Precipitation & Feedback

G M Voit / Michigan State University

- How does AGN feedback regulate itself?
- What is the significance of $t_{cool}/t_{ff} \sim 10$?
- Why does the entropy gradient matter?

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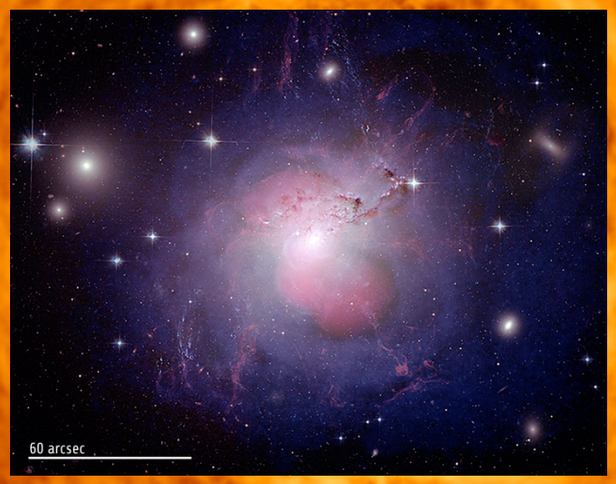

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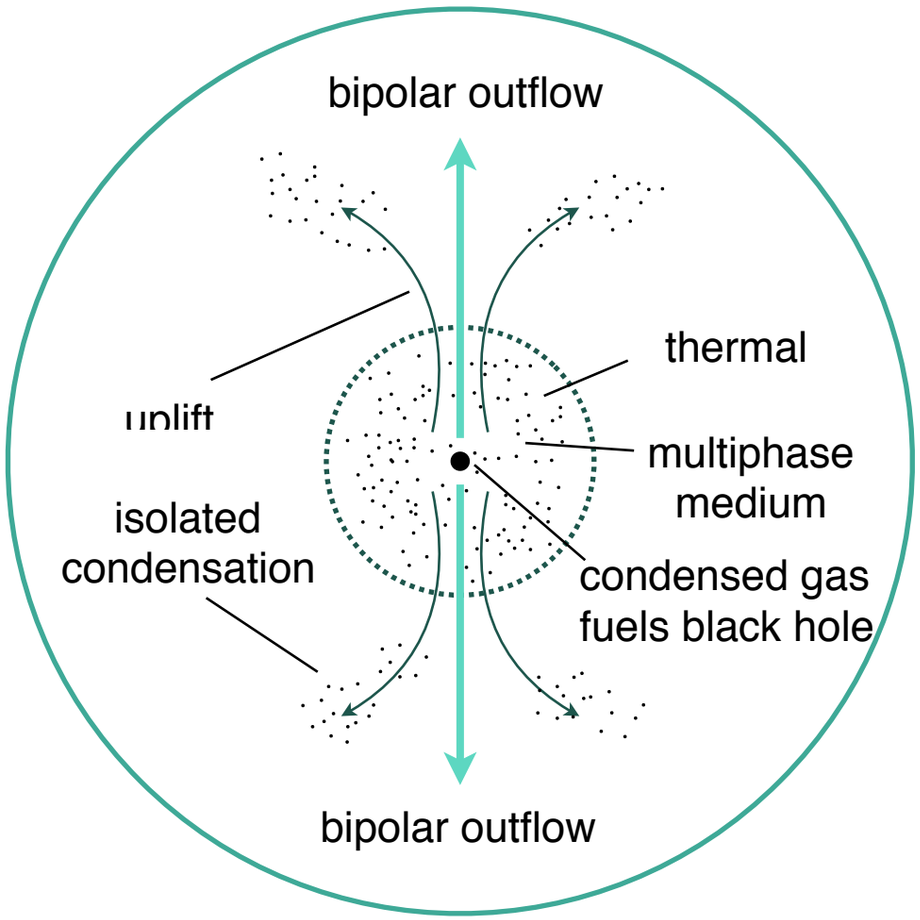
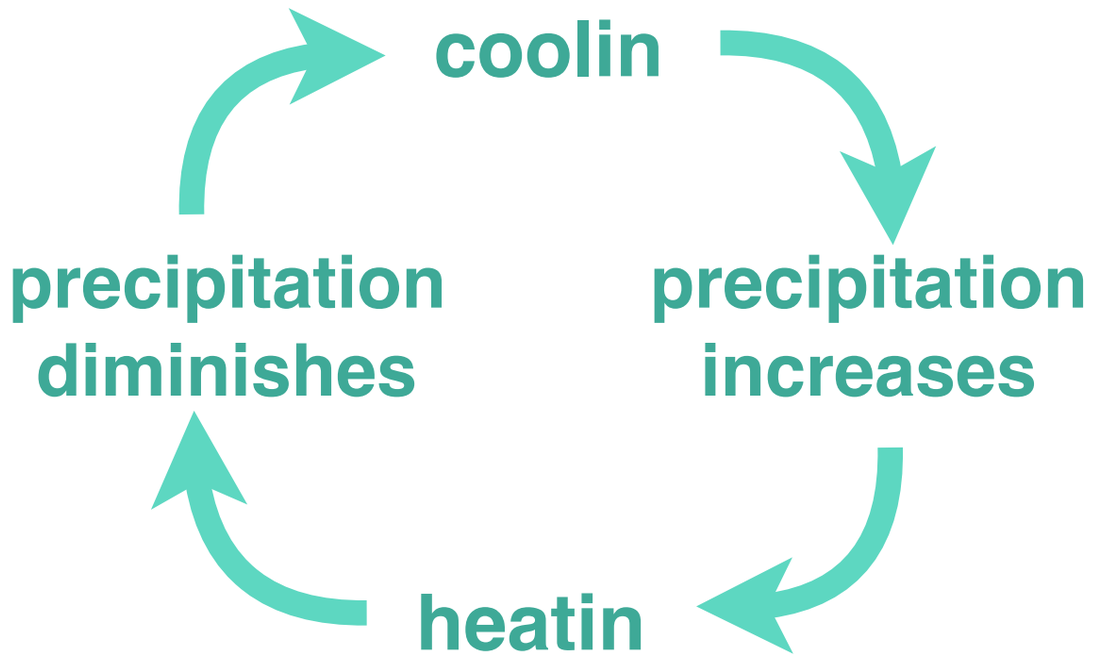
The Precipitation Hypothesis

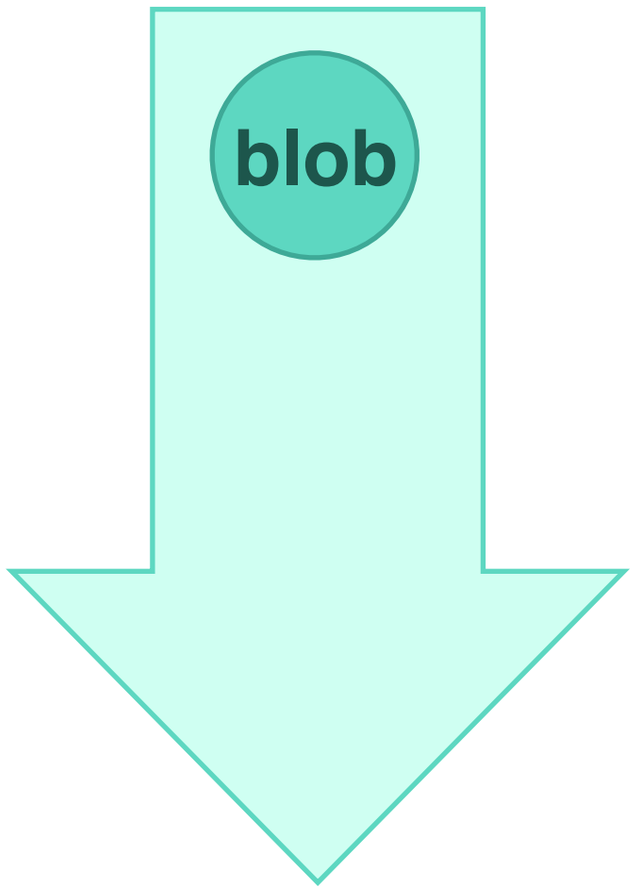
Feedback from the central black hole maintains the CGM in a state marginally unstable to condensation





Cooling Time & Freefall Time

lower density



higher density

The Condensation Question

A gas blob cools on time scale t_c

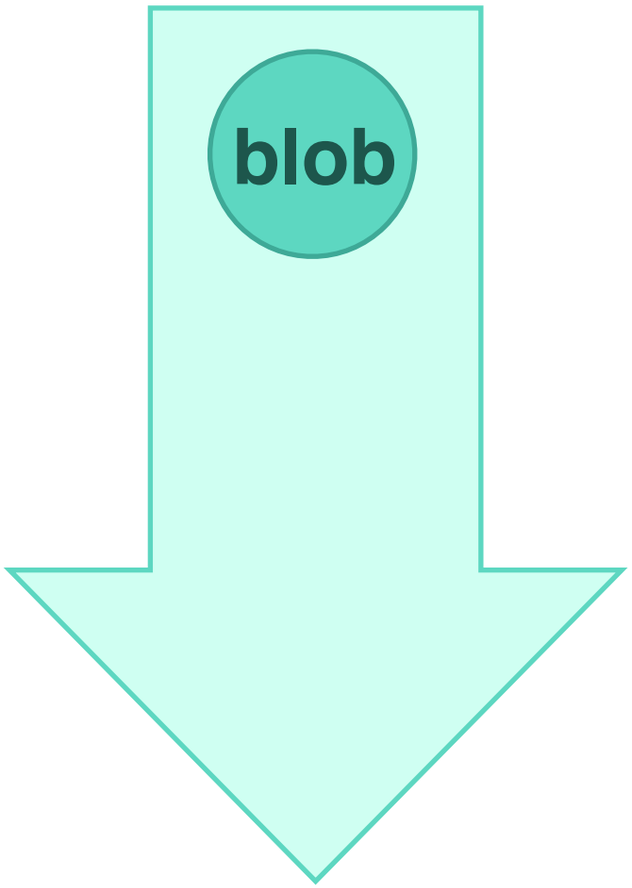
It falls on time scale t_{ff}

Does its density contrast increase as it descends?

