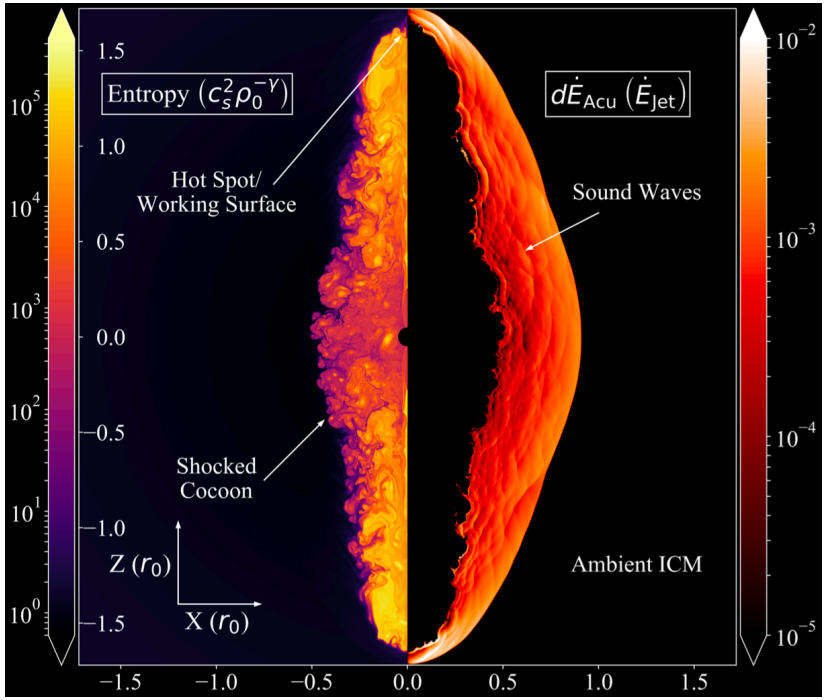
Plasma and atomic astrophysics:
some controversies and some improvements

Liyi Gu (RIKEN)

The only sin we can forgive to each other is having different opinions. – Ralph Emerson

Hitomi observation and plasma physics

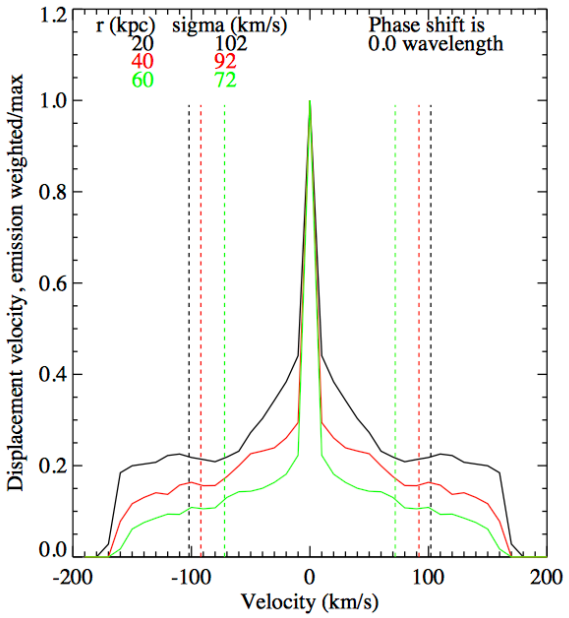
- Hitomi detected less than ~ 200 km/s turbulence in the Perseus cluster center, energy content ~4% of the thermal energy, turbulence energy dissipated locally

