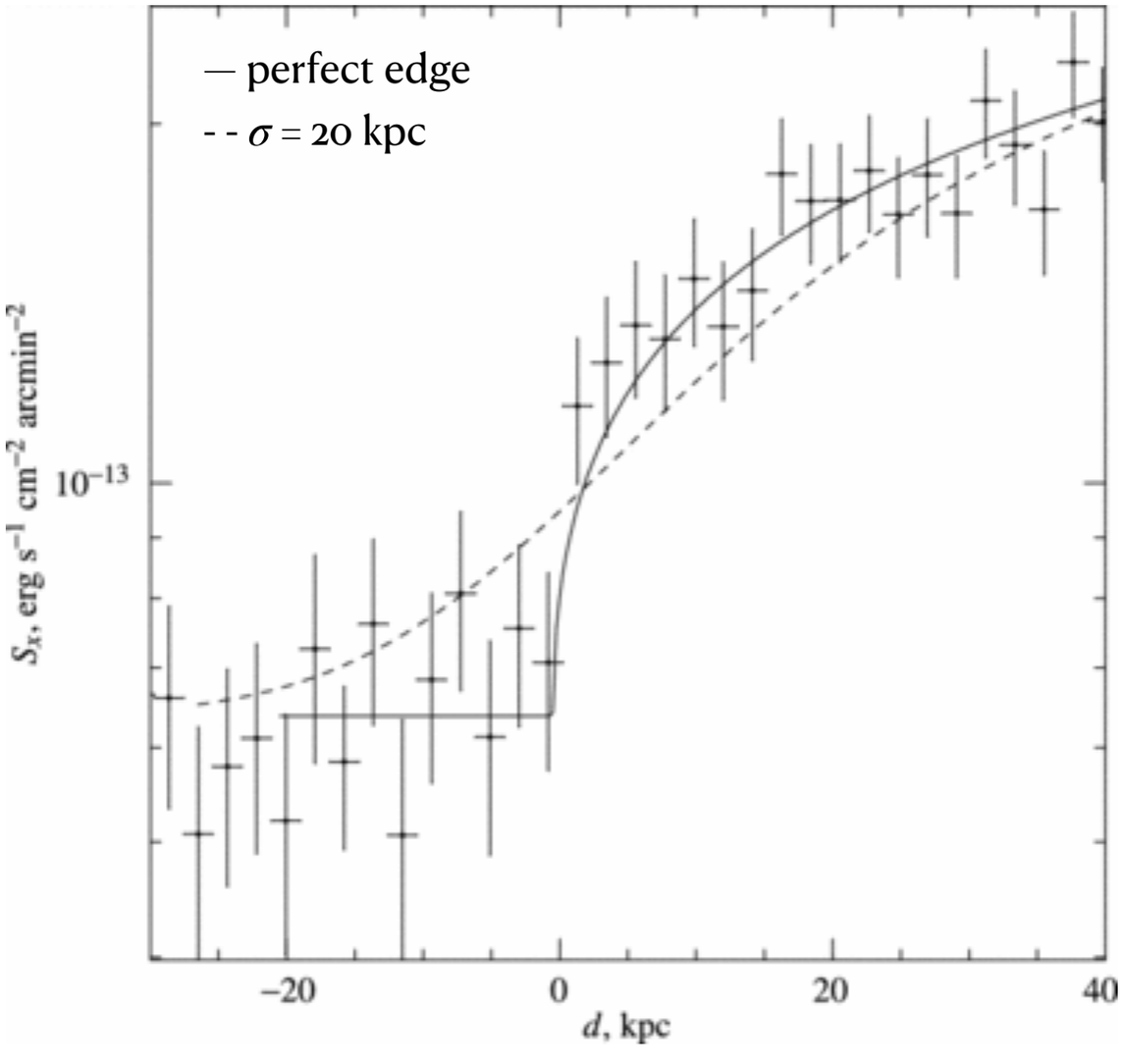
# MHD Simulations of Merging Galaxy Clusters

## A series of dampers

Urmila Chadayammuri | Aug 15, 2022
6th ICM Theory Workshop | Niels Bohr Institute, Copenhagen, Denmark

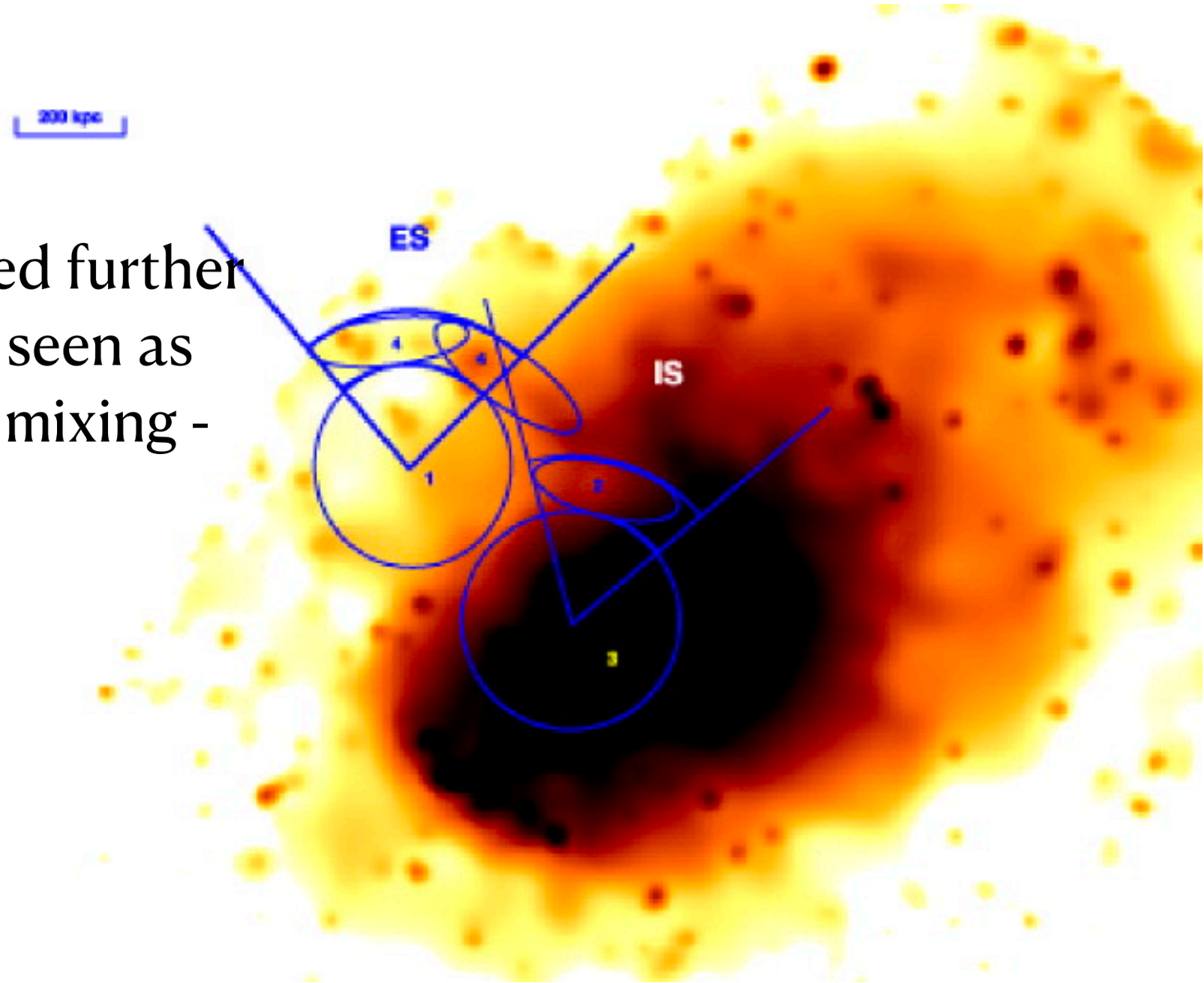
# A history of optimism: A3667

- “The cold front is remarkably sharp. The upper limit on its width, 3.5" or 5 kpc, is several times smaller than the Coulomb mean free path. **This is a direct observation of suppression of the transport processes in the intergalactic medium, most likely by magnetic fields.**” - Vikhlinin+ 2001



# A history of optimism

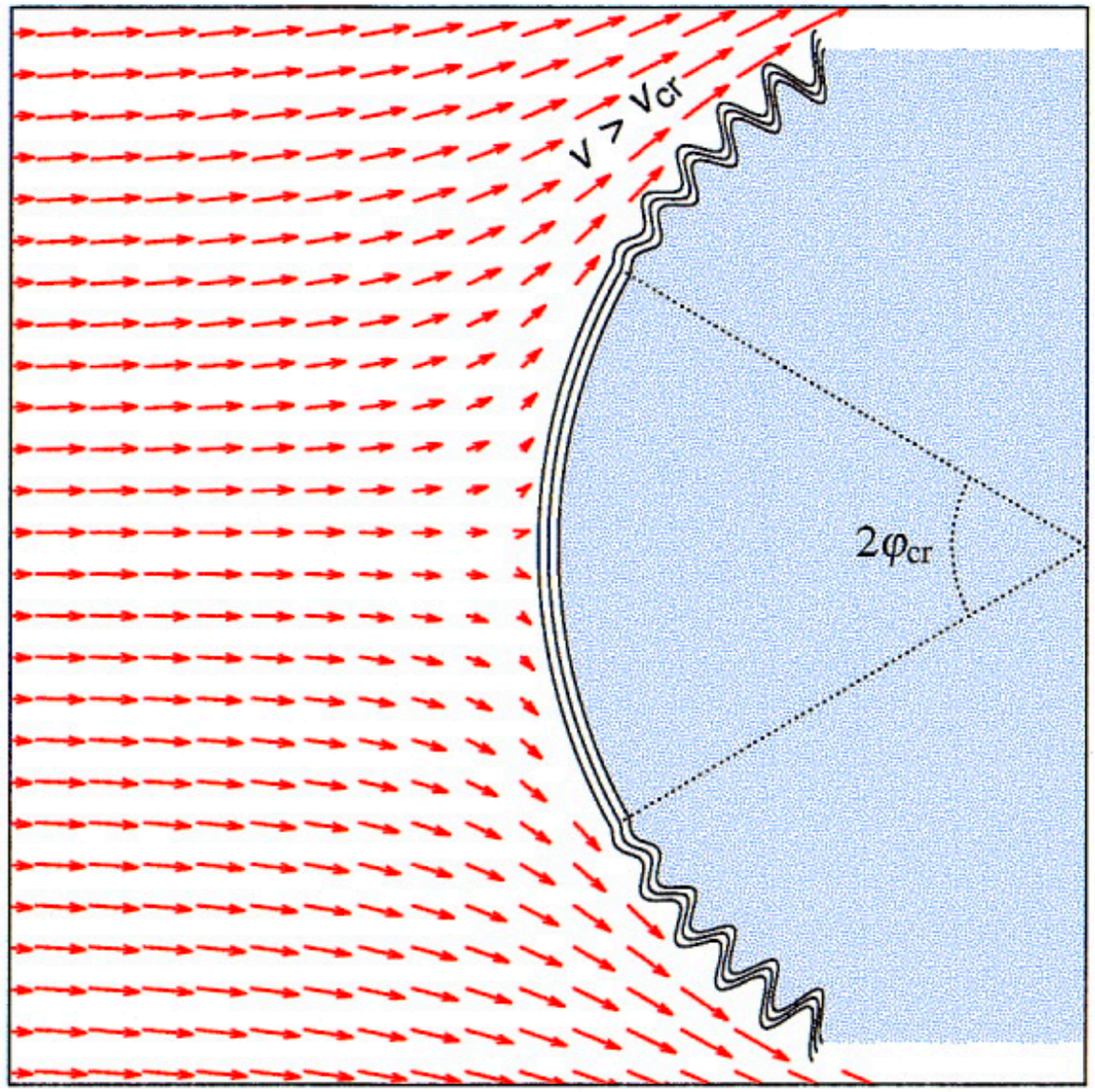
- But instability observed further away from cold front, seen as evidence of turbulent mixing - Mazzotta+ 2002



