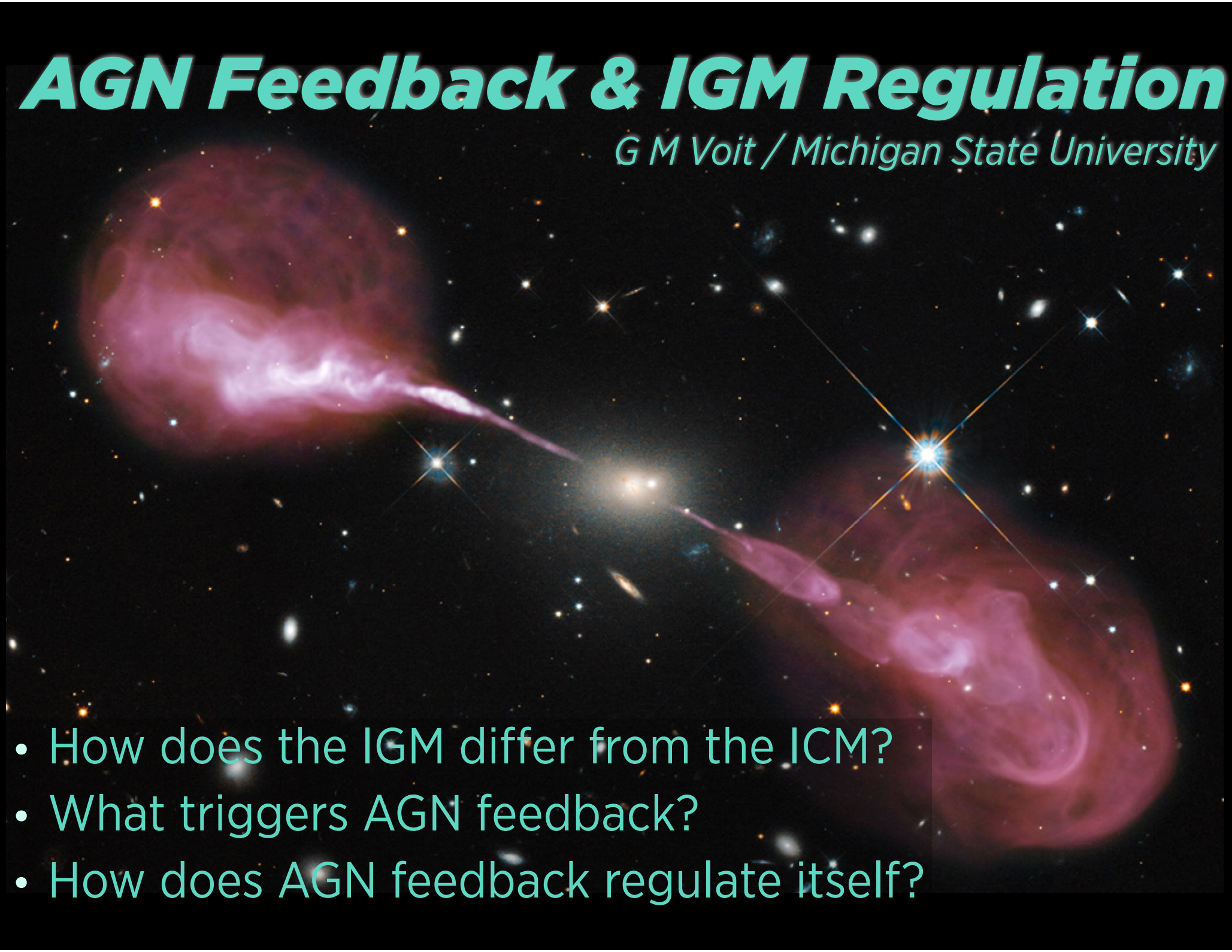
AGN Feedback & IGM Regulation

G M Voit / Michigan State University

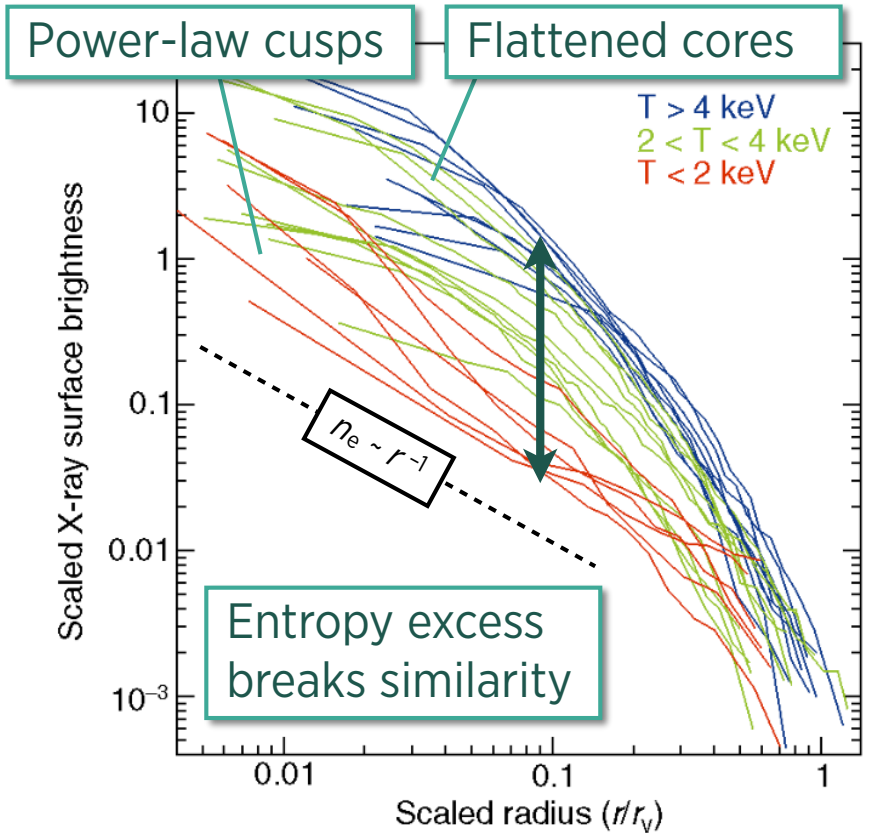


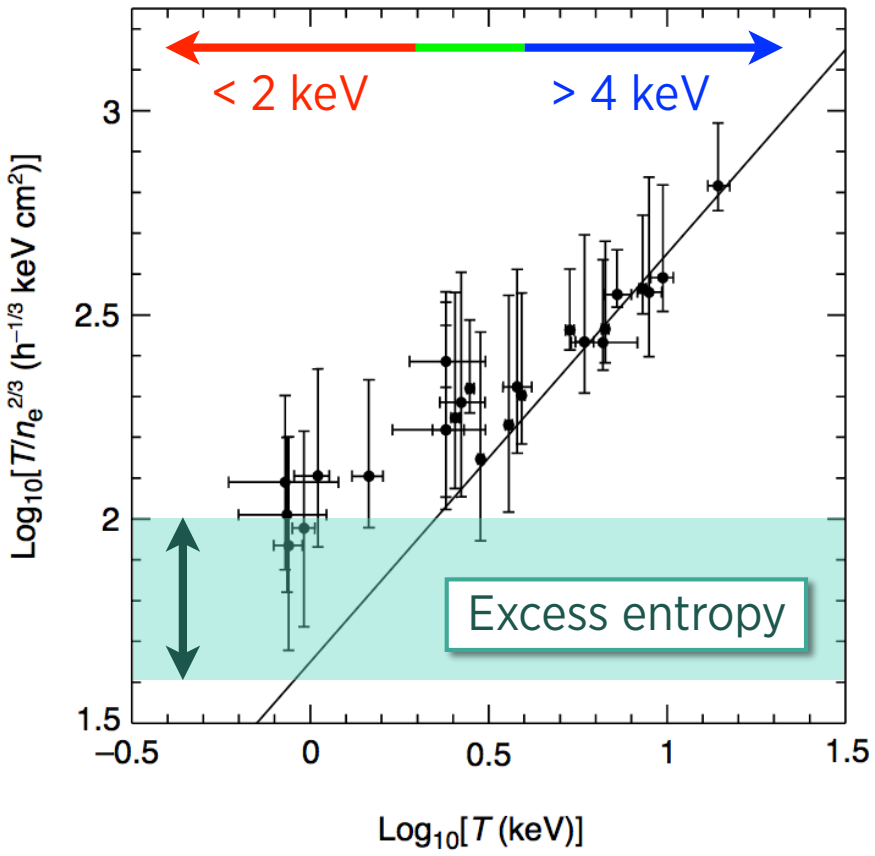
- How does the IGM differ from the ICM?
- What triggers AGN feedback?
- How does AGN feedback regulate itself?