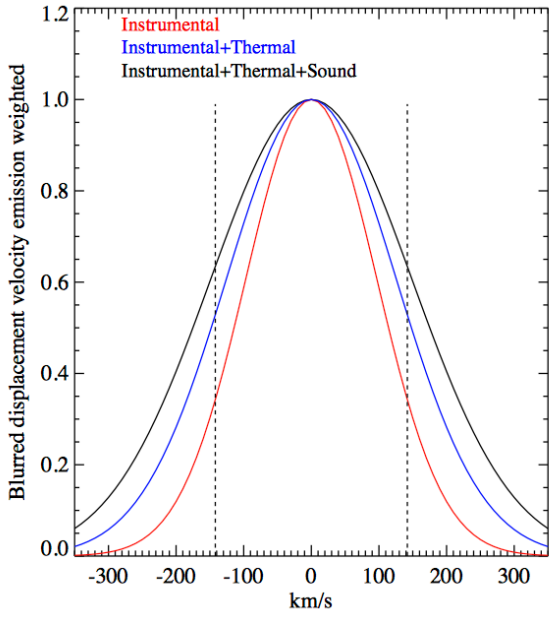


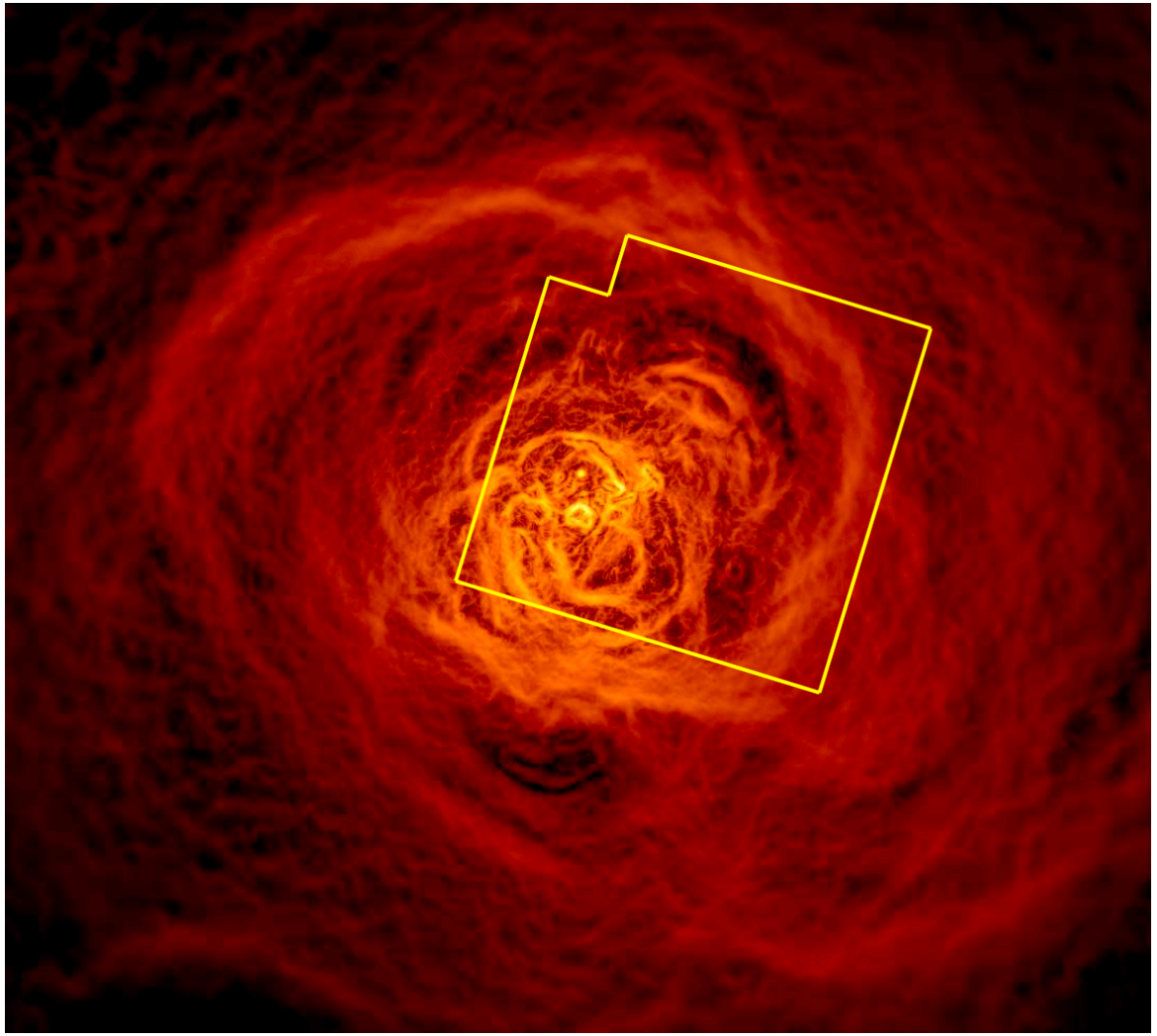
- AGN jet energy transported by sound waves across the cool core
- Member galaxies dissipate energy as they fly through the core

AGN sound wave

Small non-Gaussianity on the line.
Can we distinguish it from other line broadening process? What energy resolution is required to measure sound wave?