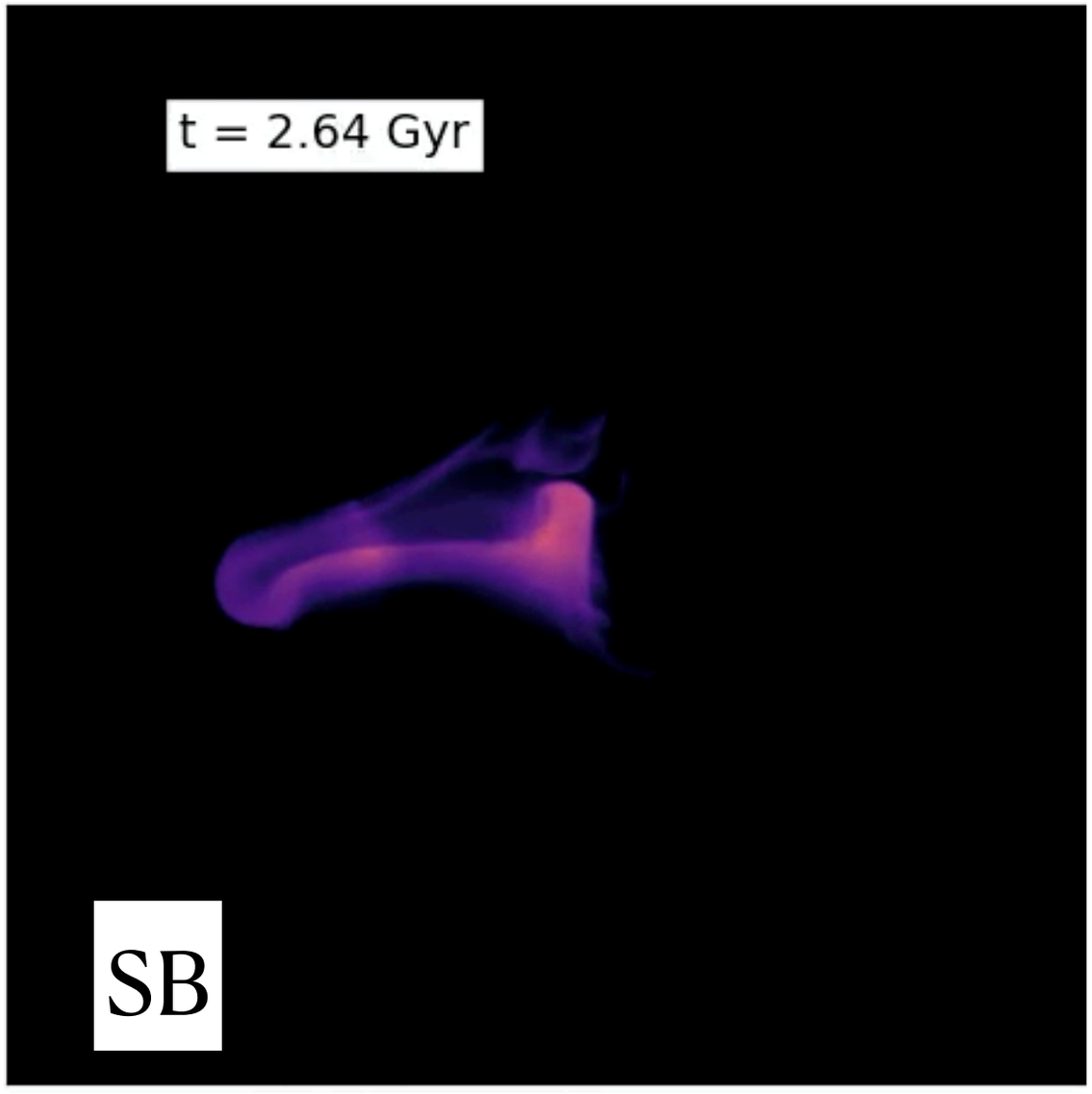
# A history of optimism

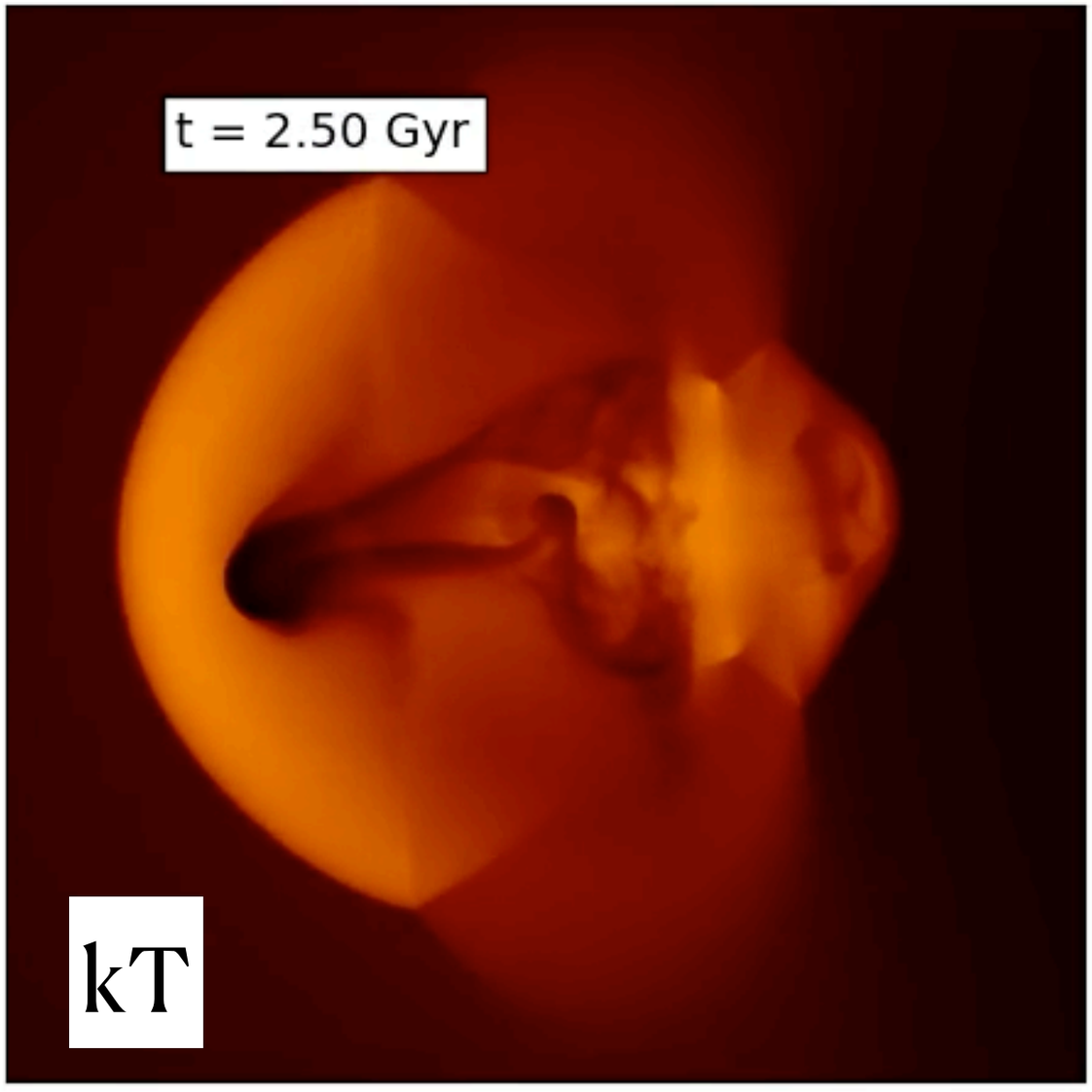
- “Aligned **magnetic fields, viscosity, or thermal conduction** can suppress the KHIs”

- “Both smooth and distorted sloshing CFs have been observed, indicating that the **KHI is suppressed in some clusters, but not in all**” - Roediger+ 2013



