Connecting turbulent velocities and magnetic fields in galaxy cluster simulations with active galactic nuclei jets

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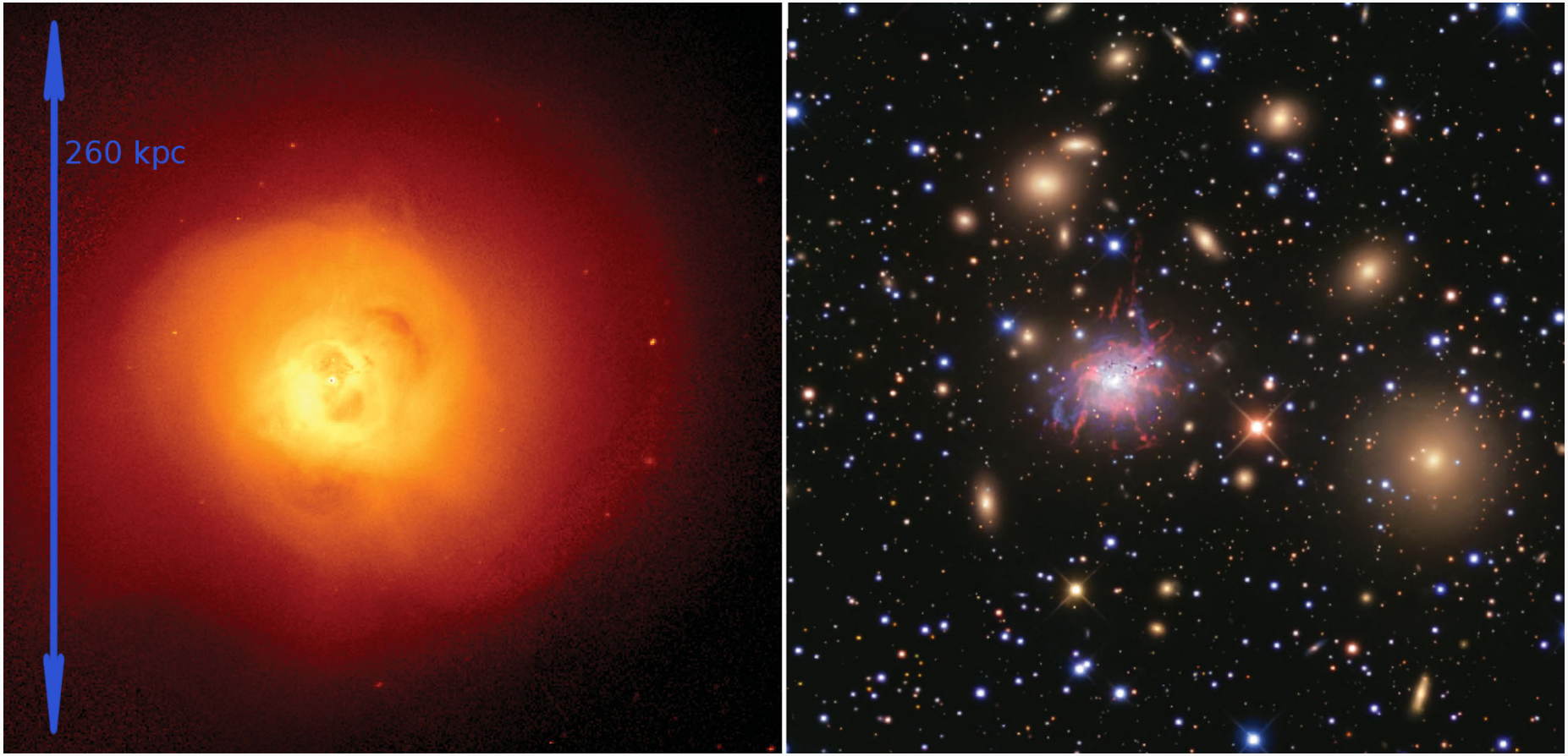
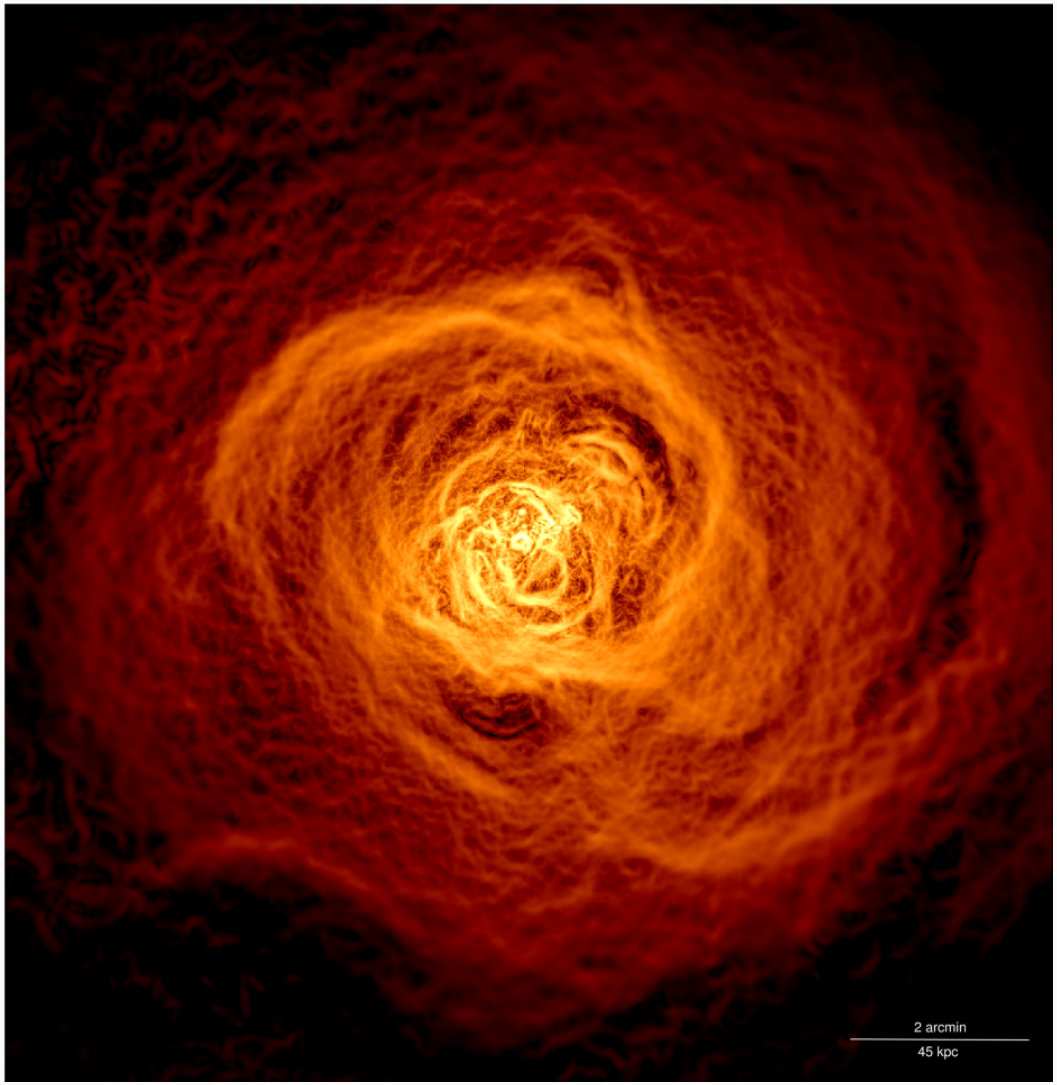
Perseus Cluster