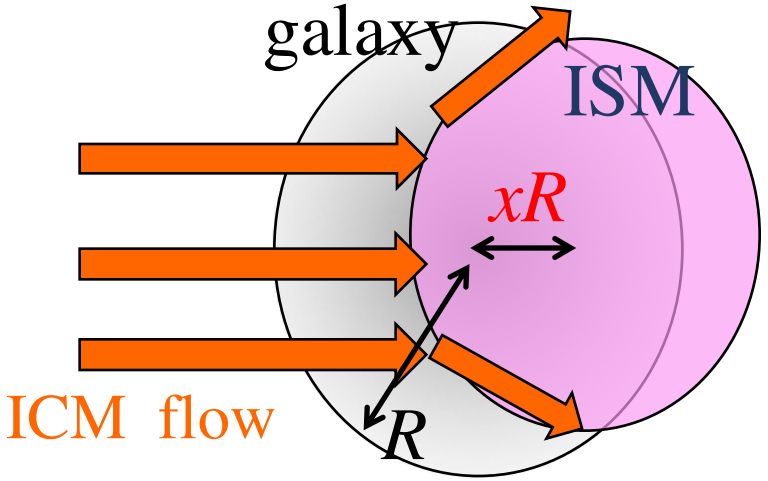
Fabian+17

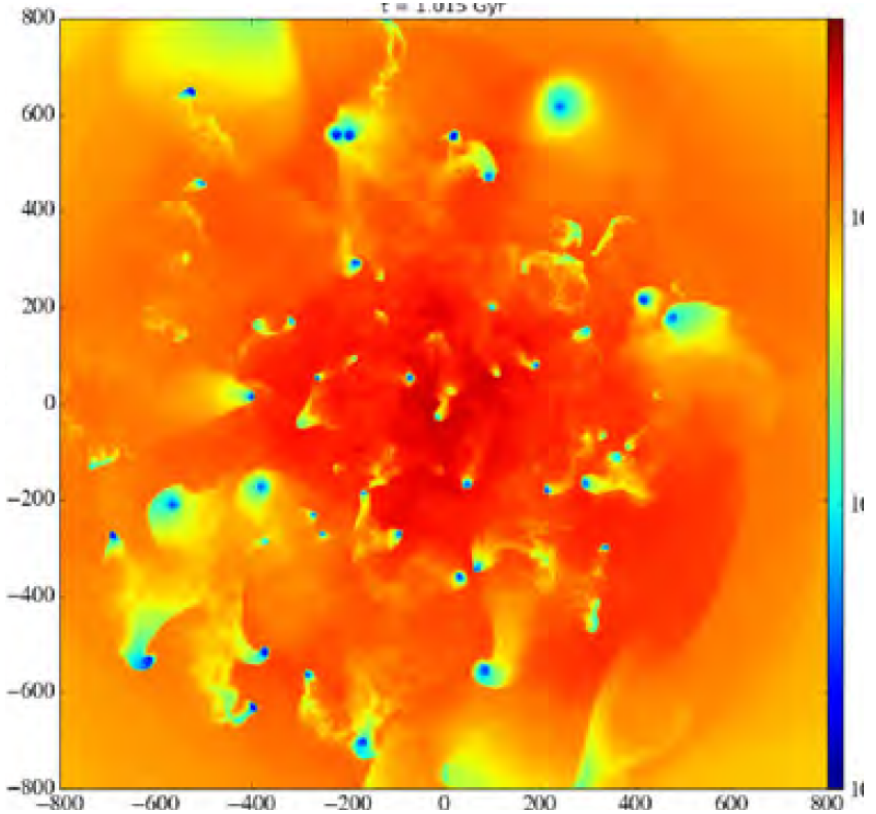
What have galaxies added

- Galaxy interaction is probably strongest when it flies through the cluster center (~ $n_e n_{gal}$); all galaxies, not only those in the center, are slowly losing their dynamical energies to the ICM.

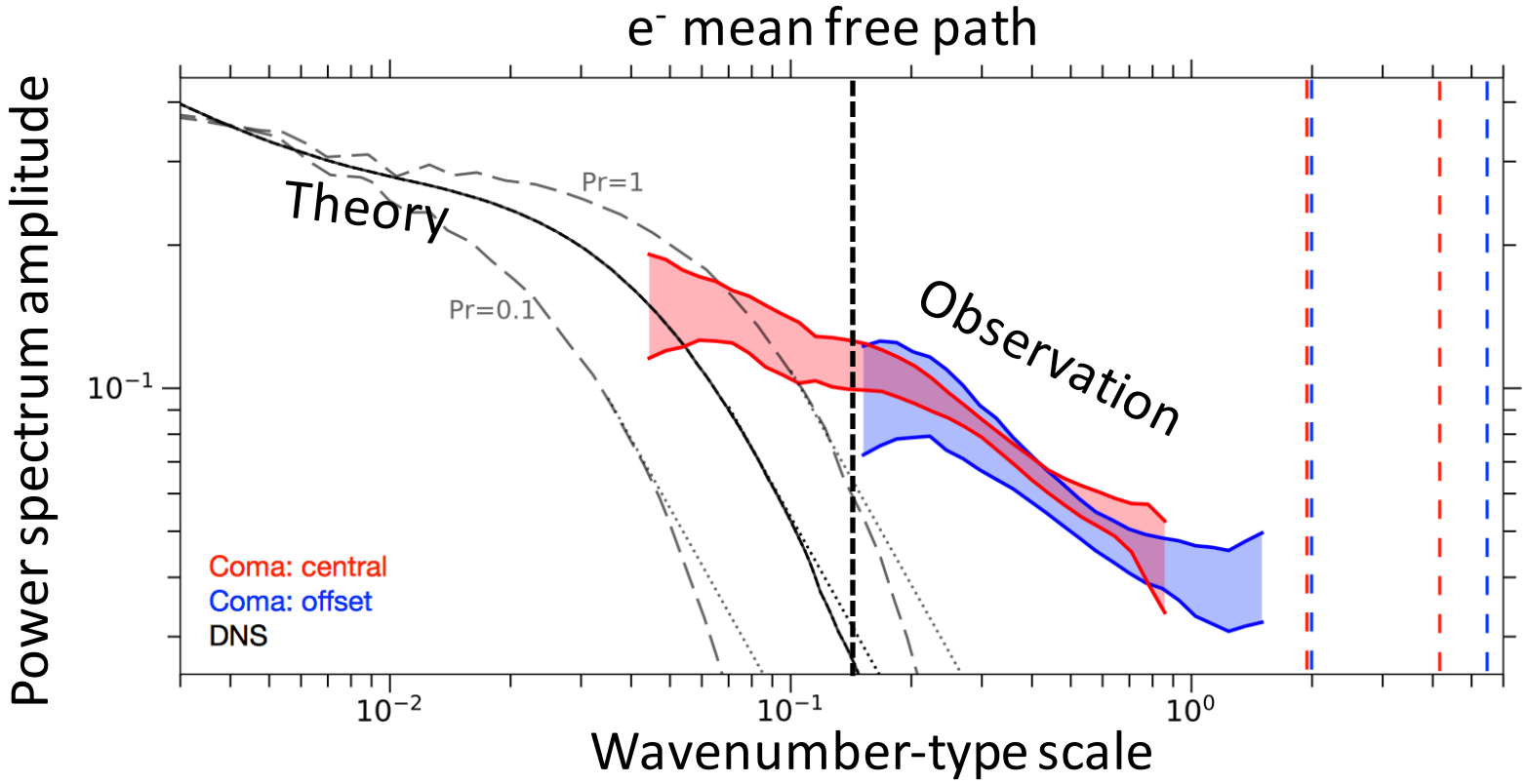
- Does it mean coupled galaxy and ICM motion? Could this be measured with XRISM and Athena?