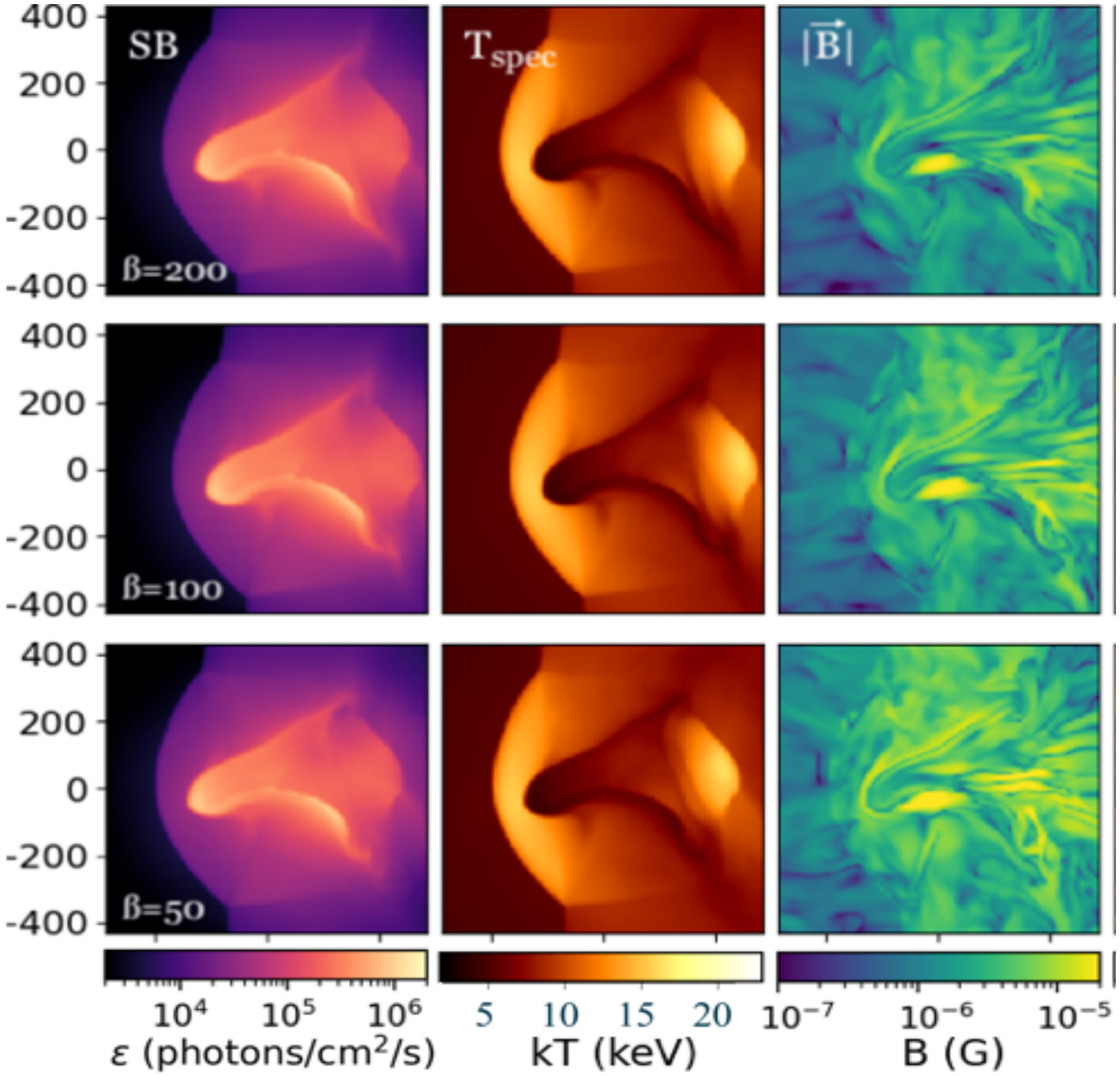
# But there is a simpler solution!

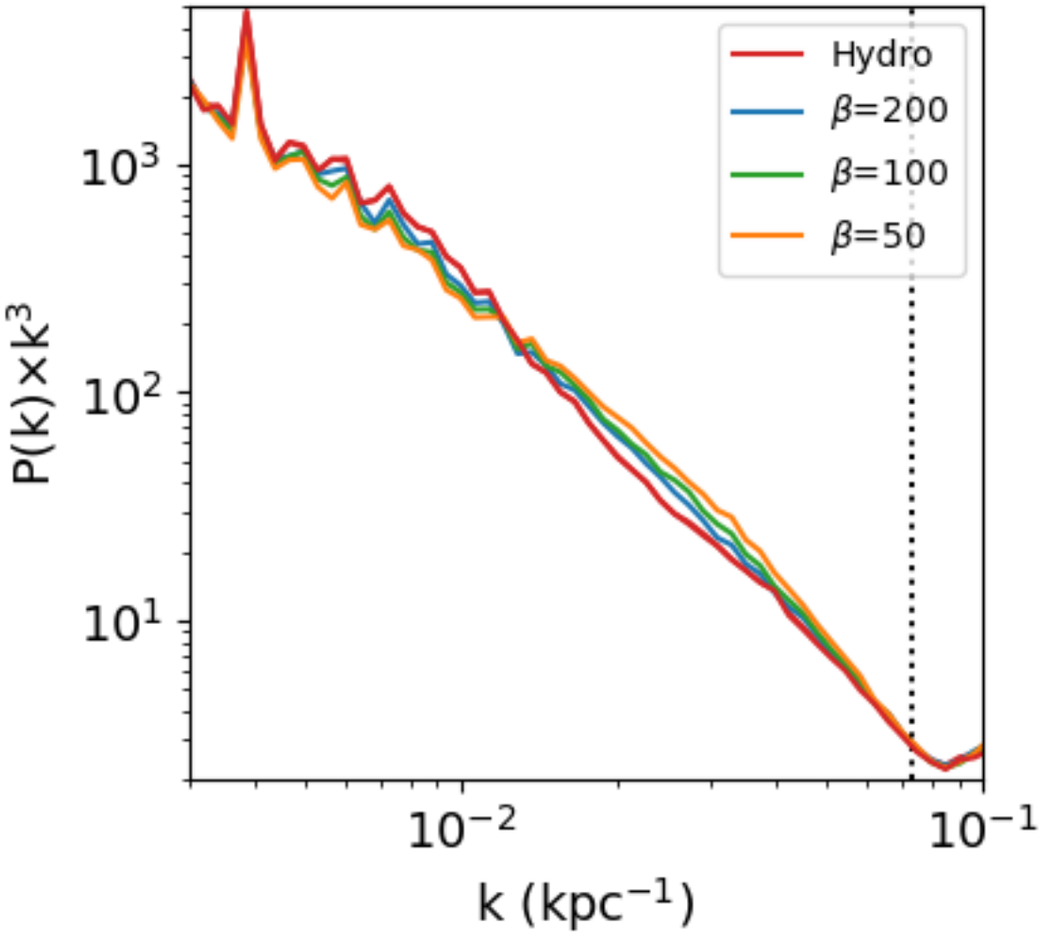



- You also get a laminar layer around a rigid-ish perturber without magnetic fields - here is HD sim of Abell 2146 - 1:3 mass ratio, $M_{tot}$ ~ $7 \cdot 10^{14}$ $M_{sun}$, similar to Abell 3667

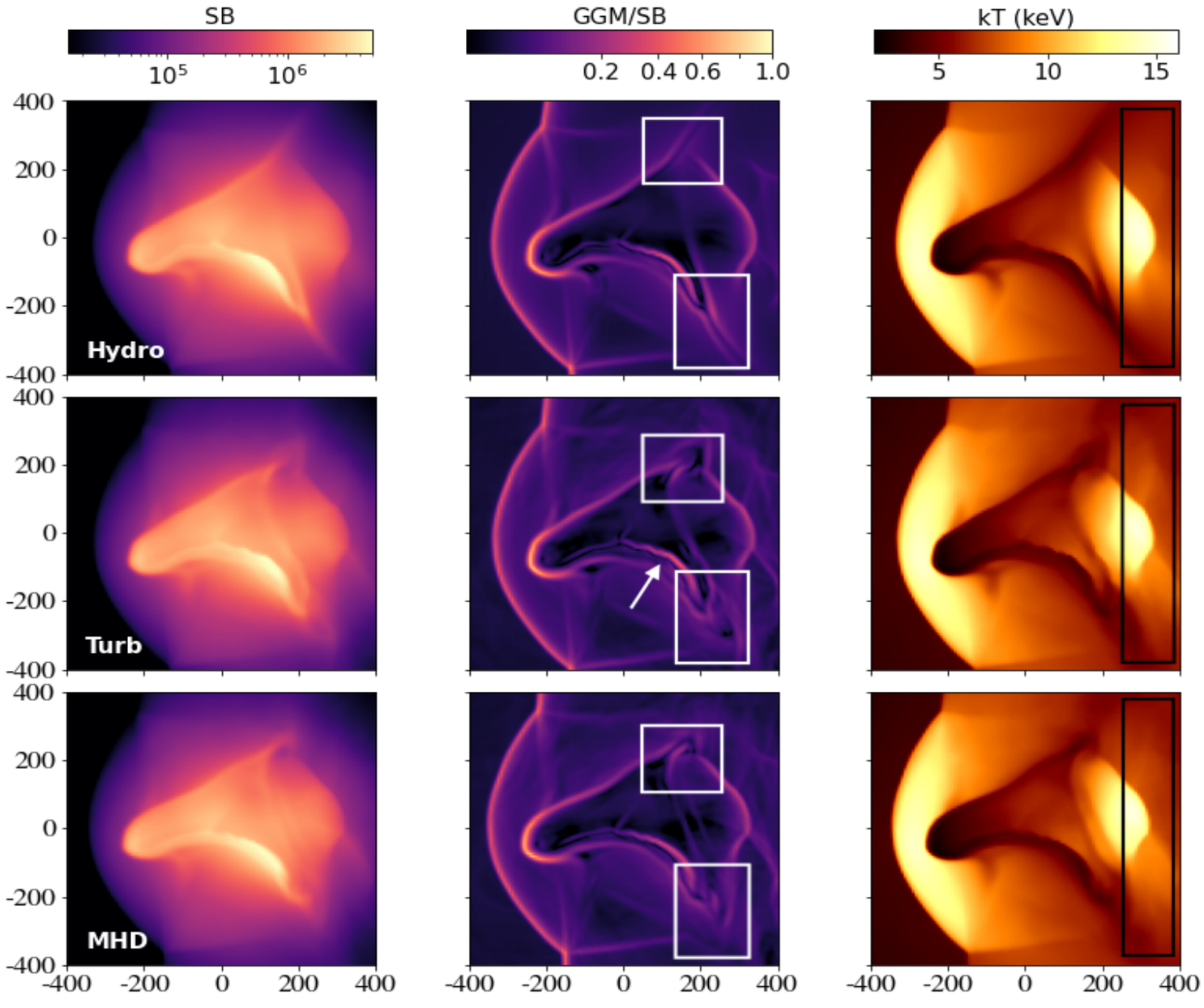
# If B is tangled, then stronger B —> <u>more</u> KHI