1 Entropy Analysis

The "Entropy Floor" in Groups

Ponman, Cannon, Navarro 1999, Nature

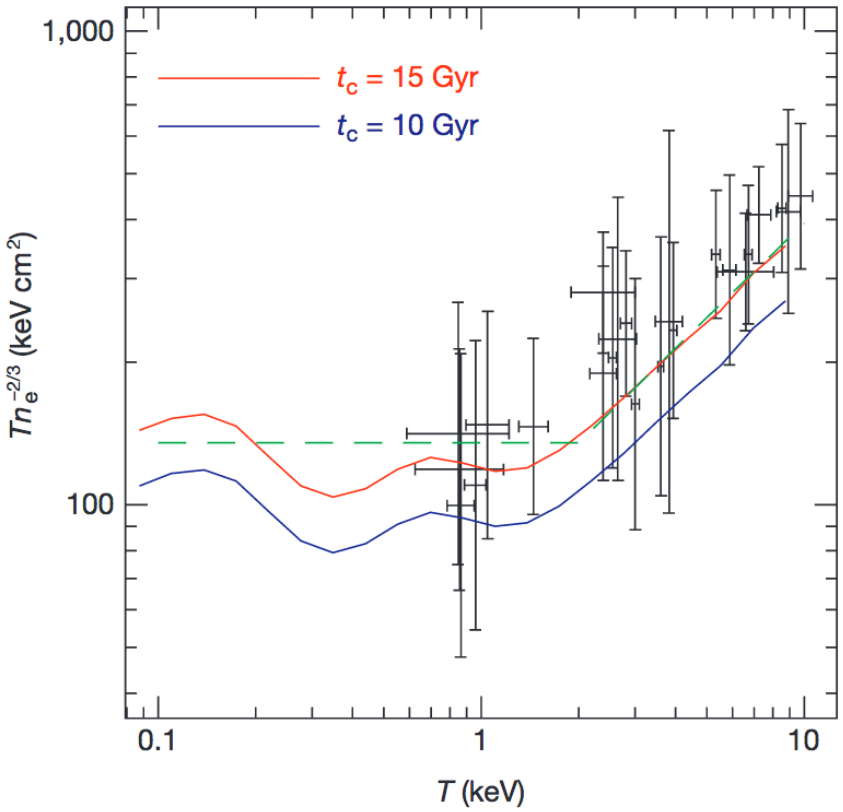




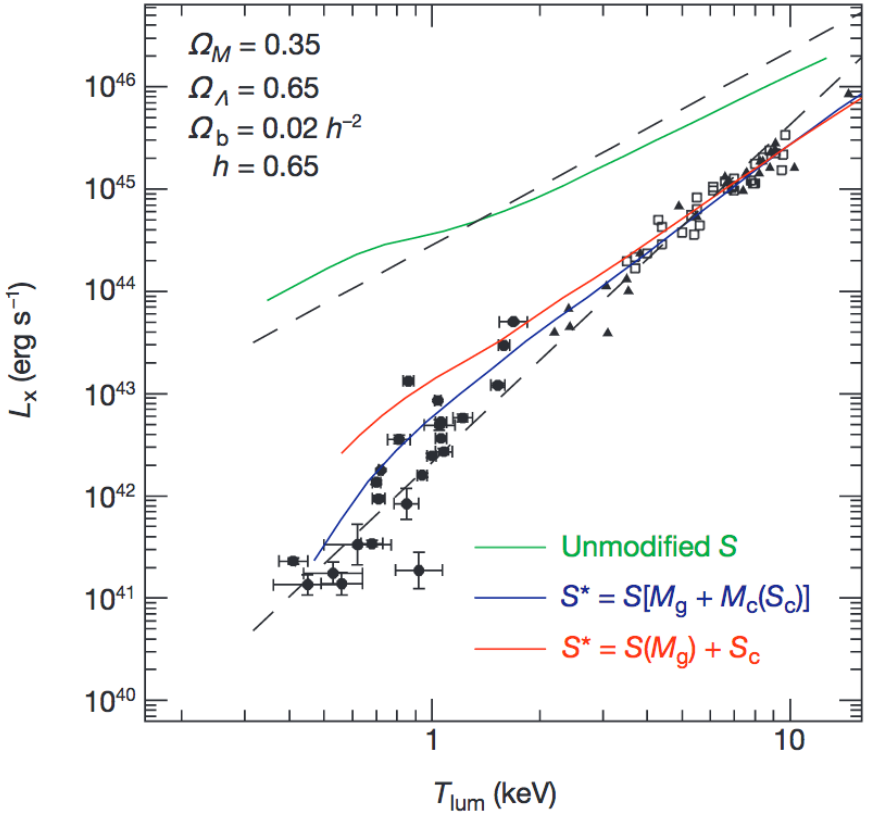
Entropy index = $\boldsymbol{K} = kTn_e^{-2/3}$

Entropy & Cooling Time

Voit & Bryan 2001, Nature



$K(0.1\,r_v)$ corresponds to $t_c \sim t_H$

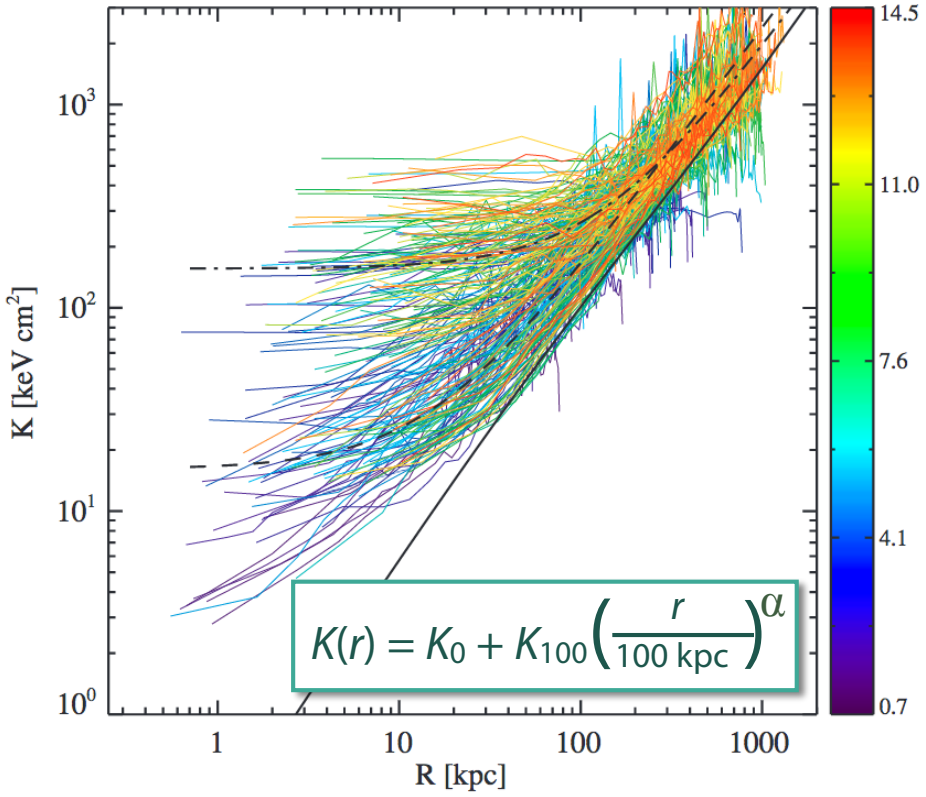


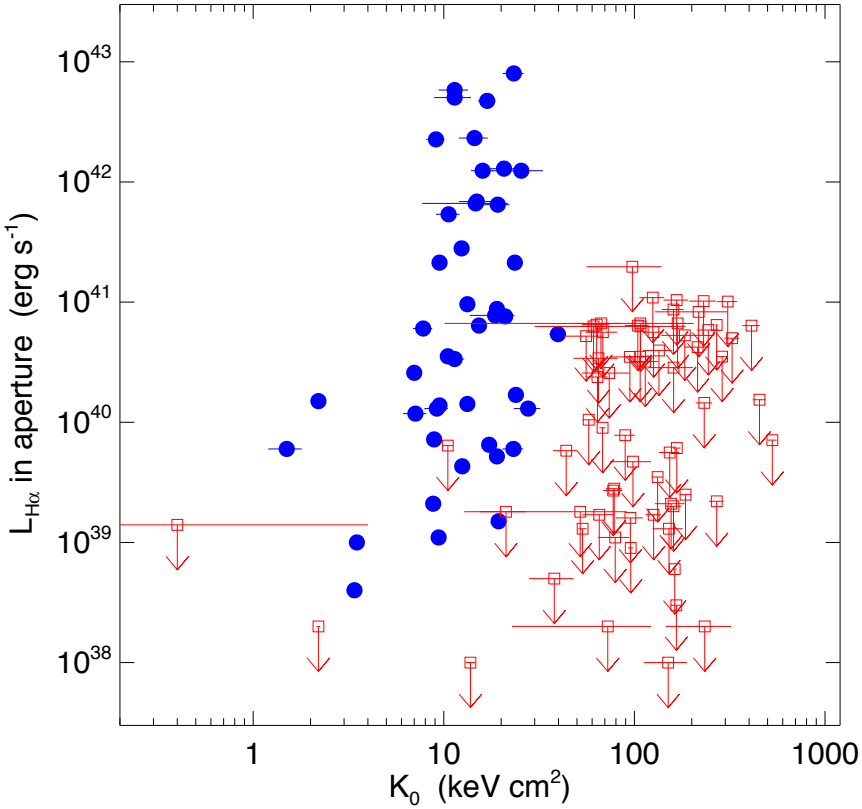
Break at $K(t_c=t_H)$ corrects L_X–T_X slope