Buoyancy Damping

Voit+ 16, arXiv:1607.02212 (see also Cowie+ 1980, etc.)

same entropy

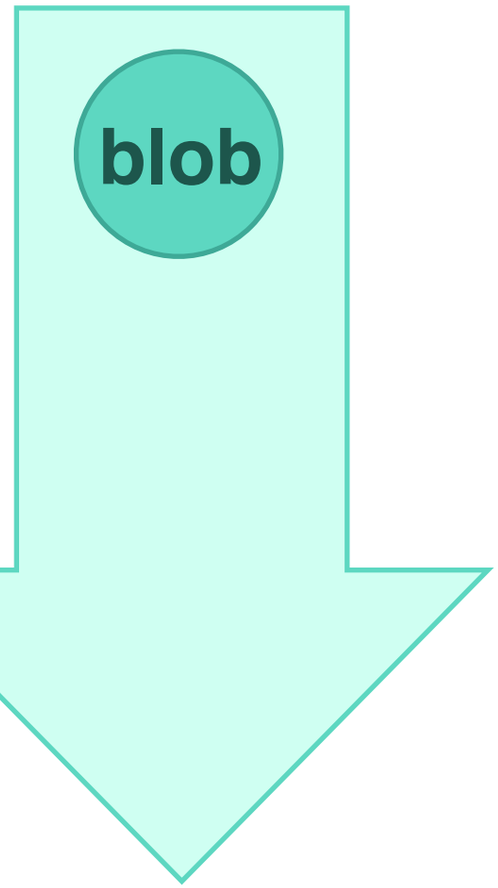


$t_c >>$

same entropy

Blob contrast increases

higher entropy

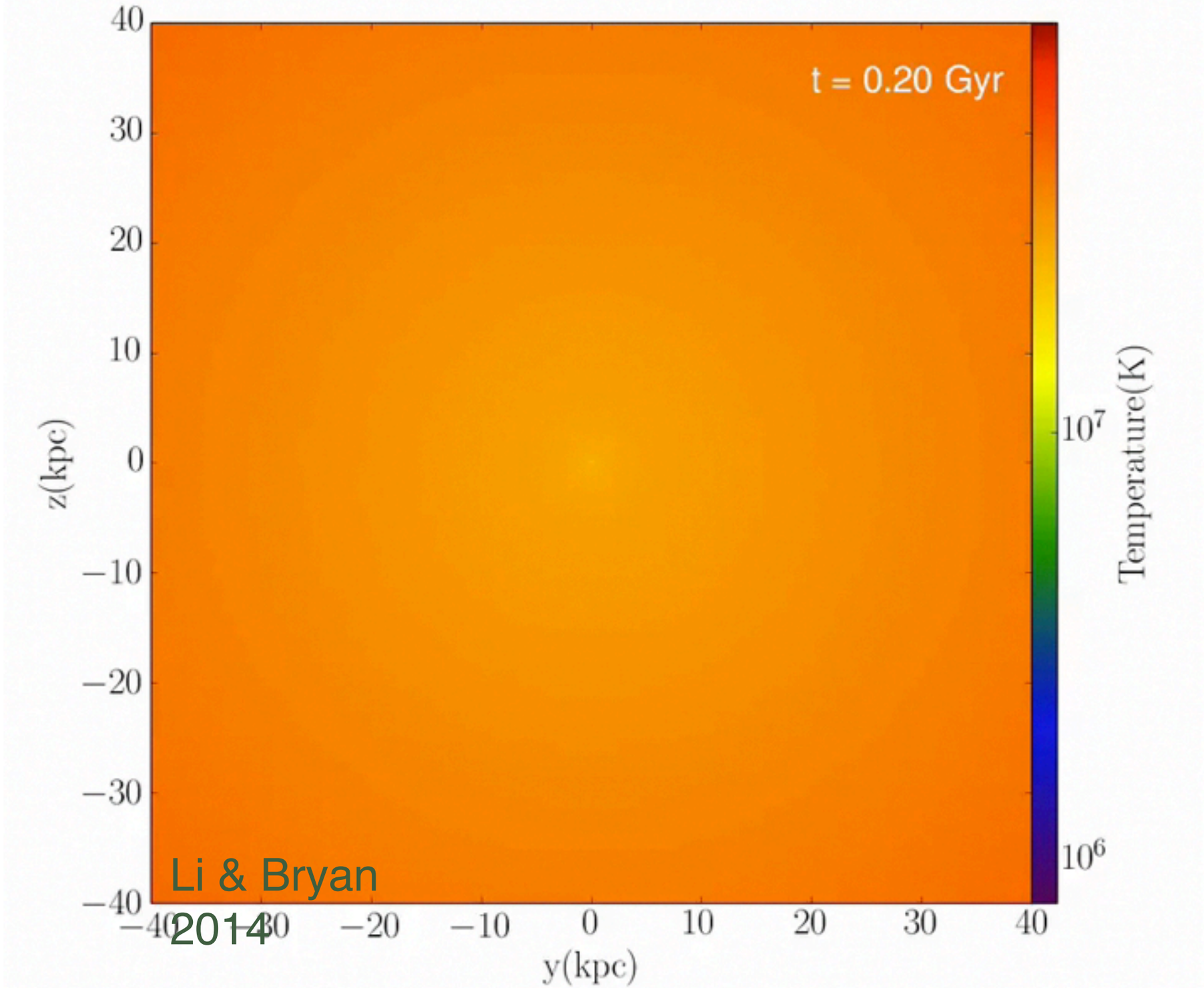


lower entropy

Blob contrast

Outflow-Induced Precipitation

Gaspari+ 2012; Li & Bryan 2014a,b



Li & Bryan 2014

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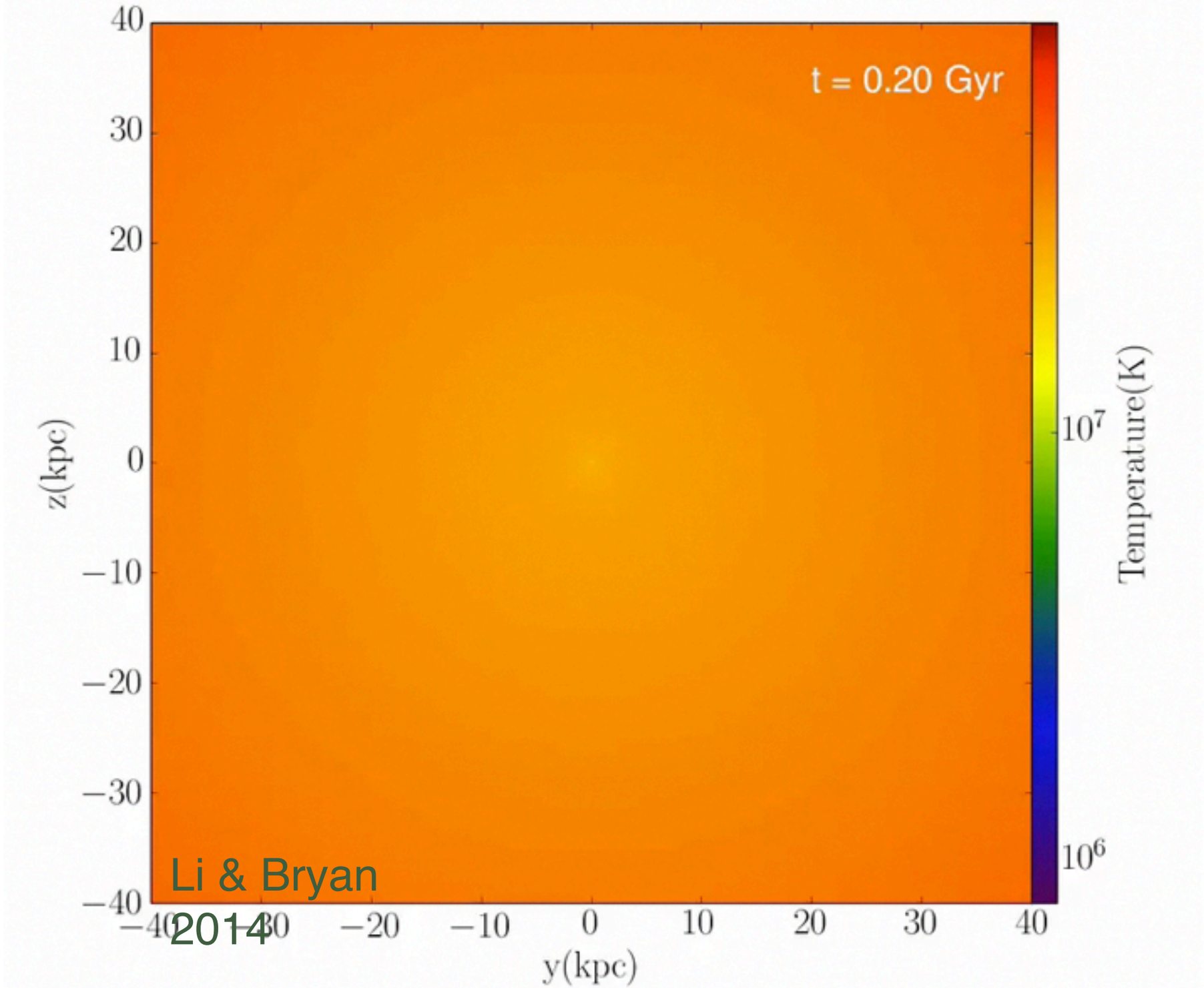

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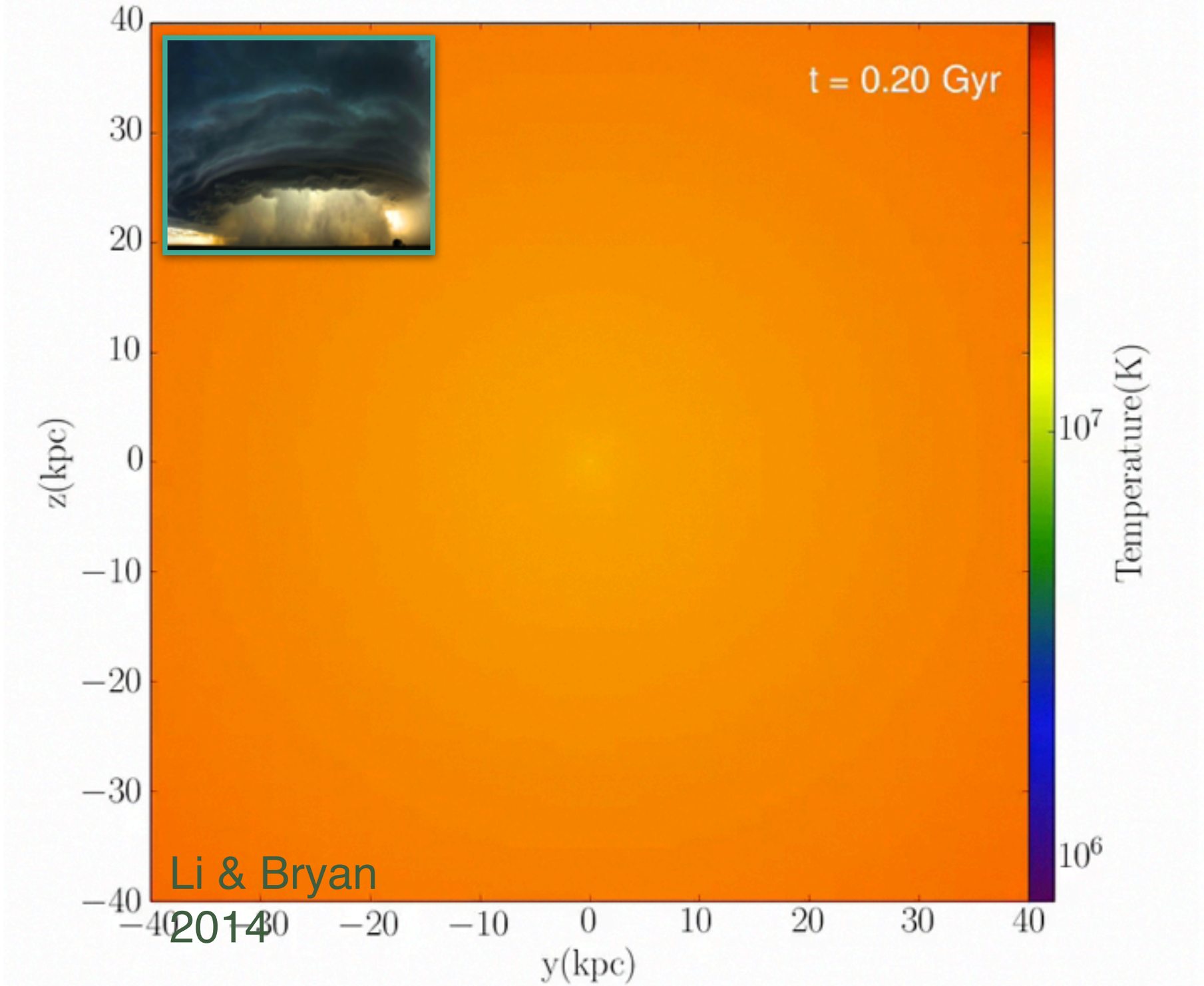