X-ray (Chandra composite) and optical (Blackbird observatory) images of the Perseus cluster (adopted from Fabian et al., 2011)

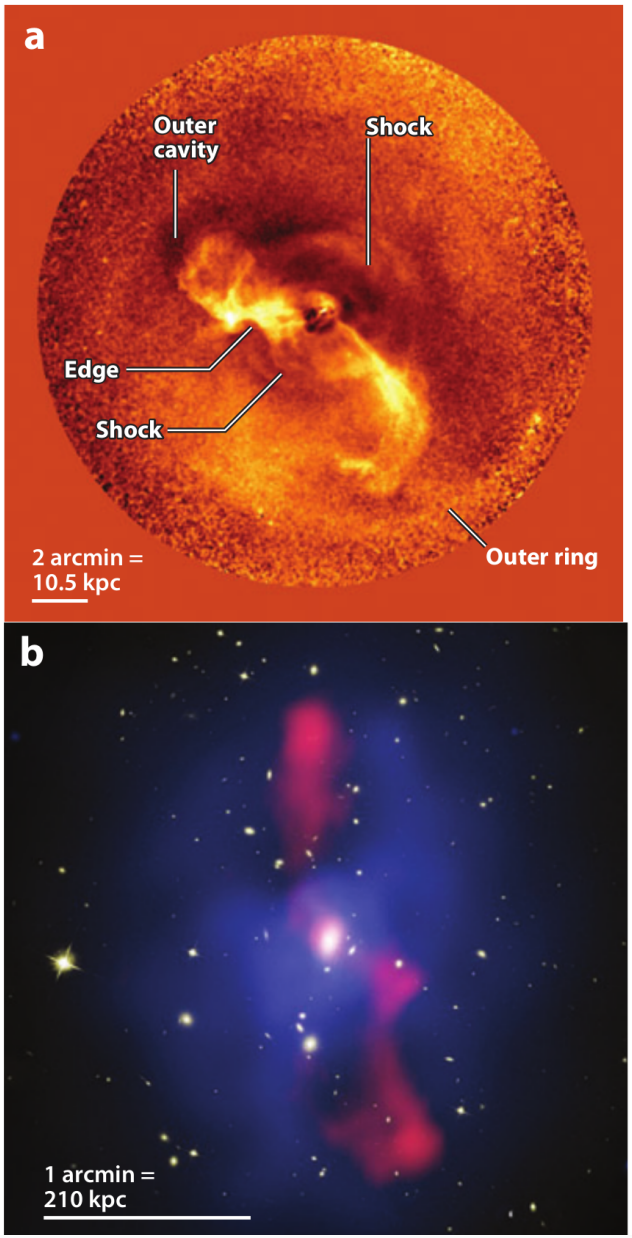
Motions ubiquitous in clusters



Gradient filtering edge detection enhances shocks and ripples in X-ray image of Perseus (Sanders et al., 2016)

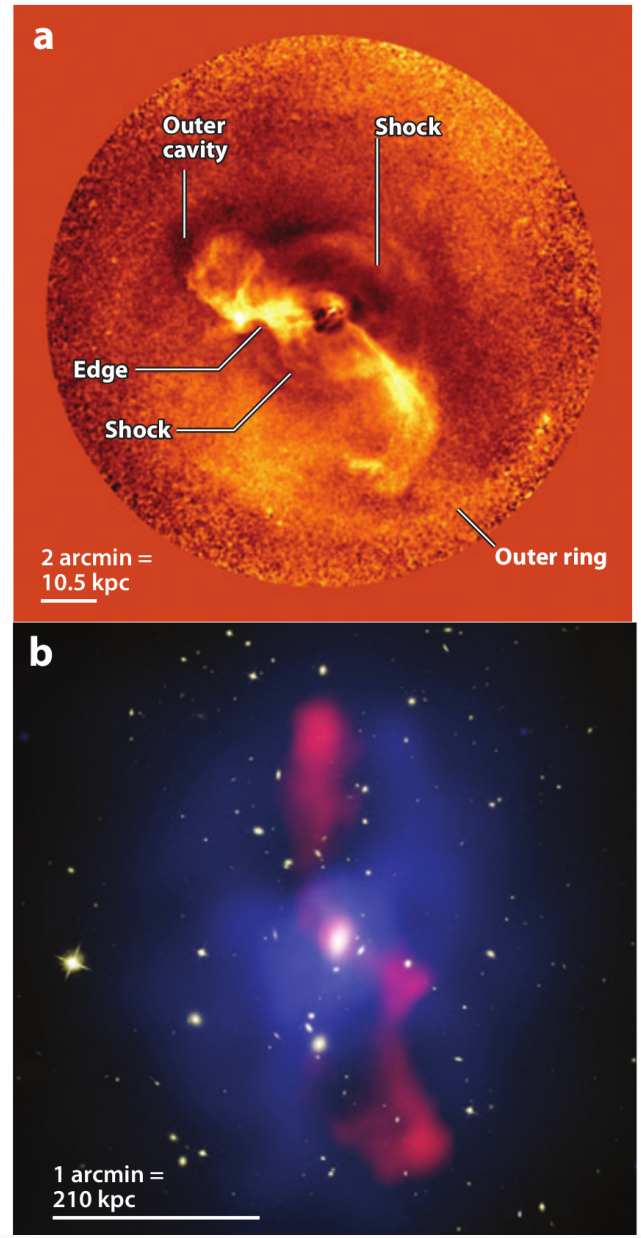
Cooling flow problem

- Observationally; $t_{\mathrm{cool}} \ll t_{\mathrm{Hubble}}$
- Clusters self-regulated through jets; exemplified in M87 and MS0735 (Fabian, 2012)
- Heating mechanism unclear