Cooling+feedback inevitably breaks self-similarity at $t_c \sim t_H$

Central Entropy & Multiphase Gas

Cavagnolo+ 2008, 2009, Voit & Donahue 2015

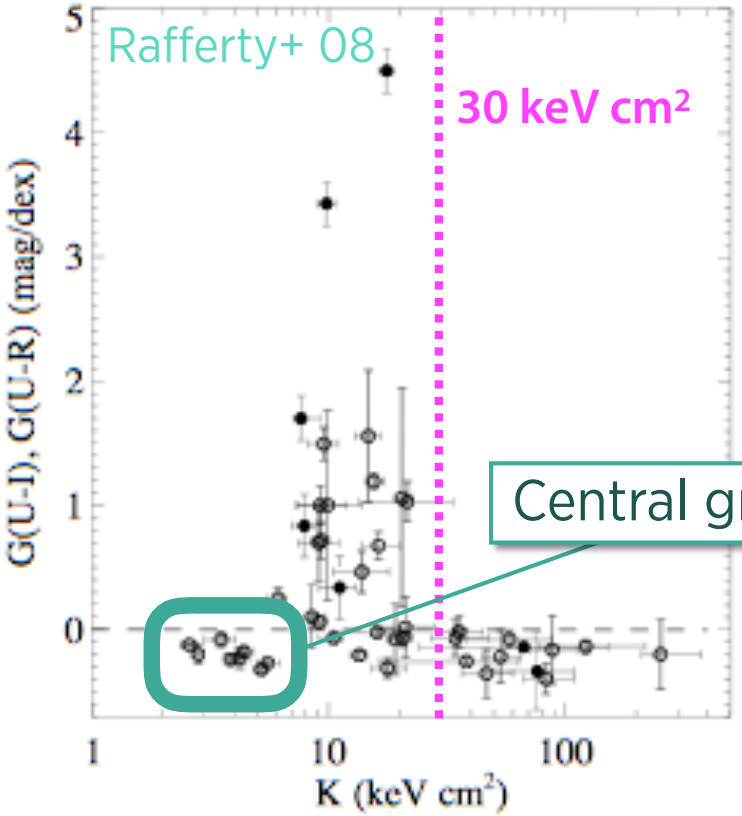


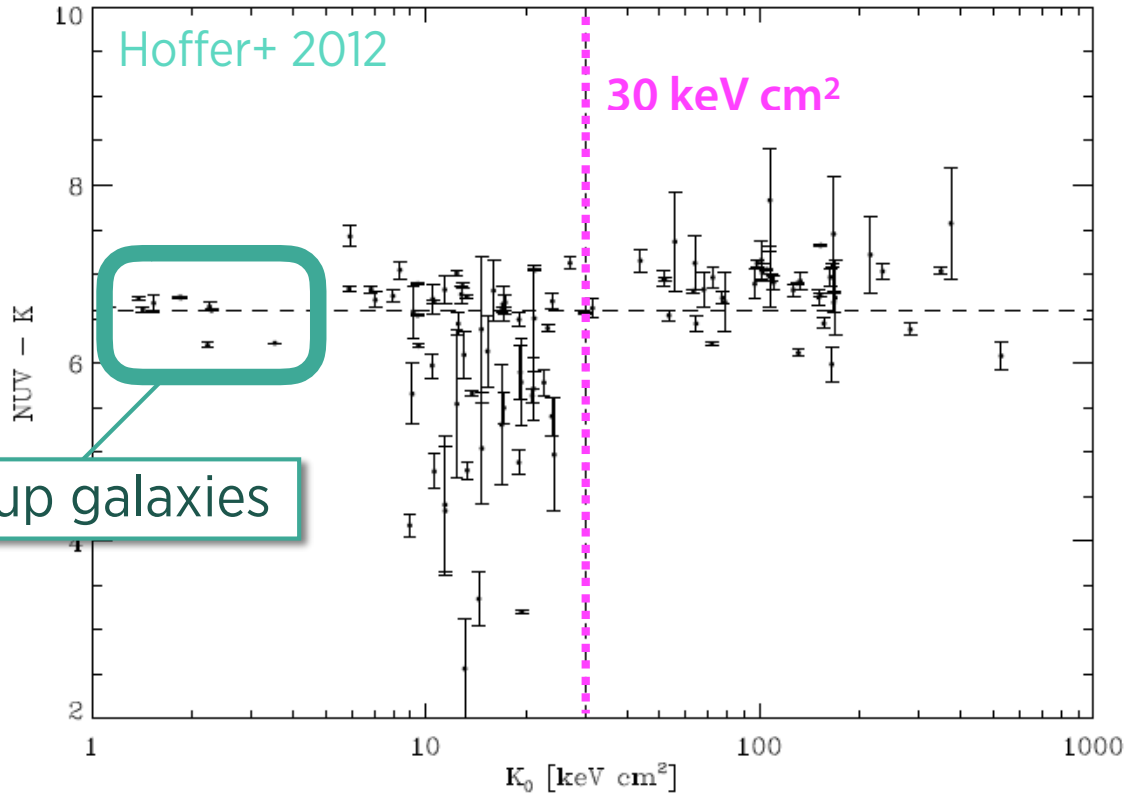


Threshold for multiphase gas and AGN activity at K_0 ~ 30 keV cm^2

Central Entropy & Star Formation

Rafferty+ 2008, Hoffer+ 2012





Central group galaxies

Central group galaxies have K_0 < 10 keV cm² but little star formation

2 Precipitation & Feedback

The "Copenhagen Interpretation"

McCourt+ 2012, Sharma+ 2012, Gaspari+ 2012, Li & Bryan 2014, Voit & Donahue 2015

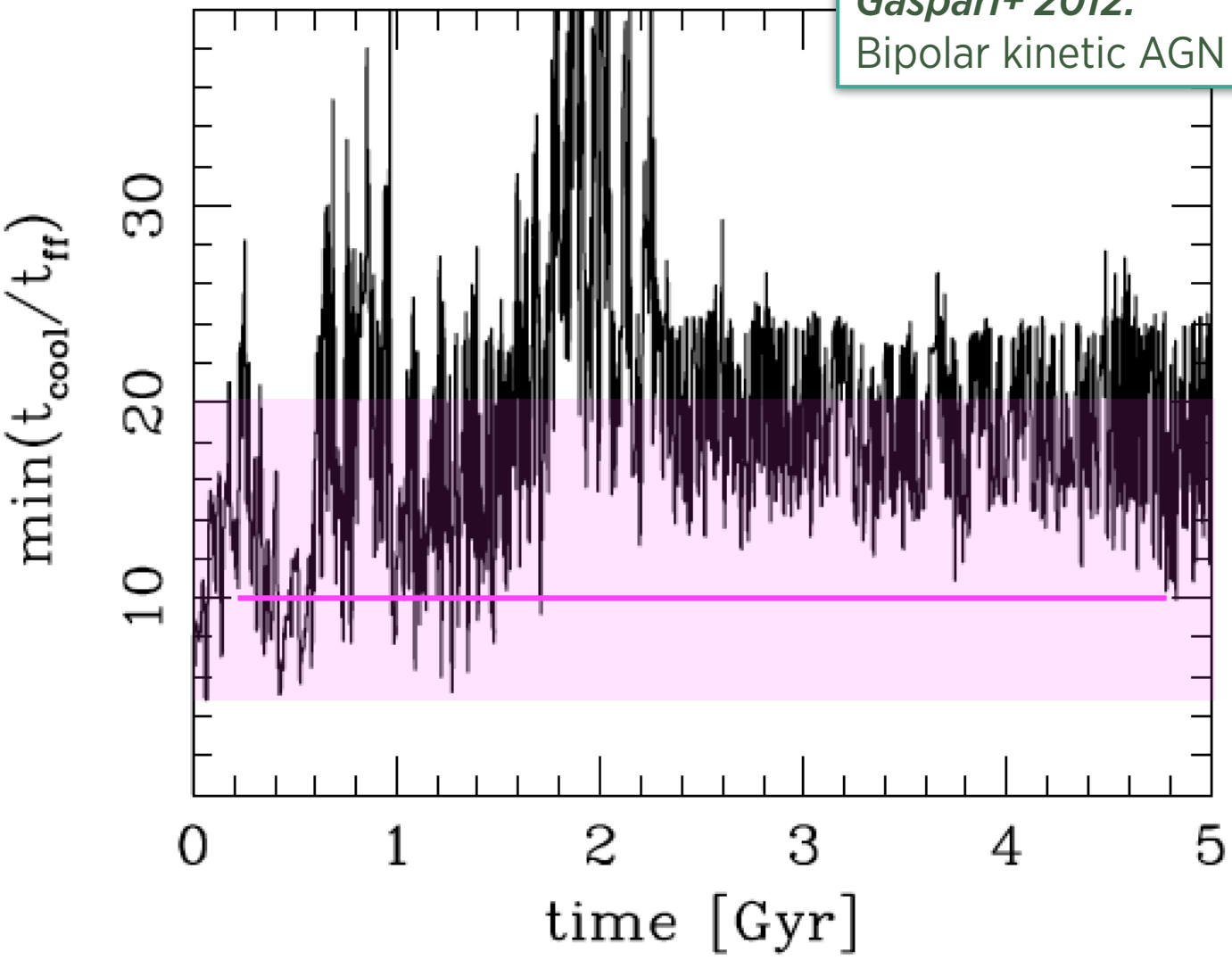
$$\frac{t_{\rm cool}}{t_{\rm ff}} \approx 10$$

Condensation triggers strong feedback at $t_{\rm cool}/t_{\rm ff}$ threshold

The "Copenhagen Interpretation"