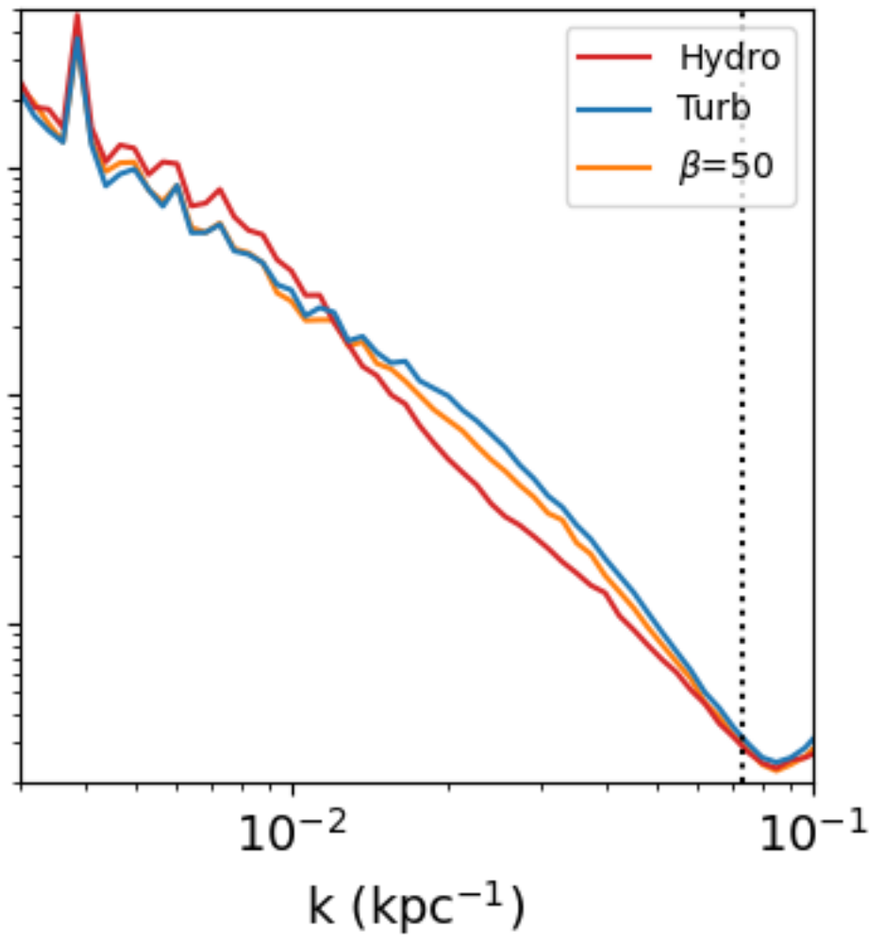



- Because $\delta B$ seed Alfvenic perturbations, i.e. more seeds for KHI to grow from.

# If B is tangled, then stronger B —> <u>more</u> KHI



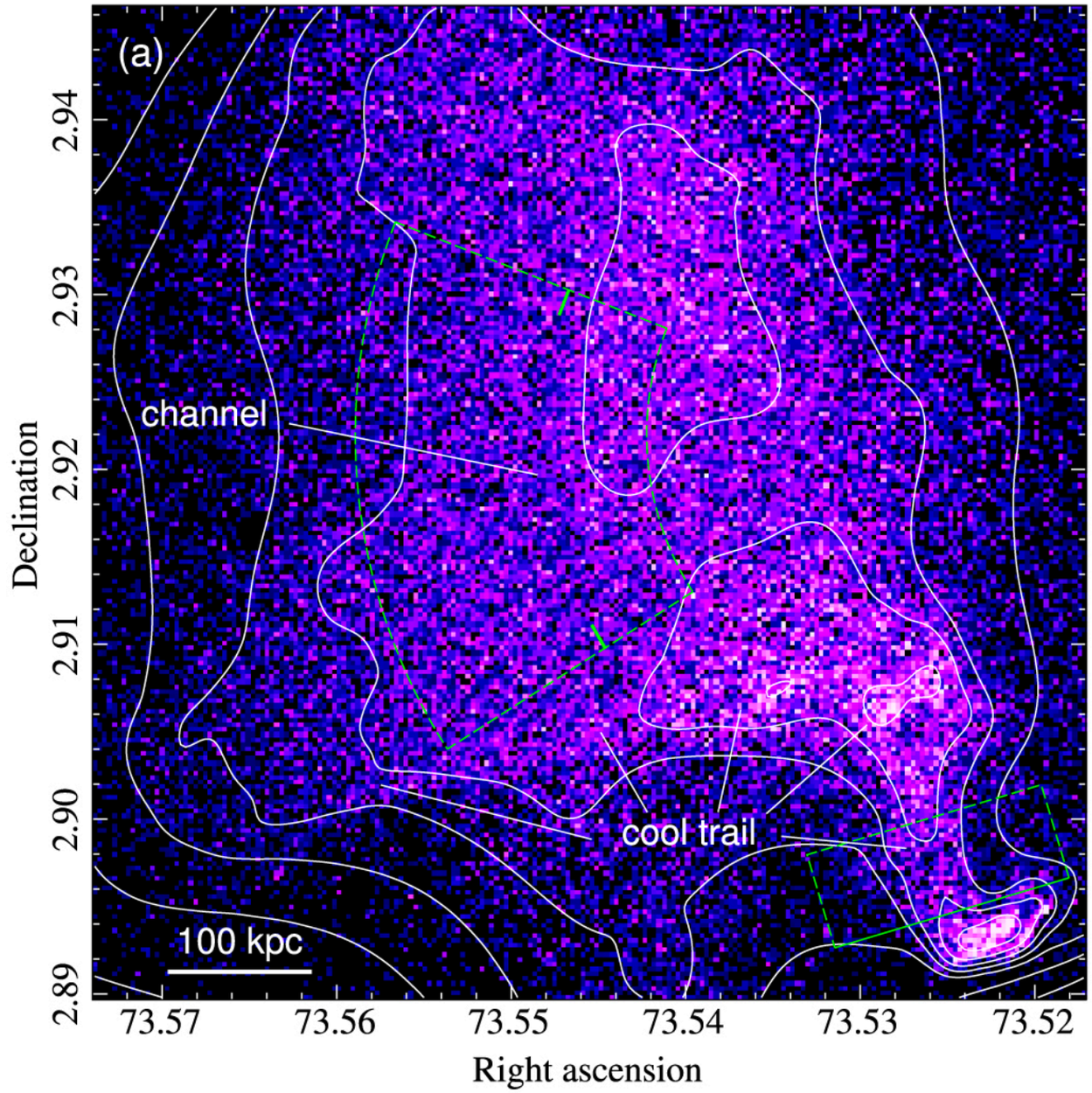




- You can check that this is the reason by giving the B field enough time to seed fluctuations, then turn it off.

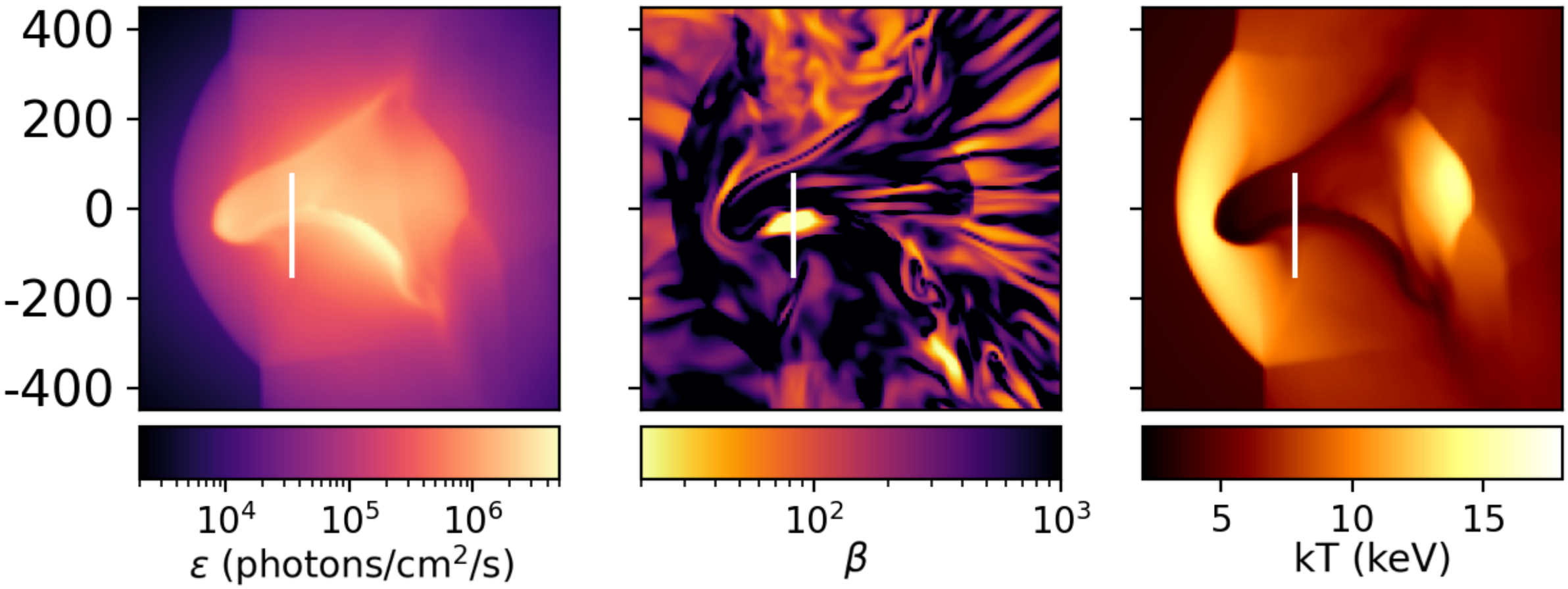
# 1: Can't constrain B from SB fluctuations without some model for the turbulence first.

