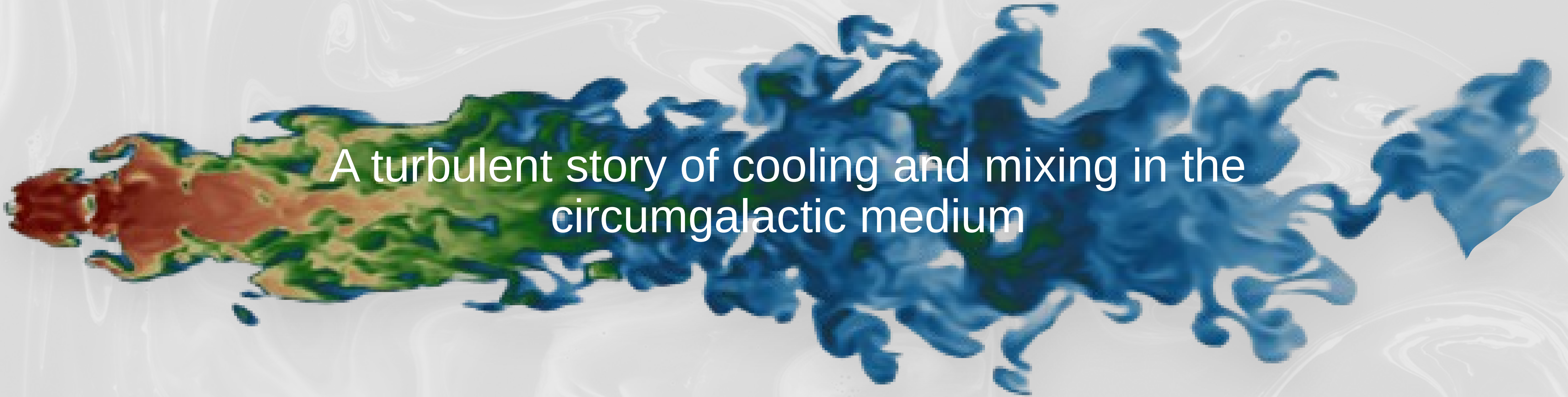
MAX PLANCK INSTITUTE
FOR ASTROPHYSICS

A turbulent story of cooling and mixing in the circumgalactic medium

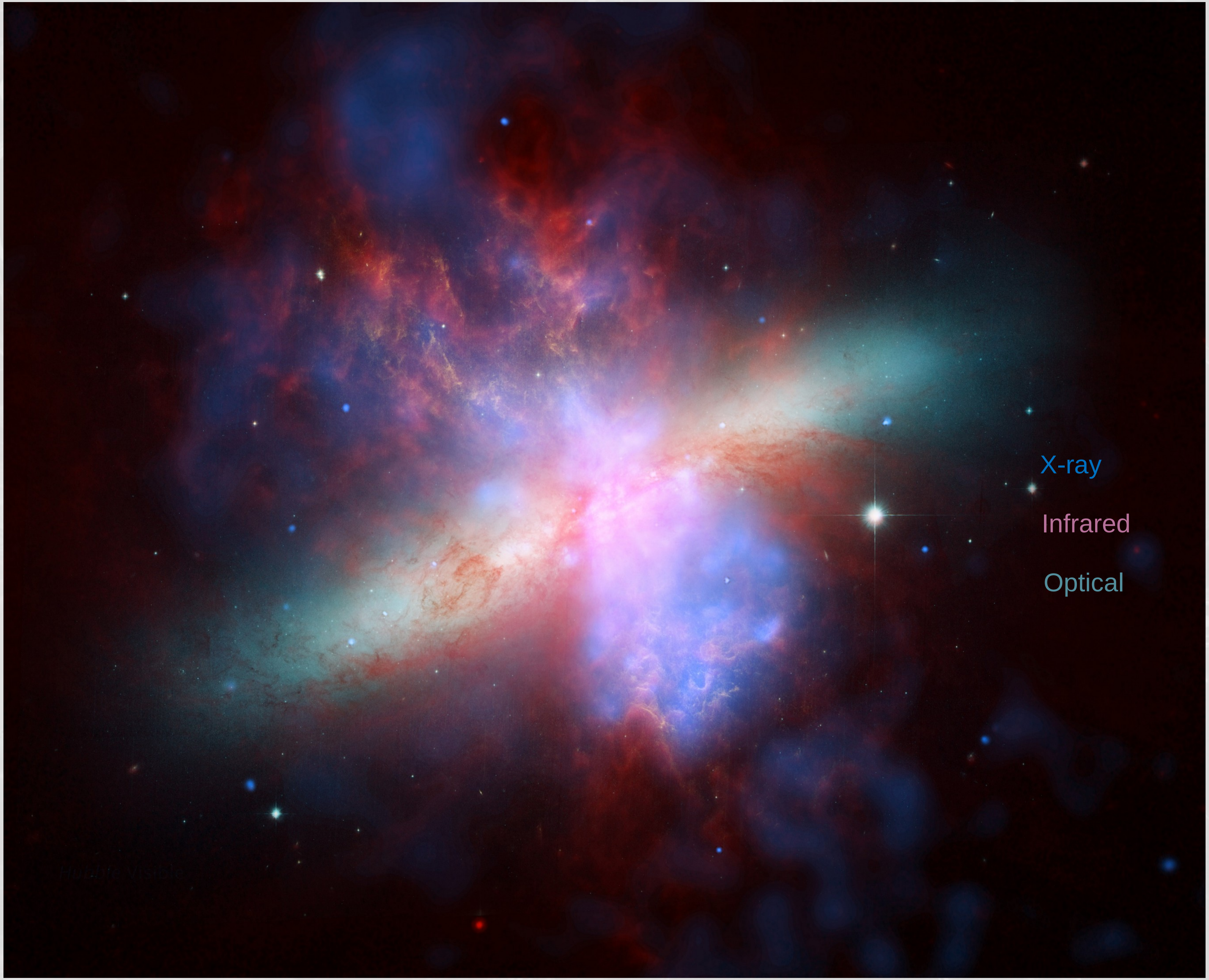


Alankar Dutta, postdoc fellow, MPA Garching

Collaborators:
Max Gronke, Mukesh Singh Bisht, Prateek Sharma, Rajsekhar Mohapatra, Ritali Ghosh, Tiago Costa, Volker Springel

Sept 9, 2026

M82: an example



X-ray: NASA/CXC/JHU/D.Strickland; Optical: NASA/ESA/STScI/AURA/The Hubble Heritage Team; IR: NASA/JPL-Caltech/Univ. of AZ/C. Engelbracht

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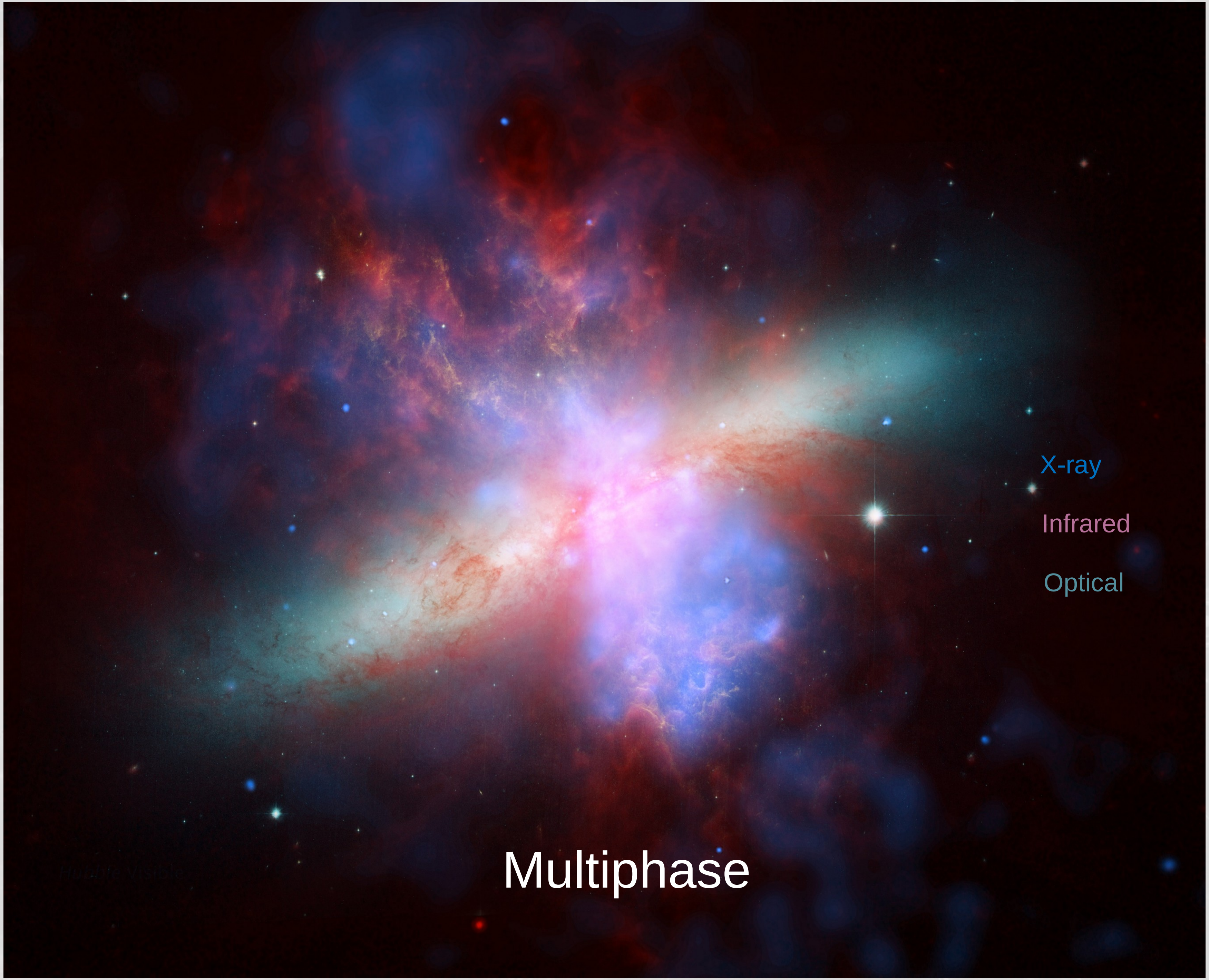

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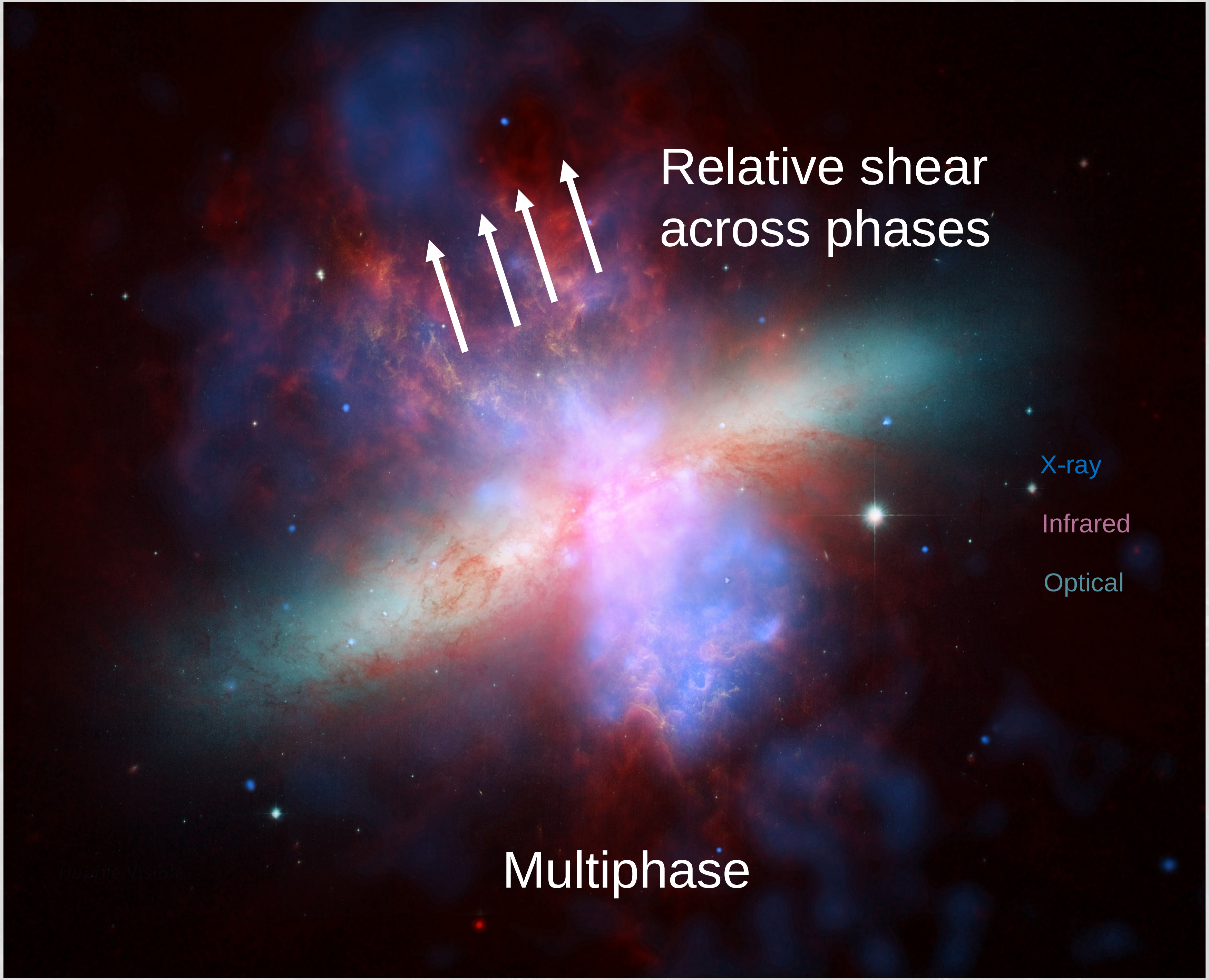

