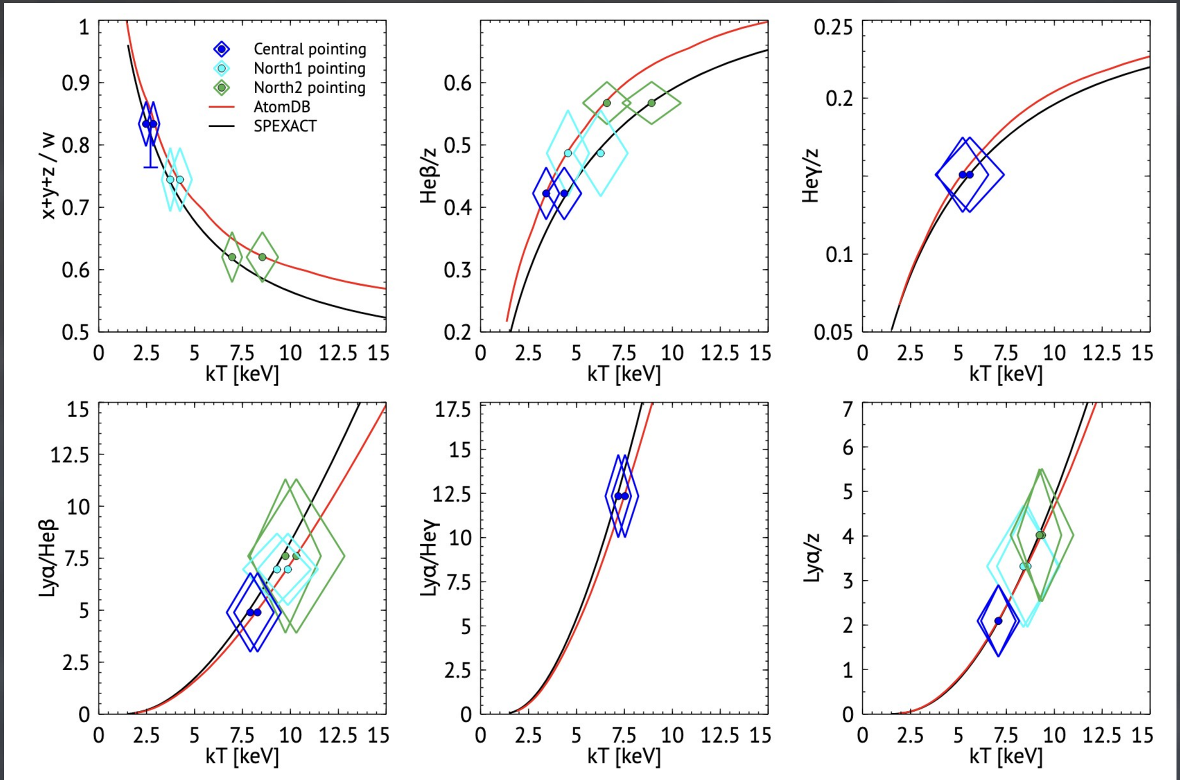


See also :
Ophiuchus, Fujita+25
A2029, Sarkar+25a

Temperature structure

- Various line ratios constrain multi-temperature structure along the line of sight