# A history of optimism

- Similar conduction-based argument in A520.
- Also claim of low-SB "channel" where gas displaced by magnetic pressure. Wang+ 2016

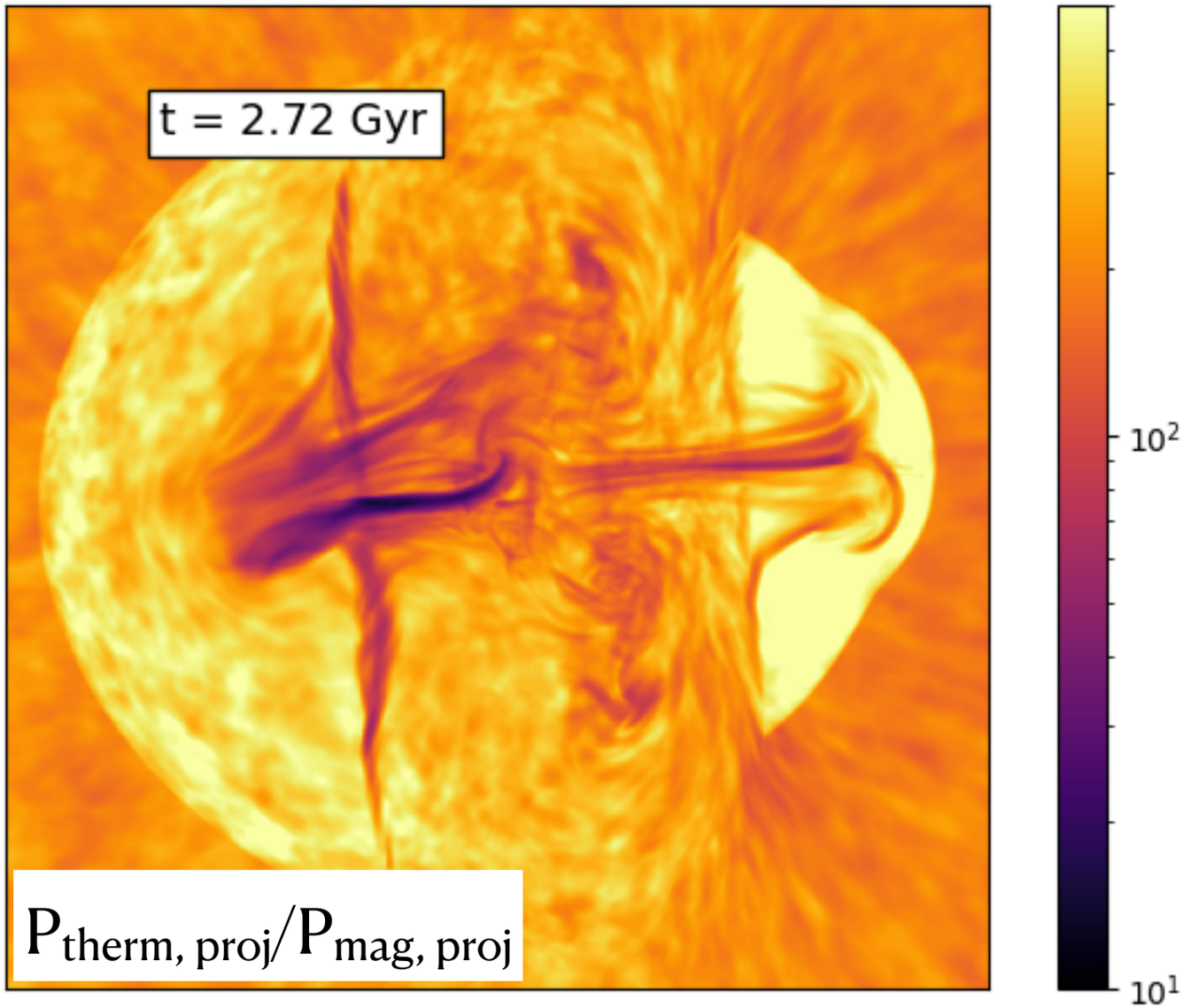


# So while you can find an SB/kT dip where B is most amplified..

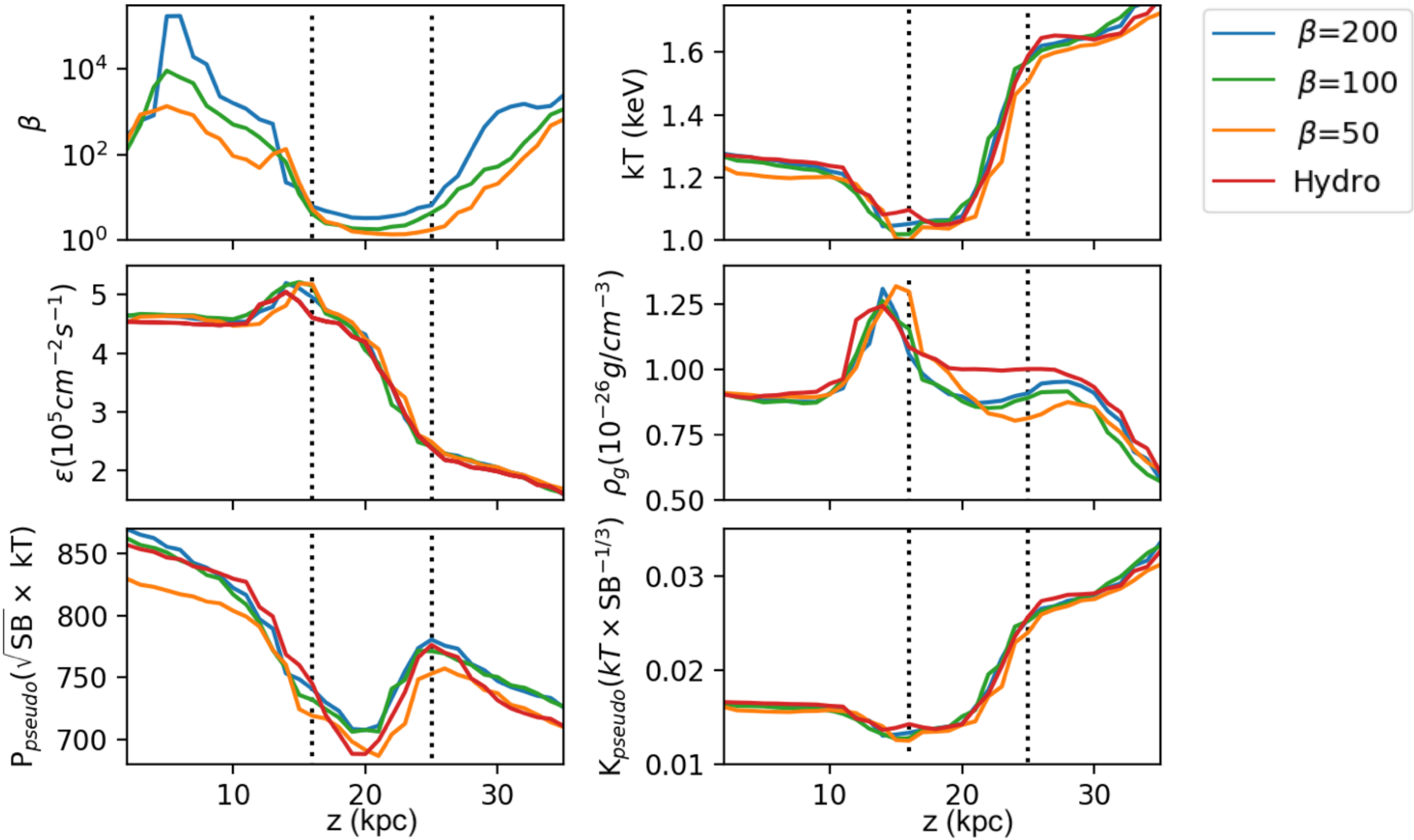



Chadayammuri+ 2022

# .. and while in principle this is true..

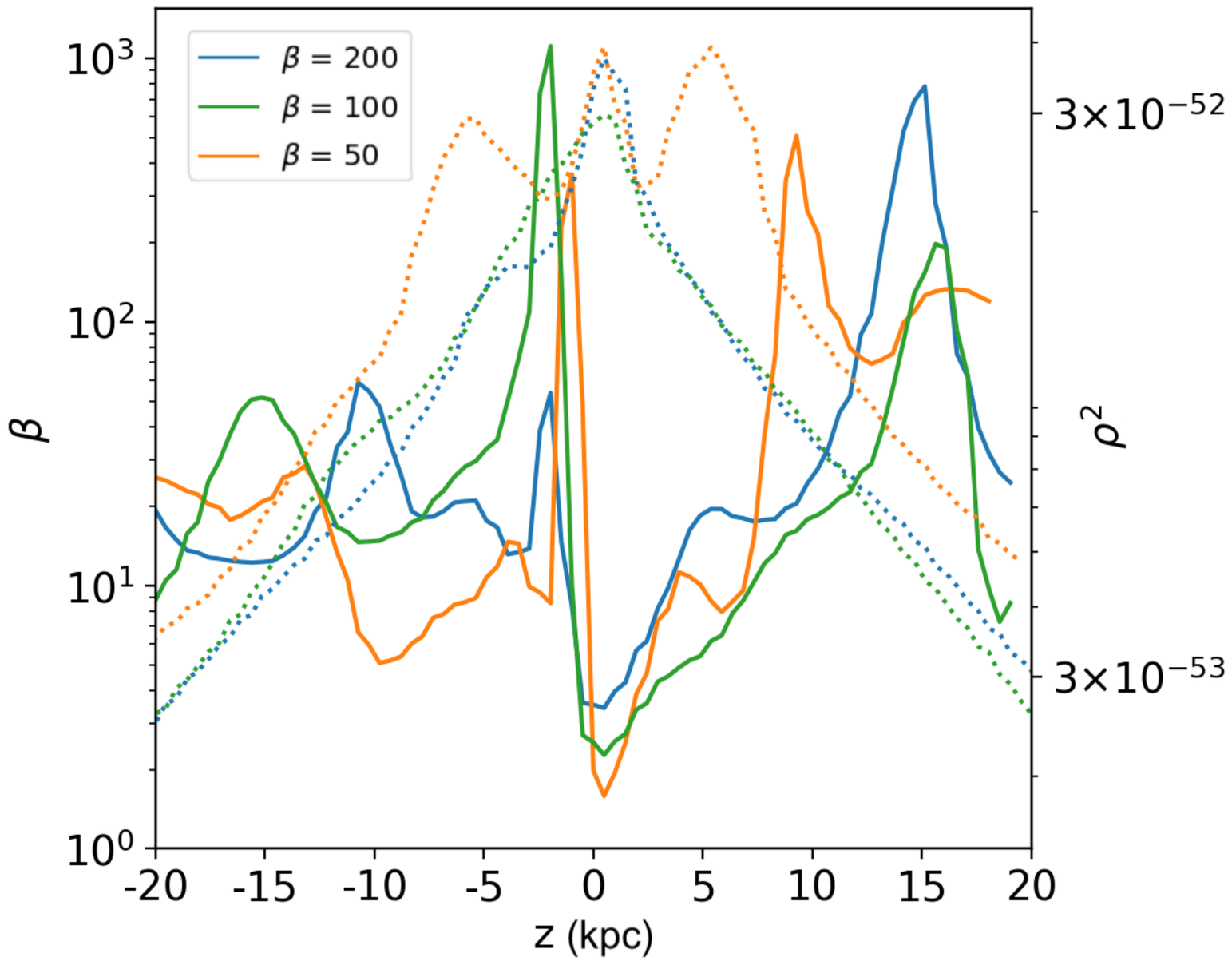


# .. you get the SB dip without B fields, too.




Chadayammuri+ 2022

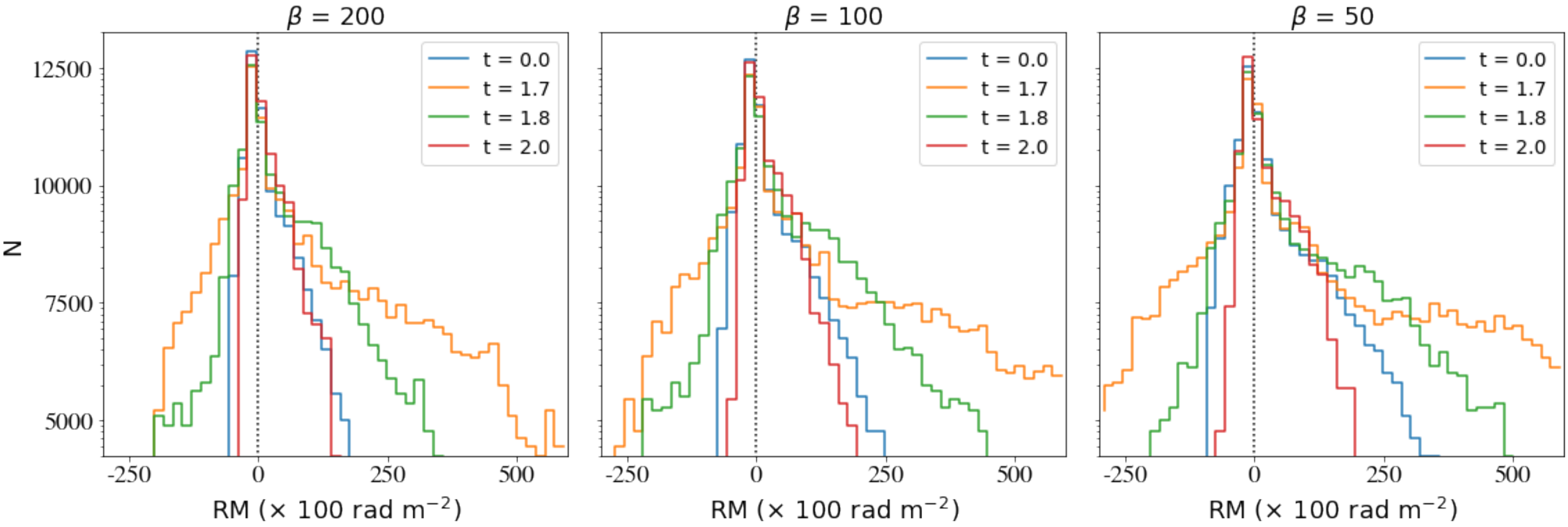
# The region of B amplification is too small in head-on mergers




Chadayammuri+ 2022