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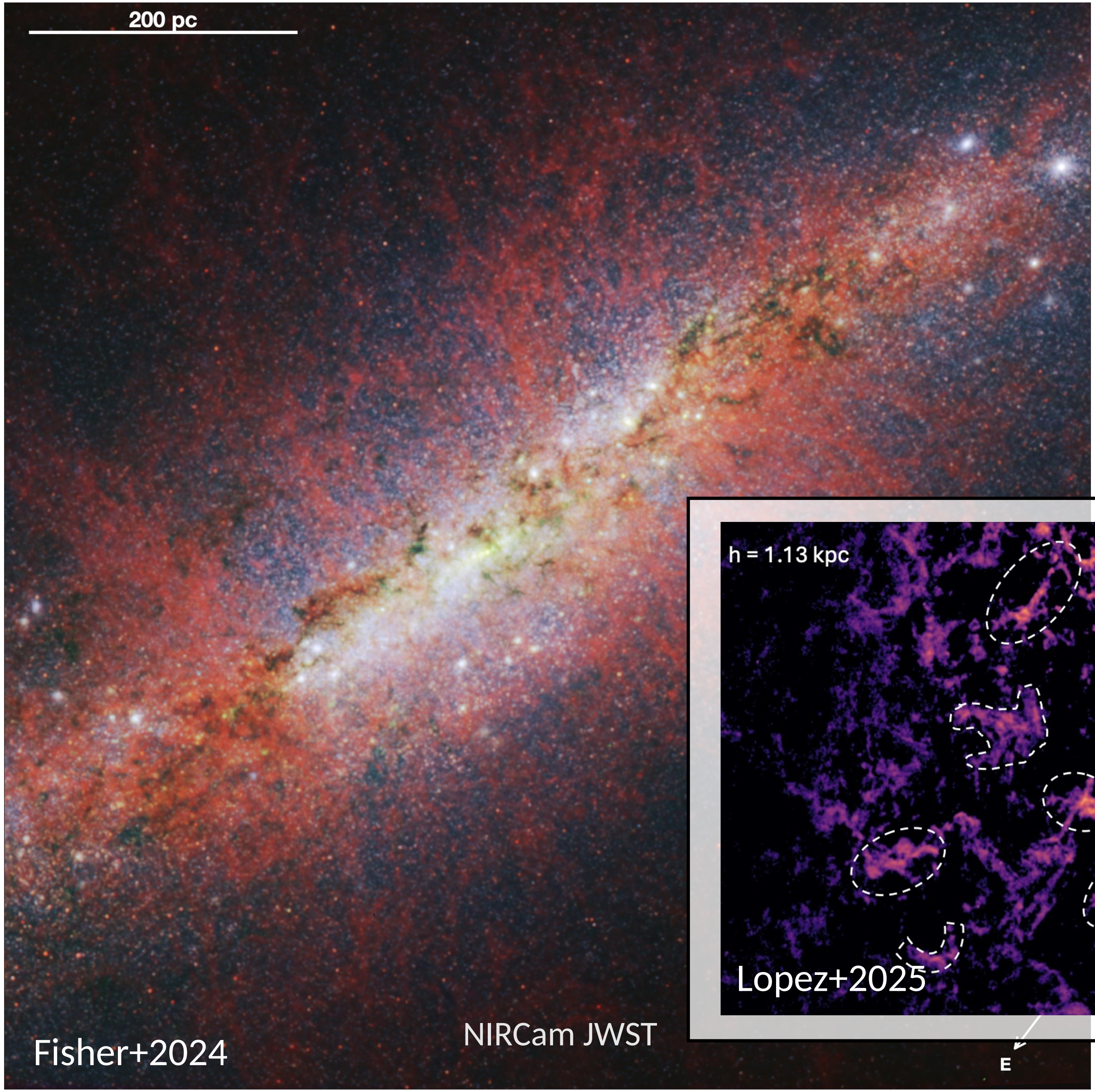
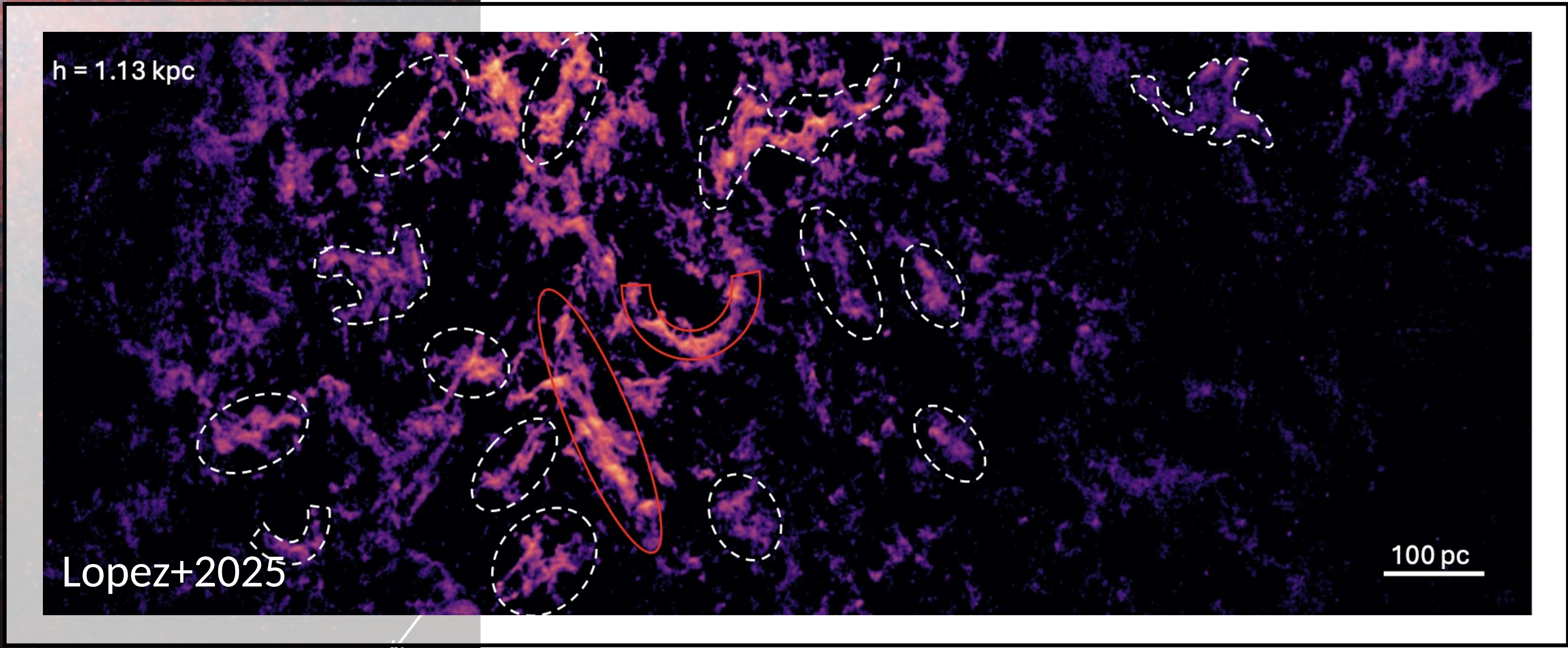
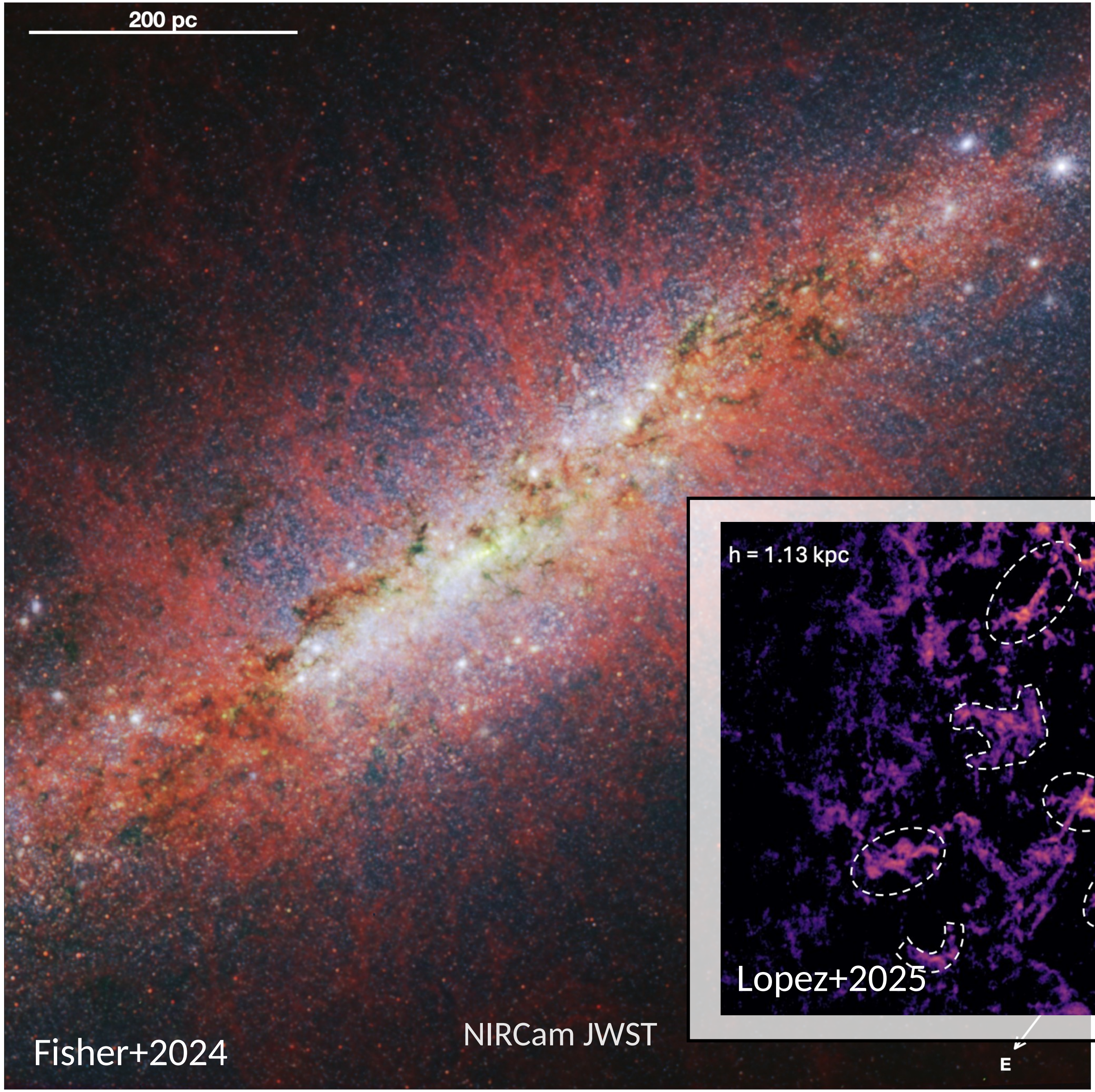
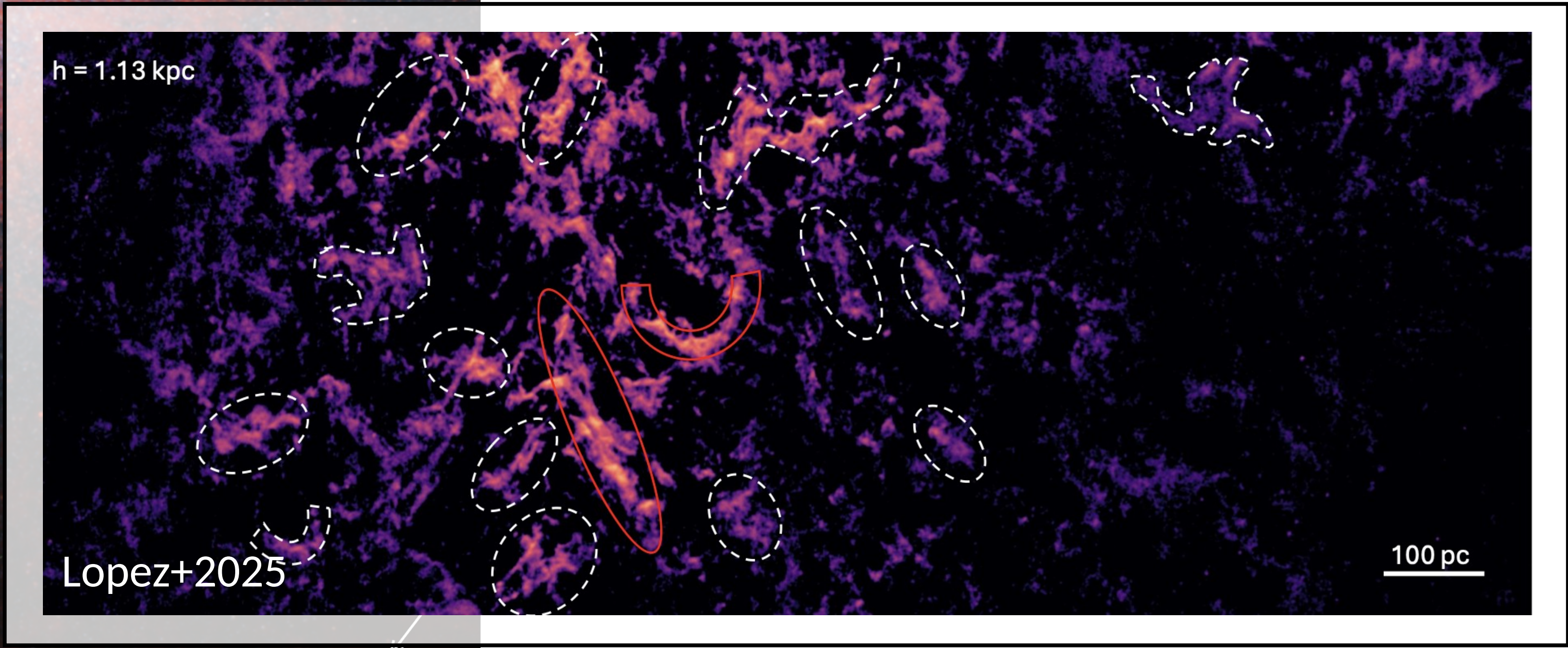