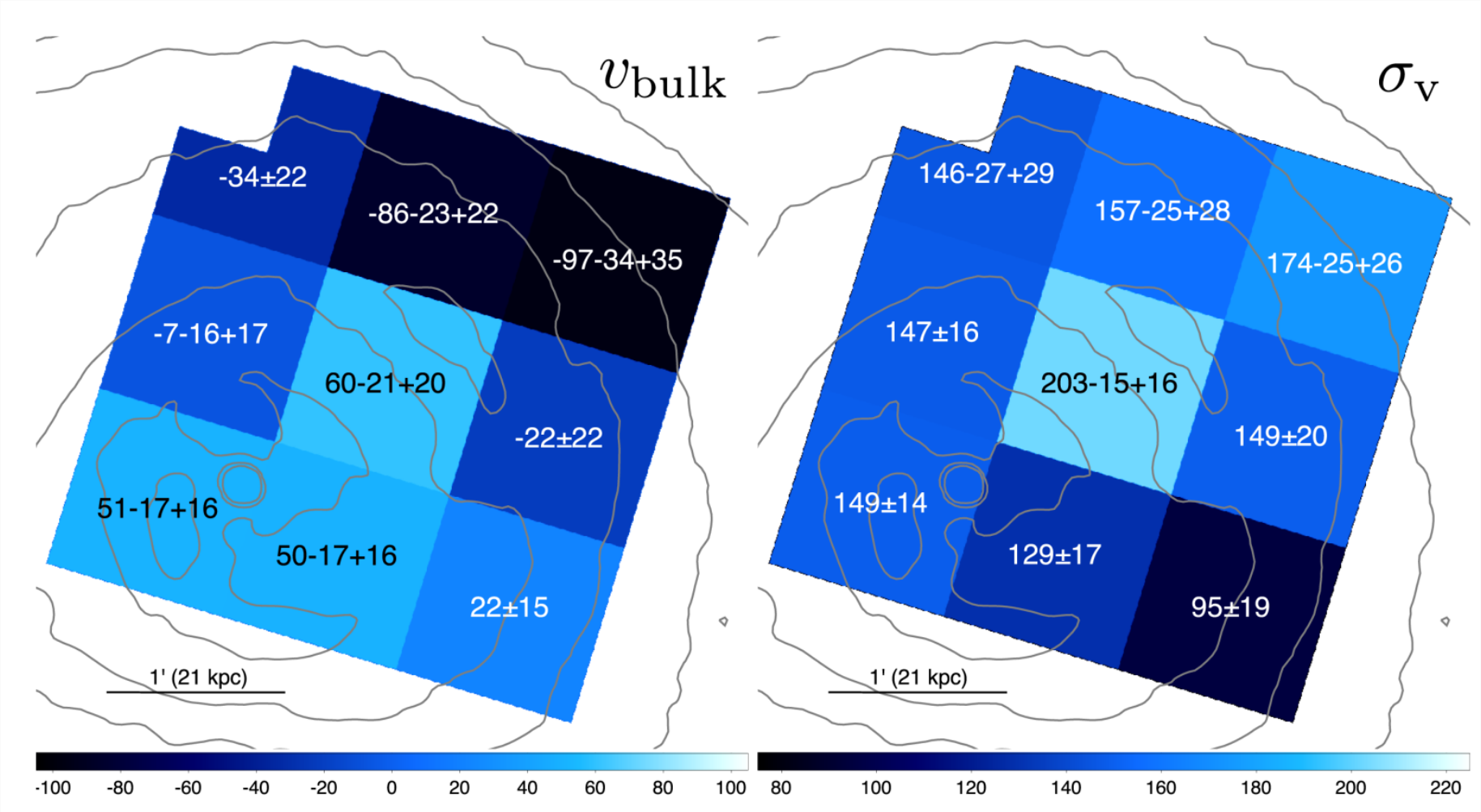


Cooling flow problem

- Observationally; $t_{\rm cool} \ll t_{\rm Hubble}$
- Clusters self-regulated through jets; exemplified in M87 and MS0735 (Fabian, 2012)
- Heating mechanism unclear
- Ideas related to velocities:
  - turbulence dissipation
  - decay of sound waves
  - shock heating
  - mixing of hot bubble material
- Magnetic field significant impact on plasma scale details of most heating mechanisms