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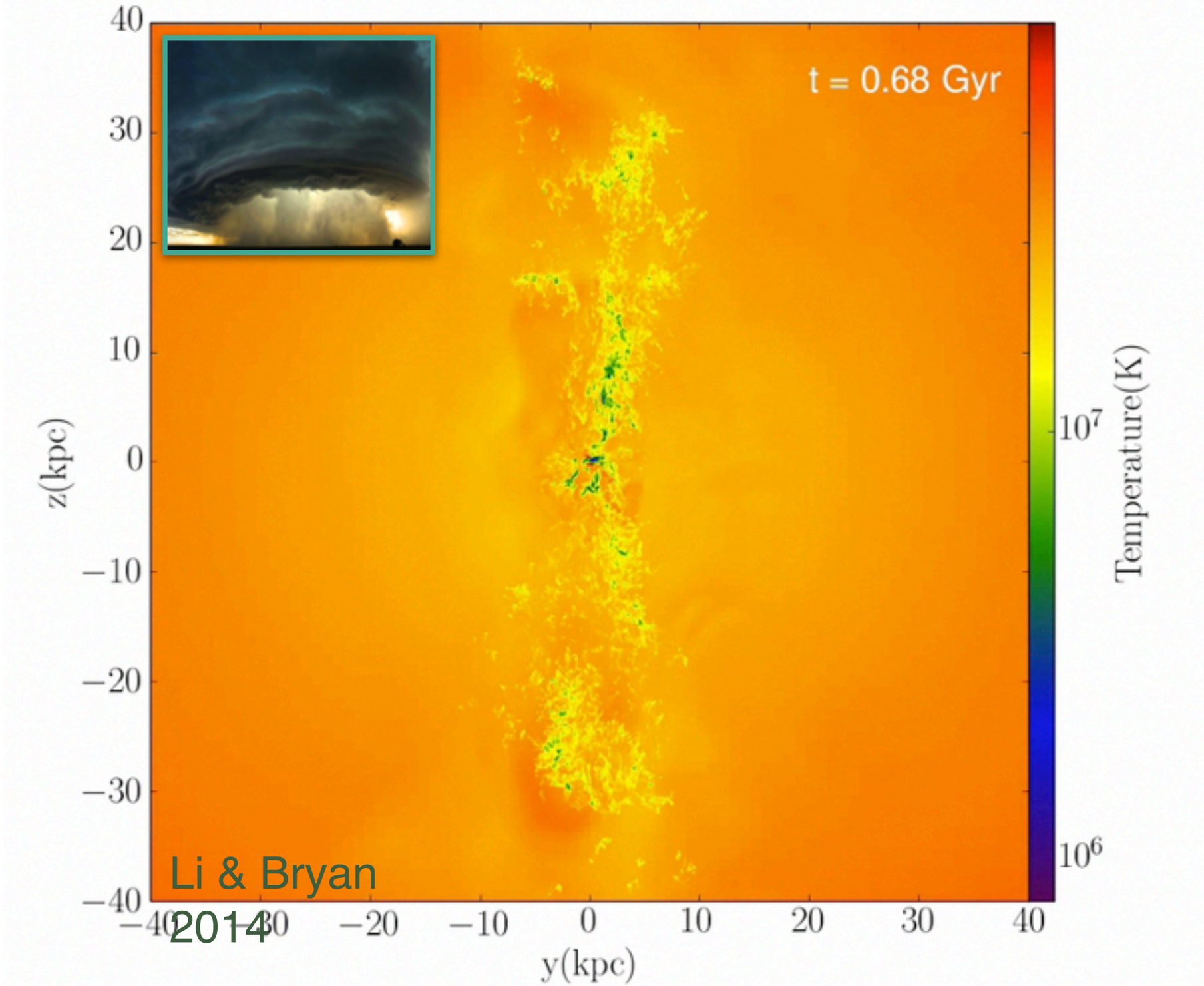

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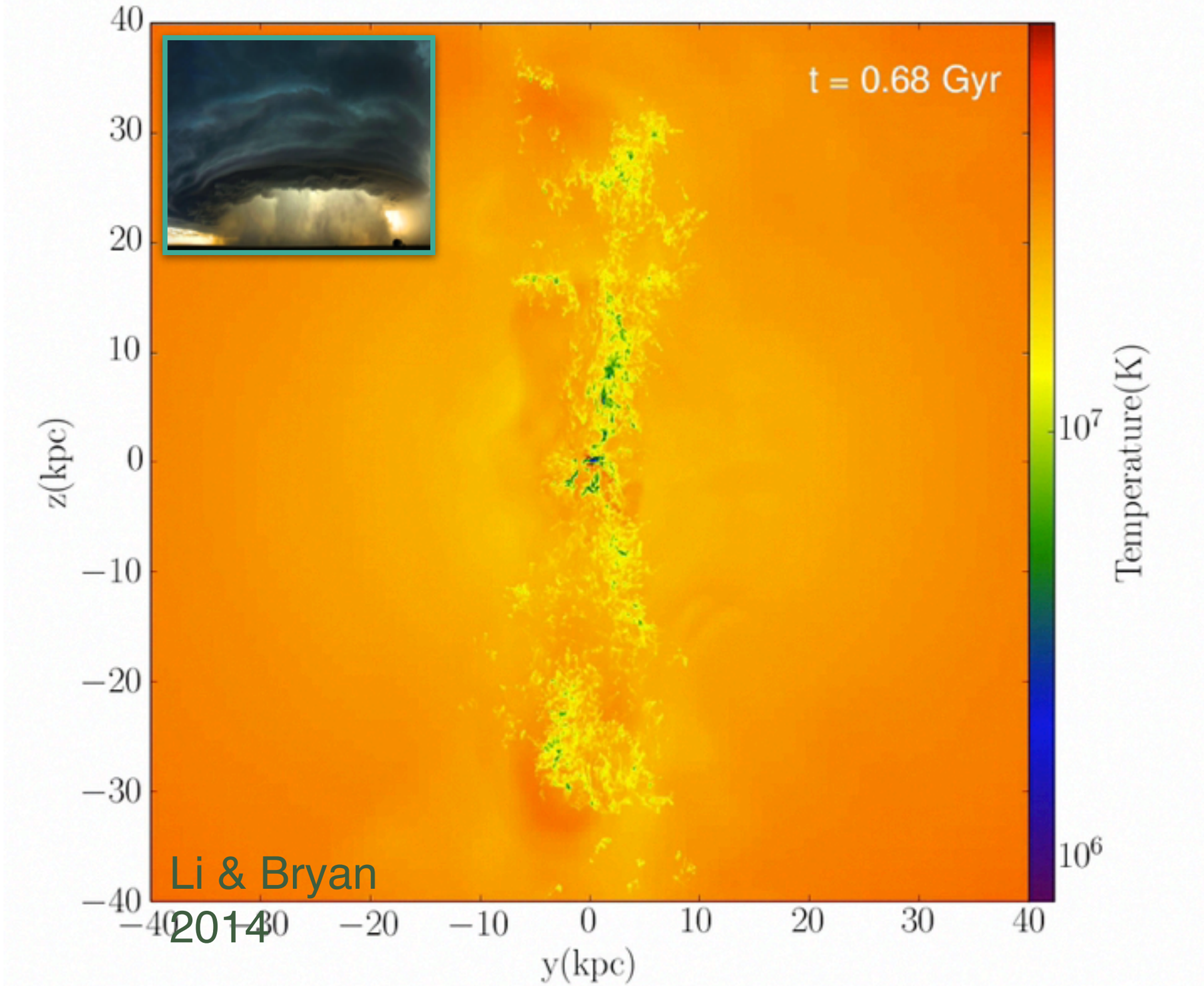
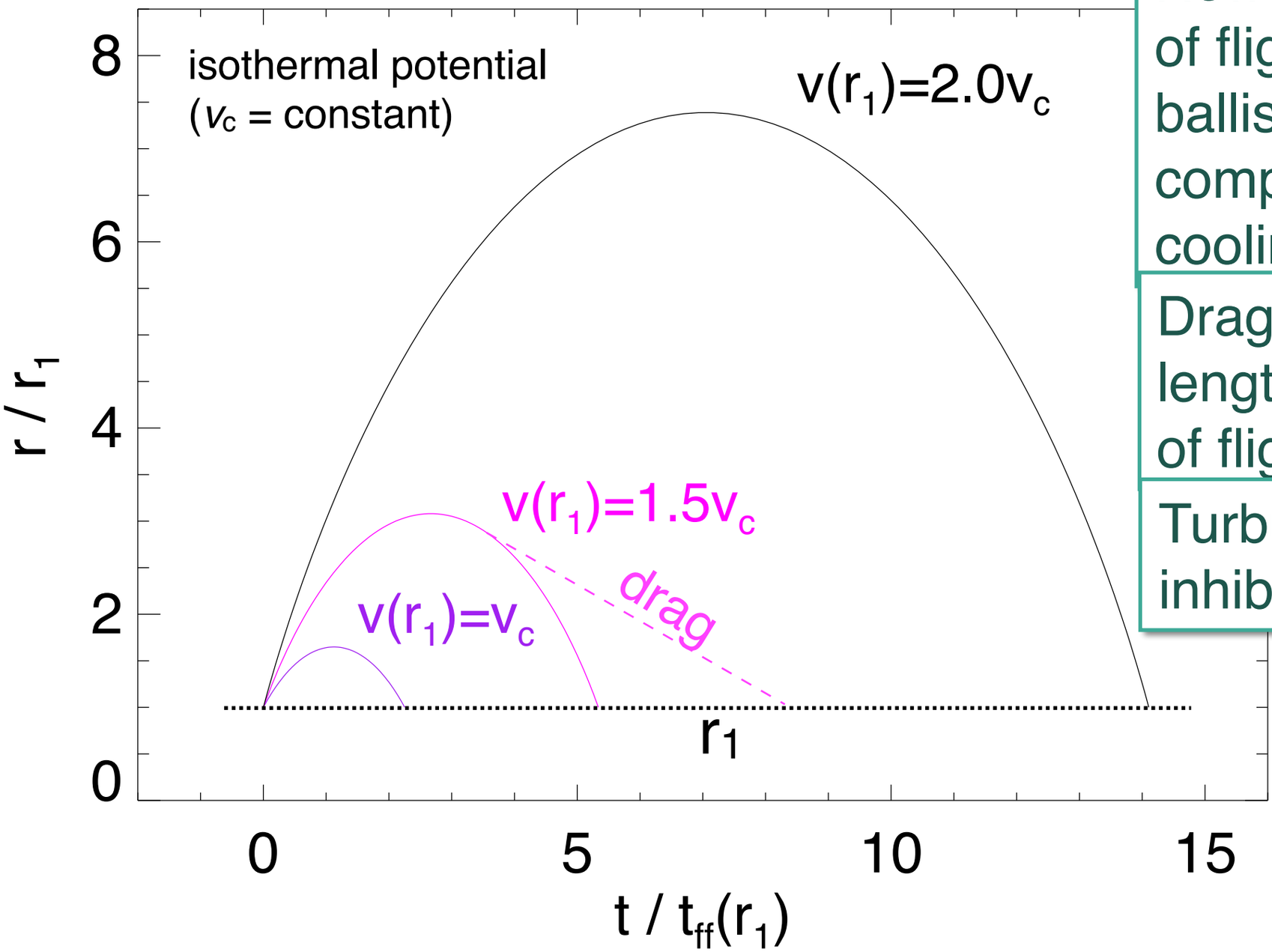


Ballistic Condensation

Voit+ 16, arXiv:1607.02212



How does time of flight of a ballistic gas blob compare to its cooling time?