200 pc
NIRCam JWST
Fisher+2024
E


h = 1.13 kpc
Lopez+2025
100 pc



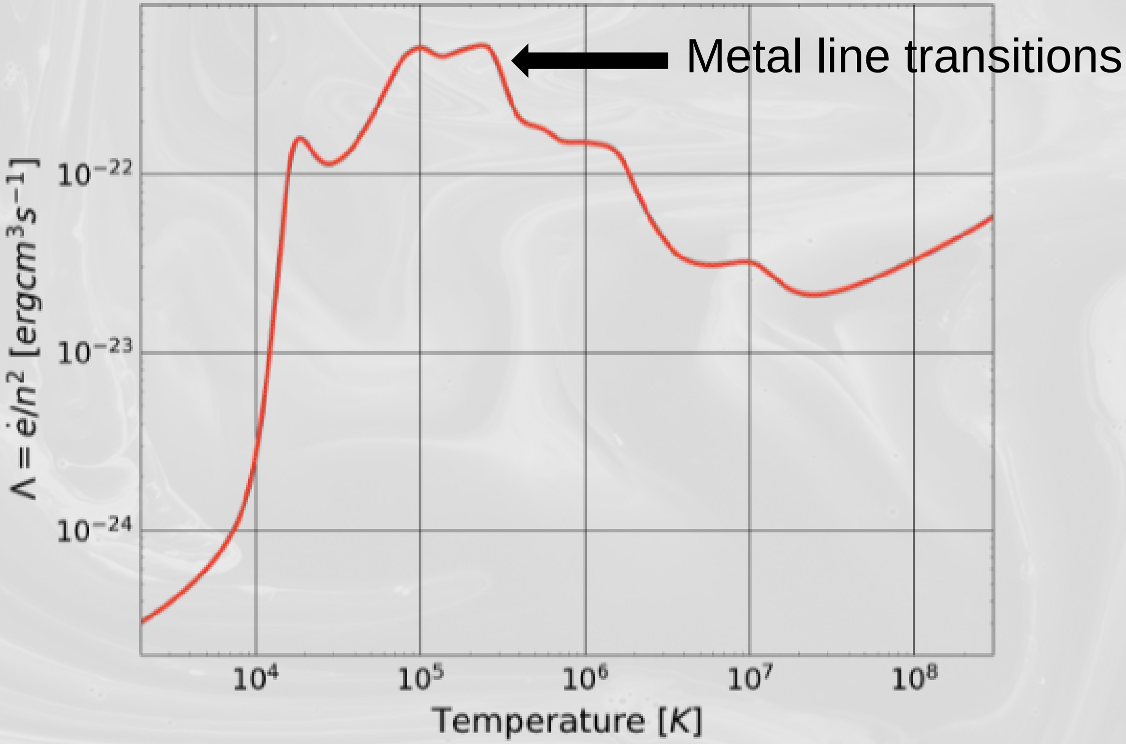


- Turbulent
- Clumpy

Radiative cooling

Radiative cooling

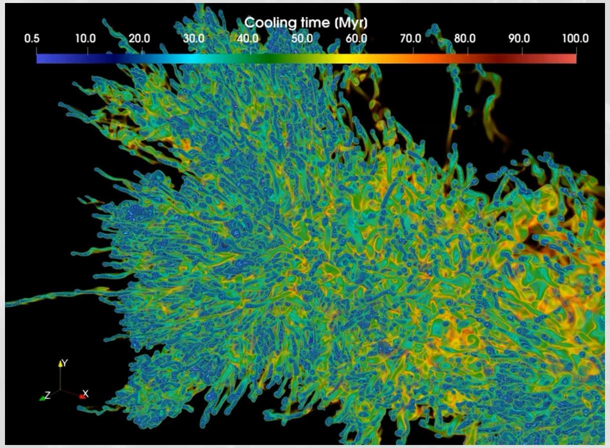
Radiative cooling



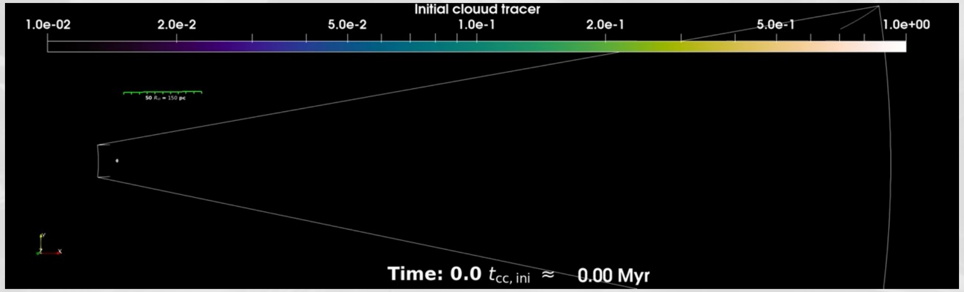
Mixed gas cooling is necessary to form cold and clumpy clouds

Turbulent multiphase gas in different contexts

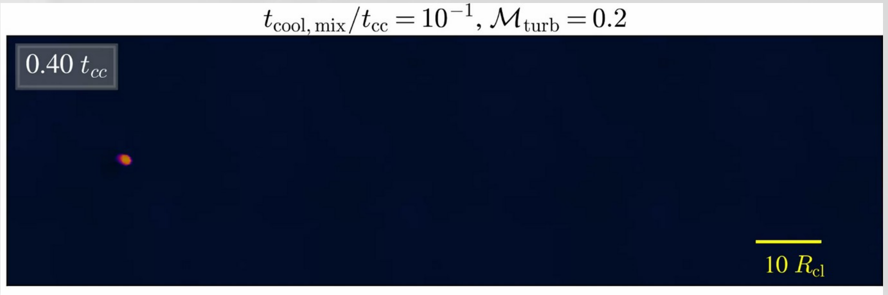
Galactic outflows



Kanjilal+20 (incl. AD)



Dutta+25

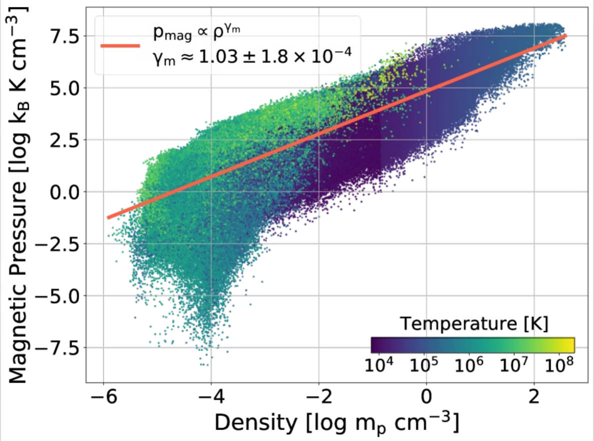


Ghosh+25 (incl. AD)

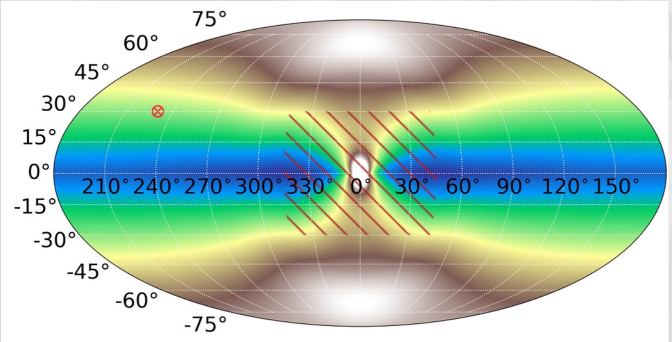
Tails of Jellyfish galaxies

Ghosh+24 (incl. AD)