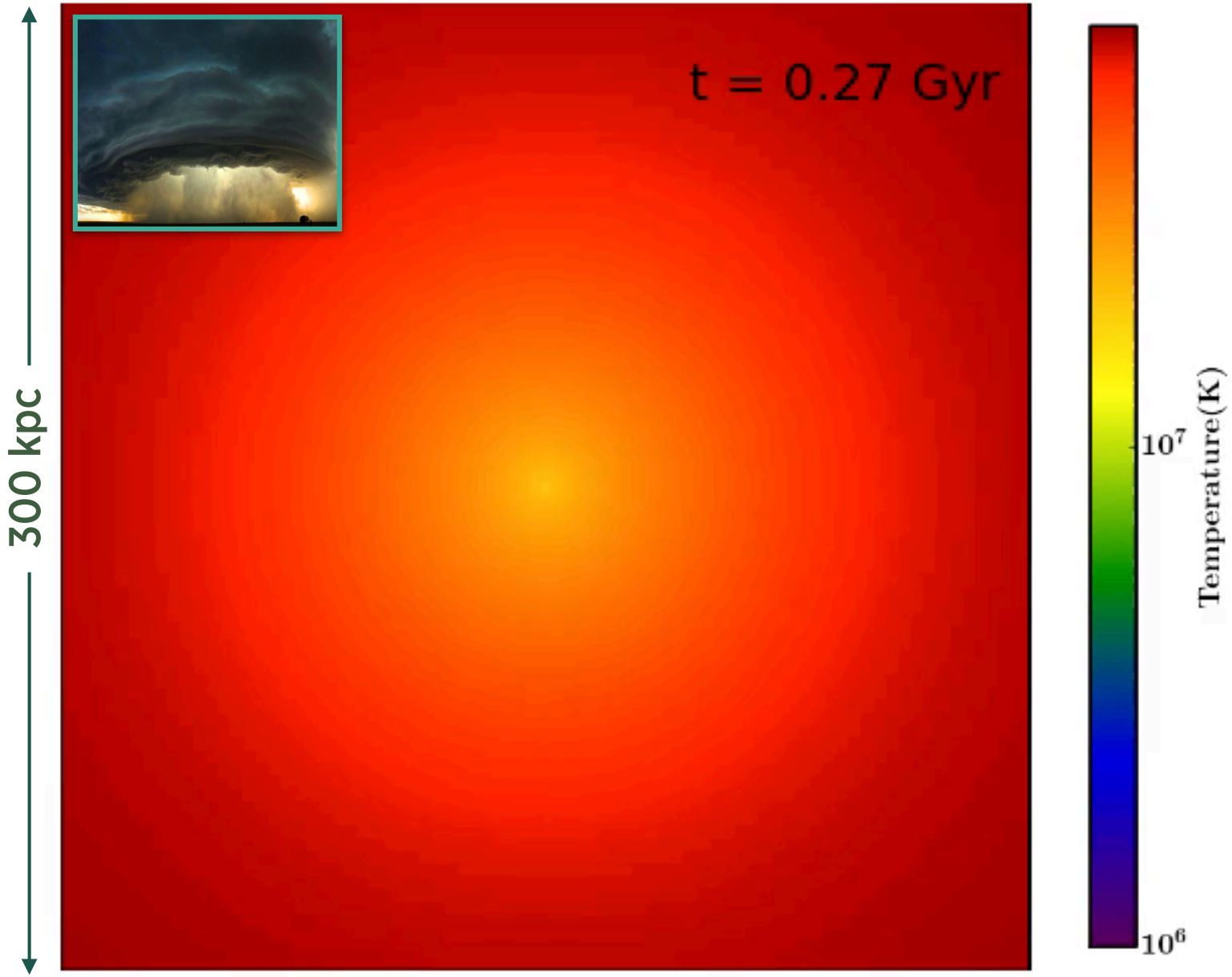
McCourt+ 2012, Sharma+ 2012, Gaspari+ 2012, Li & Bryan 2014, Voit & Donahue 2015

Gaspari+ 2012:
Bipolar kinetic AGN feedback



Precipitation-Regulated Feedback

Gaspari+ 2012,2013,2014; Li & Bryan 2014a,b; Li+ 2015



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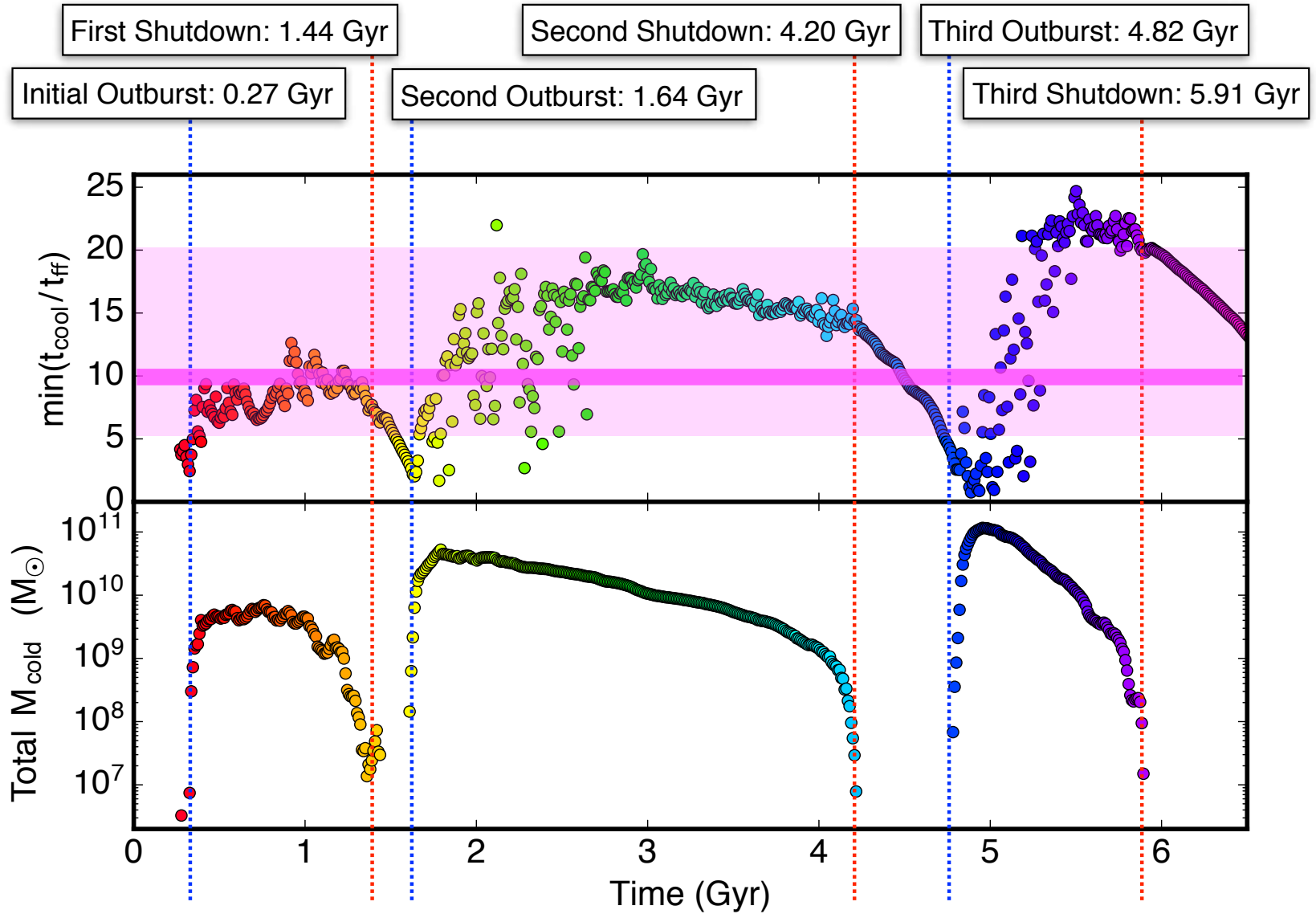
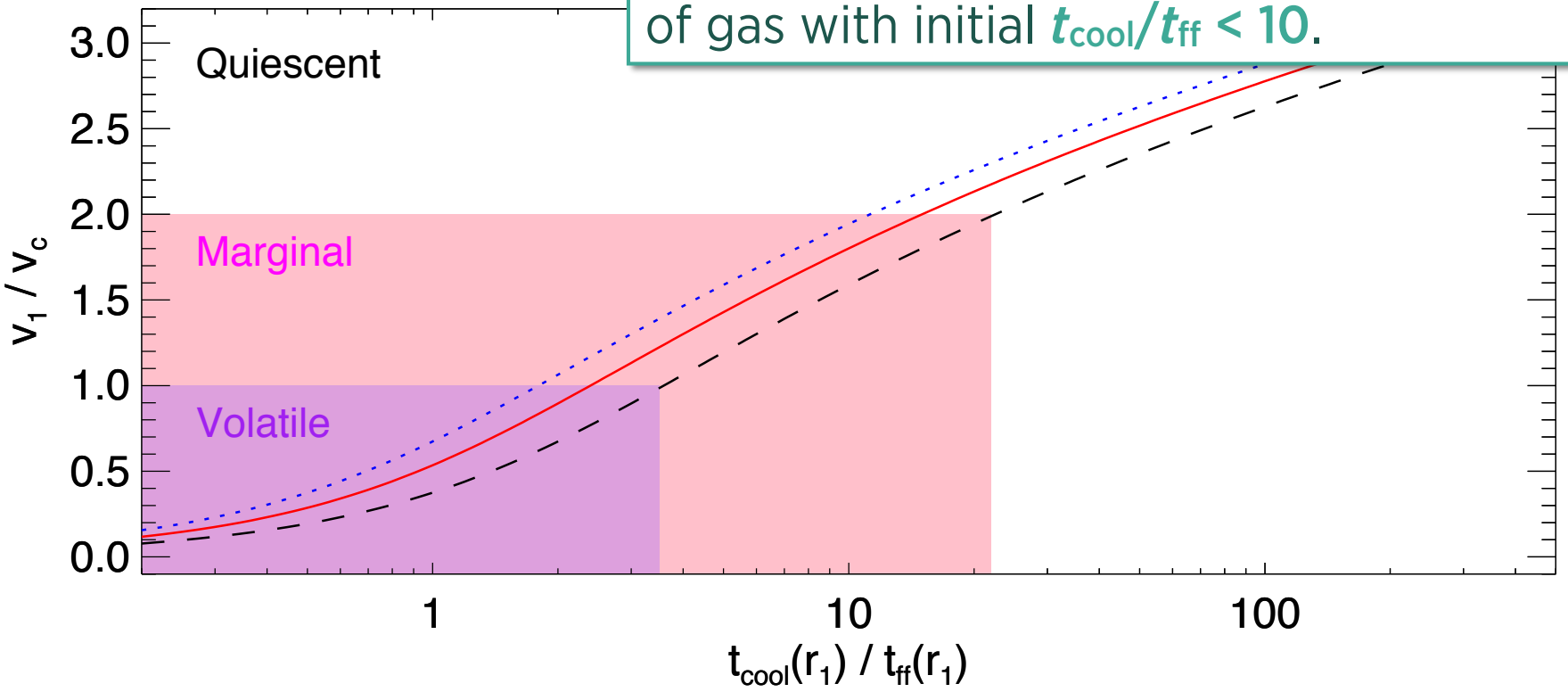