Drag lengthens time of flight

Turbulence can inhibit descent

Ballistic Condensation

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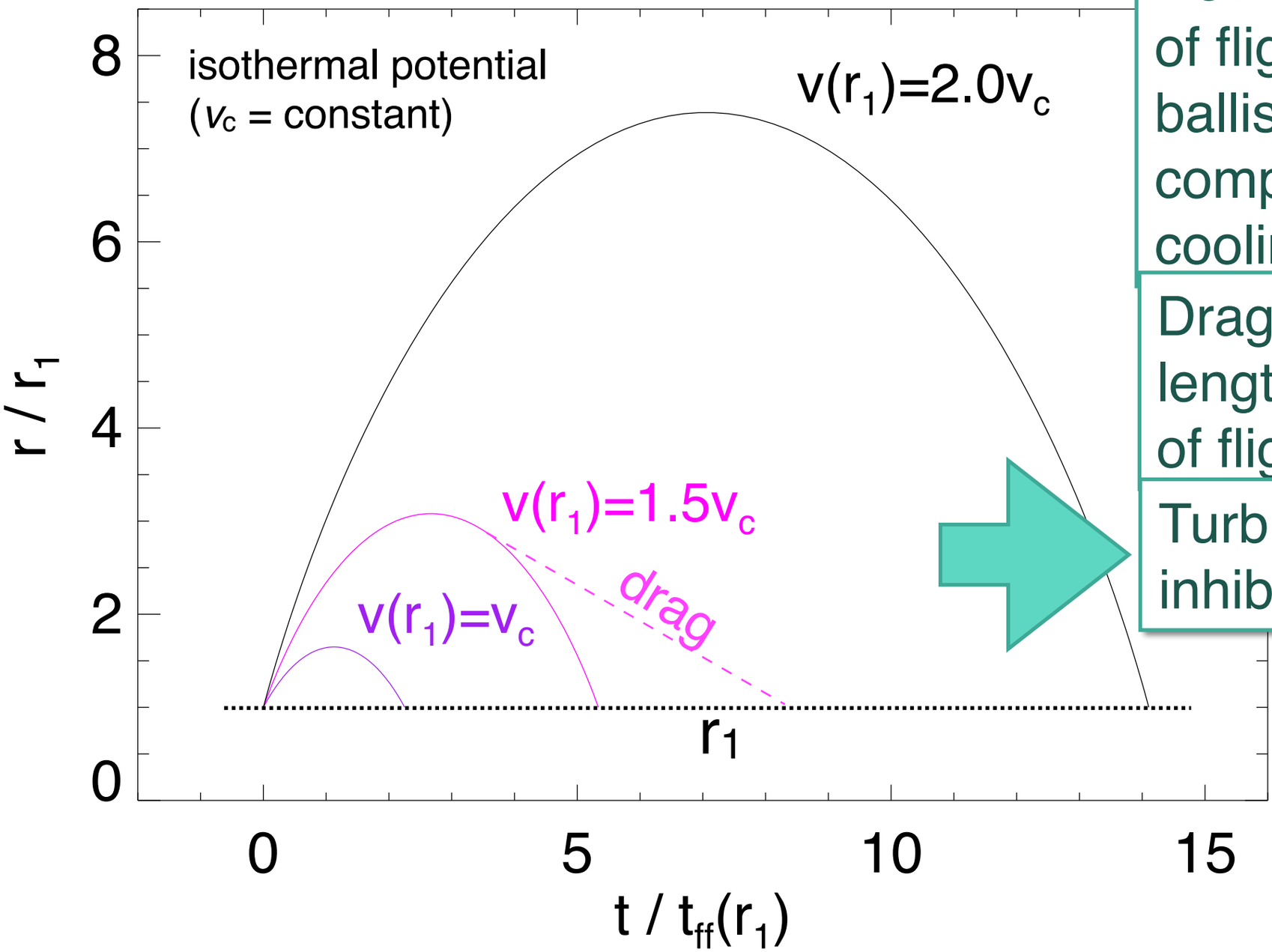

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Drag lengthens time of flight

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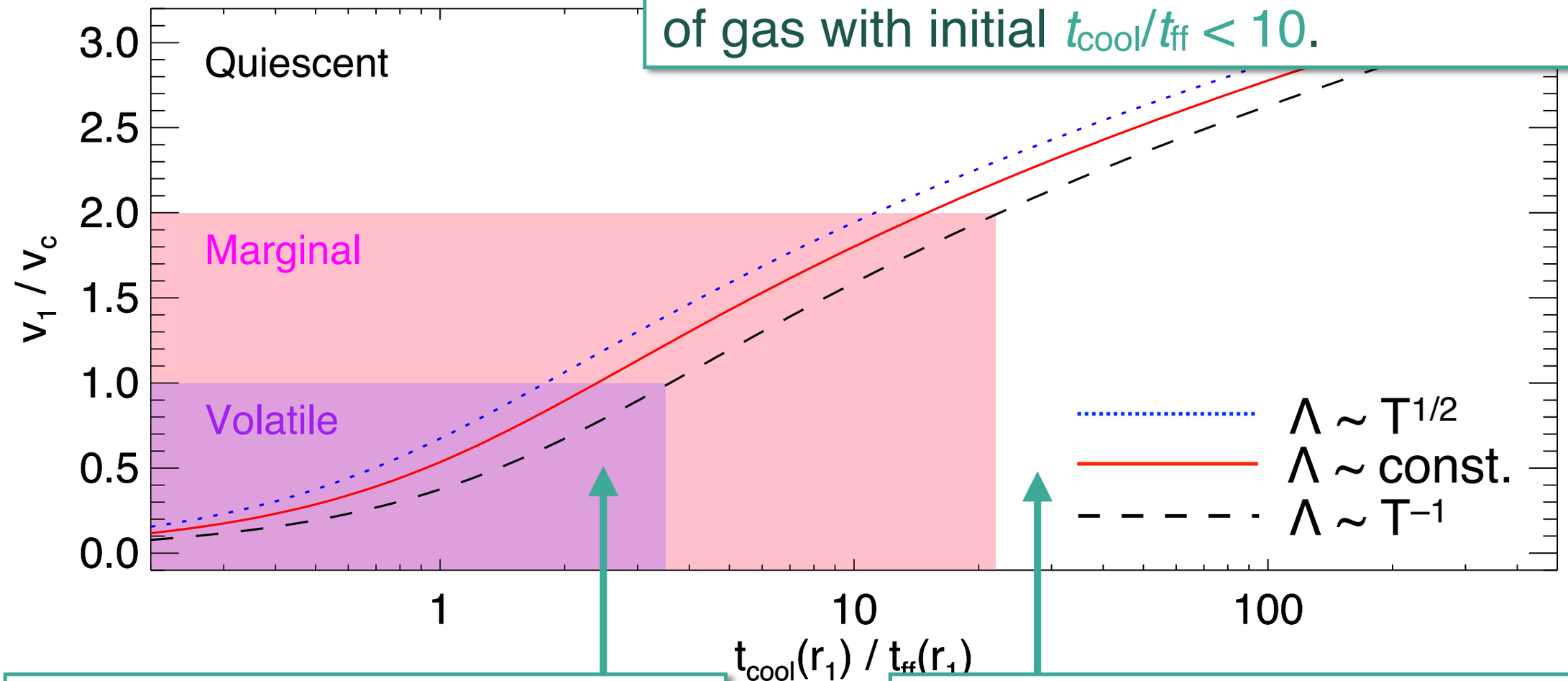
Ballistic Condensation

Voit+ 16, arXiv:1607.02212

Uplift at $< 1.5 v_c$ promotes condensation of gas with initial $t_{cool}/t_{ff} < 10$.