Empirical models and synthetic observations

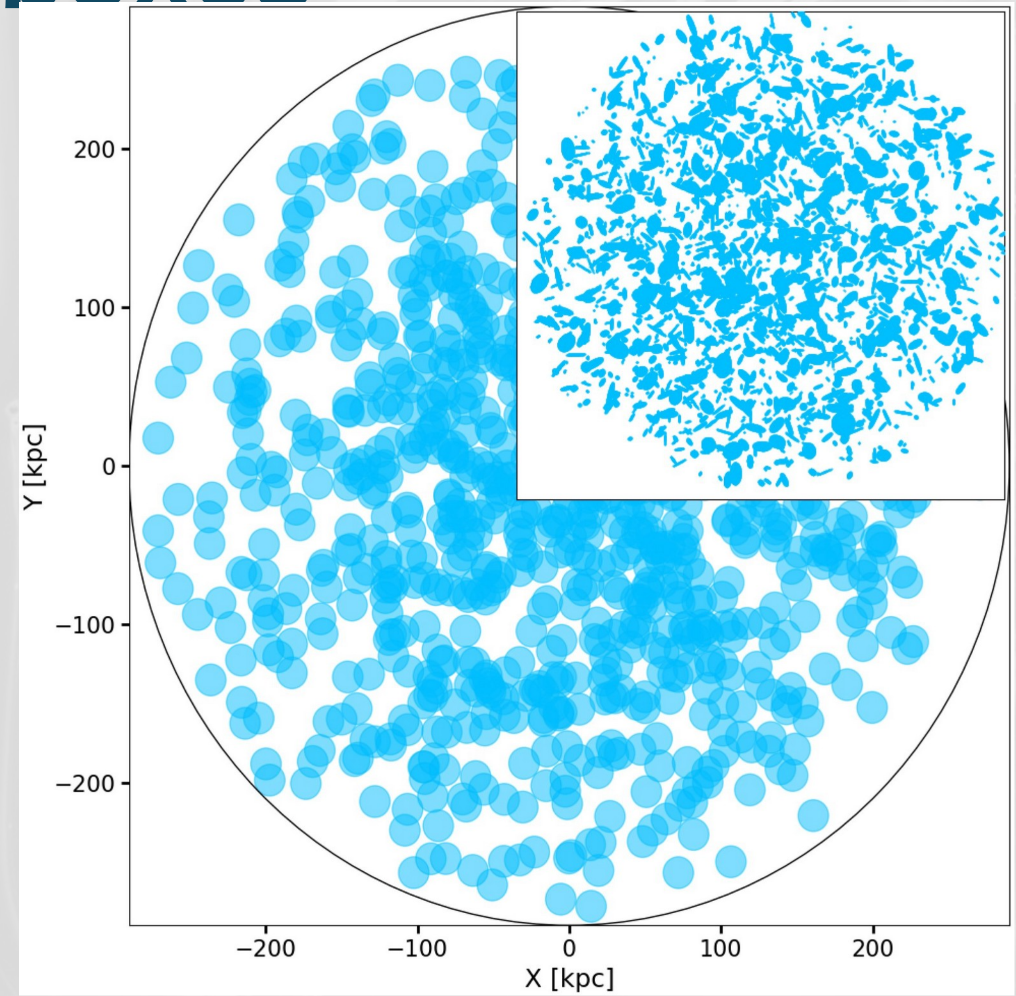


Dutta+21

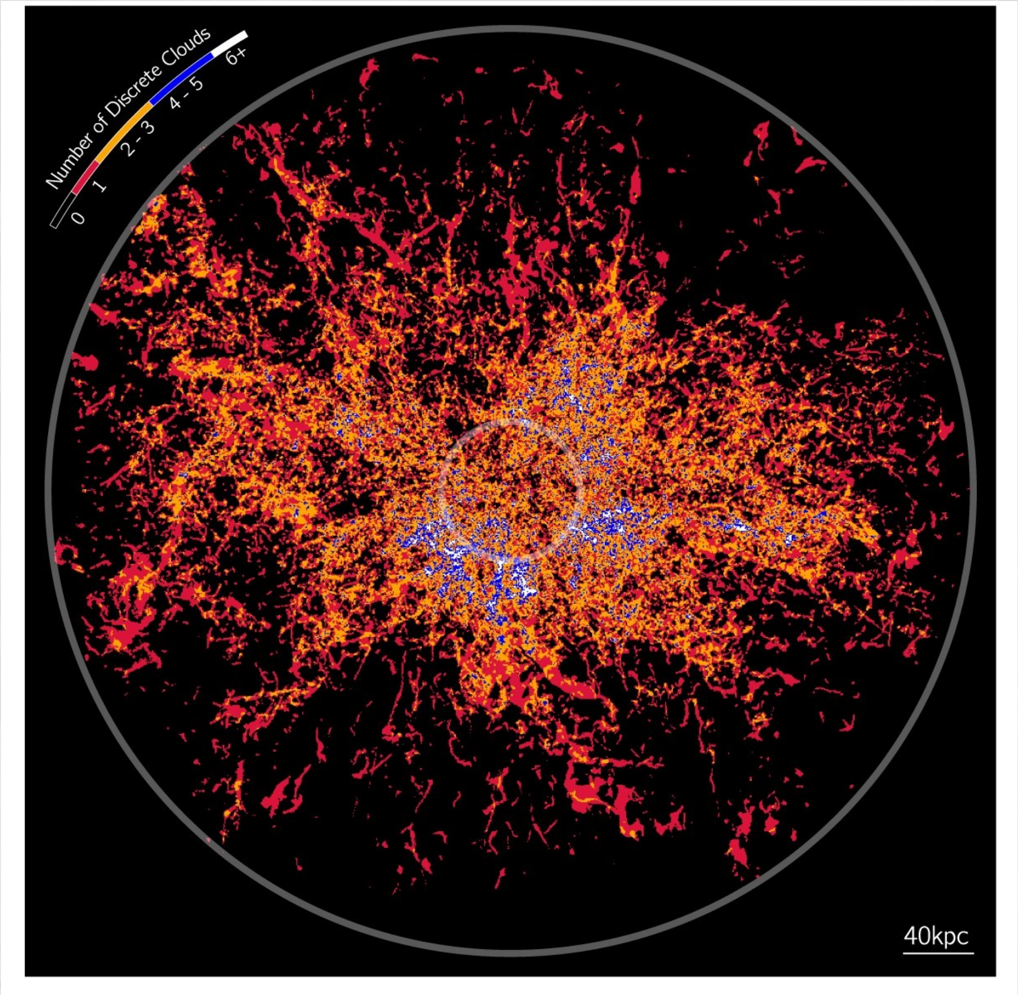


Dutta+24

Cloud complexes as multiphase turbulent boxes

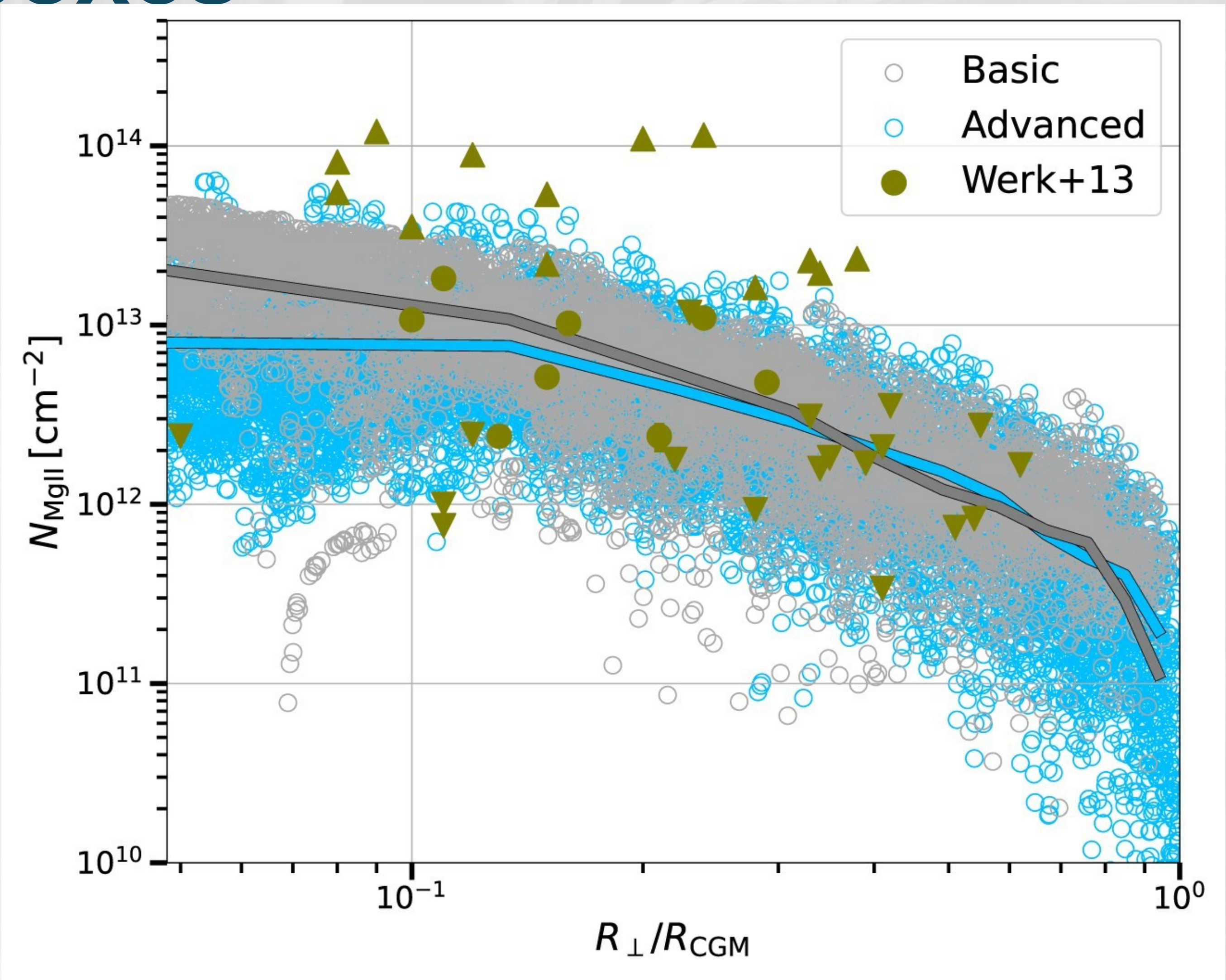


Cloud complex from Bisht+25 (incl. AD)
See also Hummels+25

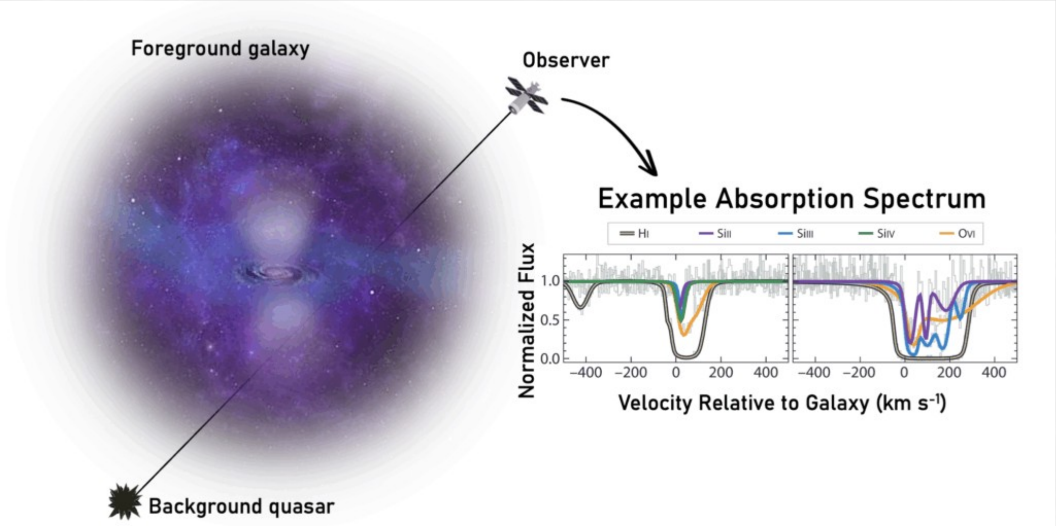


Projected cloud distribution in the CGM
(GIBLE; Ramesh+24)

Cloud complexes as multiphase turbulent boxes



Bisht+25 (incl. AD)

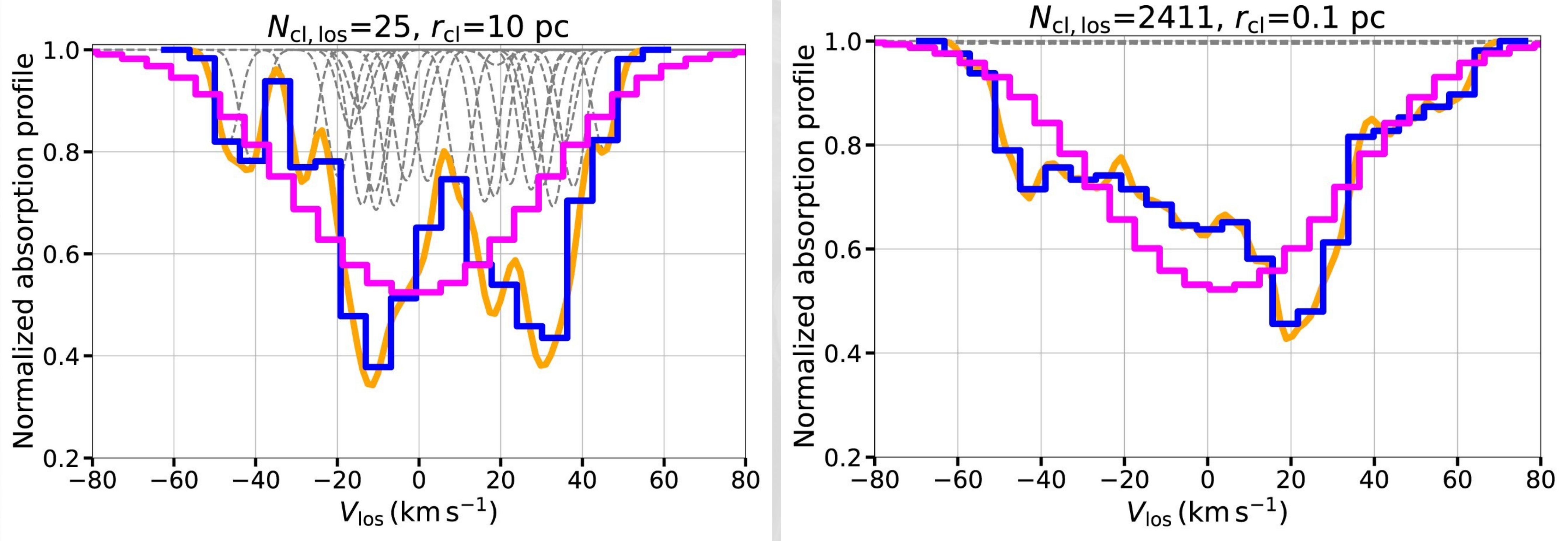


Courtesy: Astrobites (Anderson 2025)

Provides a natural explanation to the observed scatter in quasar absorption spectra from multiple quasar-galaxy pairs.

Cloud complexes as multiphase turbulent boxes

- The **size distribution of cloudlets** in a cloud complex and their **velocity dispersion** are model parameters.
- These in turn depend on the turbulent properties of the multiphase medium that they are a part of.