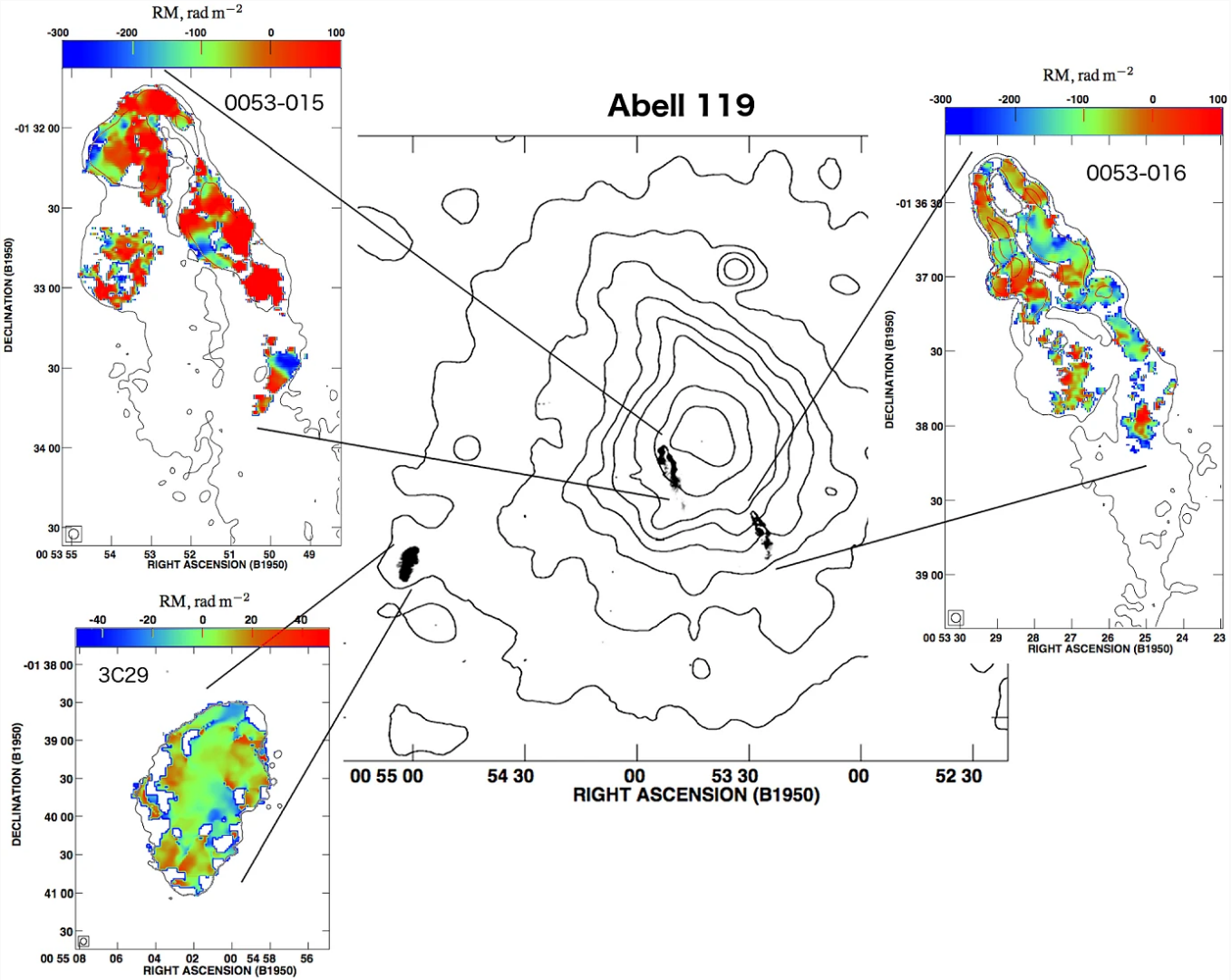


Cluster motions observed with X-ray satellite Hitomi



Bulk velocity (left) and velocity dispersion in $\mathrm{km\,s^{-1}}$ of the ICM in a central region of Perseus measured by *Hitomi* (Hitomi Collaboration, 2018)

Magnetic field modelling with Faraday rotation measure



RM images of radio sources within a galaxy cluster (Feretti et al., 1999; Beresnyak, 2019)

Connection between velocity and magnetic field

- Evolution of magnetic field given by induction equation

$$\frac{\partial \mathrm{B}}{\partial t} = -\mathrm{v} \cdot \nabla \mathrm{B} + \mathrm{B} \cdot \nabla \mathrm{v} - \mathrm{B} \nabla \cdot \mathrm{v} + \eta \nabla^2 \mathrm{B}$$

- Change of B = advection + stretching + compression + dissipation of field
- Evolution of velocity field given by

$$\frac{\partial \mathrm{v}}{\partial t} = -\mathrm{v} \cdot \nabla \mathrm{v} - \frac{\nabla p}{\rho} - \nabla \Phi + \frac{1}{4\pi\rho} \left[\mathrm{B} \cdot \nabla \mathrm{B} - \frac{1}{2} \nabla \left(\mathrm{B}^2 \right) \right], \qquad (1)$$

- Evolution of velocity = advection + pressure force + gravity + magnetic tension + magnetic pressure