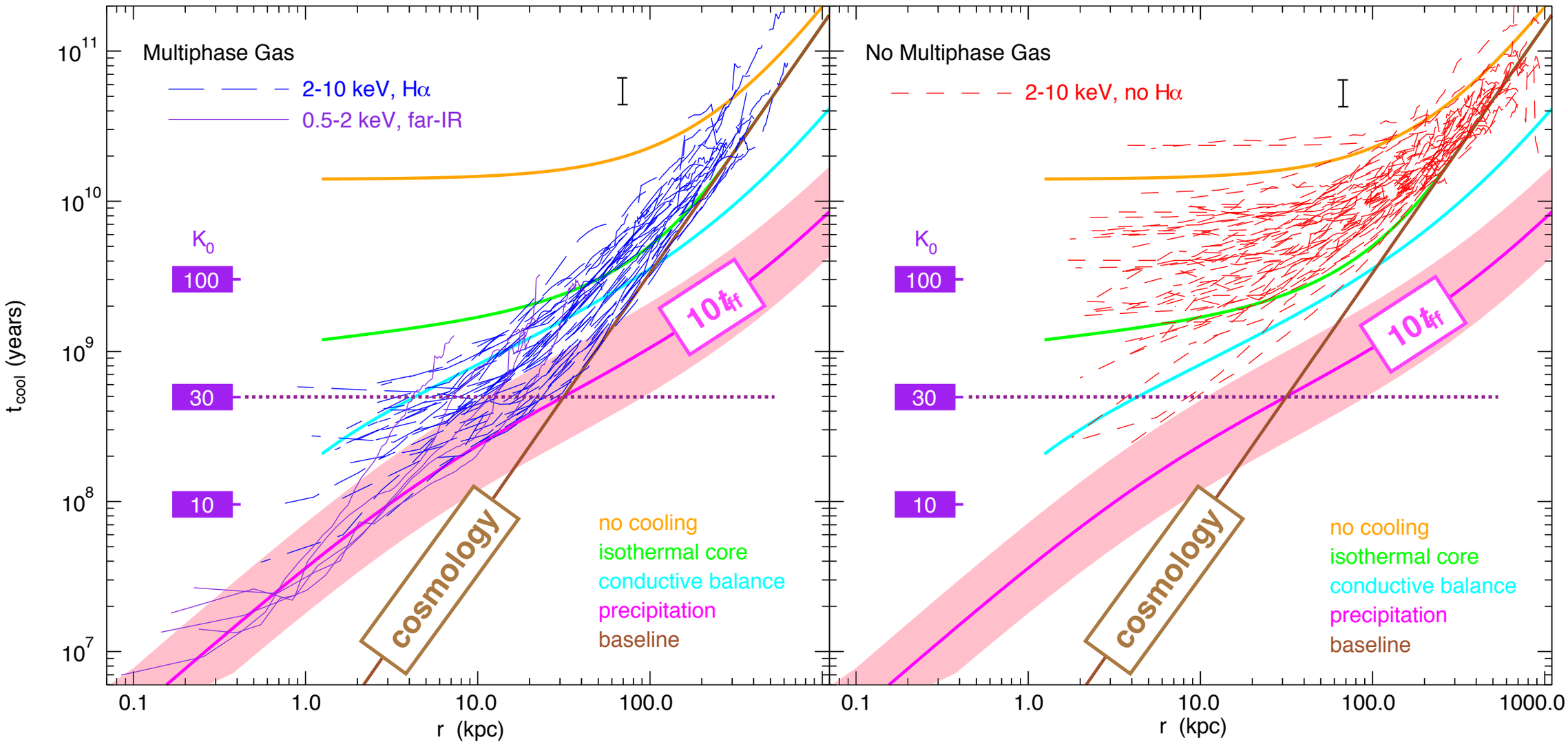
Uplift produces additional fuel

Uplifted gas does not condense

Turbulent CGM with $t_{cool}/t_{ff} < 10$ cannot persist

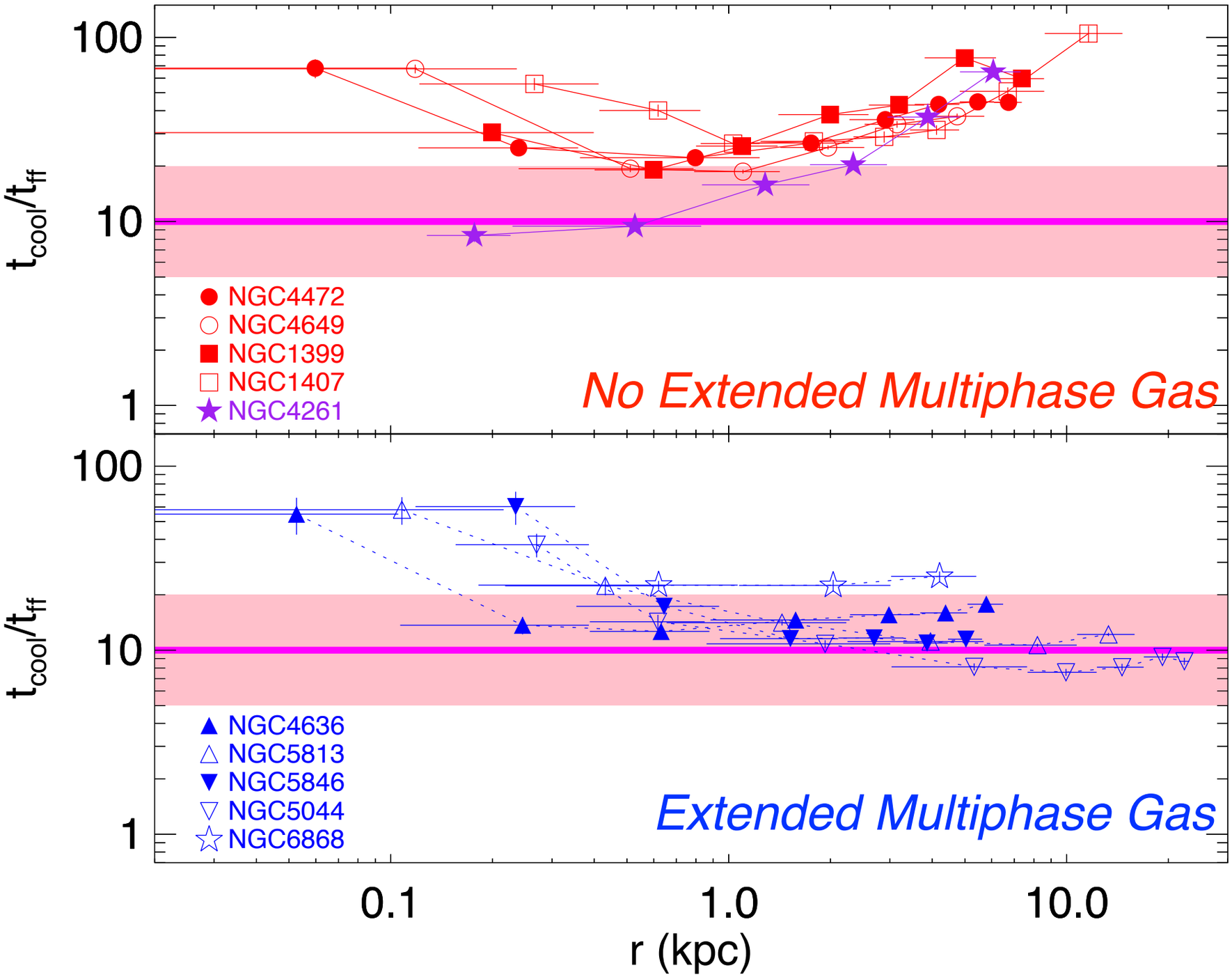
Cluster Cooling-Time Profiles

Voit+ 2015



Precipitation Threshold in Ellipticals

Voit+ 15 (Apr 2015, ApJL) , data: Werner+ 12,14



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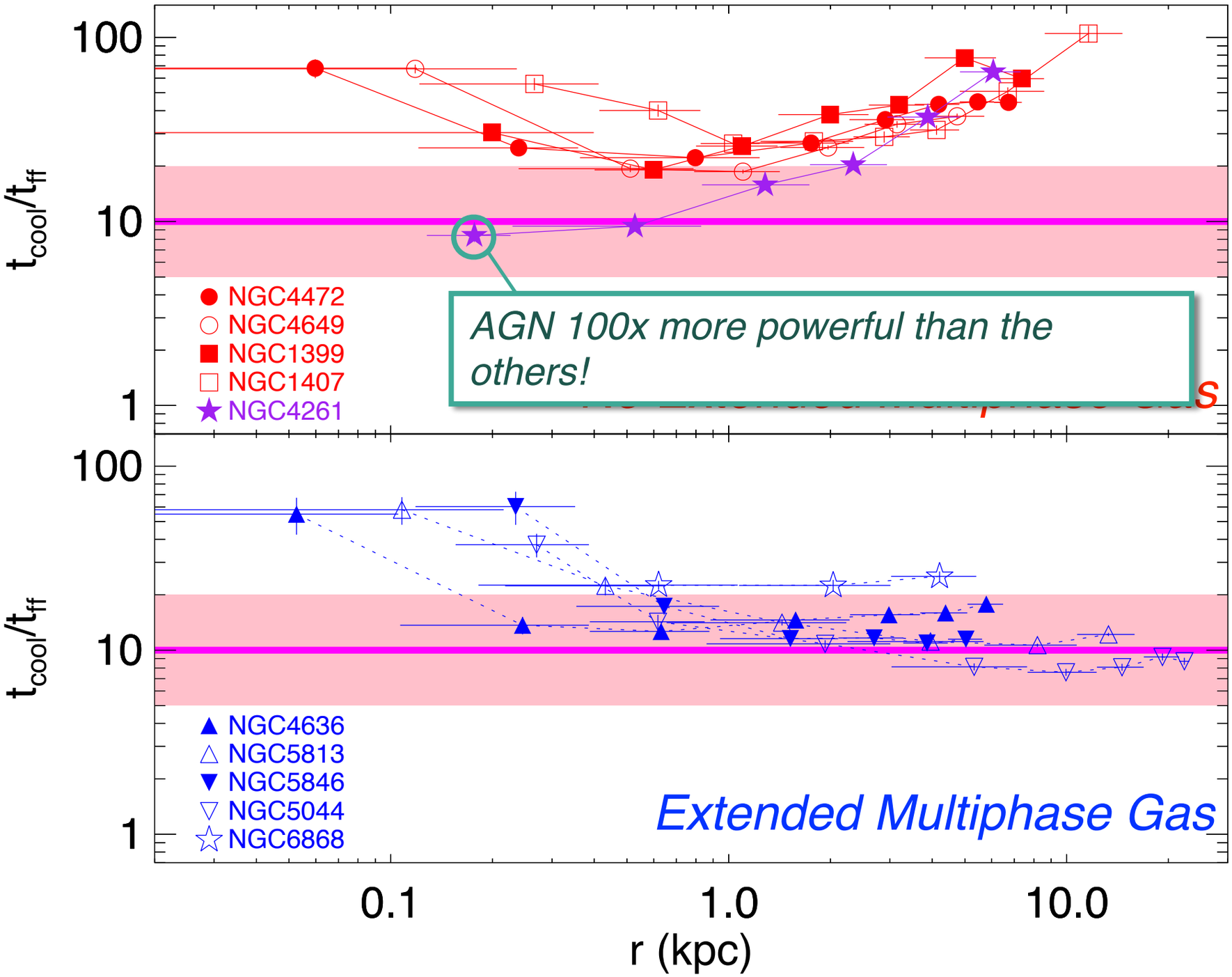


Precipitation-Limited Luminosity

Voit+ 17, in preparation

$$\frac{t_{\rm cool}}{t_{\rm ff}} \gtrsim 10$$

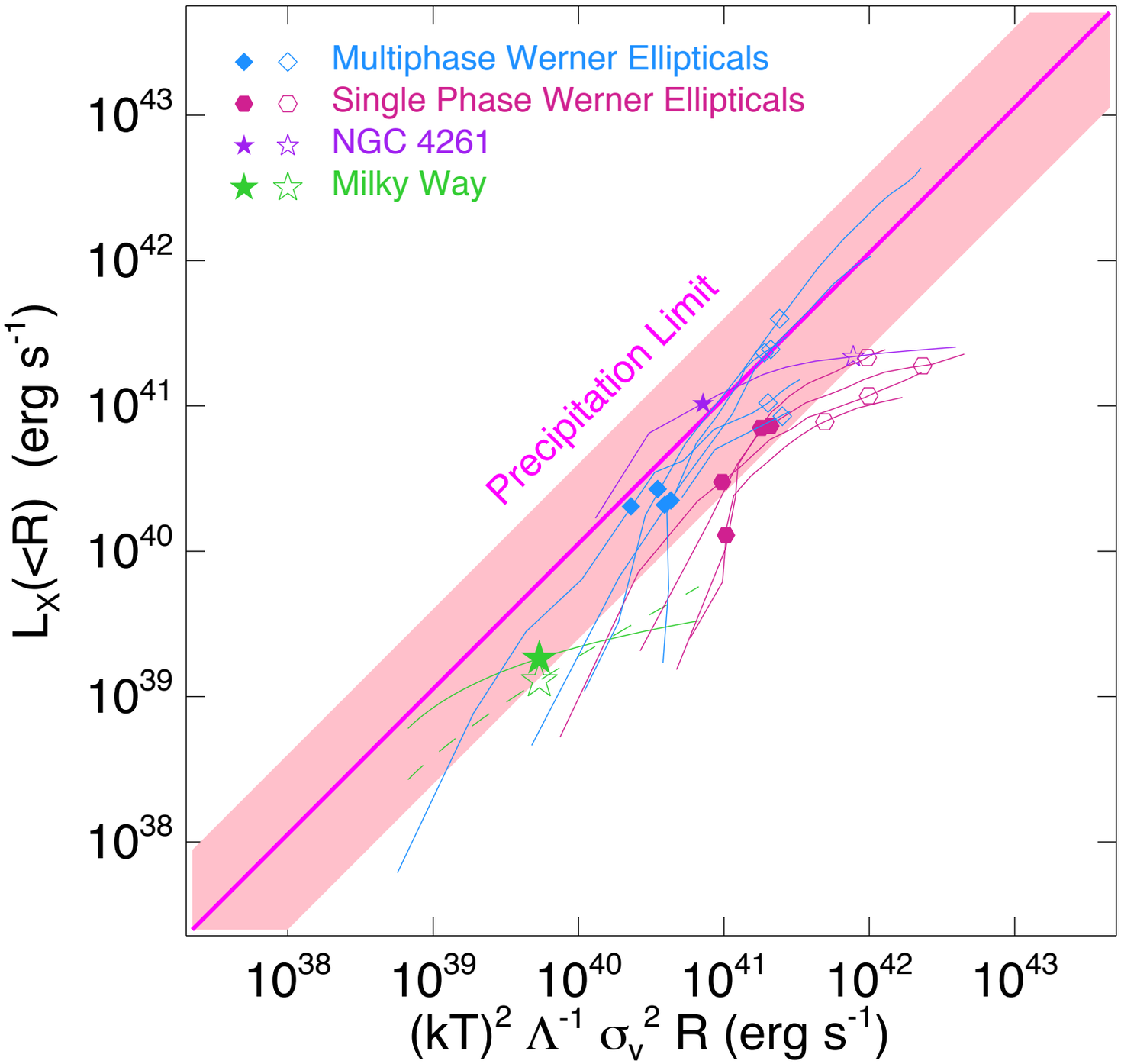
$$n_e \lesssim \frac{3kT}{10\, t_{\rm ff} \Lambda(T)}$$