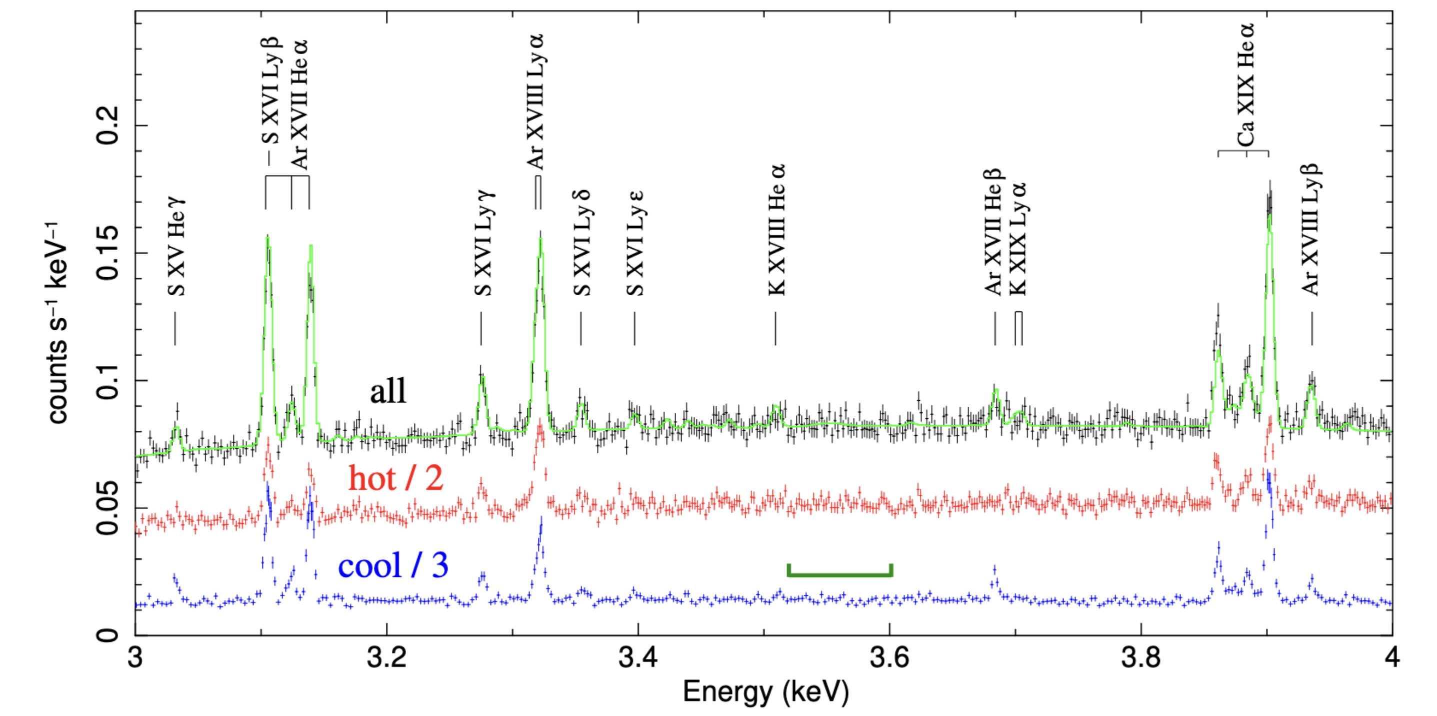


See talk by Liyi Gu

Sarkar et al. 2025b

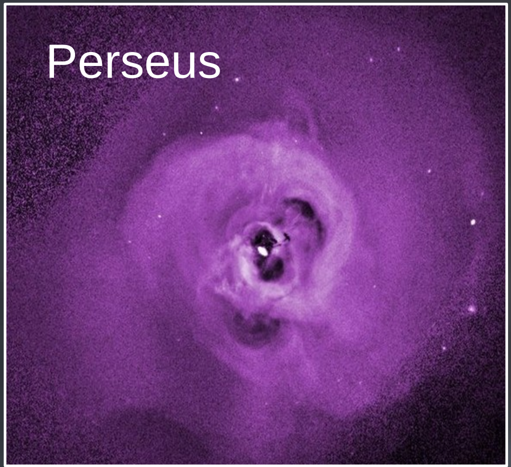
Search for unidentified lines

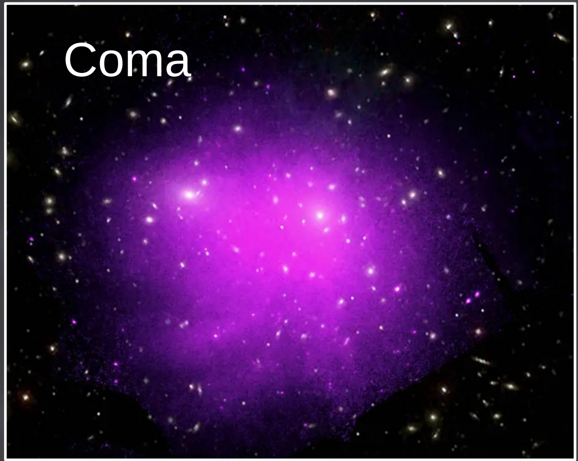
- No evidence for unknown emission lines (in particular 3.5 keV) in stacked data, although the depth is still insufficient to exclude previous claims