Ballistic Condensation

Voit+ 16, arXiv:1607.02212

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

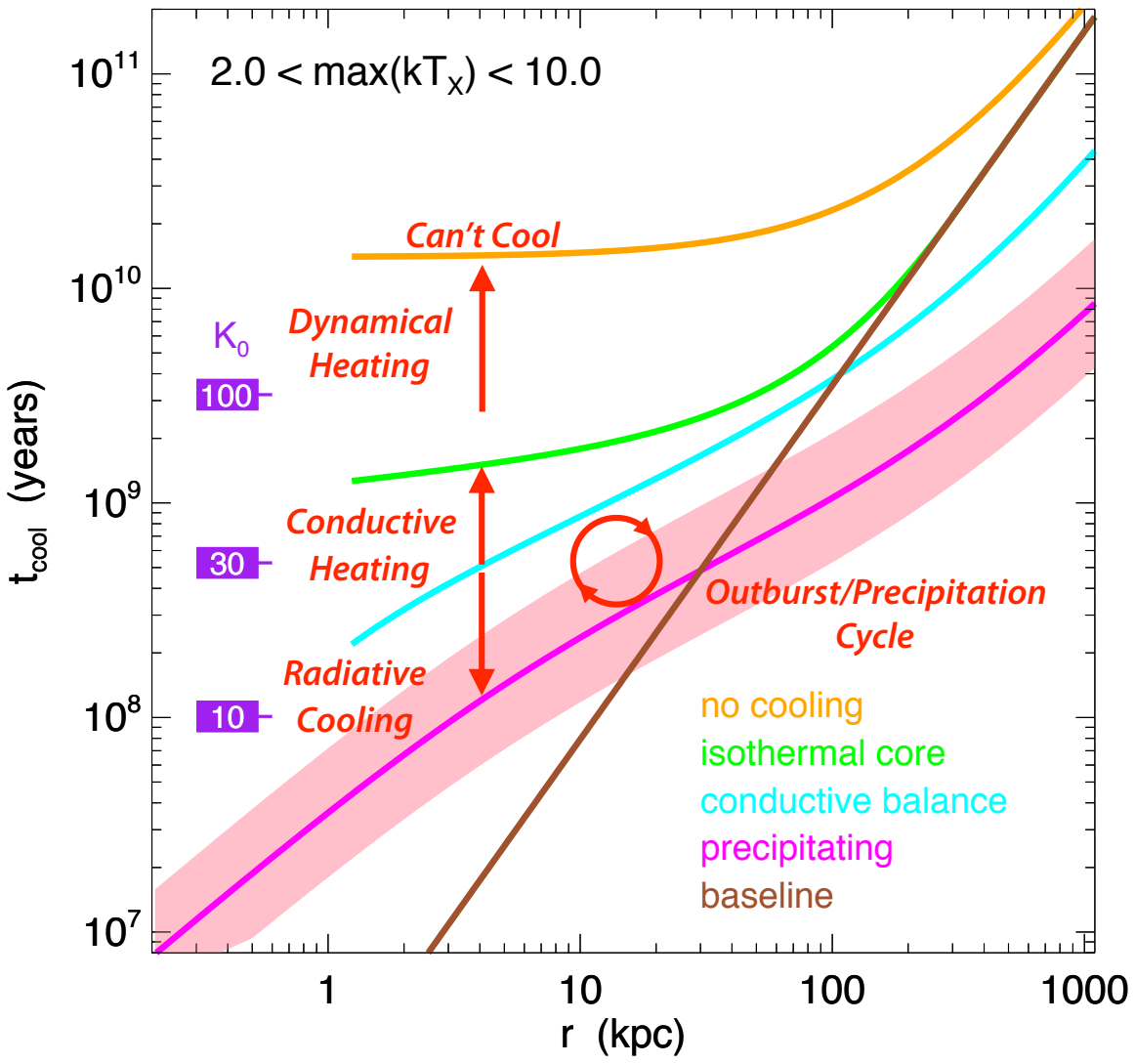


3

Evidence for a Threshold

Cooling-Time Profiles

Voit+ 2015, Nature



Precipitation Threshold:

1. Use 250 km/s singular isothermal sphere for the stars.
2. Use NFW halo with $c_{500} = 3$ for the dark matter.
3. Calculate $t_{ff}(r)$.
4. Multiply by 10.