Idea

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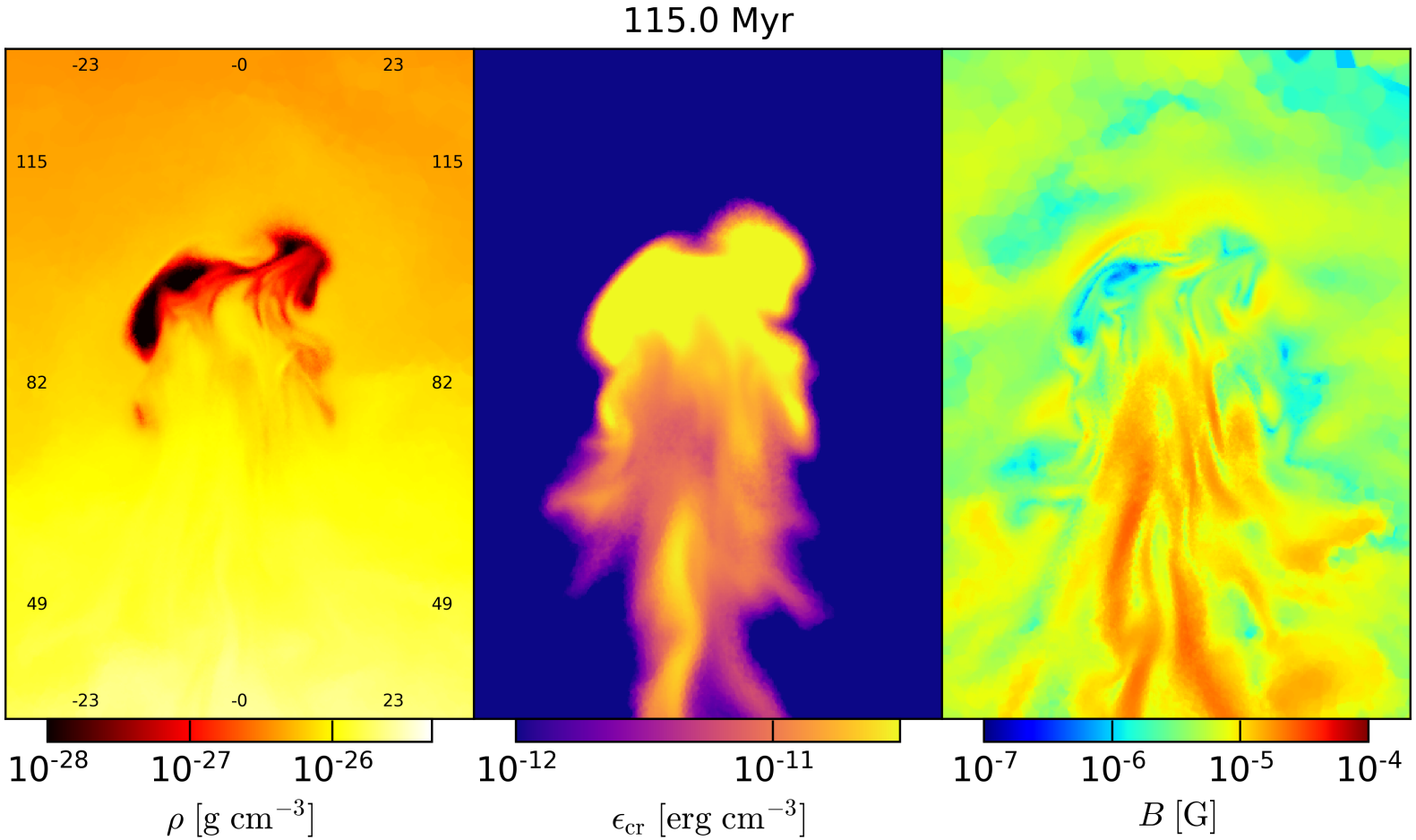
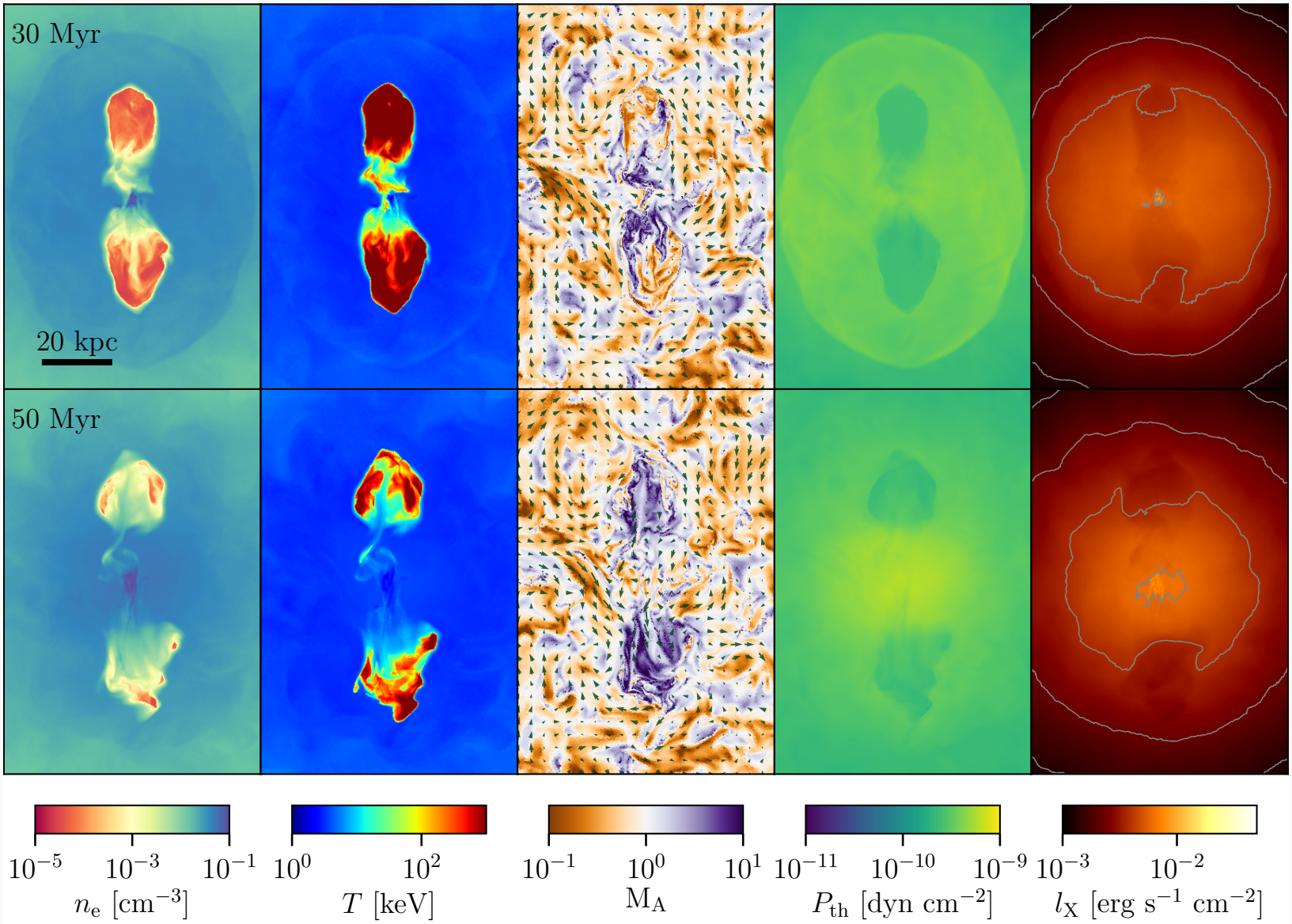
- Impact of AGN on ICM velocity structure unclear
- Focus on simple setup of decaying turbulence:
  - idealized cluster with turbulent magnetic field
  - high density contrast jets filled with CRs