- Complete galaxy data available for Virgo, Coma, and Fornax (Venhalo+2018), and probably soon also for Perseus (Wittmann+).



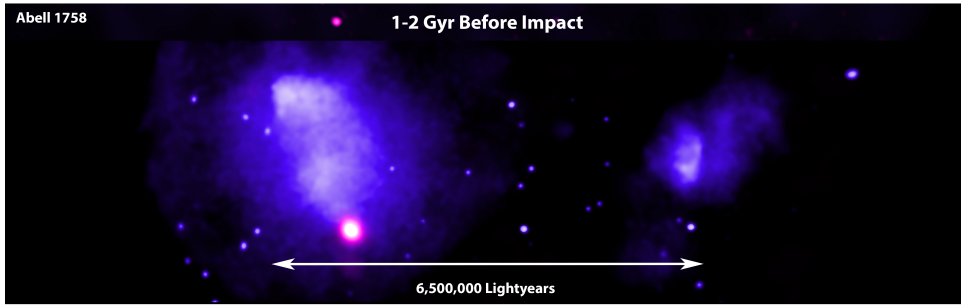


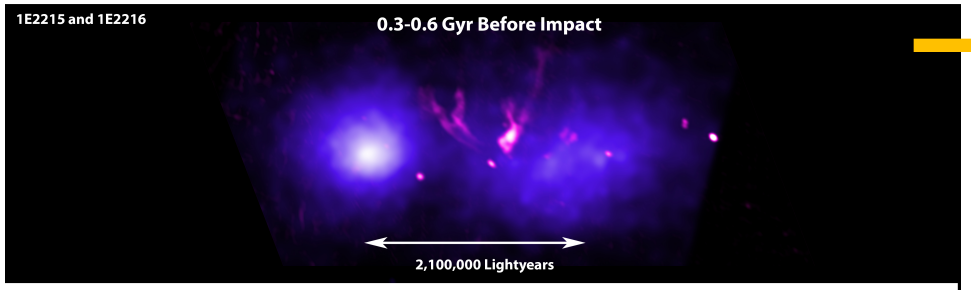
micro-turbulence in clusters of galaxies

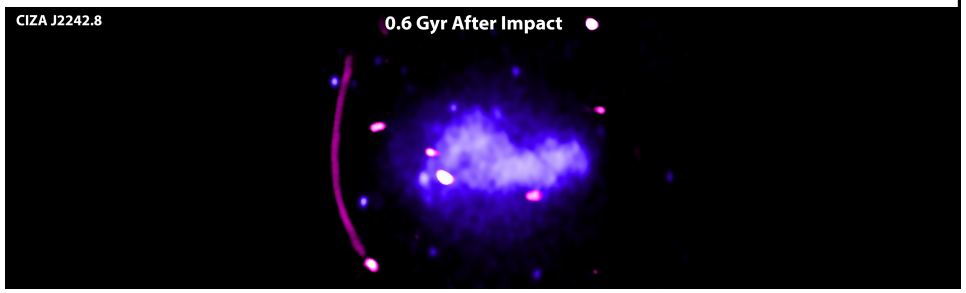


Significant turbulence at small scales found in Coma (Zhuravleva+19, Nature Astronomy), implying for suppressed viscosity / enhanced collision rate