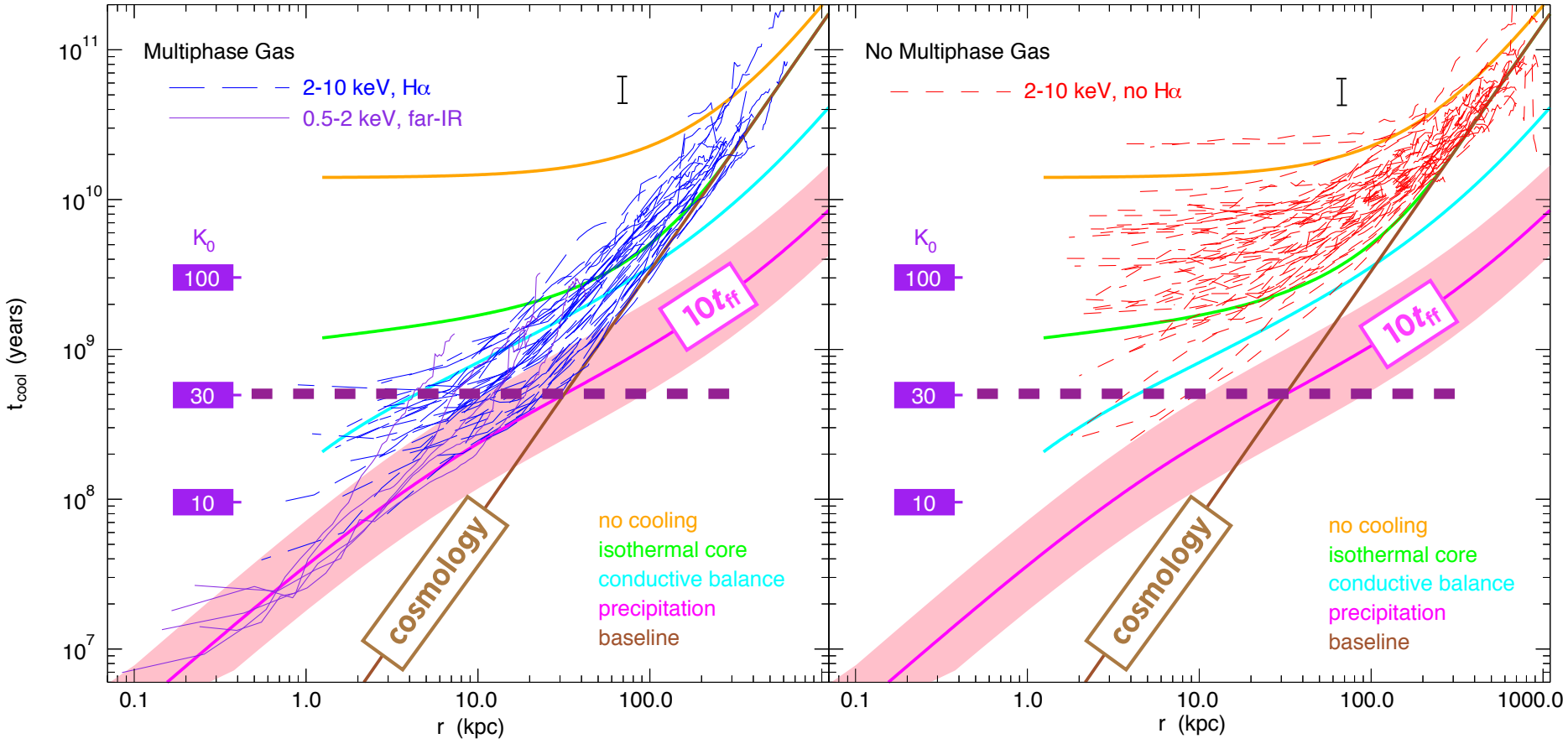
Baseline: Voit+ 2005

No Cooling: Voit+ 2002

Conduction: Voit 2011

Cooling-Time Profiles

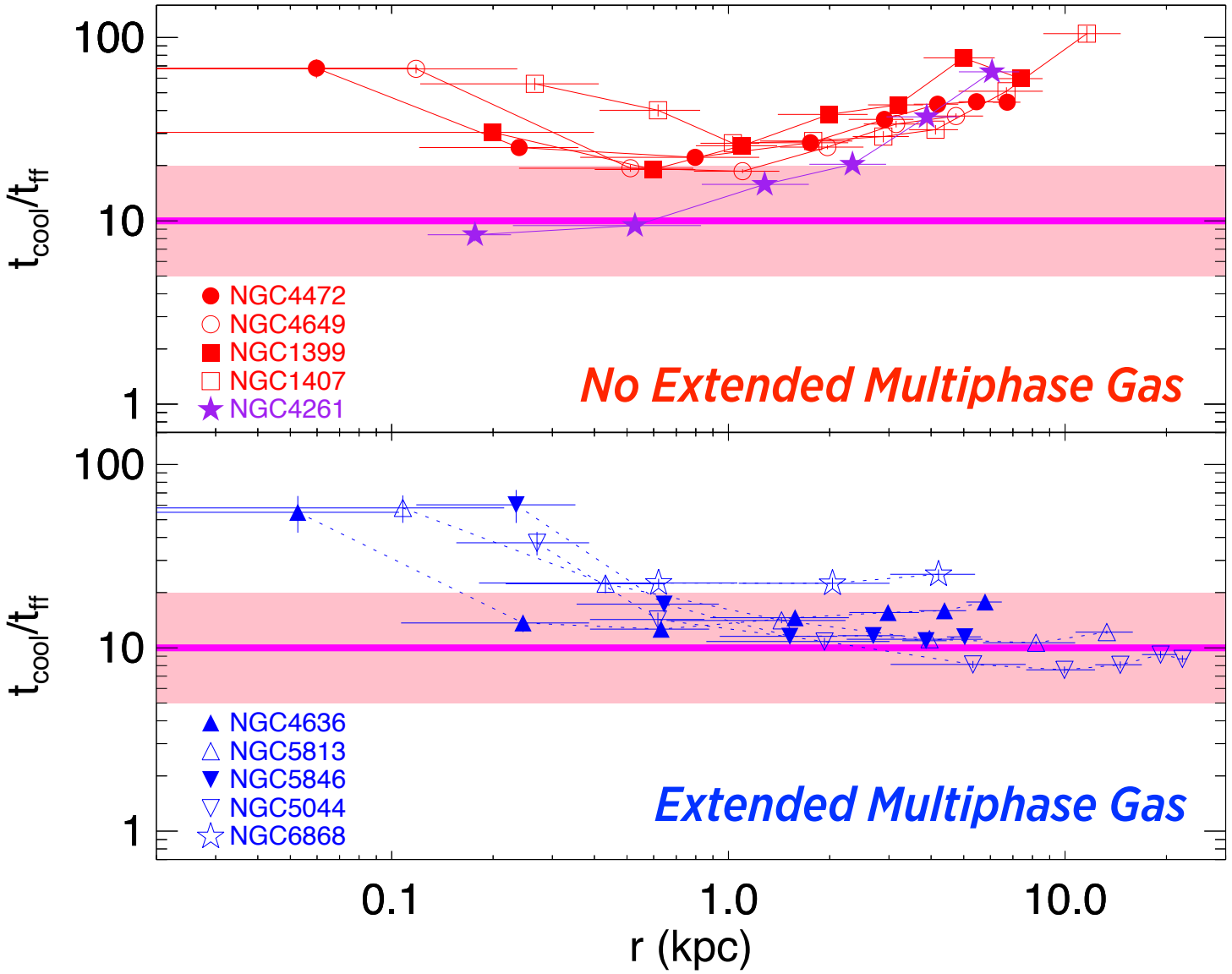
Voit+ 2015, Nature



G M Voit

Precipitation Threshold in Ellipticals

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



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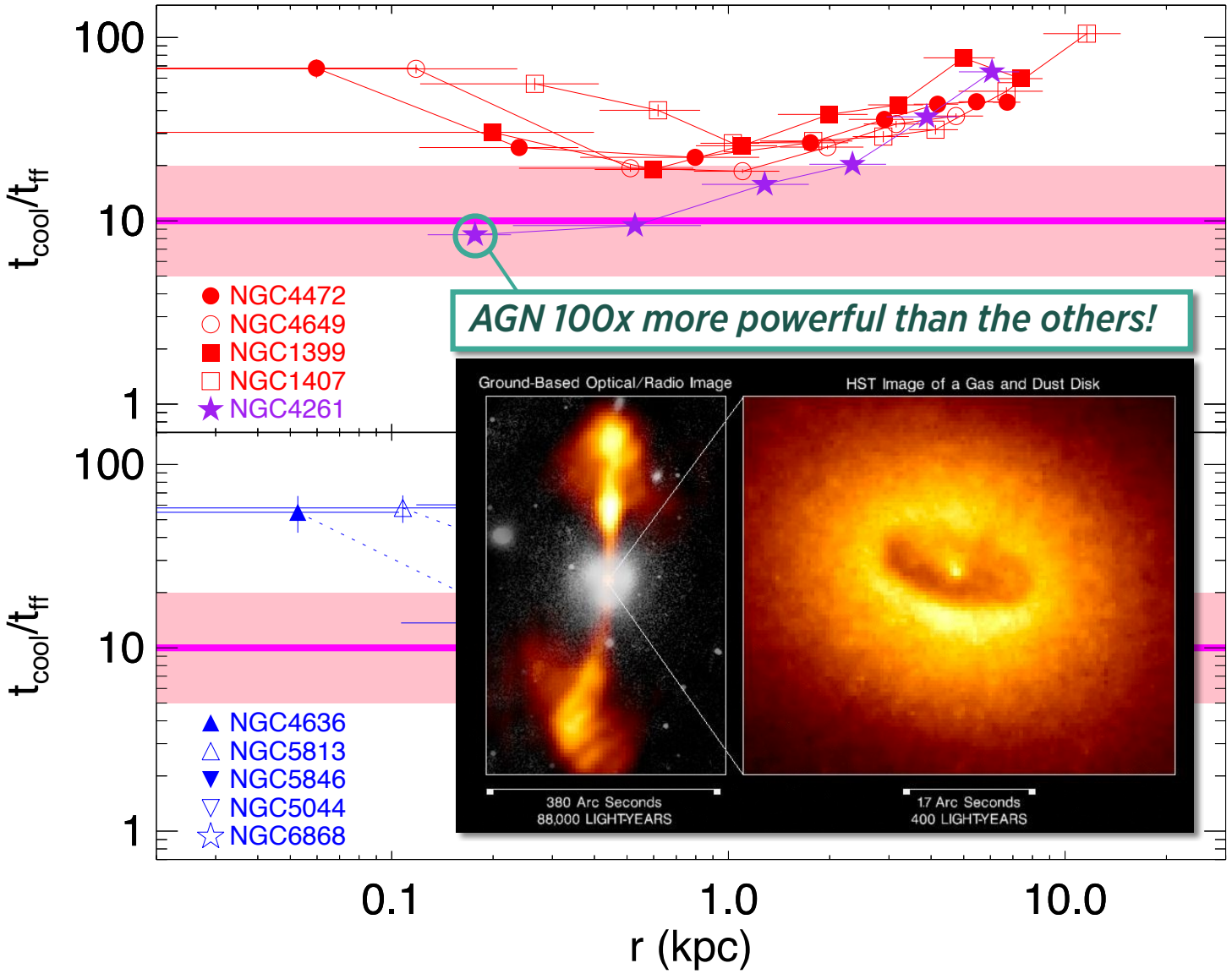
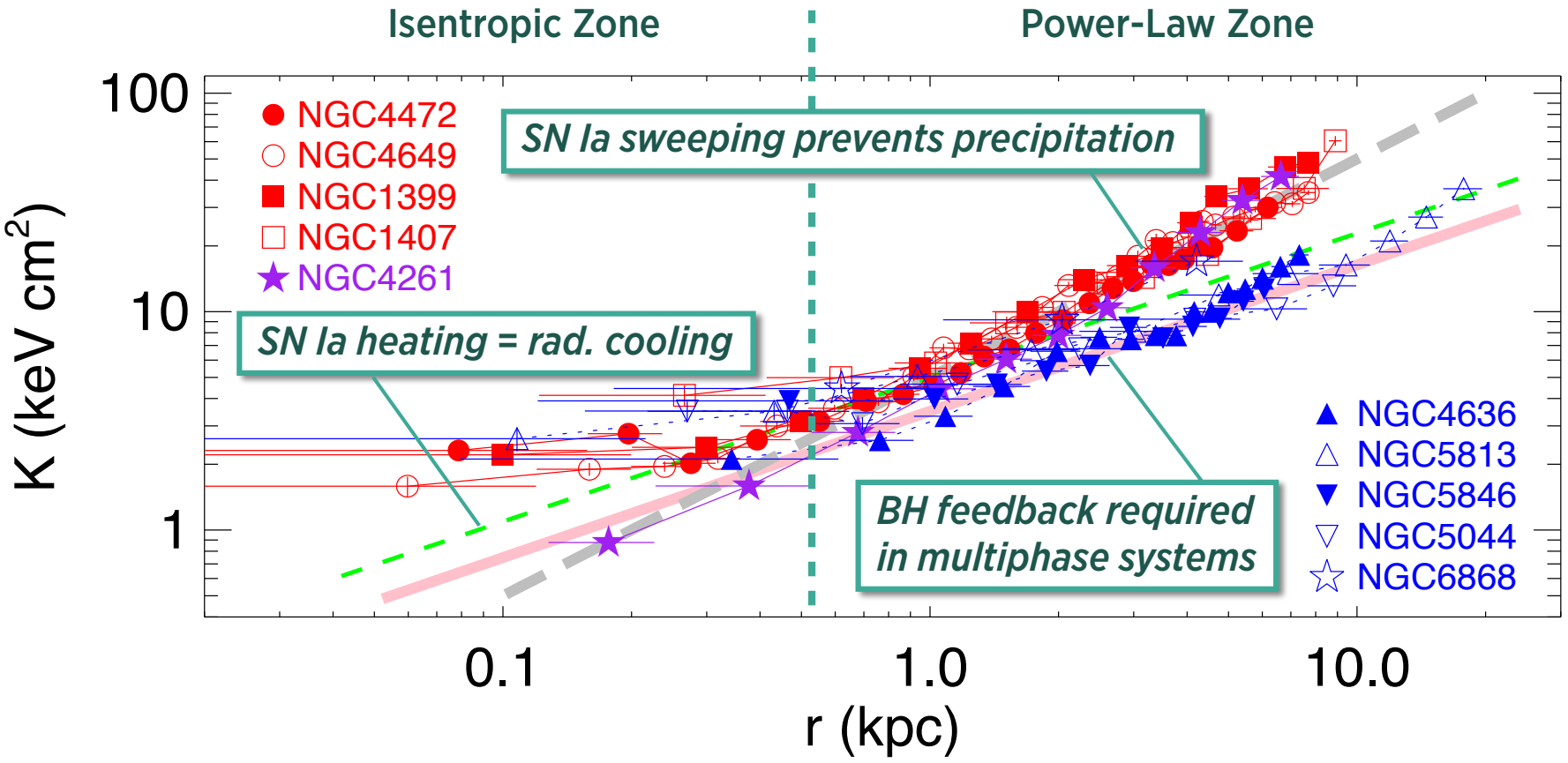