Bubble dynamics

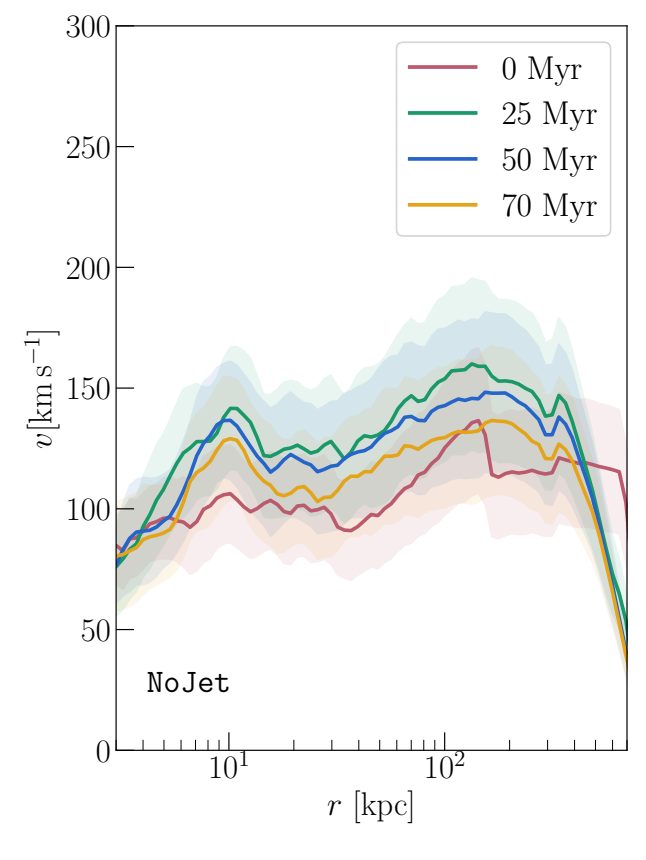


Overview of simulation



Fiducial jet in turbulent magnetized cluster

Jet little impact on cluster turbulence



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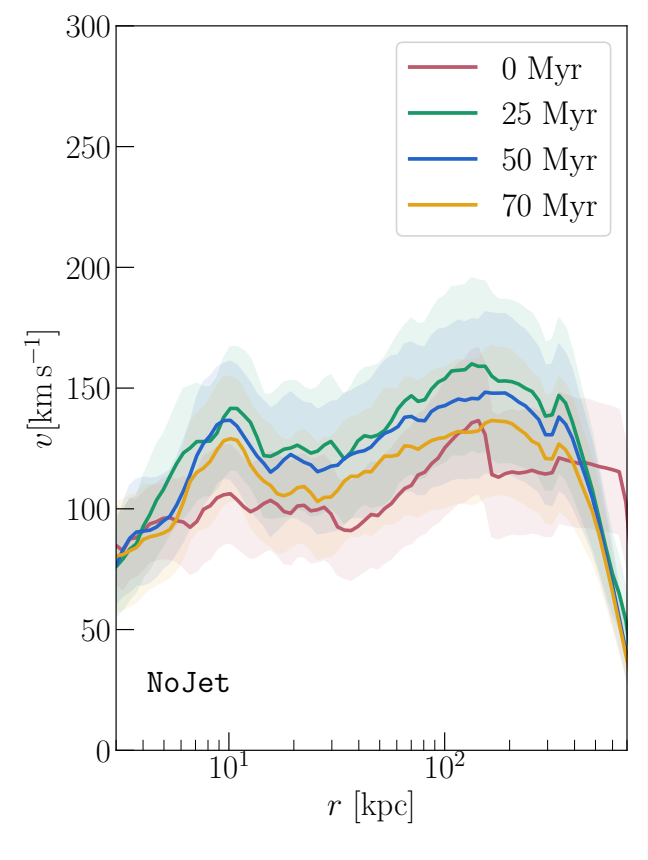