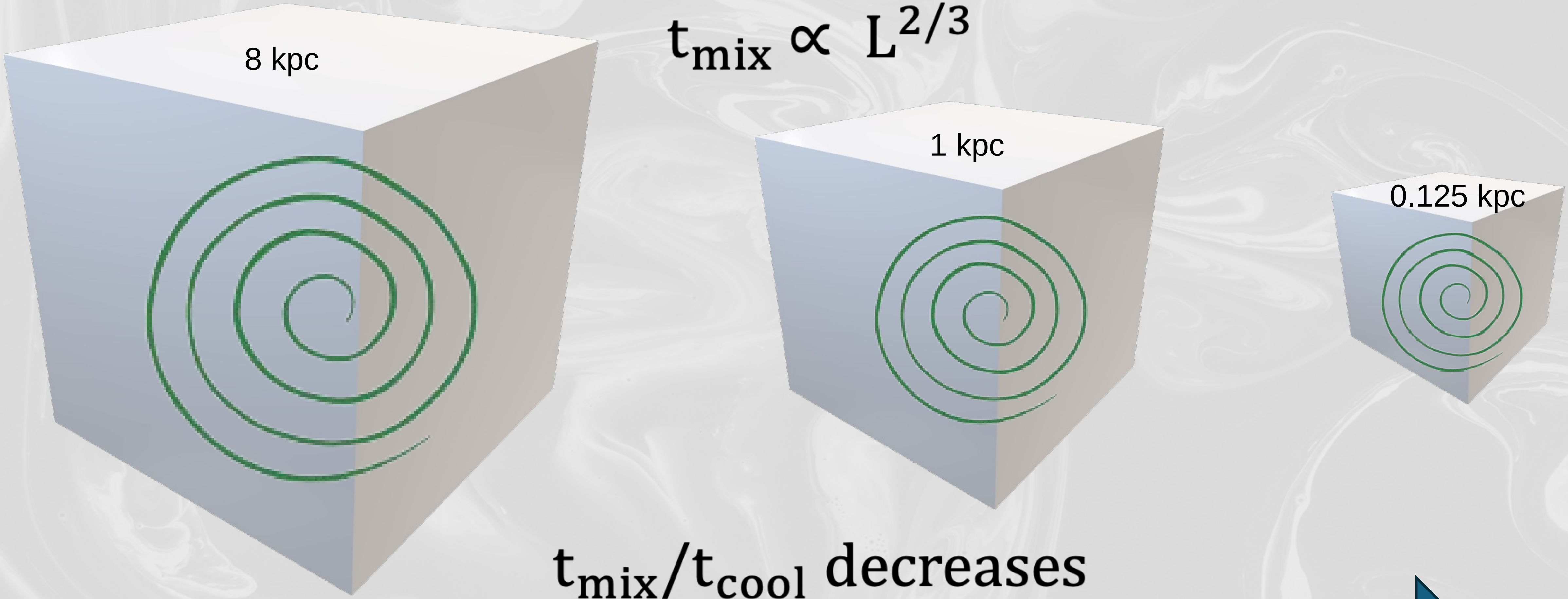
Cloud complex from Bisht+25 (incl. AD)

Cloud complexes as multiphase turbulent boxes

Scenario 1

$$u_{\mathrm{turb,L}} \propto L^{1/3}$$

$$t_{\mathrm{mix}} \propto L^{2/3}$$



$t_{\mathrm{mix}}/t_{\mathrm{cool}}$ decreases

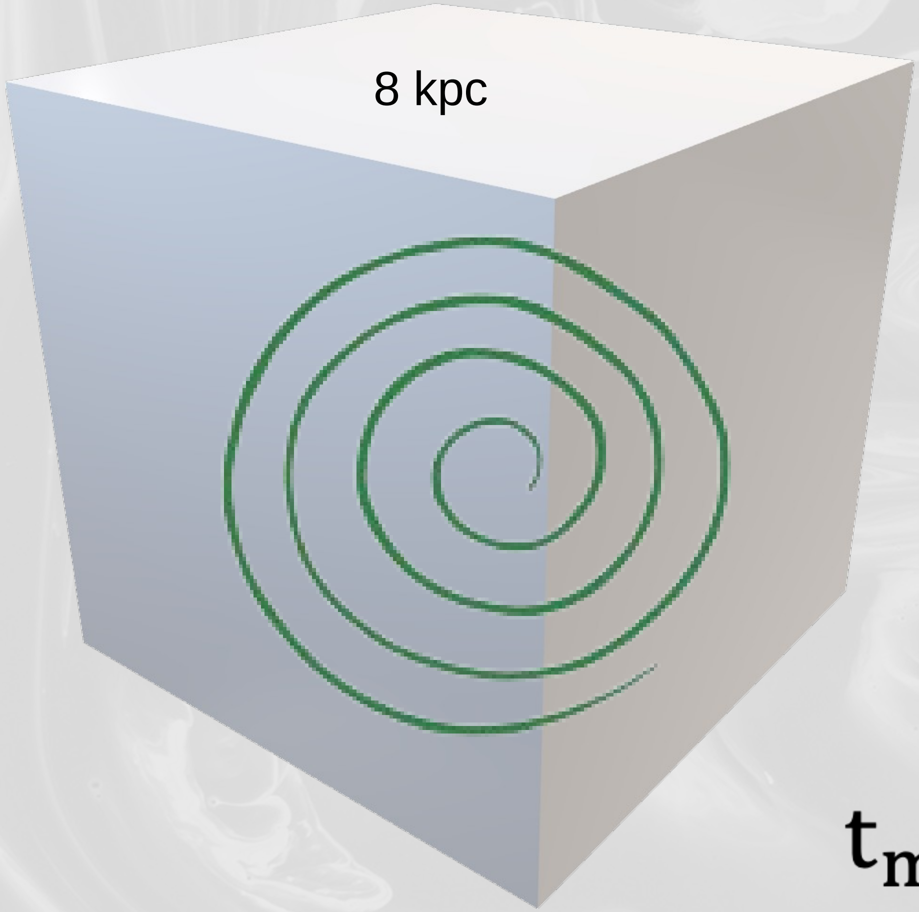
Lossless energy transfer: Kolmogorov cascade

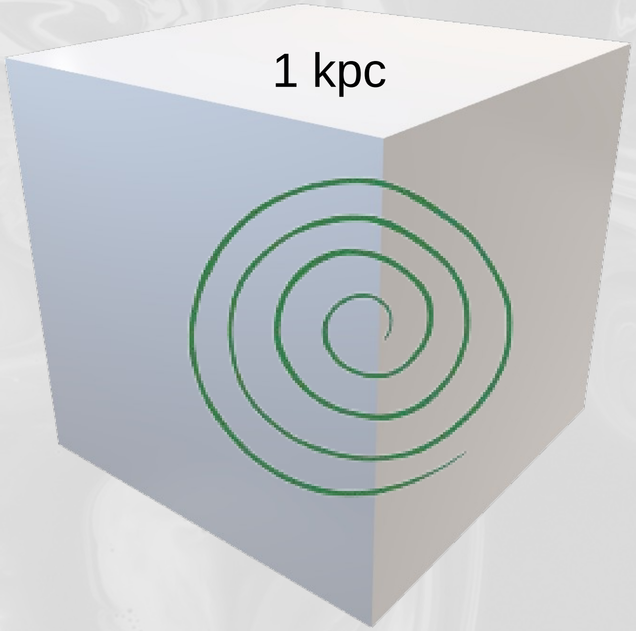
Cloud complexes as multiphase turbulent boxes

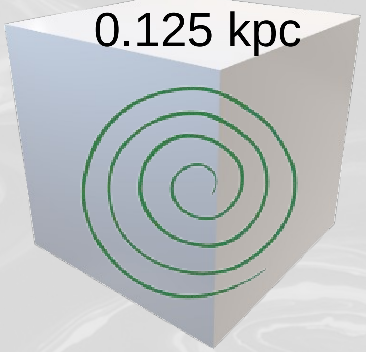
Scenario 2

$u_{\mathrm{turb},L} \propto L$

$t_{\mathrm{mix}} \propto$ constant





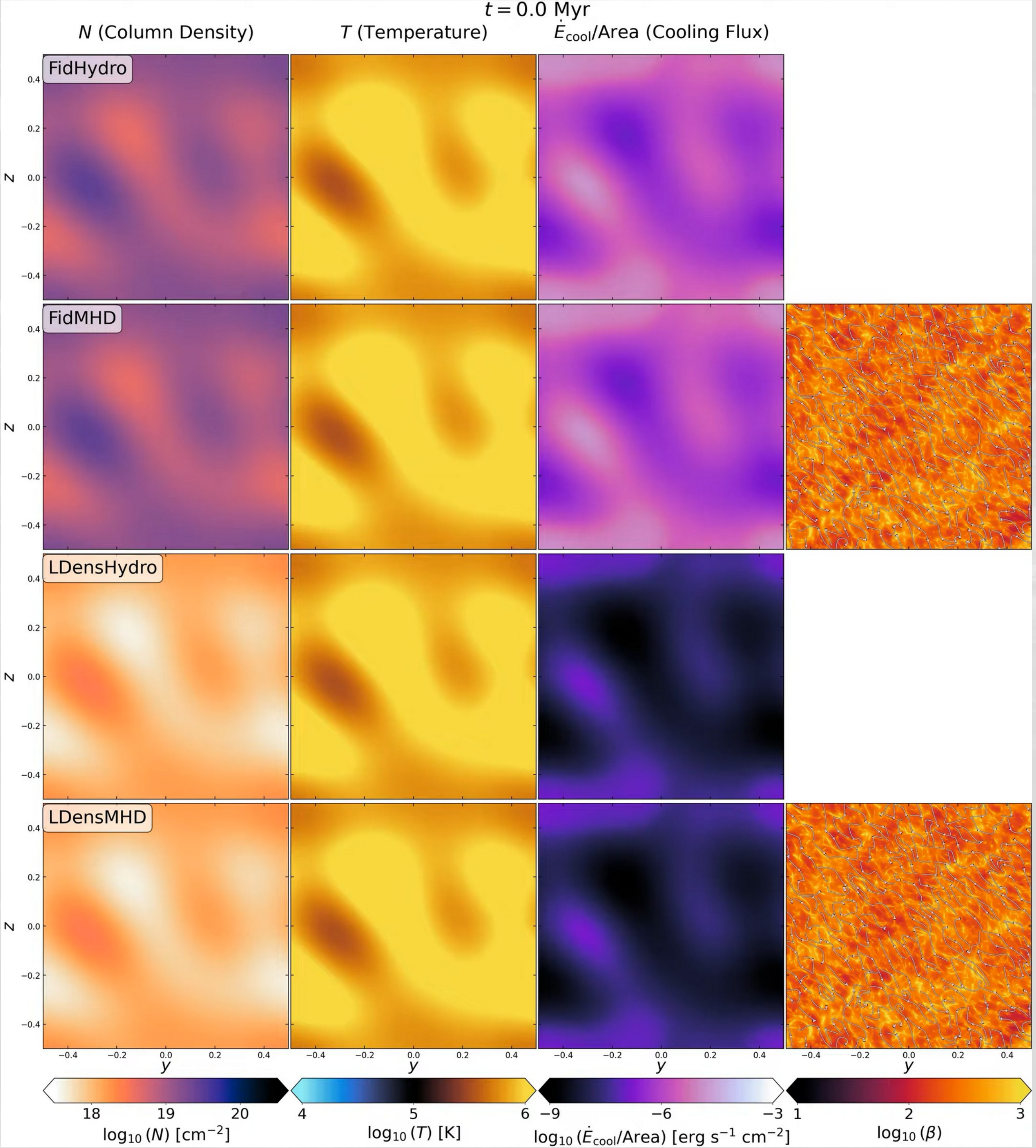


$t_{\mathrm{mix}}/t_{\mathrm{cool}}$ constant

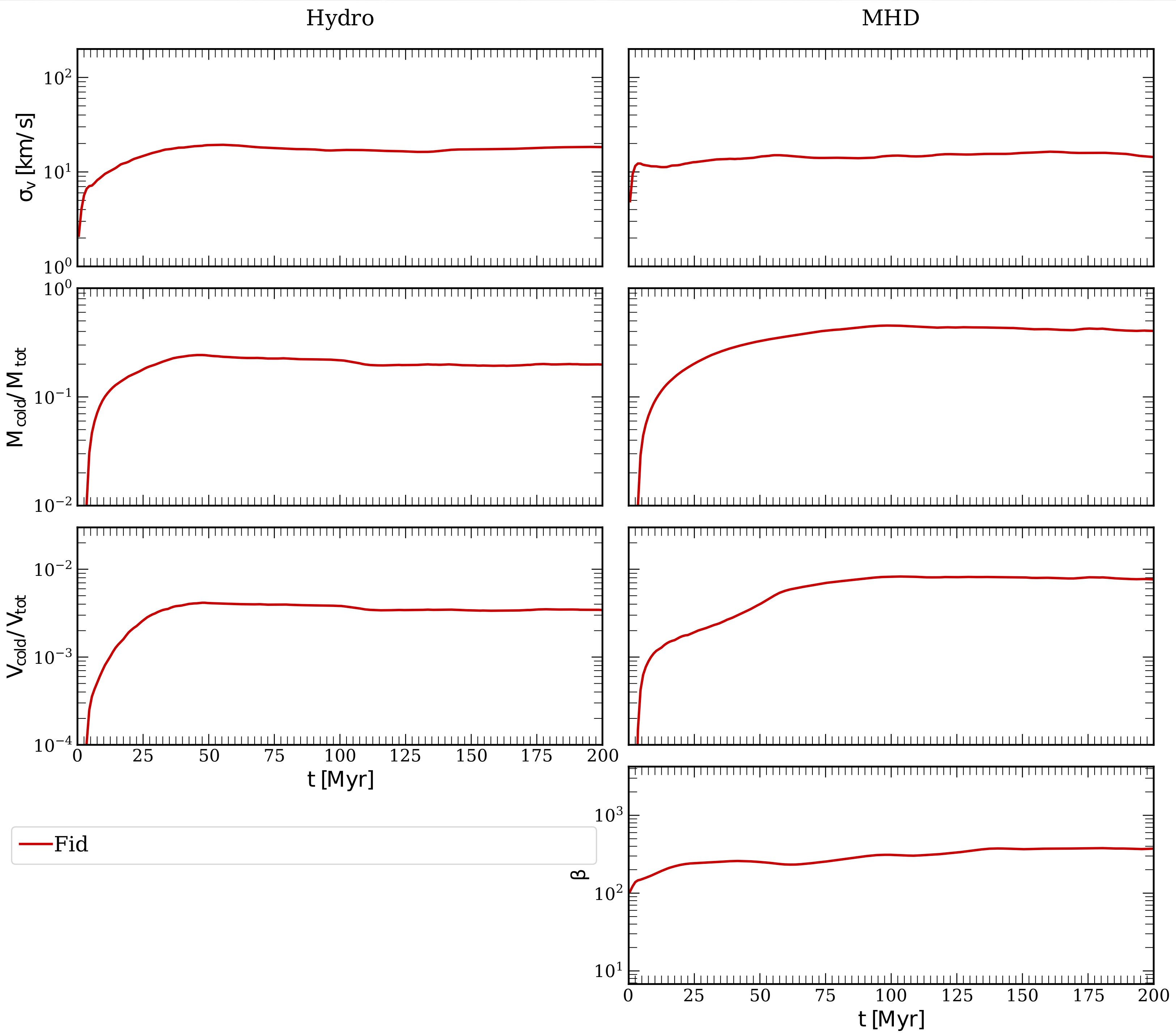
Reduced turbulent stirring

High t_{mix}/t_{cool}

Low t_{mix}/t_{cool}



Mohapatra+26 (incl. AD)