Bistable Regulation of Ellipticals

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



Single-phase ellipticals: $K \approx (5\ \mathrm{keV\ cm^2})\ r_{\mathrm{kpc}}$

Multiphase ellipticals: $K \approx (3.5\ \mathrm{keV\ cm^2})\ r_{\mathrm{kpc}}^{2/3}$

4 A General L_X–T–R Relation

Precipitation-Limited Luminosity

Voit+ 16, in preparation

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

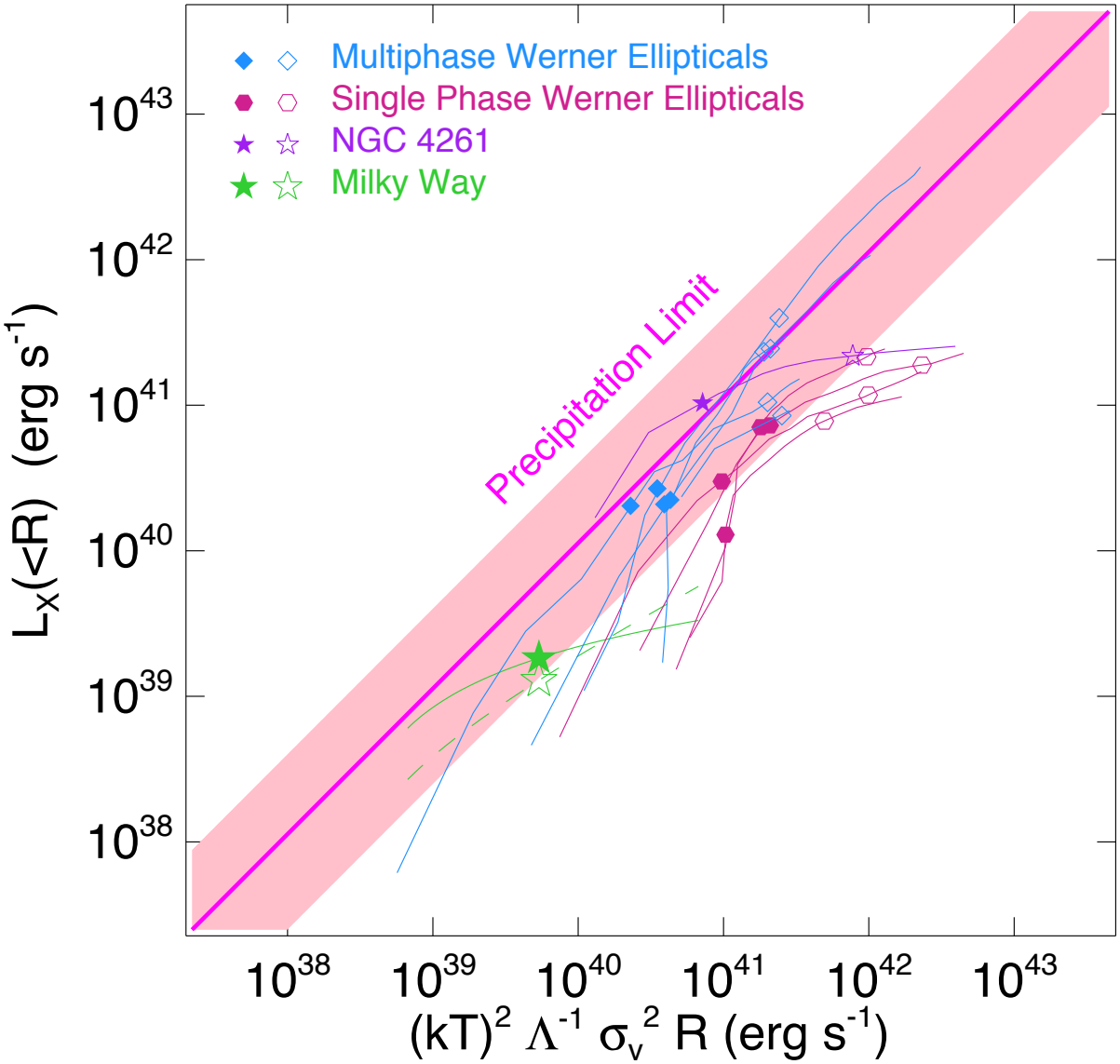
$$n_e \lesssim \frac{3kT}{10\, t_{\rm ff}\, \Lambda(T)}$$