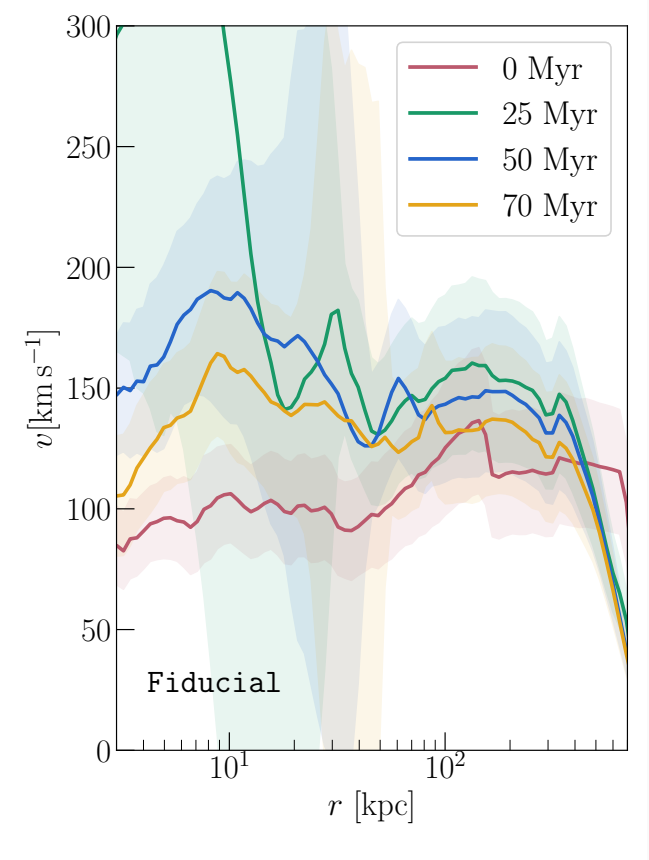

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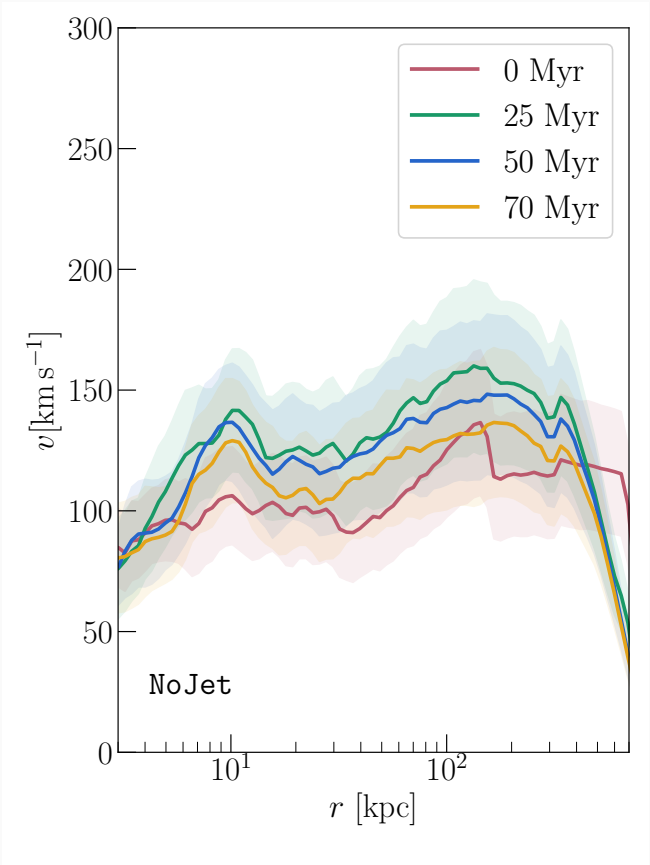
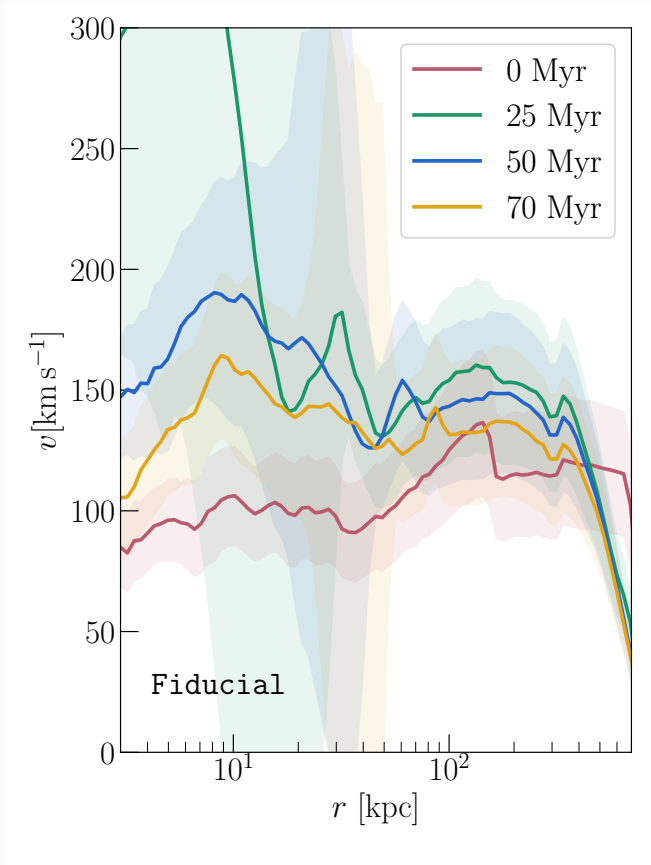
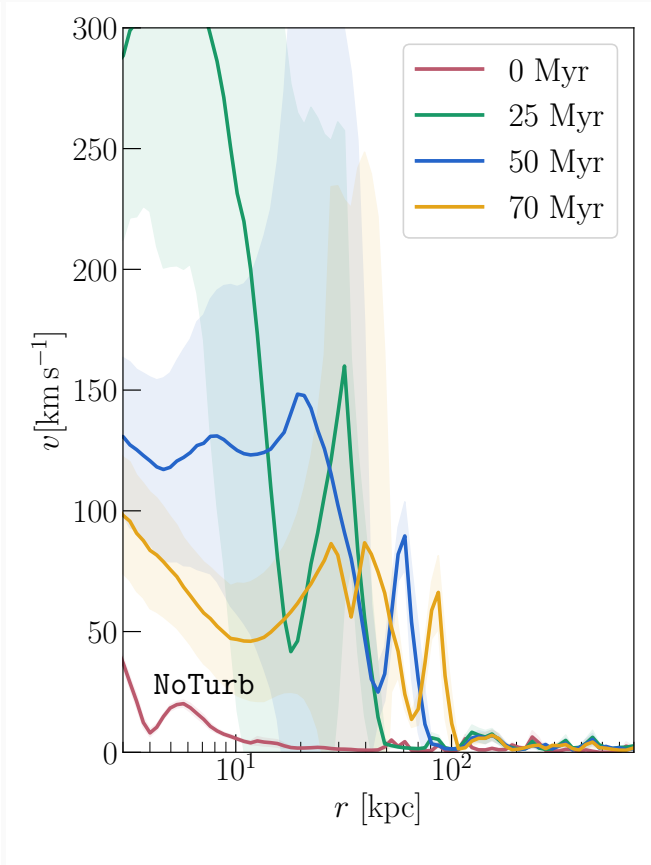
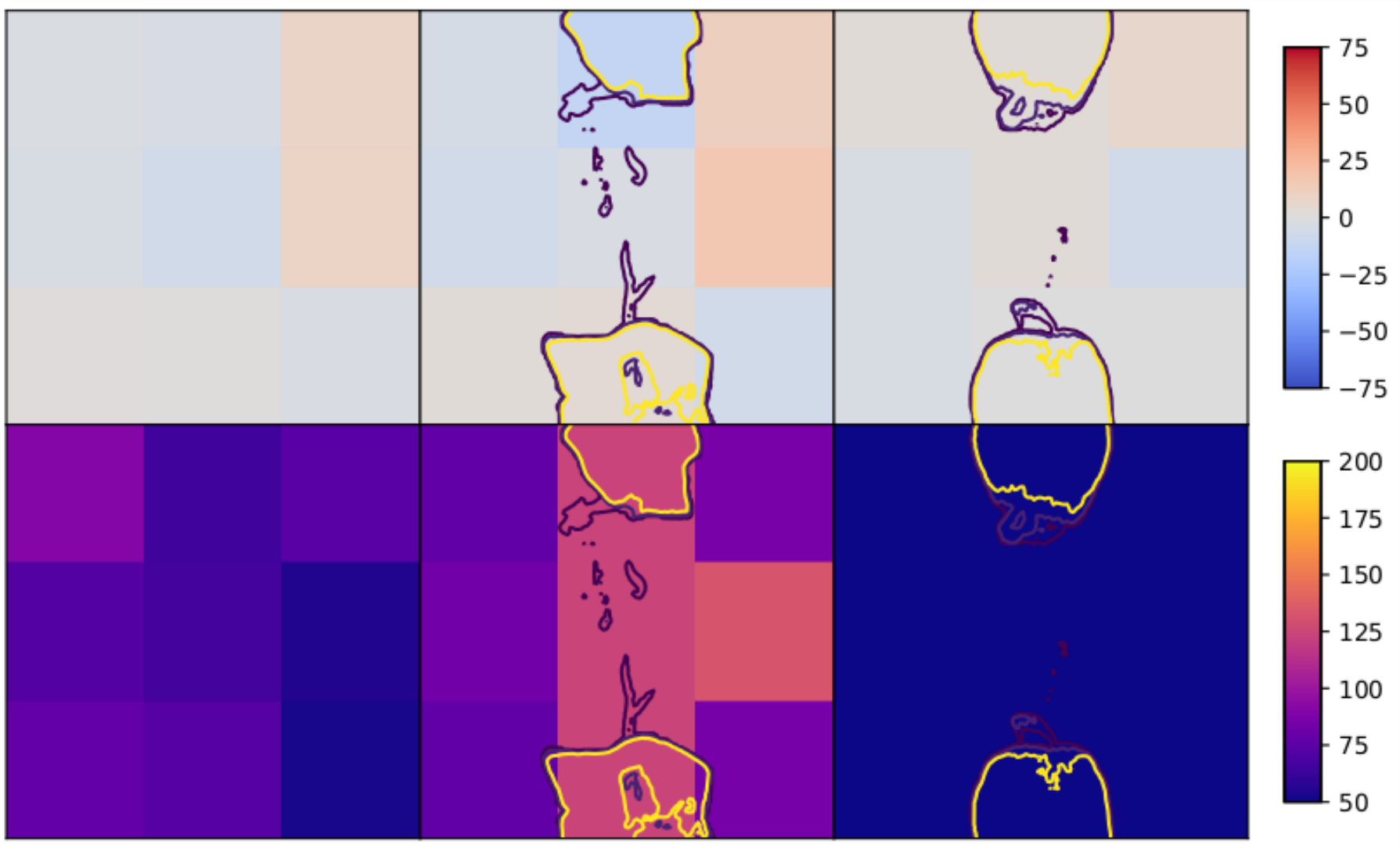