$$L_X(<R) \lesssim \int_0^R 4\pi r^2 \Lambda \left(\frac{3kT}{10 t_{\rm ff} \Lambda} \right)^2 dr$$

$$L_X(<R) \lesssim \frac{9\pi}{25} (kT)^2 \Lambda^{-1} \sigma_v^2 R$$

Precipitation-Limited Luminosity

Voit+ 17, in preparation



Precipitation-Limited Luminosity

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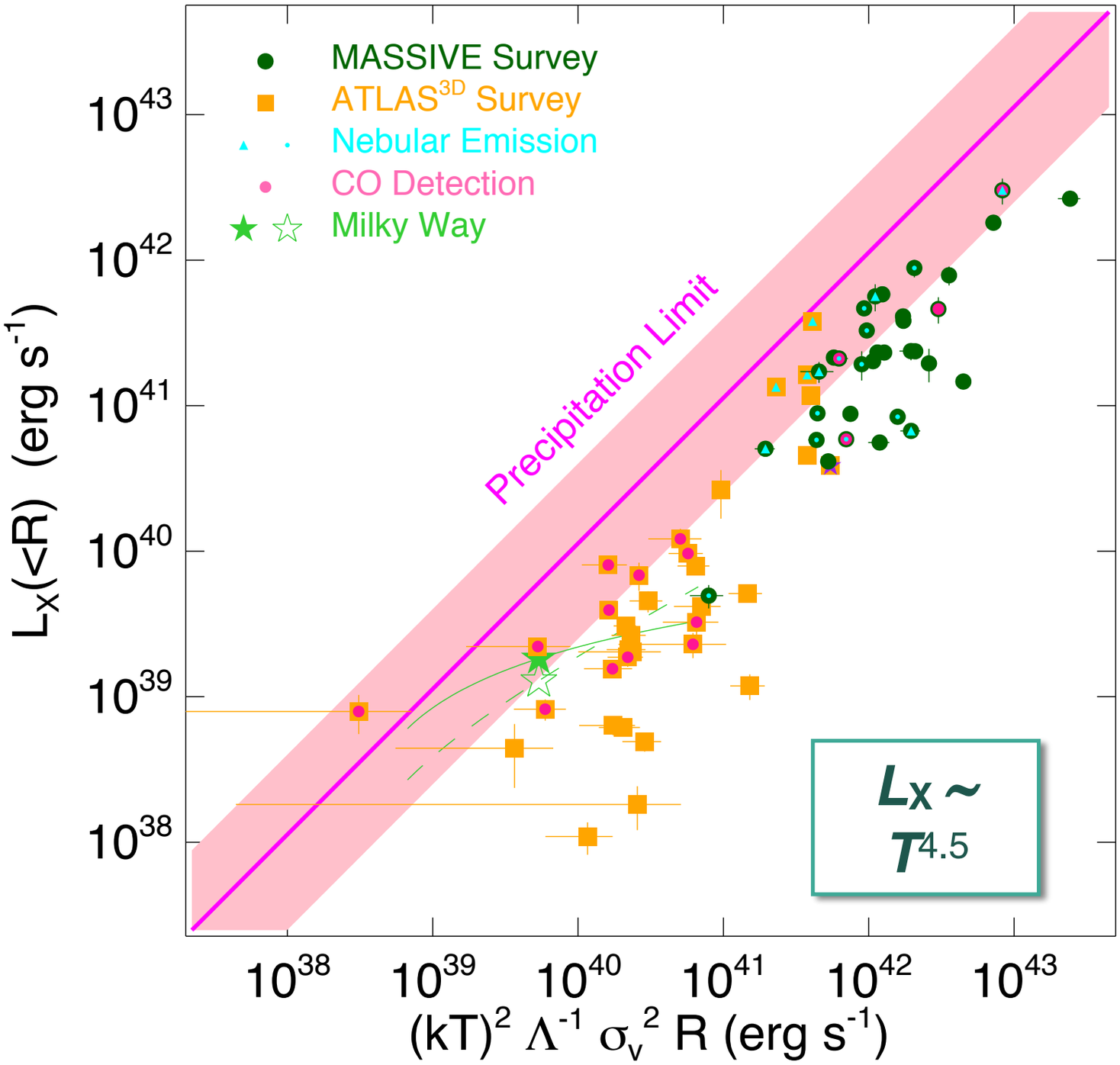

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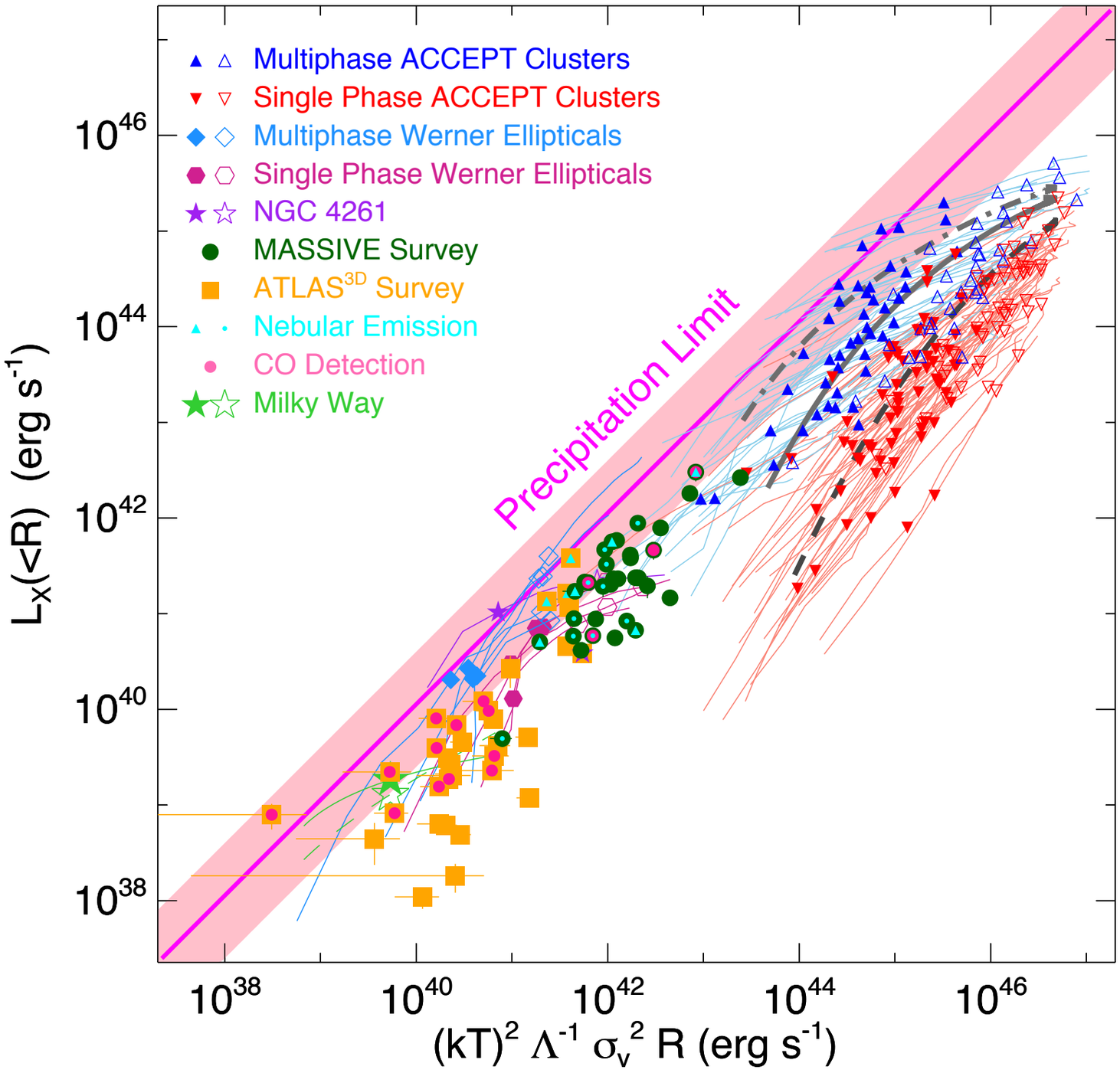
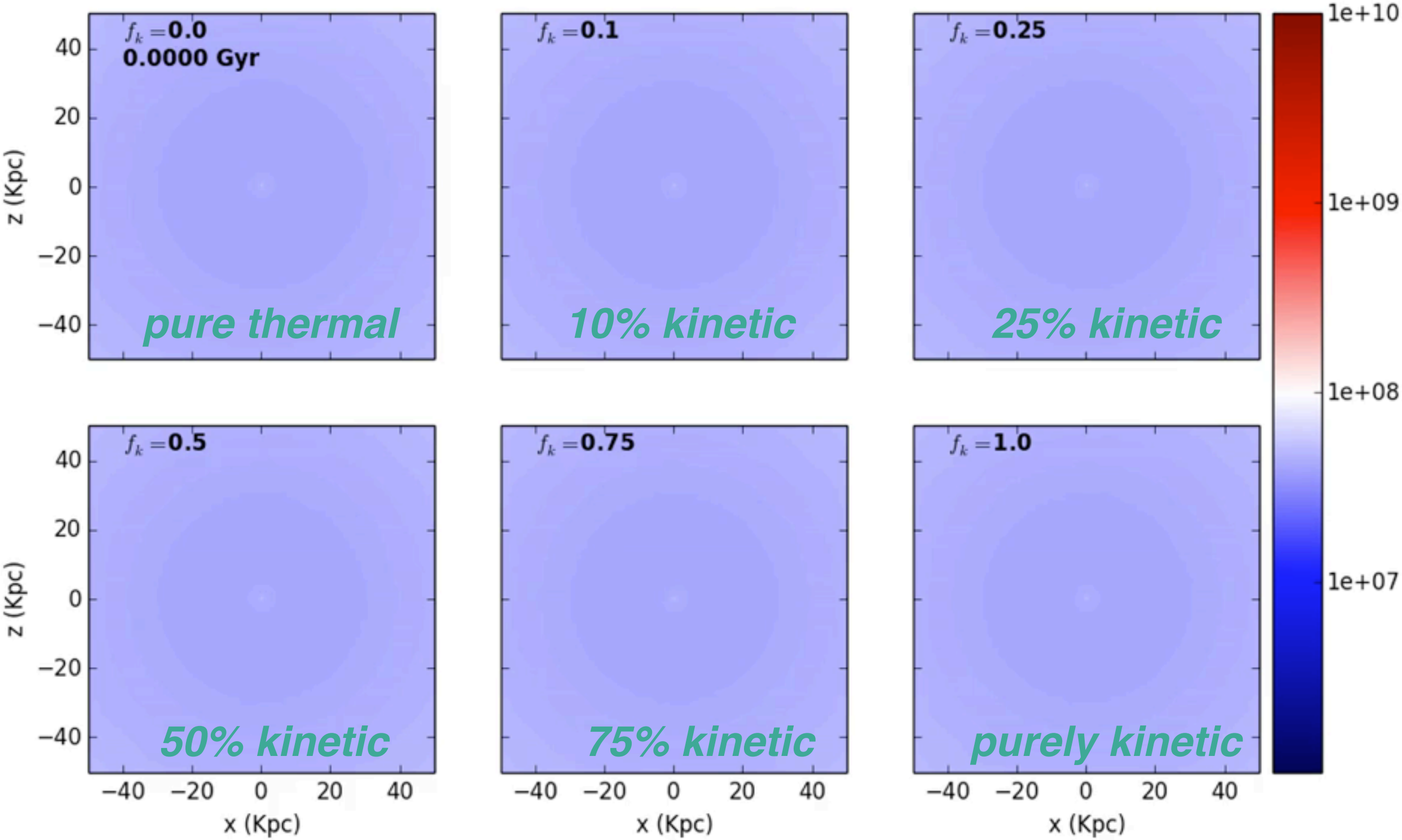