Mohapatra+26
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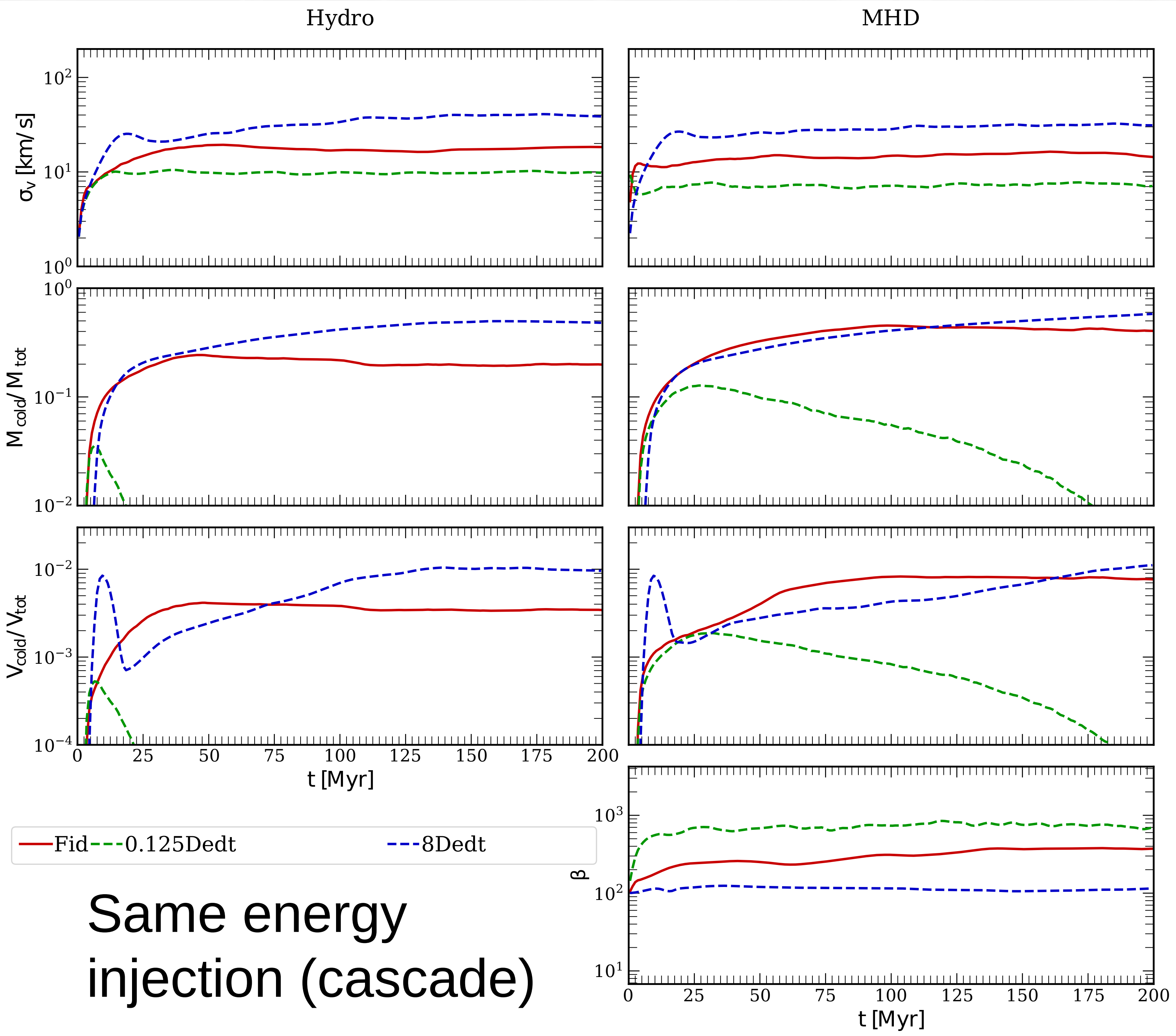
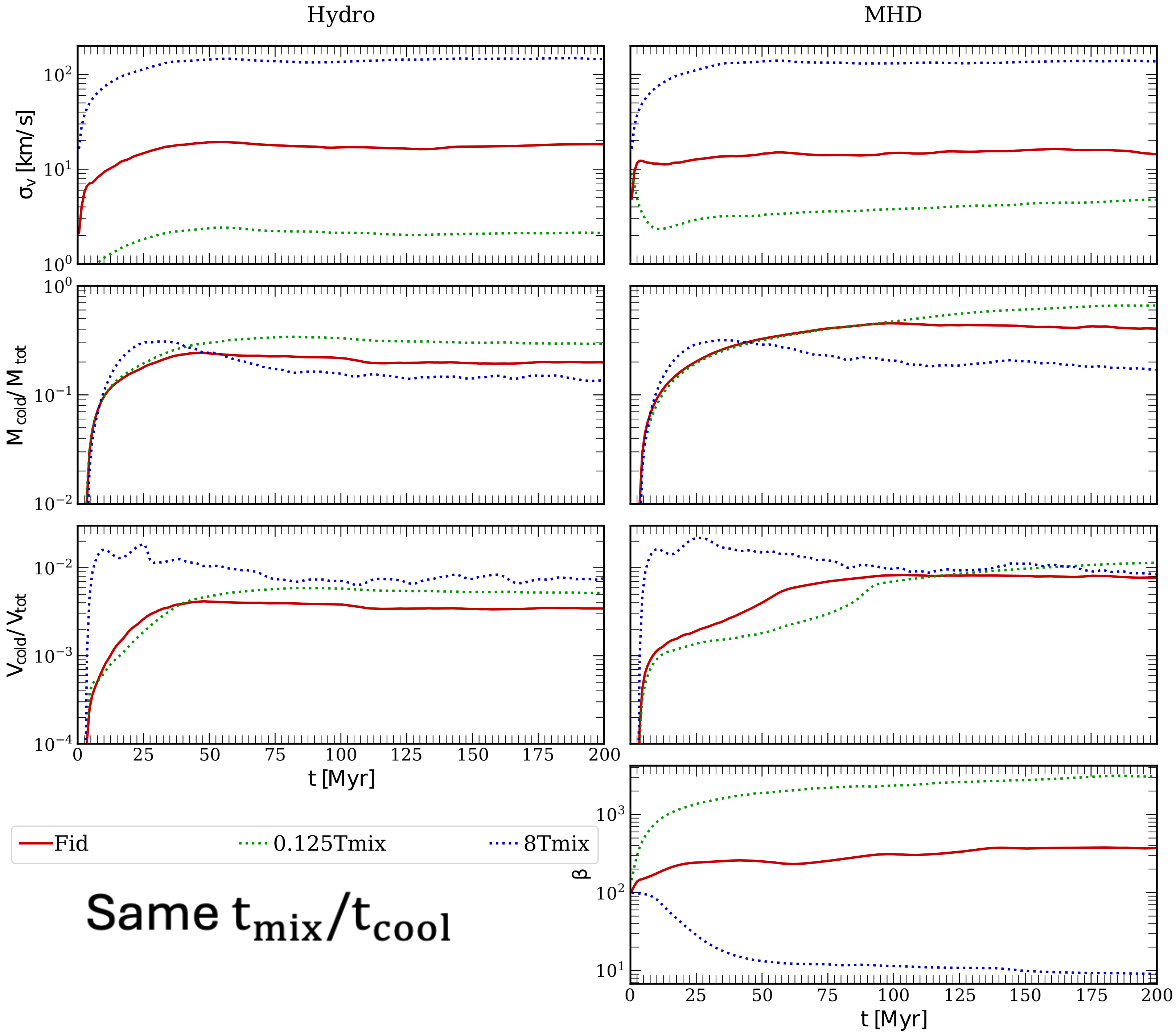


Same energy injection (cascade)

Mohapatra+26
(incl. AD)



Same t_{mix}/t_{cool}

Mohapatra+26 (incl. AD)

What does all this mean?

- Boxes of different sizes but with the same t_{mix}/t_{cool} show similar cold gas properties.
- Smaller boxes following the Kolmogorov cascade cannot sustain cold gas.
- Cold clouds dominate mass but are compact have a low volume filling fraction.

Takeaway message:

- Turbulent multiphase cloud complexes (size $\lesssim$ 10 kpc) are unlikely to be stirred by Kolmogorov-like driving from larger scale eddies.
- Instead, cold cloudlets in cloud complexes arise in mildly turbulent regions of the CGM.

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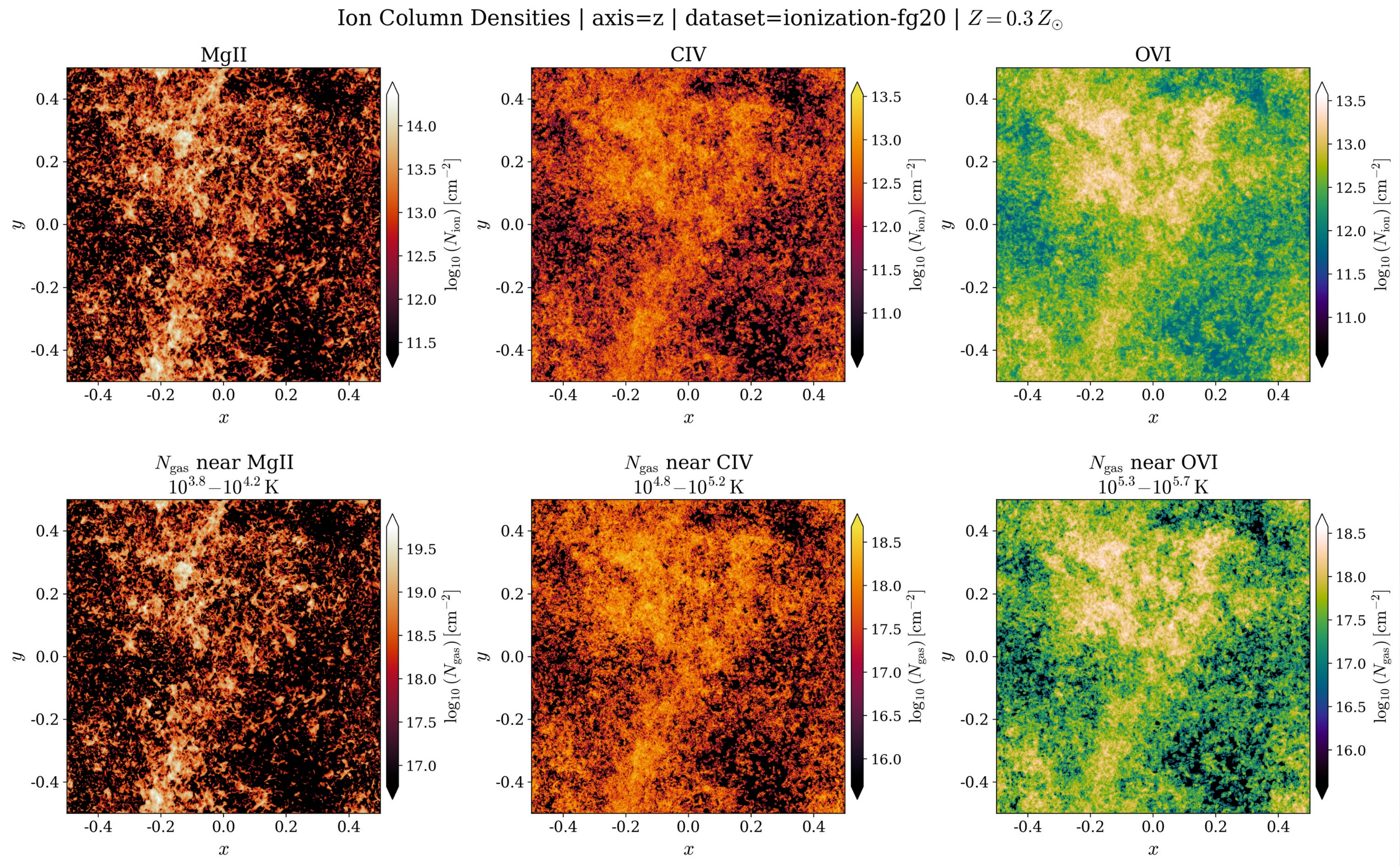
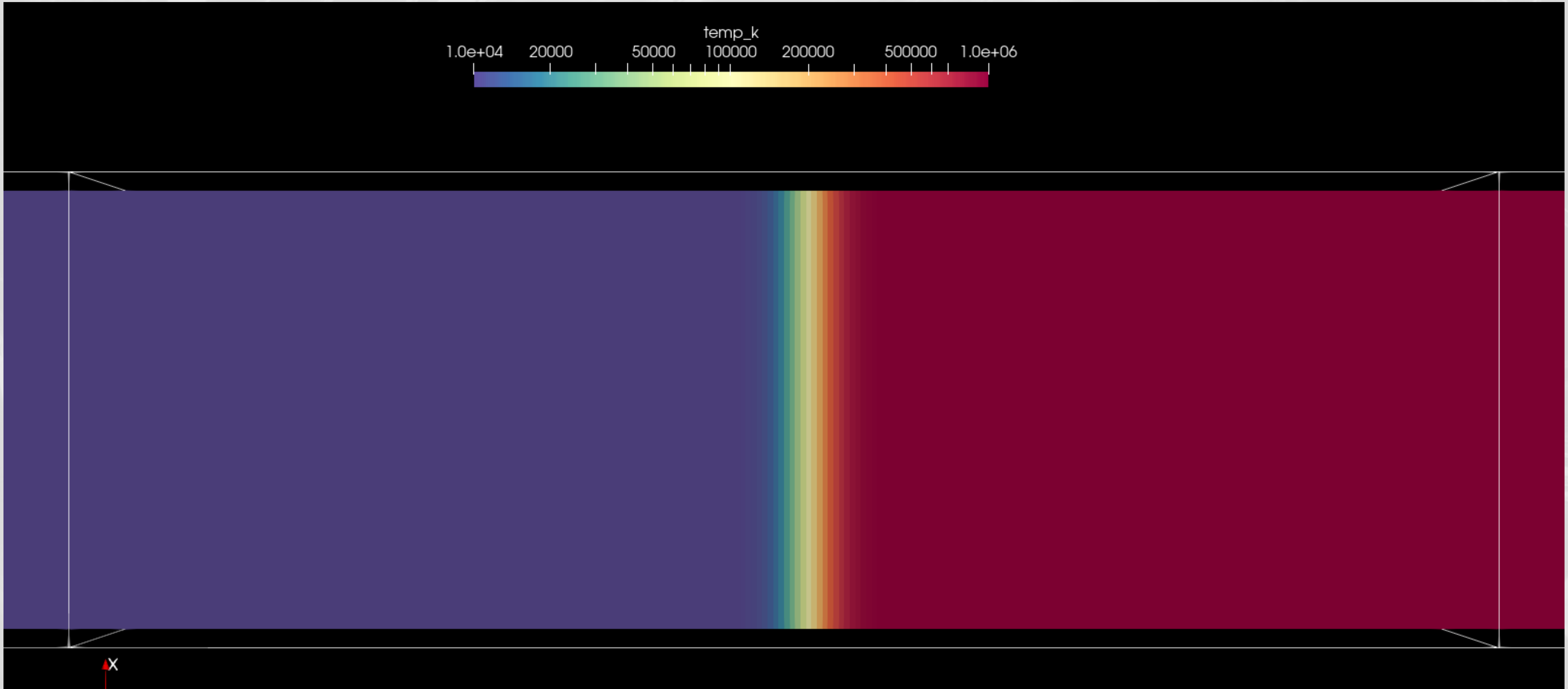
Watch out for t_{mix}/t_{cool}!