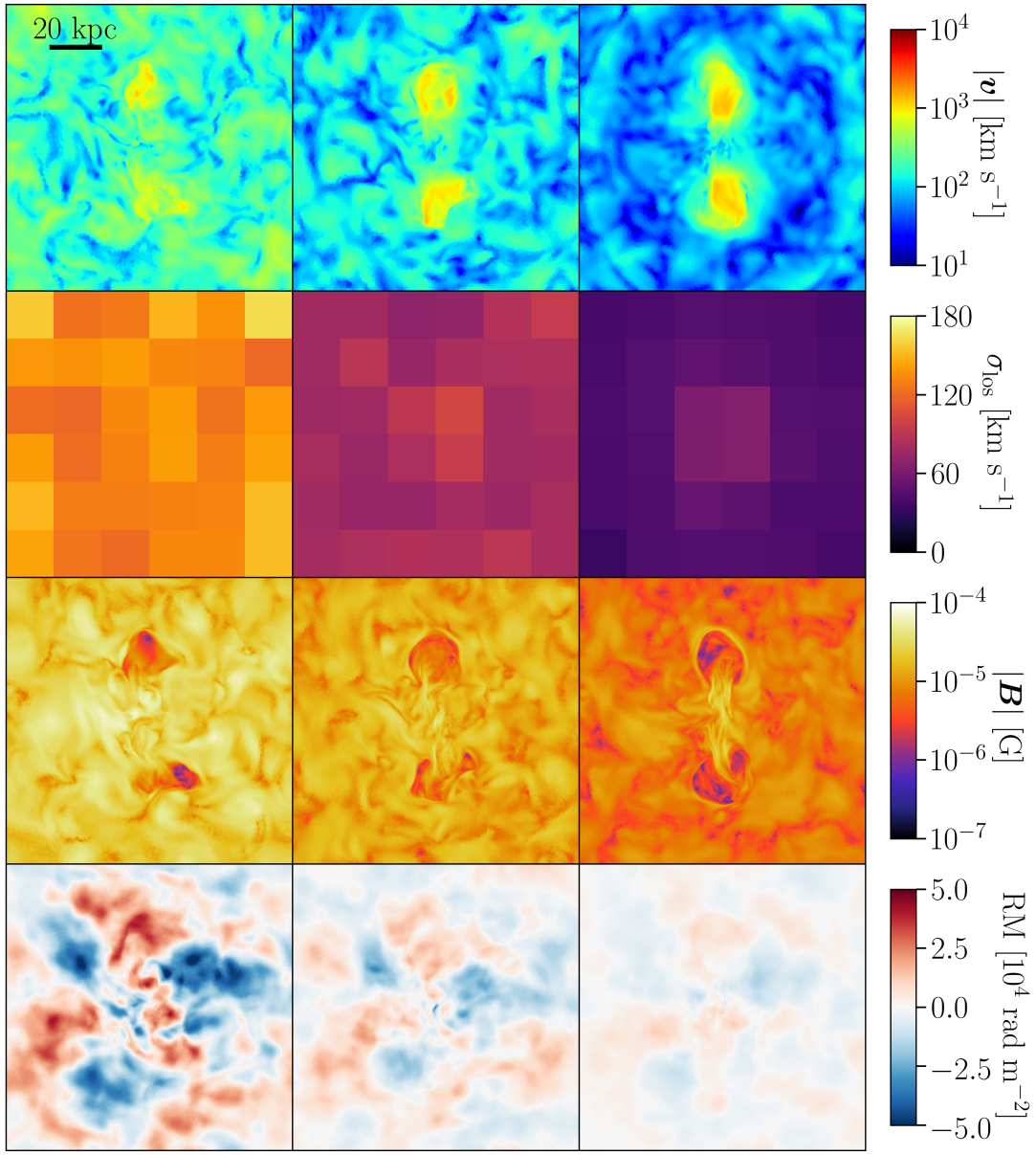


Hitomi view on simulations



Mock *Hitomi* measurements of mean velocity field and velocity dispersion in $\mathrm{km\,s^{-1}}$ for `NoJet`, `Fiducial` and `NoTurb`.

Velocity dispersion $\propto$ magnetic field strength



Summary

- Direct link between magnetic field strength and cluster velocity fields
- Sophisticated simulations may directly relate magnetic field strength to velocity dispersion and vice versa
- Jet-induced velocities negligible
- *Hitomi* observes turbulence that is not caused by AGN

References

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