# 2. Magnetic channels are usually wiped  out in projection, at least in head-on mergers

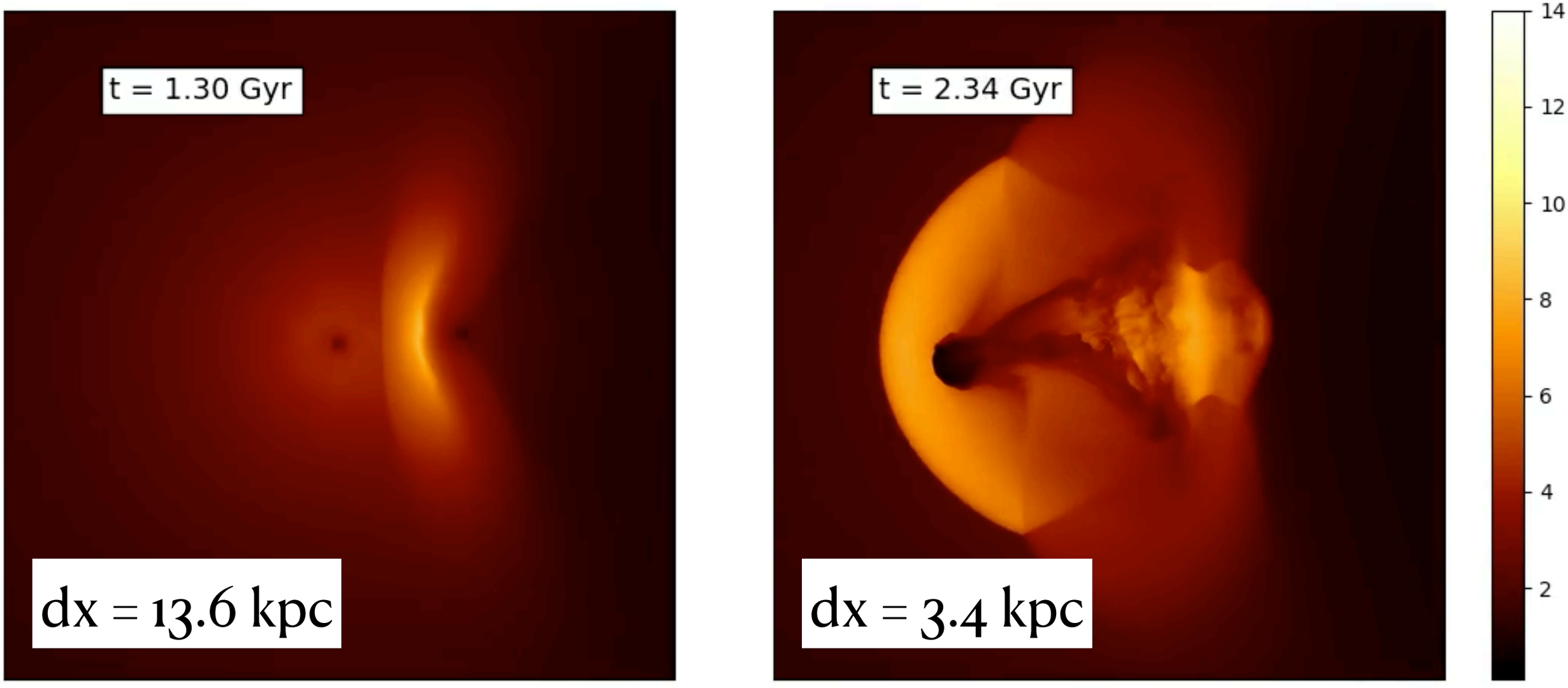
# So what can we do??




Chadayammuri+ 2022

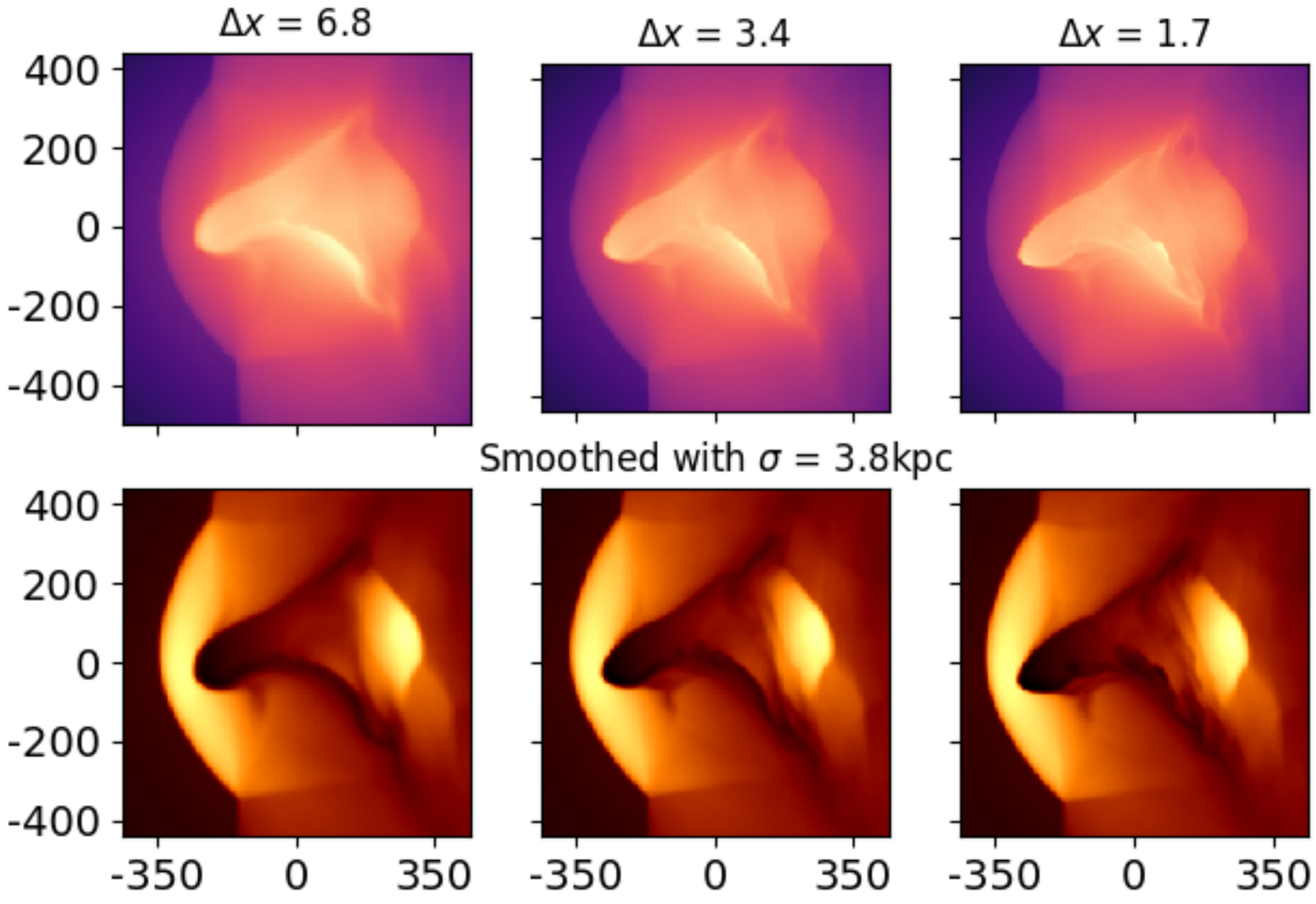
- **Faraday rotation measure** works really well!
- If many pencil beams, can distinguish between higher average $\beta$ and merger-based amplification

# Lastly, turbulence cares about scale, i.e. resolution




- At some point, plasma viscosity will start to act like lower resolution, but unclear how to break this degeneracy.