Kinetic vs. Thermal Feedback

Meece, Voit, & O'Shea 2017



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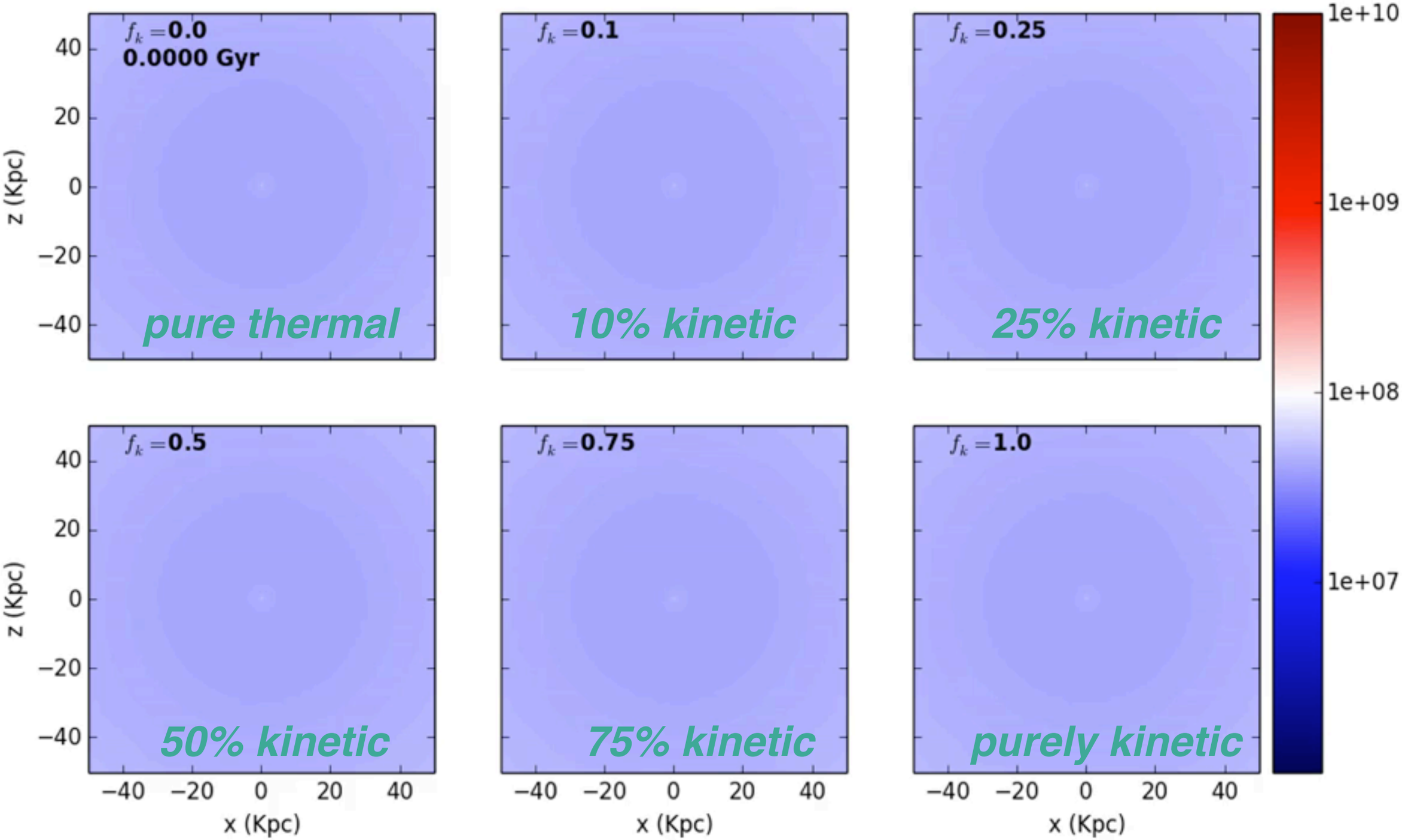

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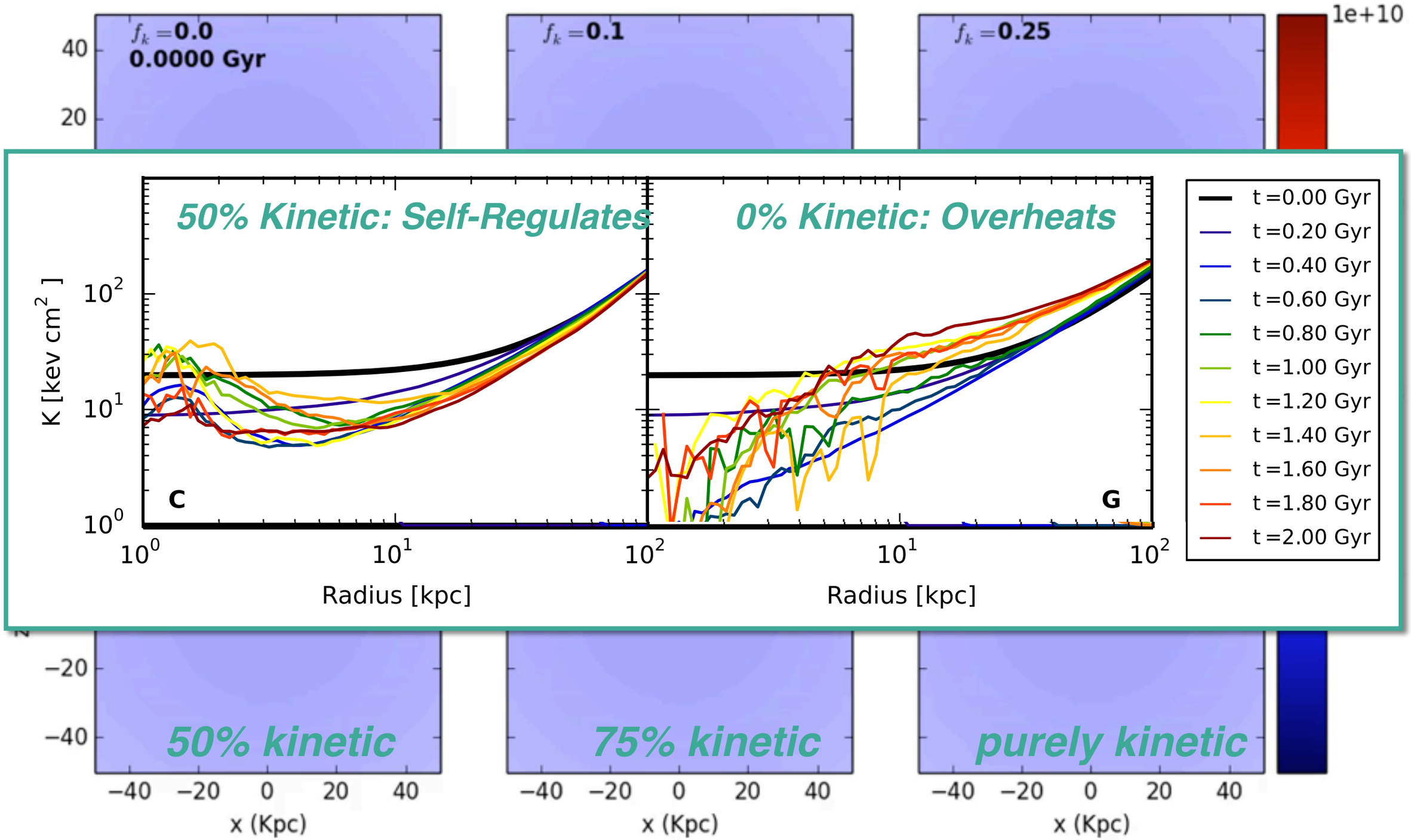
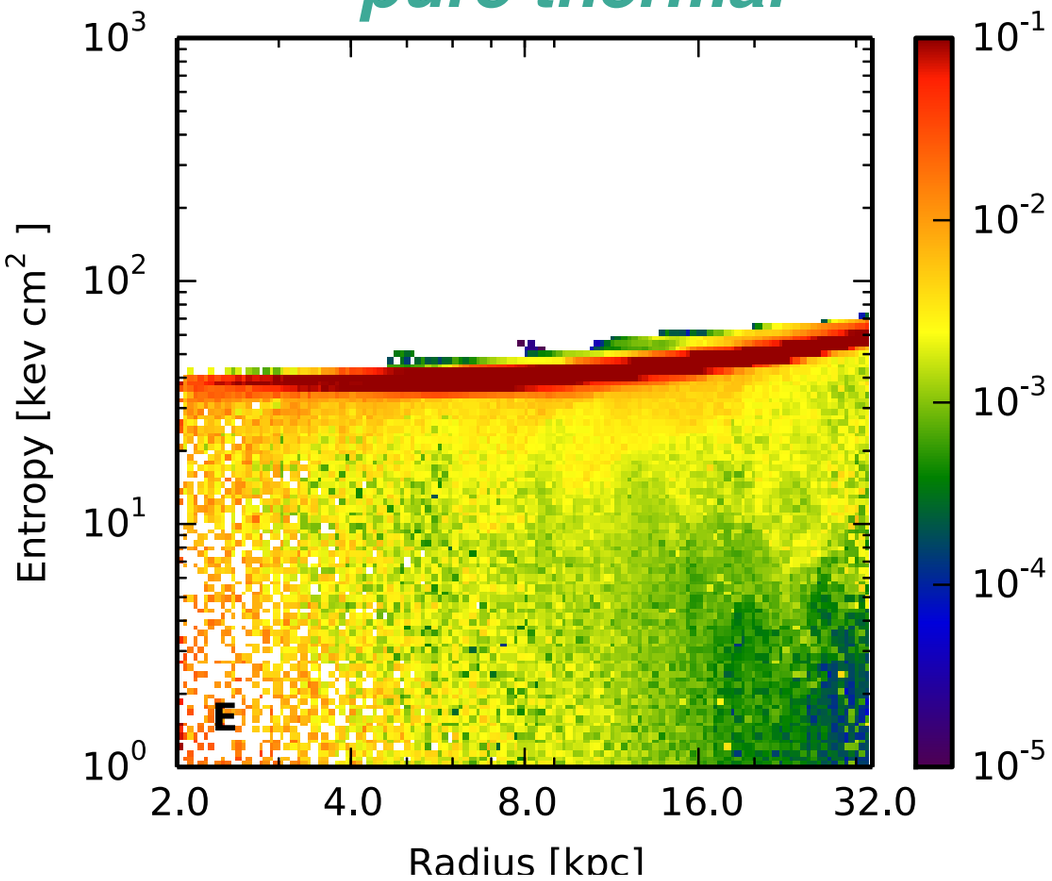