Connecting to large scale sims and observations

Constrain and develop a self-consistent parameter space for cloud complexes from simulations.



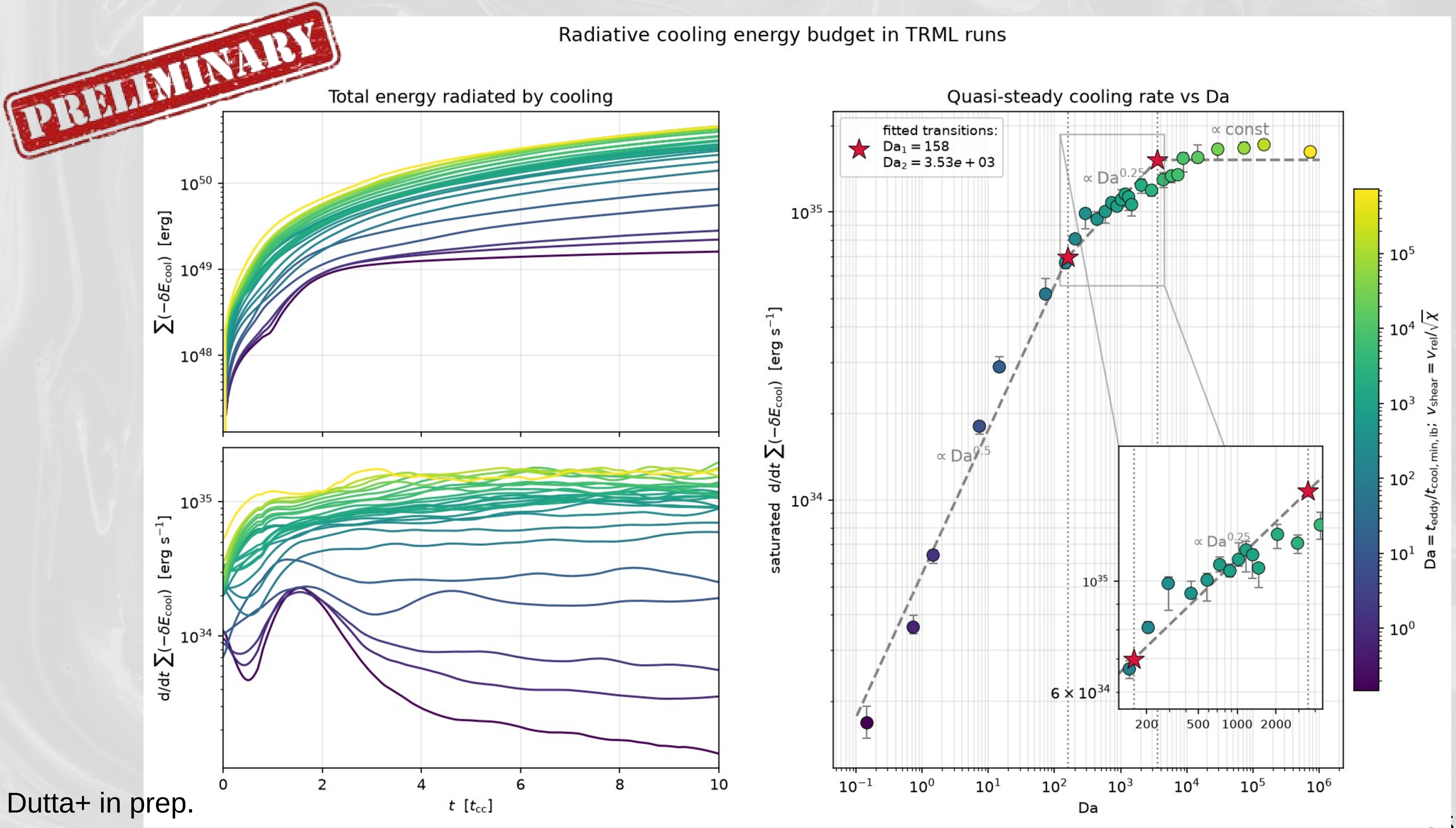
Turbulent radiative mixing layer



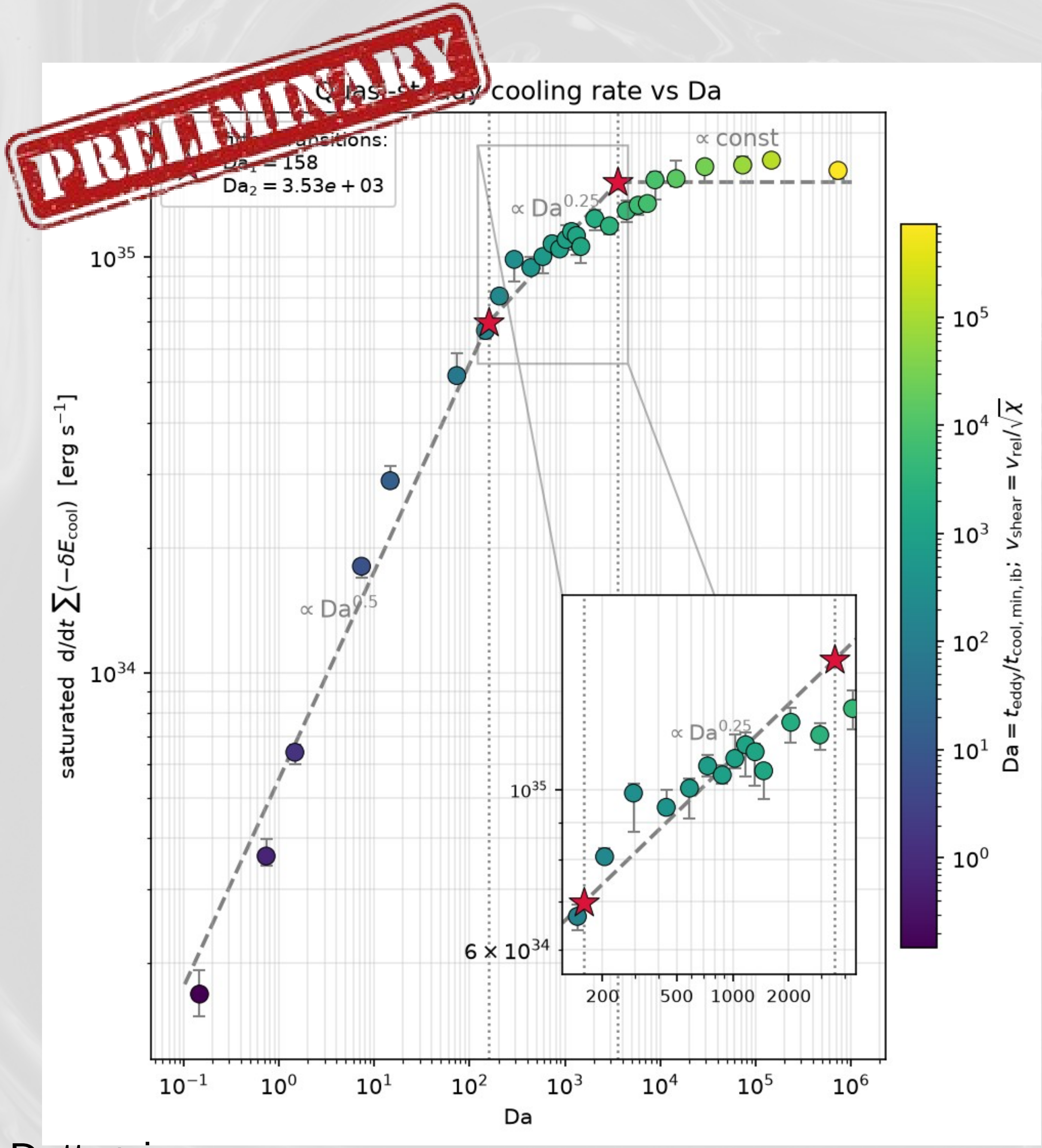
Watch out for Da = t_{eddy}/t_{cool}!

Turbulent radiative mixing layer

Watch out for $\mathrm{Da} = t_{eddy}/t_{cool}$!



Dutta+ in prep.