# Lastly, turbulence cares about scale, i.e. resolution

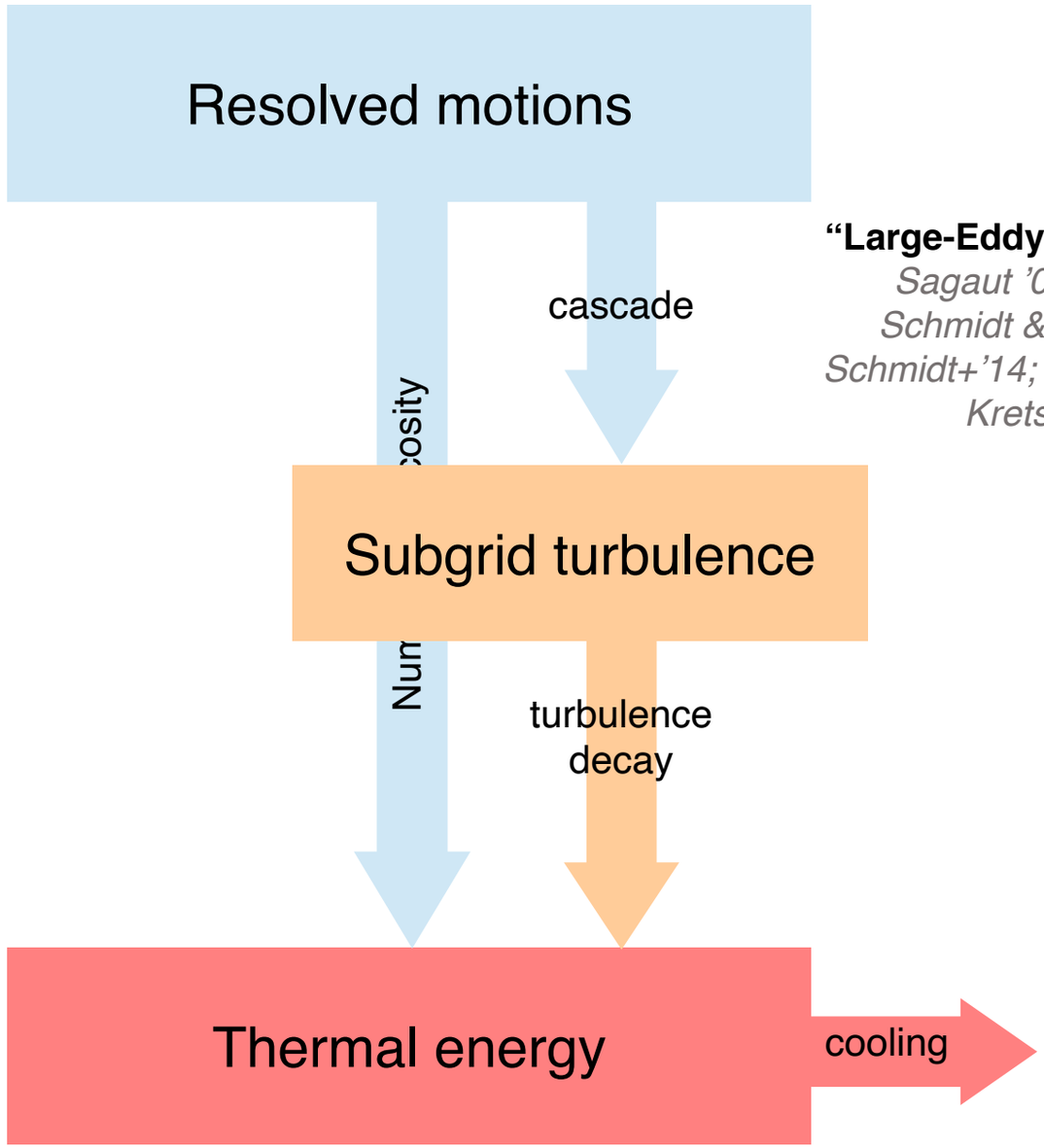



Chadayammuri+ 2022

- At some point, plasma viscosity will start to act like lower resolution, but unclear how to break this degeneracy.

# Can we build a model for sub-grid turbulence?

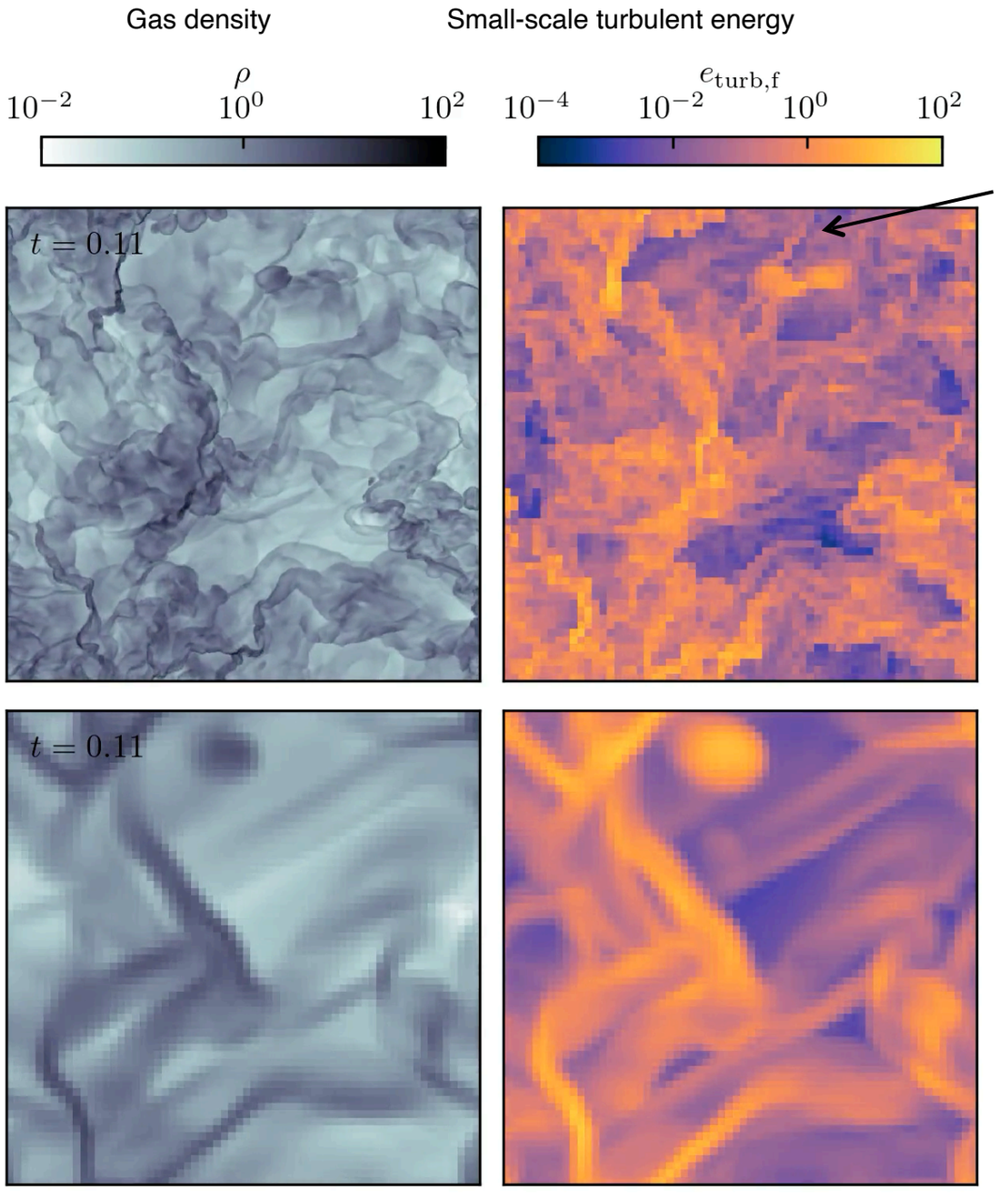
- Large eddy simulations:
  - Assume that turbulence follows same power spectrum on unresolved scales as on resolved inertial scales
  - Store energy on smallest resolved scale + dissipate on turnover timescale of smallest resolved eddy




**“Large-Eddy Simulations”**
*Sagaut ’07; Garnier’ 09; Schmidt & Federrath ’11; Schmidt+’14; Semenov+’16; Kretschmer+’20,‘21*

# Can we build a model for sub-grid turbulence?

- **The ART code (AMR)**
- **Initial Mach ≈ 9**
- **ICs from Kritsuk+'11**




Direct simulation
**$1024^3$**

Low-resolution simulation
with
subgrid turbulence
**$64^3$**

Coarse-grained
direct simulation
**$1024^3 \rightarrow 64^3$**

$$\left\langle \frac{\rho v^2}{2} \right\rangle - \frac{\langle\rho\rangle\langle v\rangle^2}{2}$$