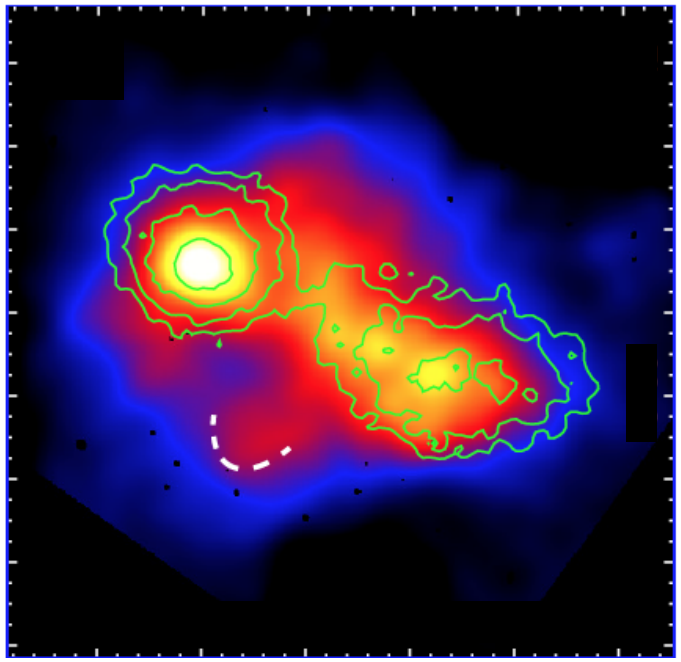
Equatorial shocks in merging clusters





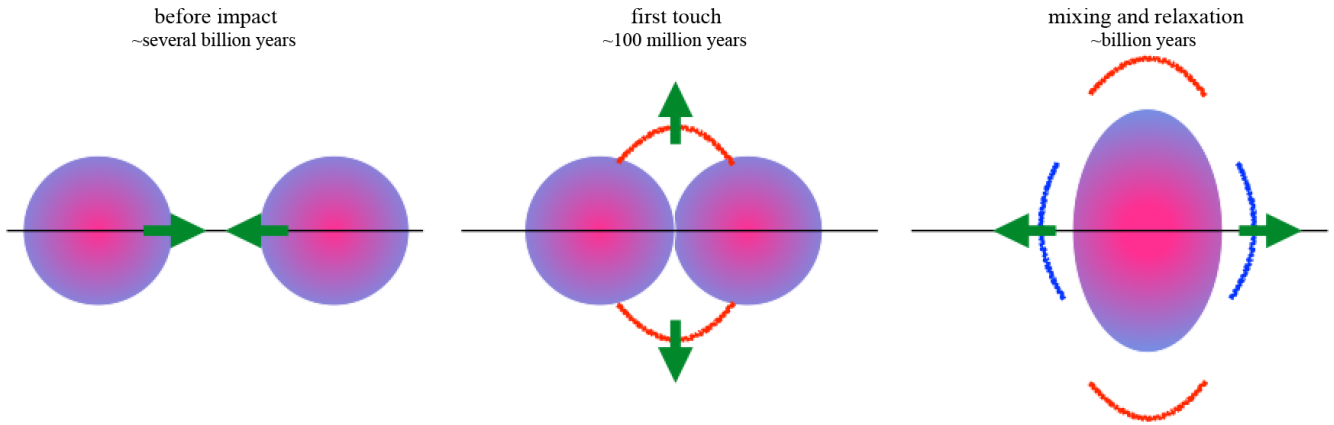


Pressure



Equatorial shock found in the first moment of collision (Gu+19, Nature Astronomy).

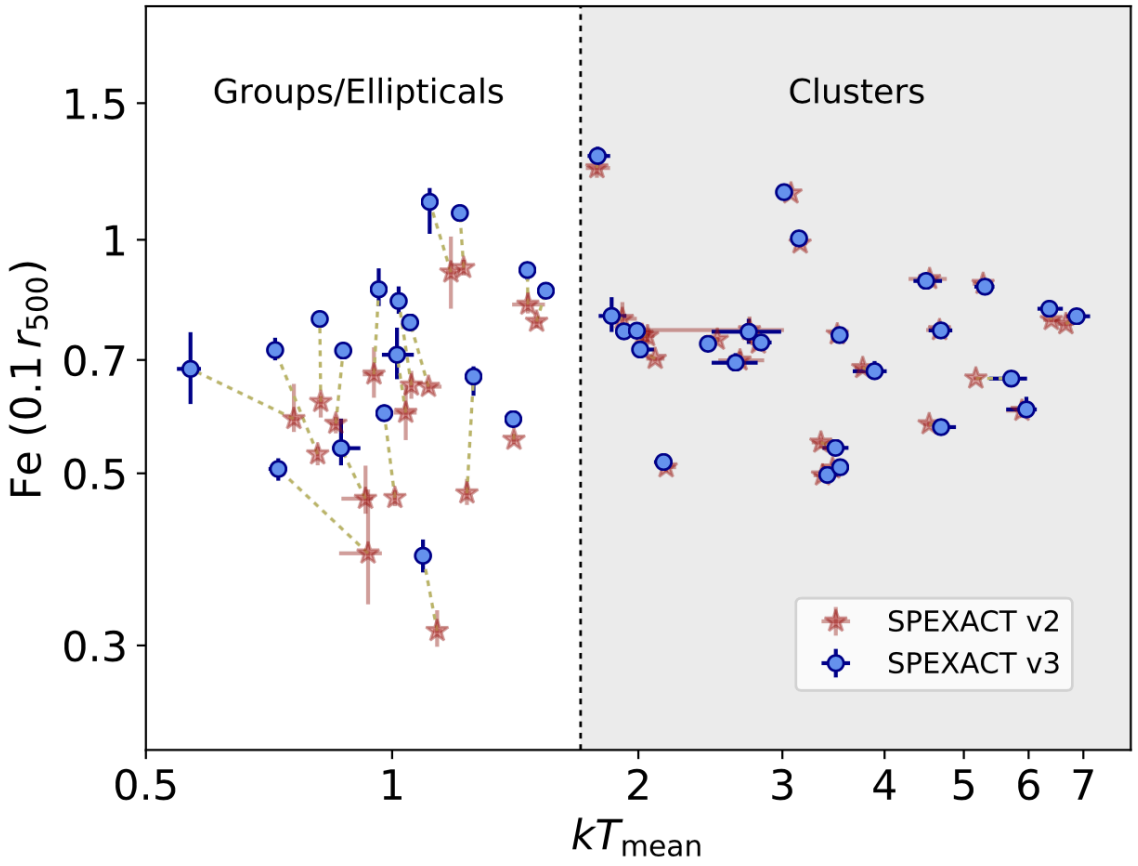
What XRISM can do for mergers?