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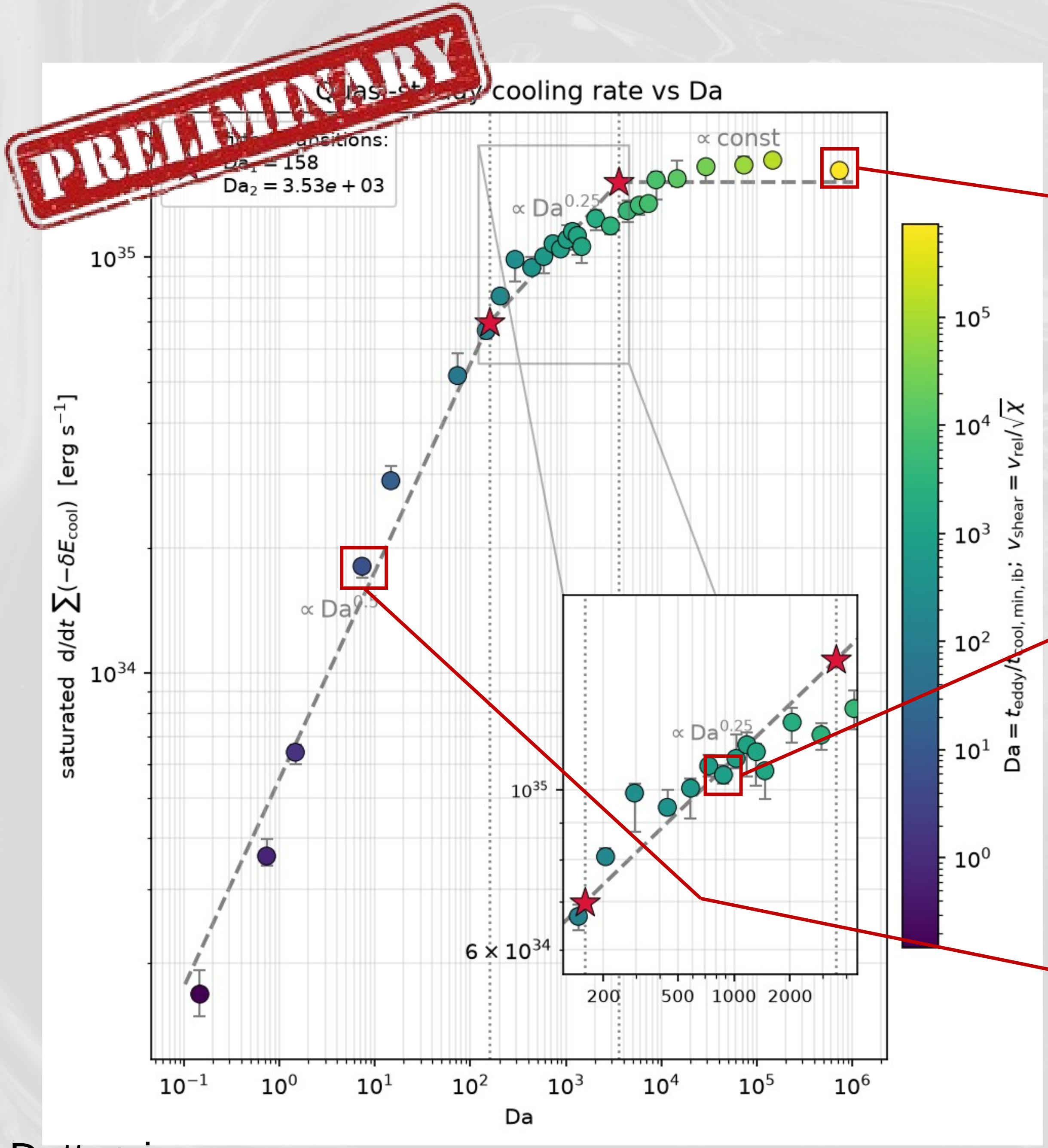
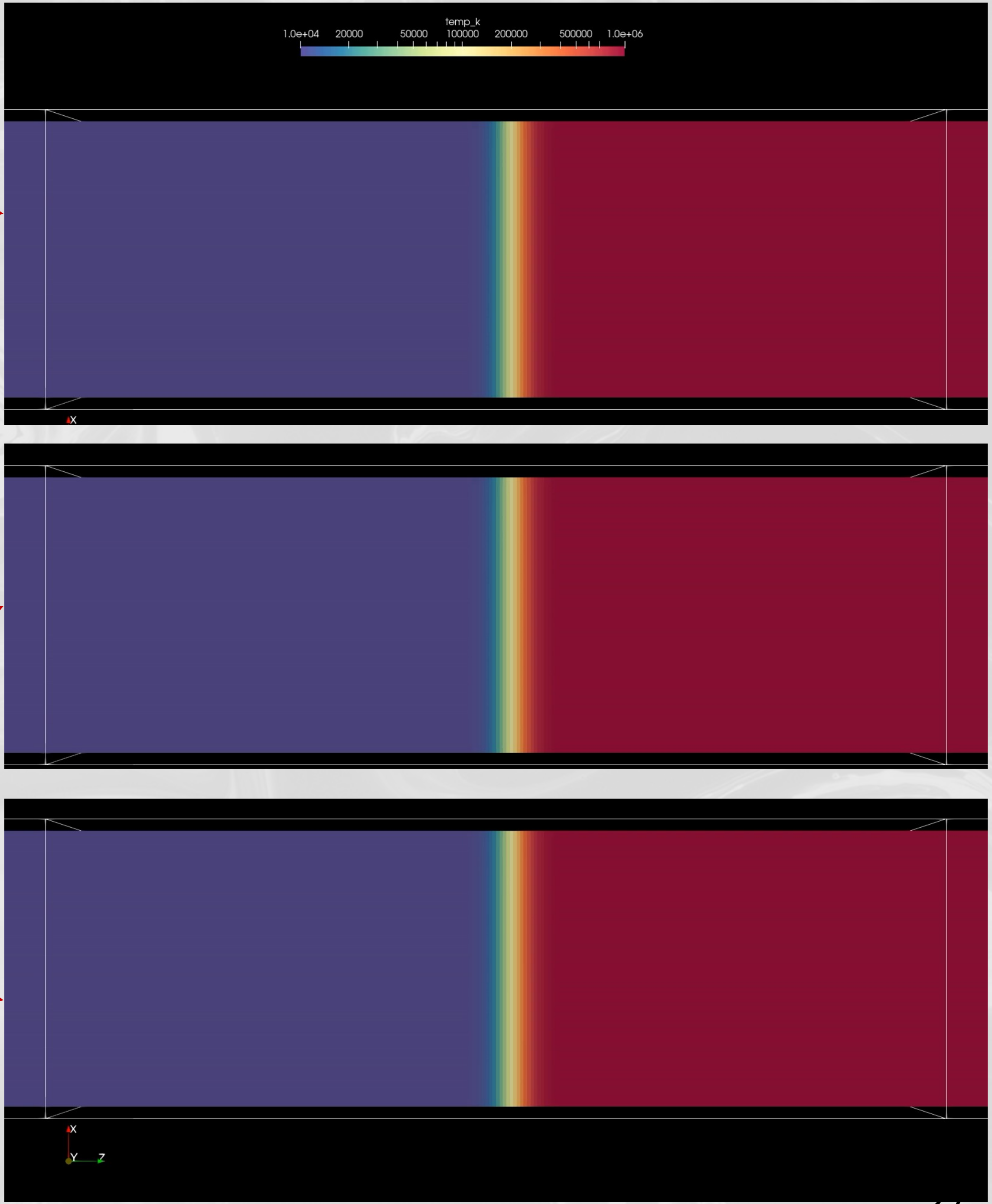
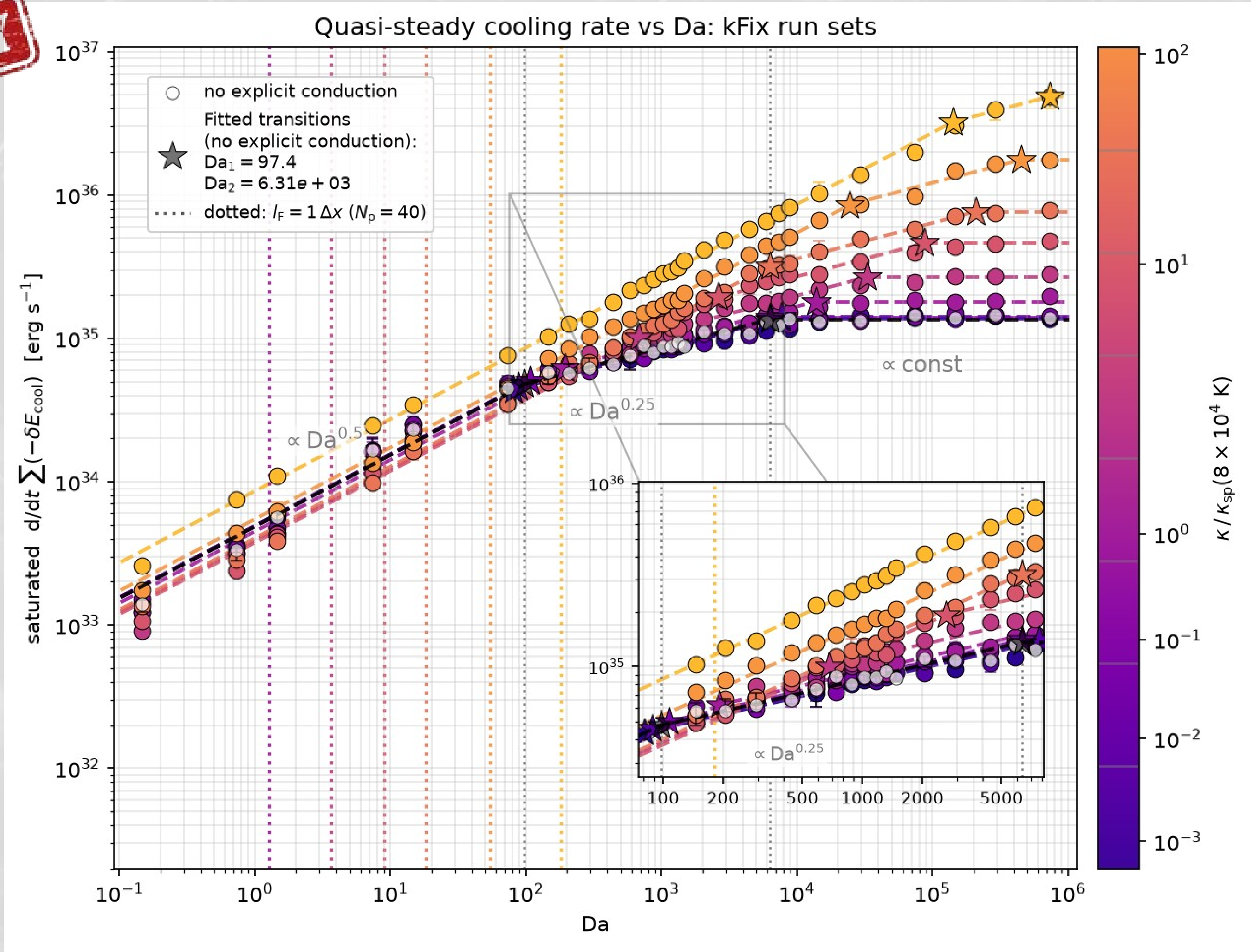




Dutta+ in prep.

PRELIMINARY

Thermal conduction can significantly alter cooling and mass transfer rate between the hot and cold phases!



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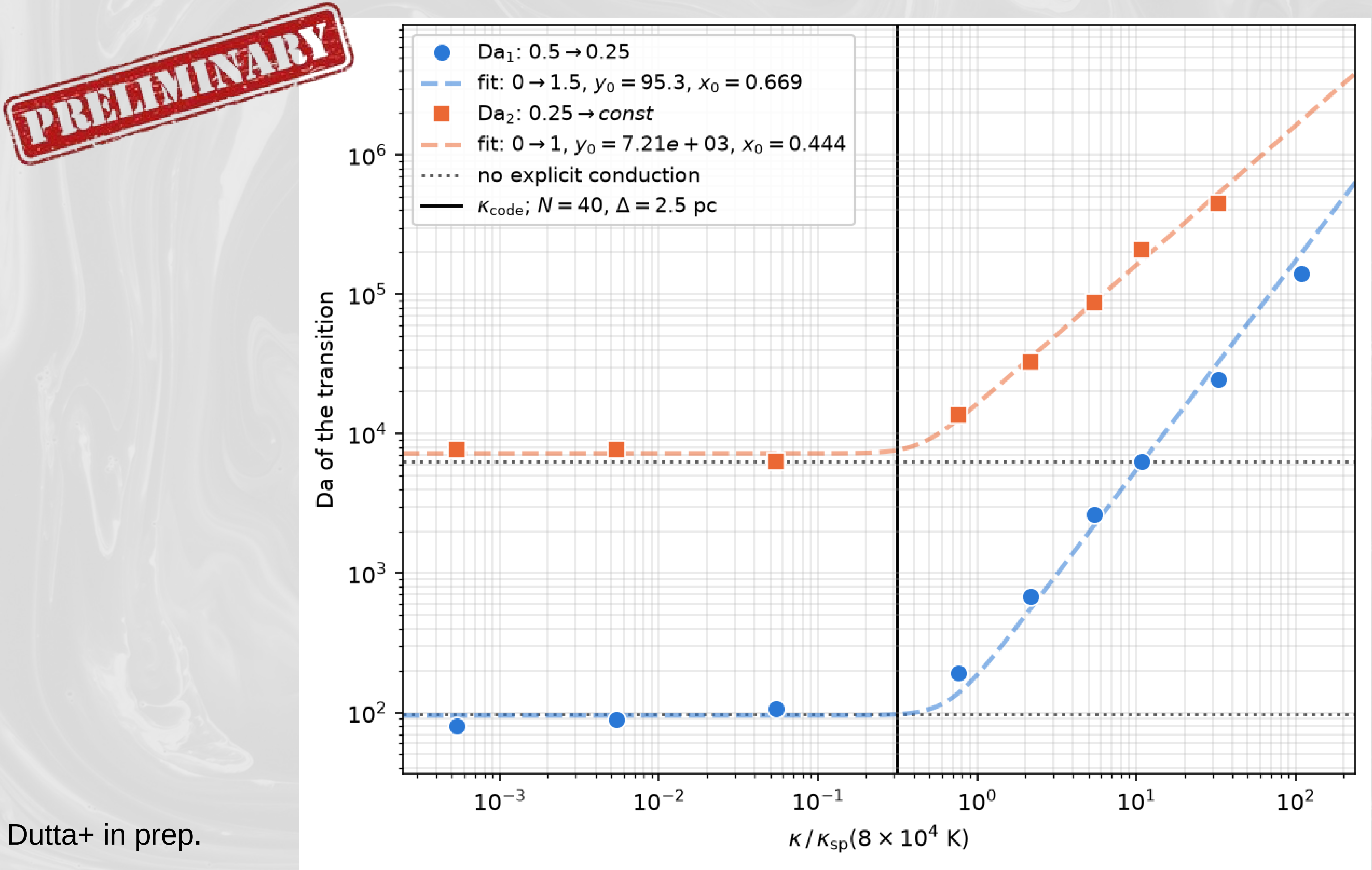

Dutta+ in prep.

Looking ahead …

- Strongly cooling systems compress the mixing zone.
- Does this compression suppress turbulence?
  - This might be form the mildly turbulent multiphase cloud complexes
- What sets the minimum size of the mixing zone?
  - Maybe the answer lies in thermal conduction!
  - This would determine saturation of the cooling rate
- This would mean magnetic fields would introduce anisotropic cooling saturation.

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Thank you!