G M Voit

Kinetic vs. Thermal Feedback

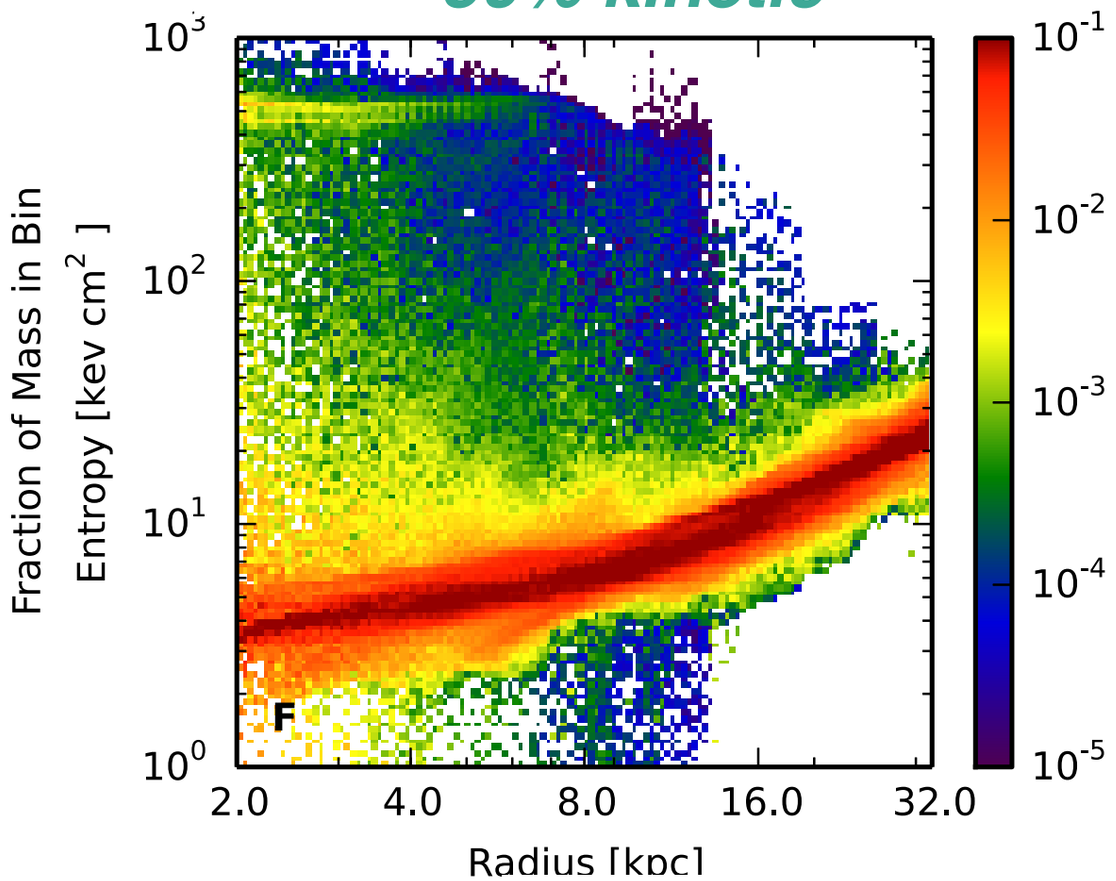
Meece, Voit, & O'Shea 2016

pure thermal



Condensation not damped

50% kinetic

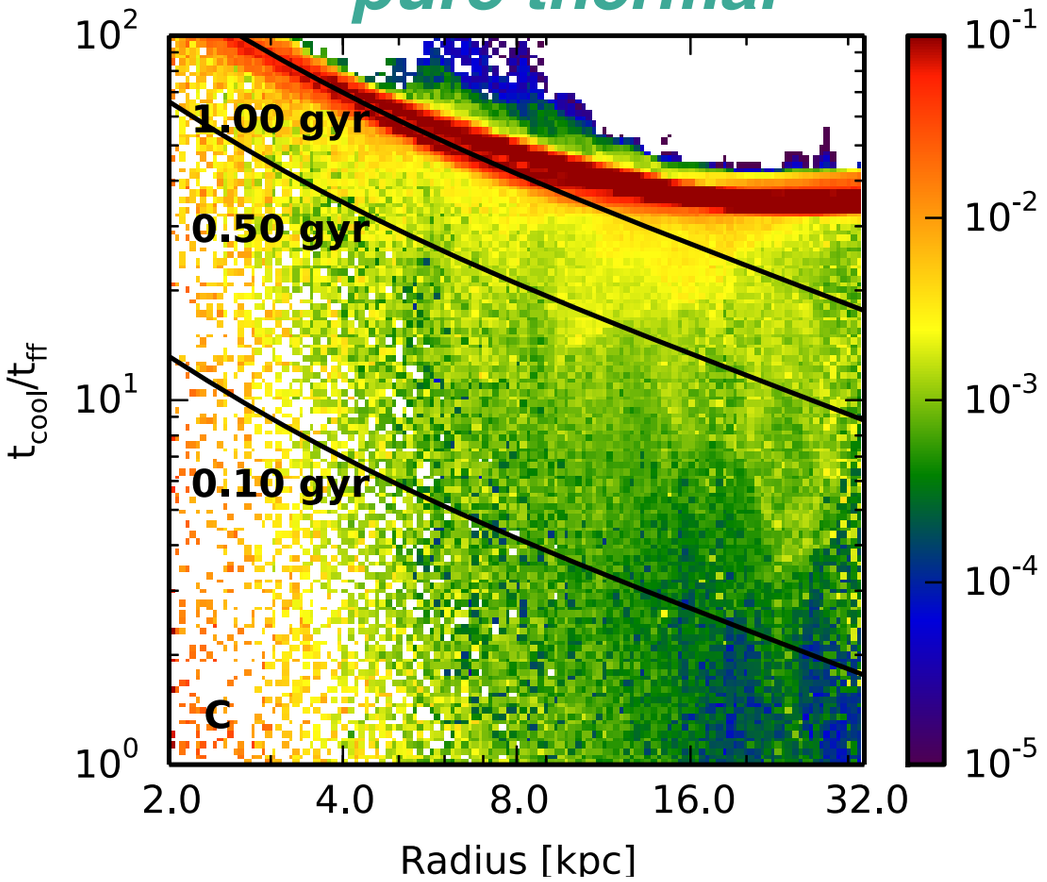


Condensation is damped

Kinetic vs. Thermal Feedback

Meece, Voit, & O'Shea 2017

pure thermal



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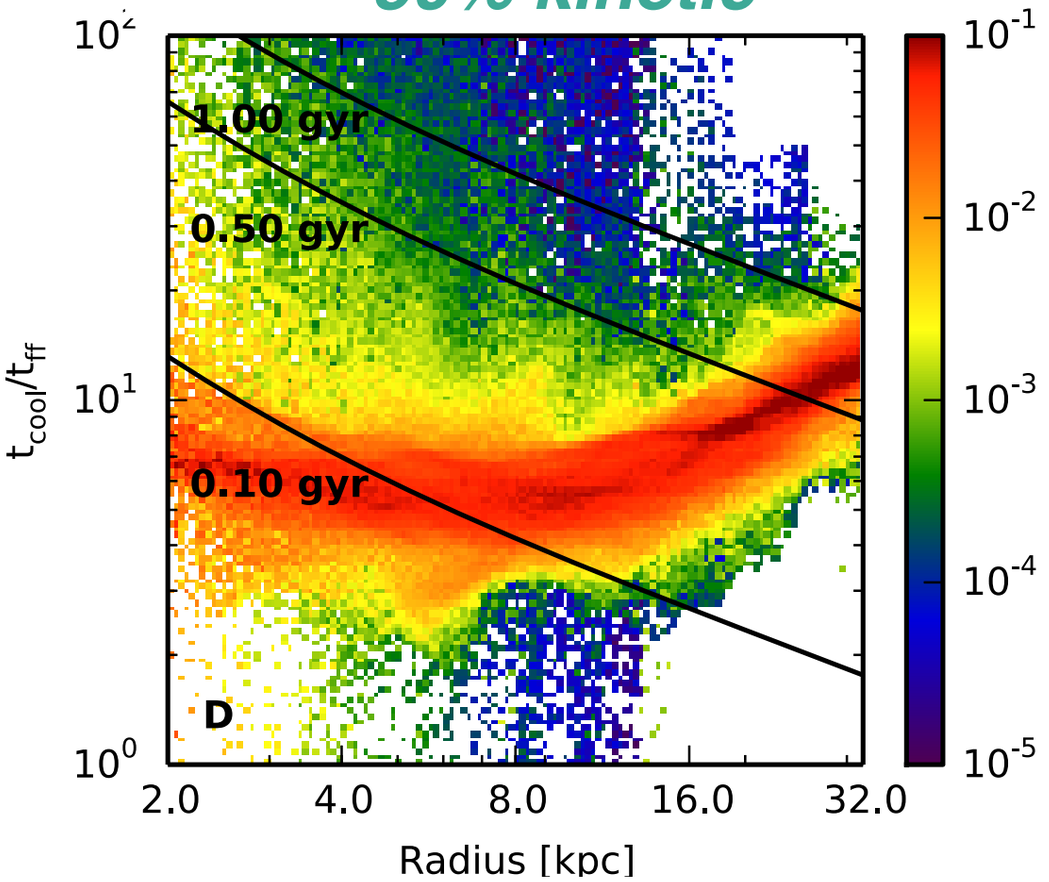

Central t_c rises with time

Central t_c/t_{ff} nearly flat