Era of high resolution spectroscopy

- Turbulence will become a standard plasma parameter like temperature and density
- Open up to a new set of physics (viscosity, magnetism, MHD waves…) utilizing precise dynamics
- Velocity structure diagnostic with line non-Gaussianity, Voigt profile, resonant scattering
- Non-standard components: NEI (low ionization lines), supra-thermal (DR to Heα ratio); reviewed in Gu+18
- Microscopic surface interaction (charge exchange)
- many plasma physics (shocks, SNR, solar corona) not covered in this meeting

Atomic physics: challenges and improvements

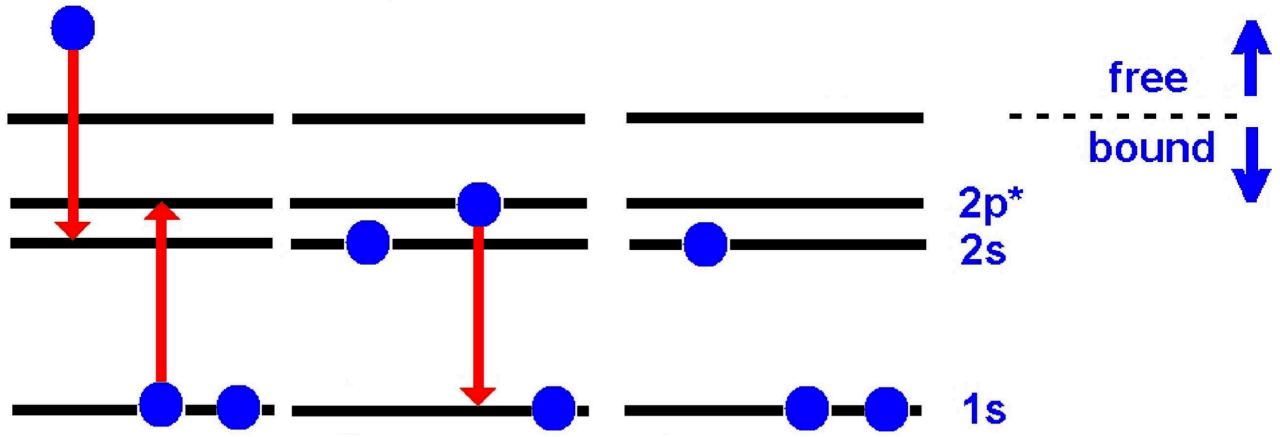


Mernier+2018

- Most of the people in the room know now X-ray spectroscopy heavily dependent on atomic modeling (thanks to the Hitomi spectrum).
- From simple (spex v2) to sophisticated (spex v3) codes, abundances of galaxy groups increases by ~ 20%, leading to different physical interpretations (Mernier+2018).
- However, with the latest calculation (Gu+19) the abundances bounce back by 10-15%.