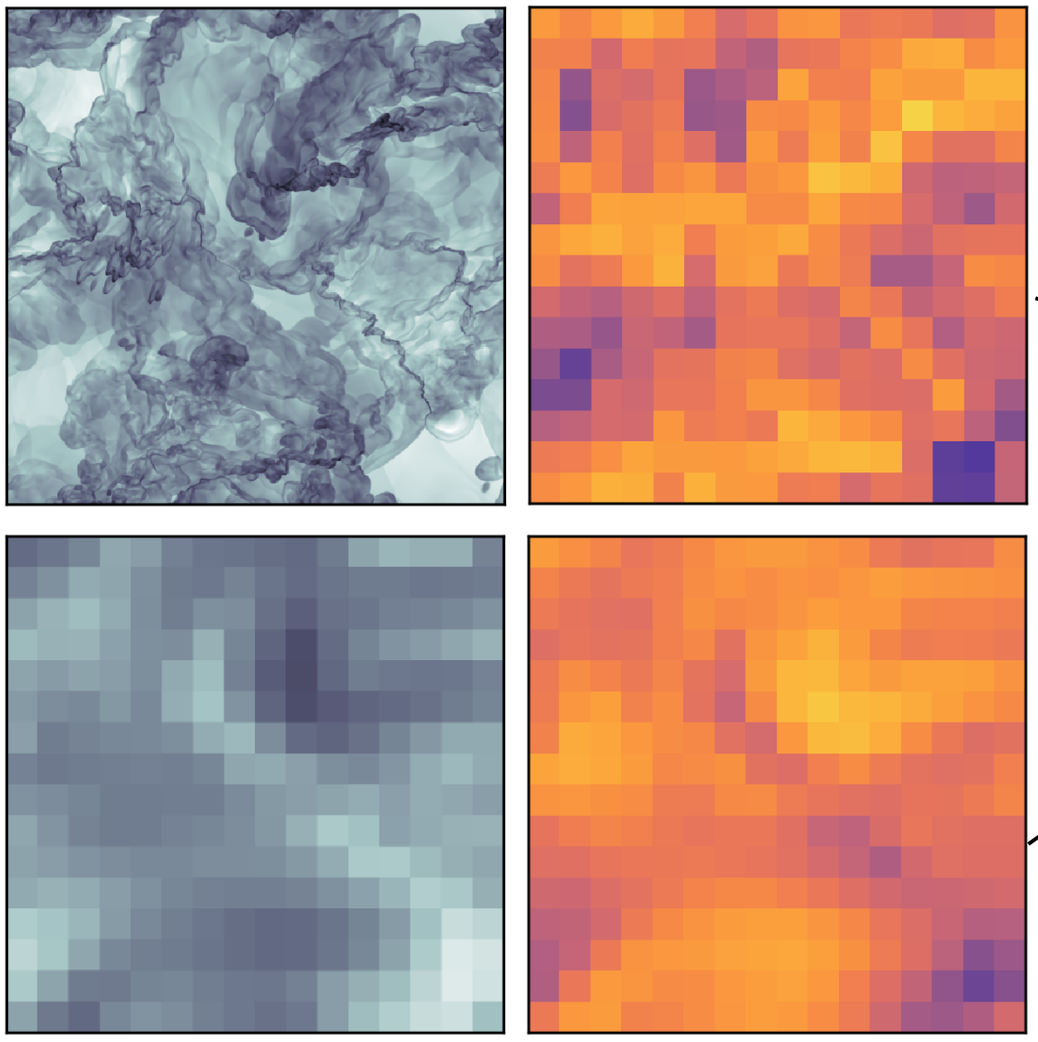
Predicted
subgrid turbulence
sourced by numerical
dissipation
**$64^3$**

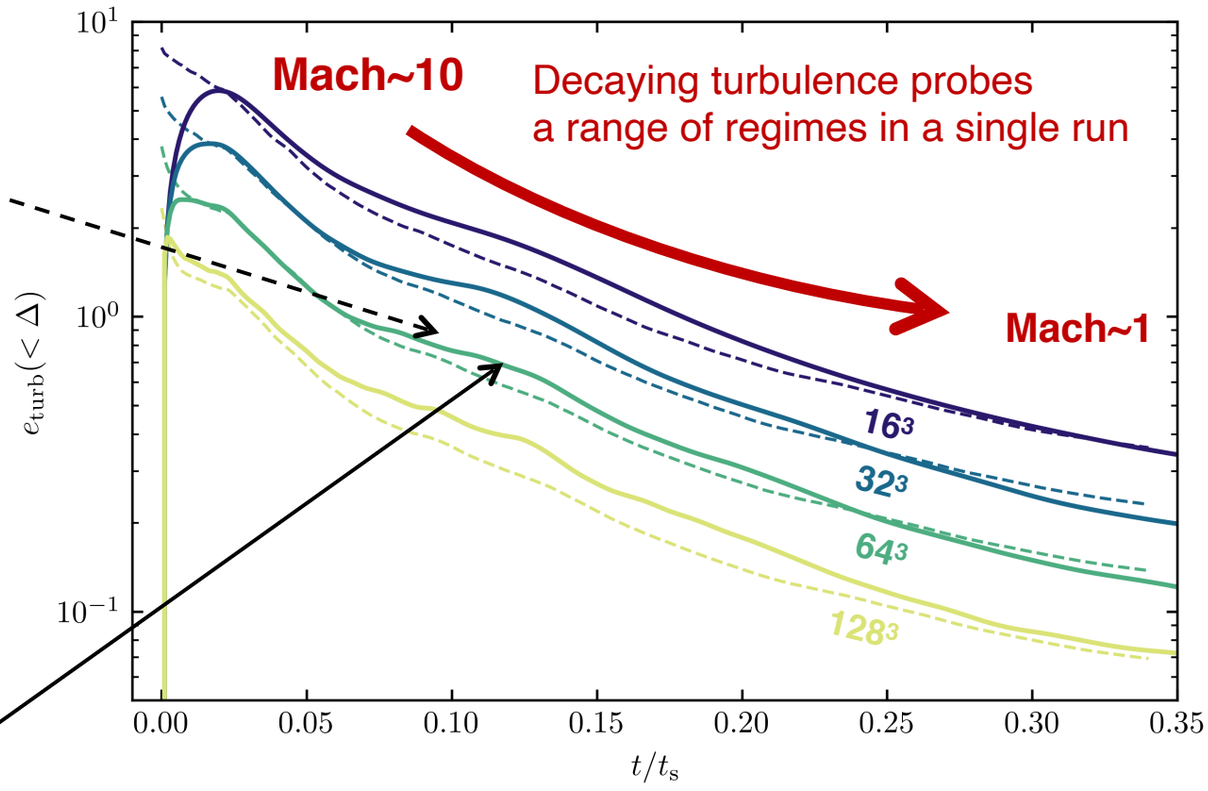
Semenov+ in prep

# Can we build a model for sub-grid turbulence?

Direct simulation

Low-res sim with subgrid turbulence

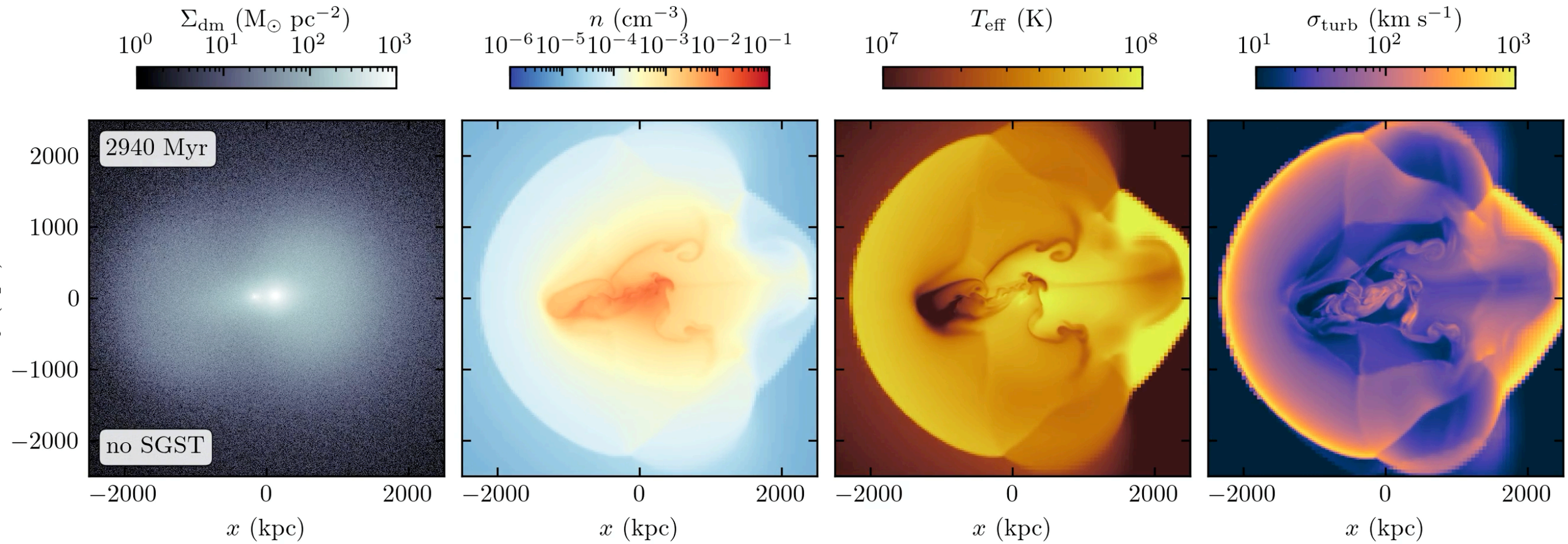





**Time**
(in box sound-crossing times)

Semenov+ in prep

# Cluster mergers with sub-grid turbulence




- Applied here to binary cluster merger
- Numerical artefact at refinement boundaries - work in progress

Chadayammuri+ in prep

# Crucial next step:

Models for how to transfer tracked sub grid turbulence to **magnetic fields, viscosity, thermal conduction**

**PIC and/or analytic models?**

# Summary

- I can probably spoil any dreams you have about measuring magnetic field strengths using X-ray images
- Unless it's a statistical measurement including a model for turbulence
- Radio measurements remain promising; especially Faraday rotation can identify merger-related amplification
- Sub-grid models of turbulence can help move past resolution effects in modelling B fields and plasma microphysics. Let's talk about analytic prescriptions for this!