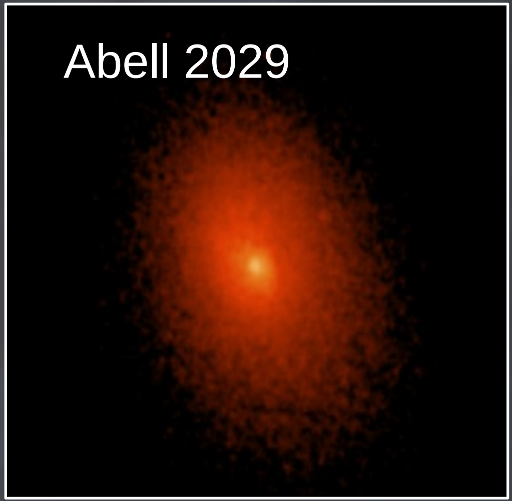


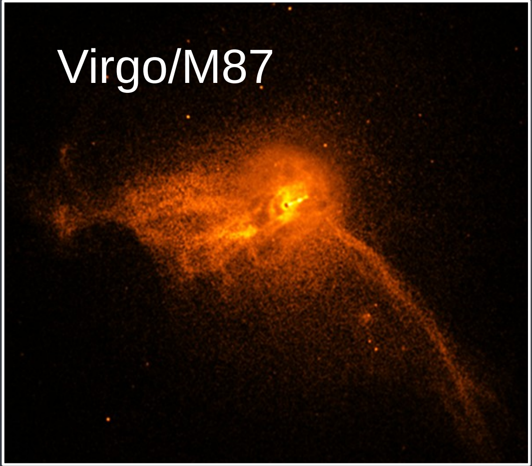
XRISM Collab. 2025h, CA : Sun

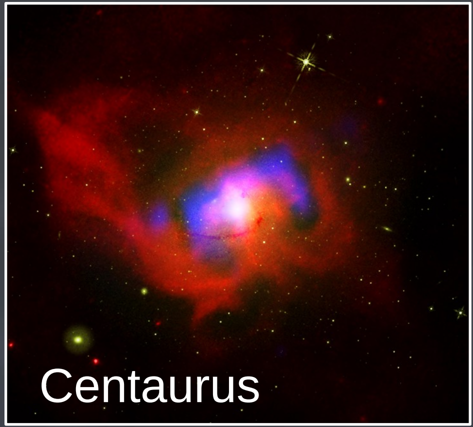
Summary : XRISM results on clusters





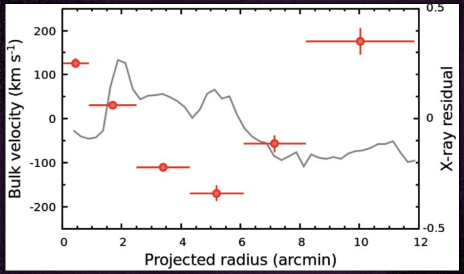




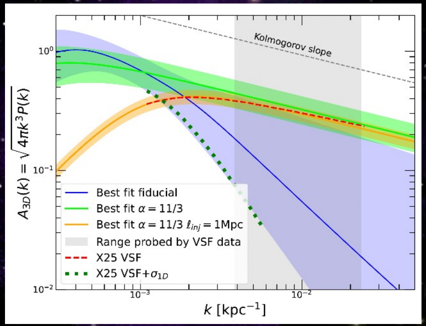


Summary : XRISM results on clusters

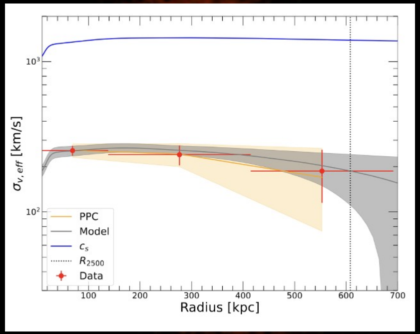
Perseus



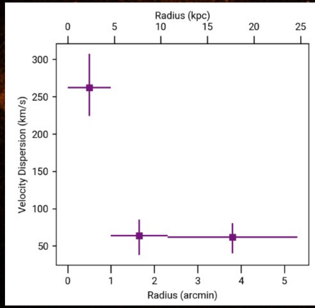
Coma

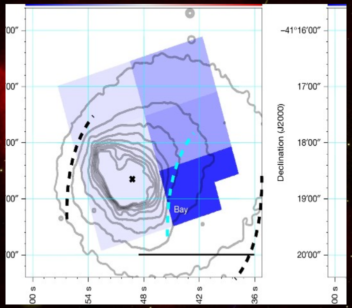


Abell 2029



Virgo/M87





Centaurus