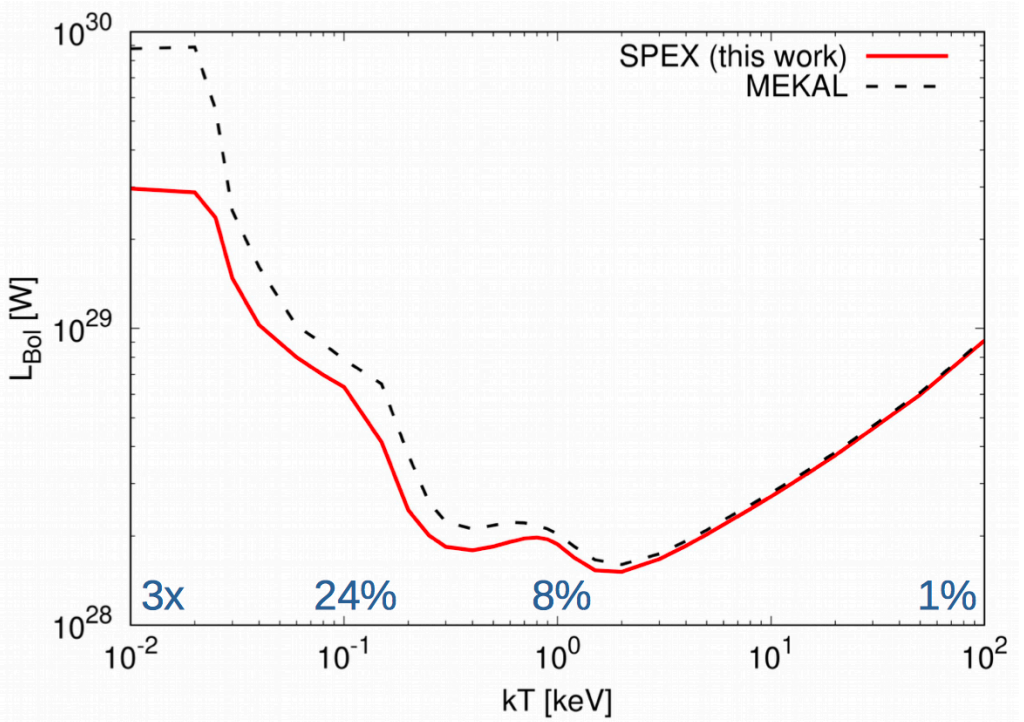
Current issues

- Ten thousand levels are needed to calculate an ion, old-fashioned Gaussian line fits does not take advantage of this wealth of information

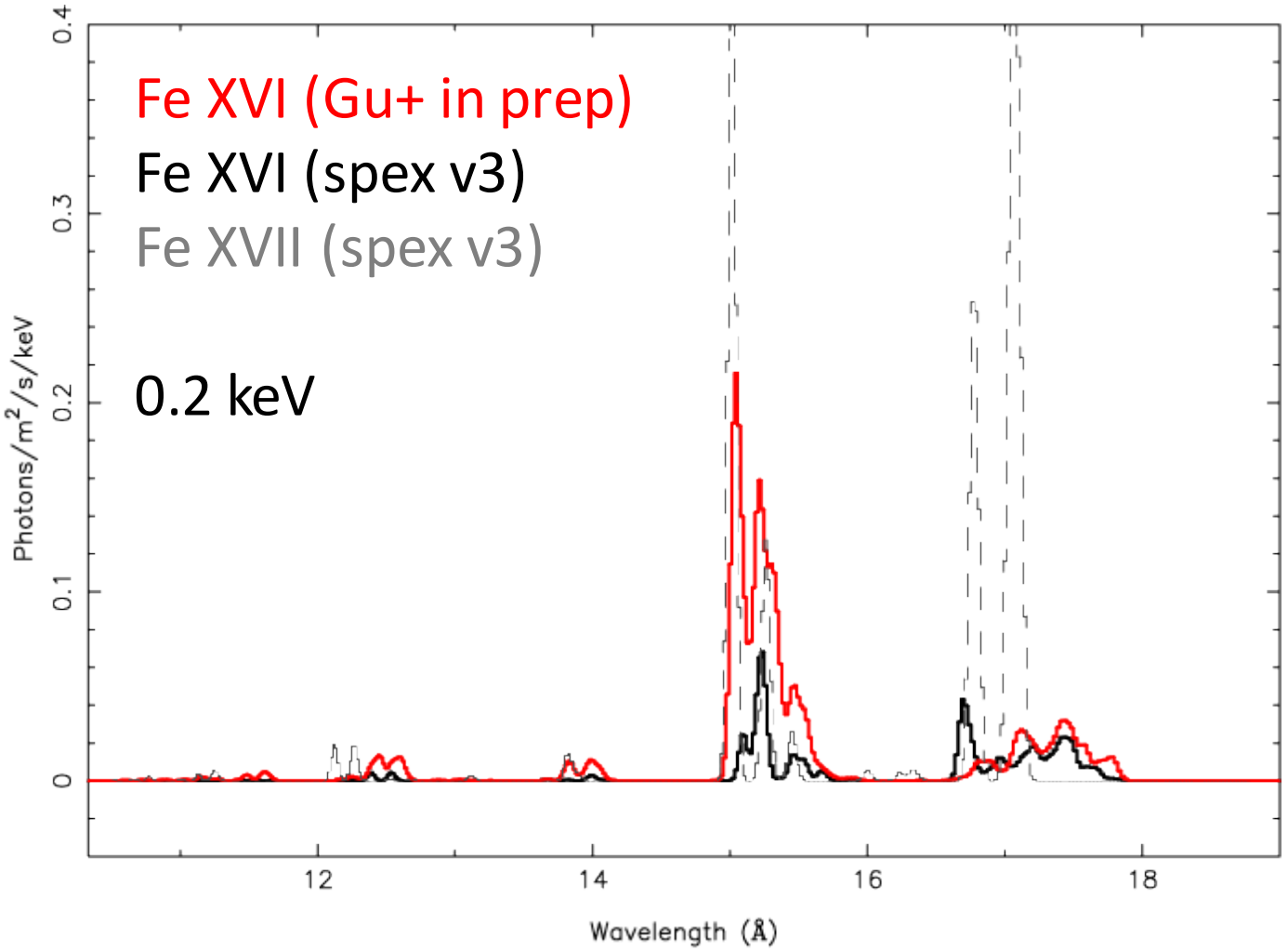


- Collisional cooling still uncertain at low temperature and low ionization status – true for many other processes

- XRISM lab astro WG will look into these problems. Solution might be expensive and time-consuming.

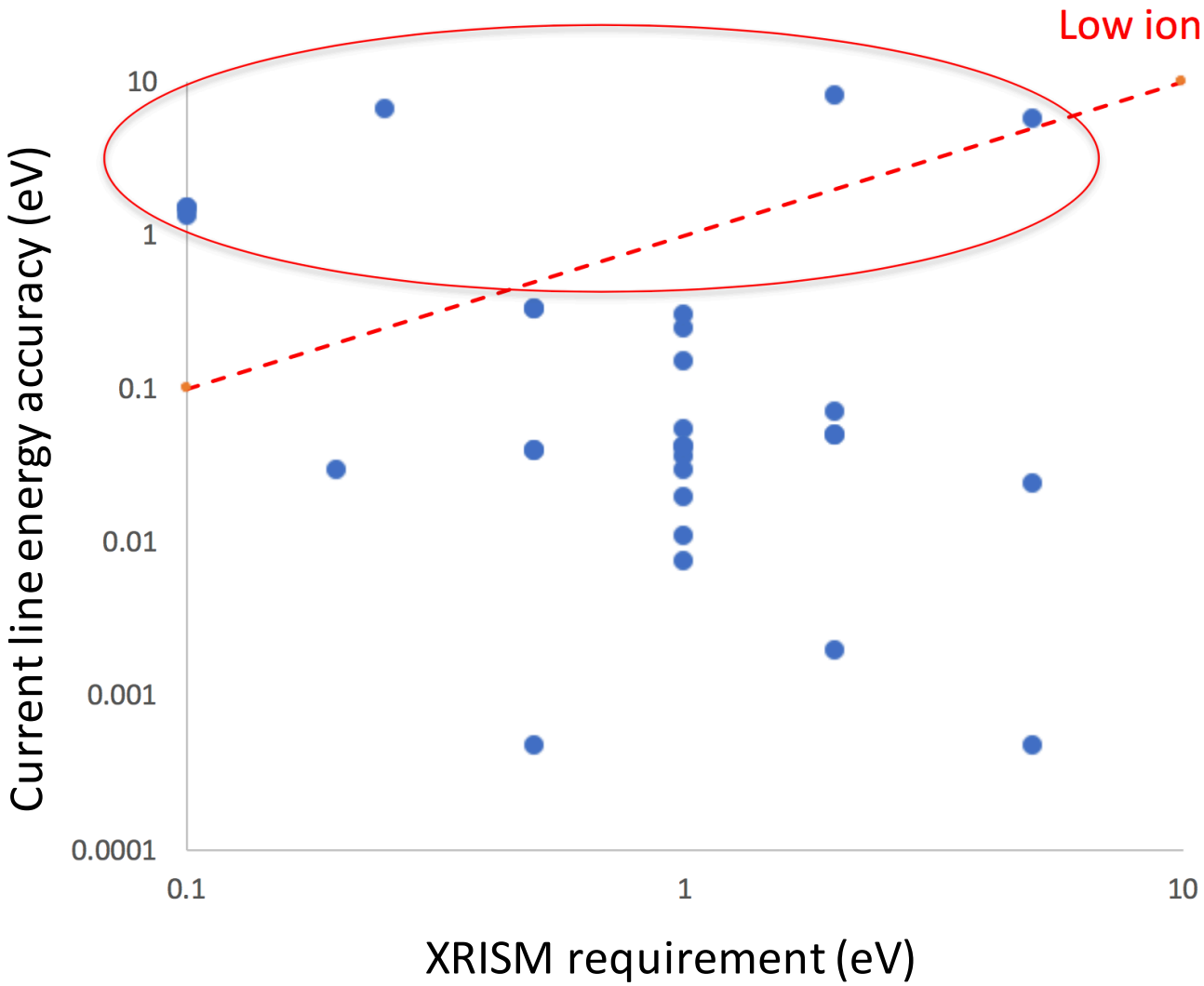


problem with data completeness



- Fe XVII lines at 15A are significantly contributed by DR from Fe XVI, which is missing in the present codes.
- Noticed in an EBIT experiment at Heidelberg
- The new result might affect abundance and resonant scattering based on Fe XVII.
- How many problems are there?

Data accuracy



- XRISM requires line center to be accurate at 10^{-5} ~ 10^{-3}, depending on science cases.
- Highly ionized species are known with < 10^{-4} , main challenges are lowly ionized and inner shell transitions.
- Lab data are limited for many non-Fe ion.
- Imaging if we have a high quality spectrum of shocked and photoionized gas

Atomic physics for high-resolution spectroscopy

- Codes and databases are continuously improving, both in preparation to and after the launch of XRISM.
- It requires a concerted effort between theorists, experimentalists, and observers.
- But the issues are always more than we thought.
- Systematic uncertainty – correlation between transition probabilities

For the users:

- Identify relatively safe science cases – those less affected by atomic issues
- No perfect model. Fit data with two or more atomic codes; compare different analysis methods; talk to atomic experts on the difference.
- Support the (funding proposals…) of lab astrophysicists and modelers.

Questions in the box

- Which are the prospective of using meta-stable transitions as density diagnostics with XRISM and Athena? How do uncertainties in the cooling rates affect the density determination this way?
- Are we entering an age when we are limited by computing power in terms of modelling plasma? Do we need to think outside the box (e.g., machine learning)?