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

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

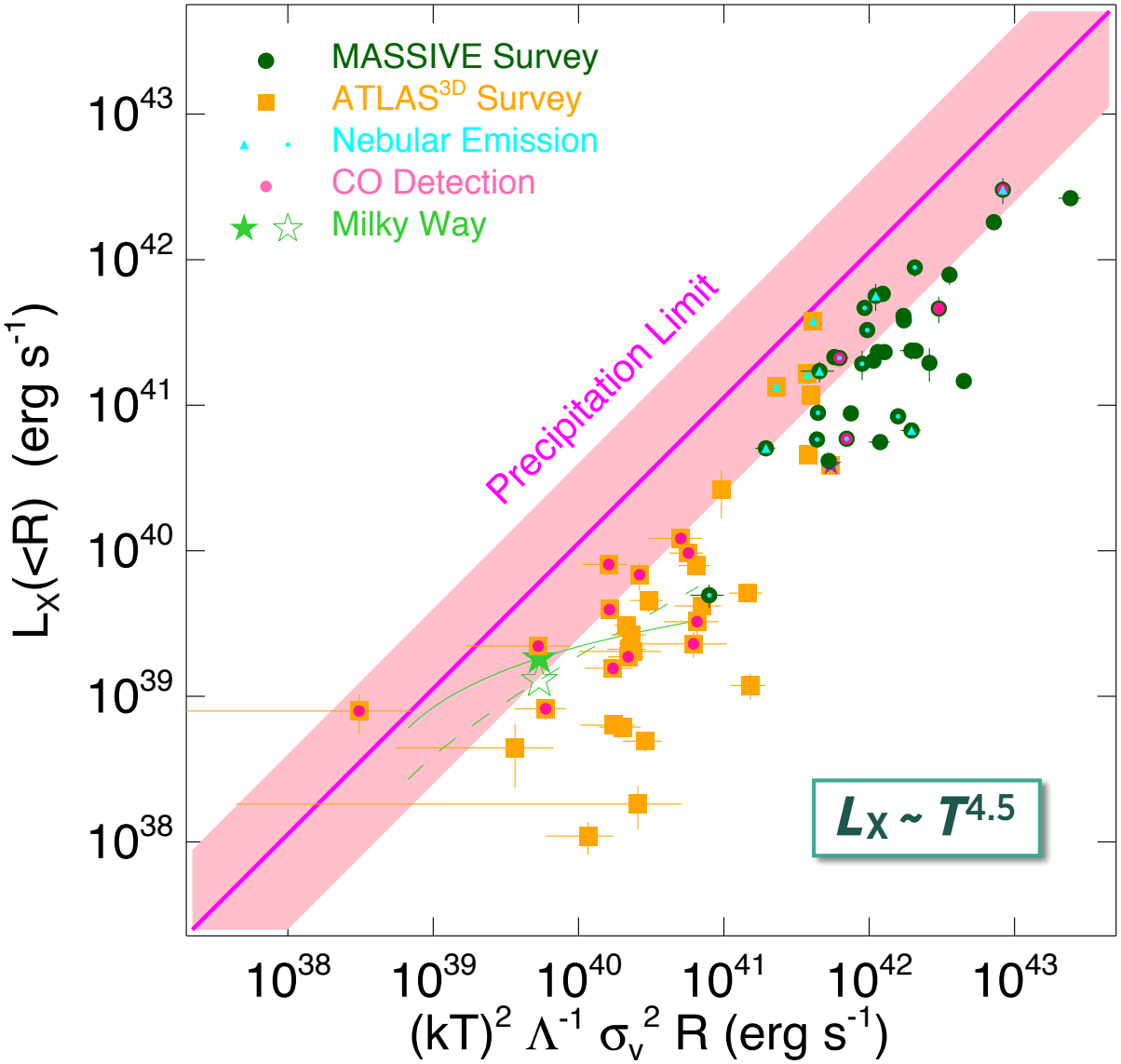
Precipitation-Limited Luminosity

Voit+ 16, in preparation



Precipitation-Limited Luminosity

Voit+ 16, in preparation



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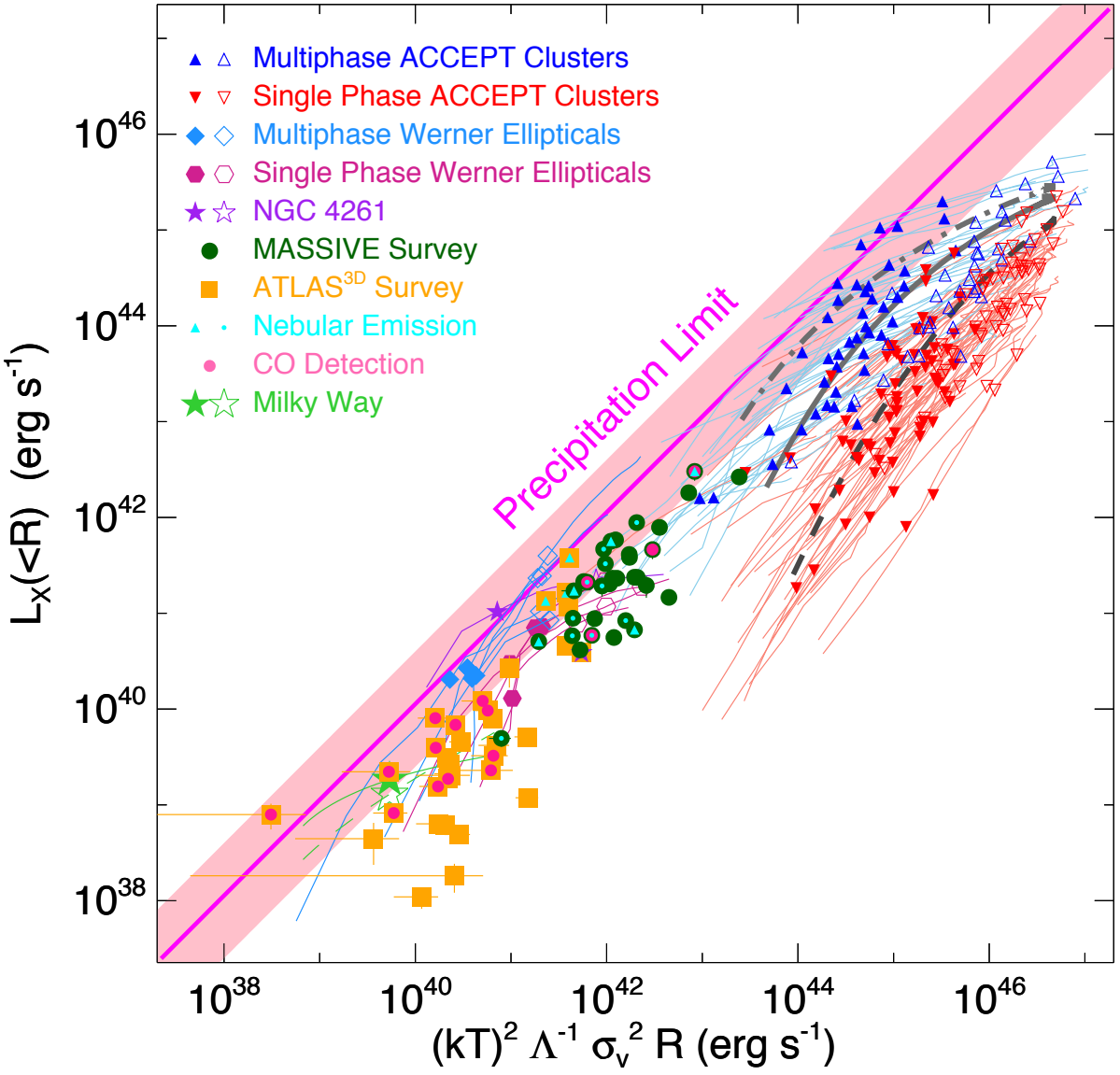
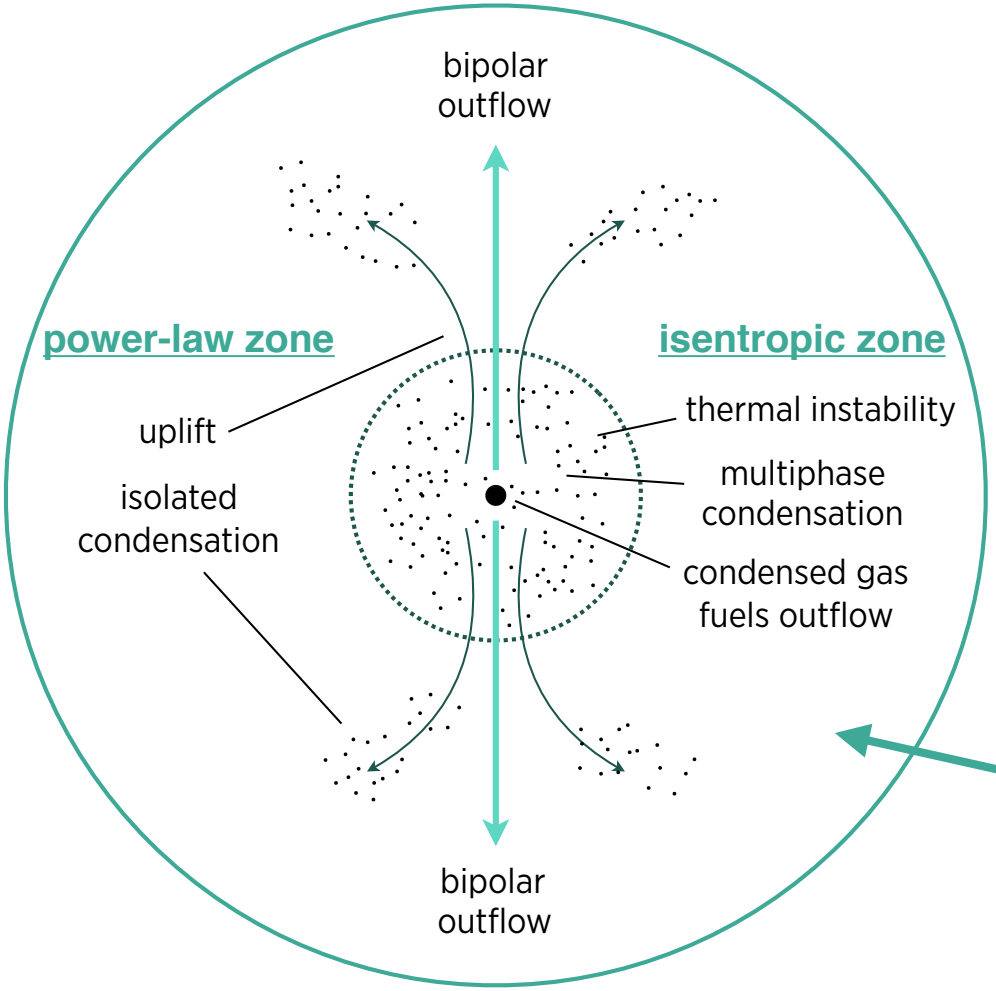
Voit+ 16, in preparation

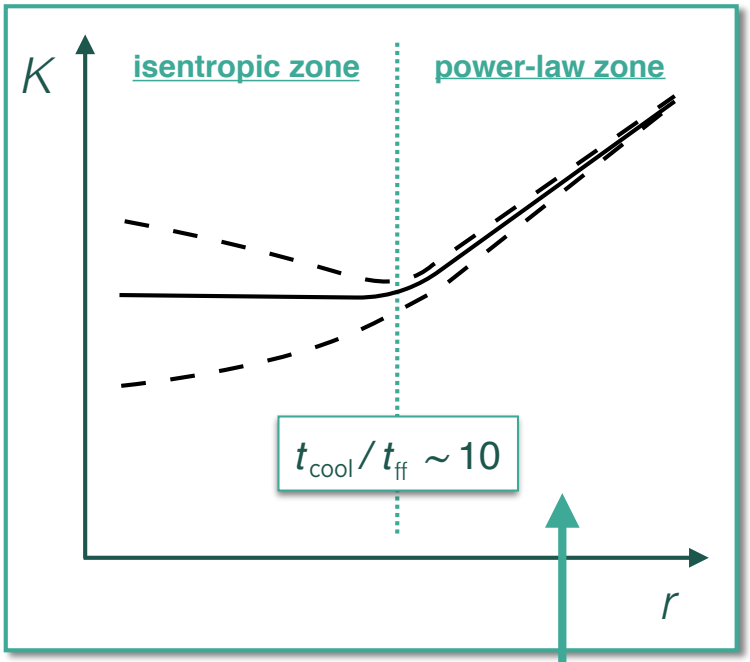


5 The Feedback Valve

Thermal Instability & Feedback

Voit+ 16, arXiv:1607.02212

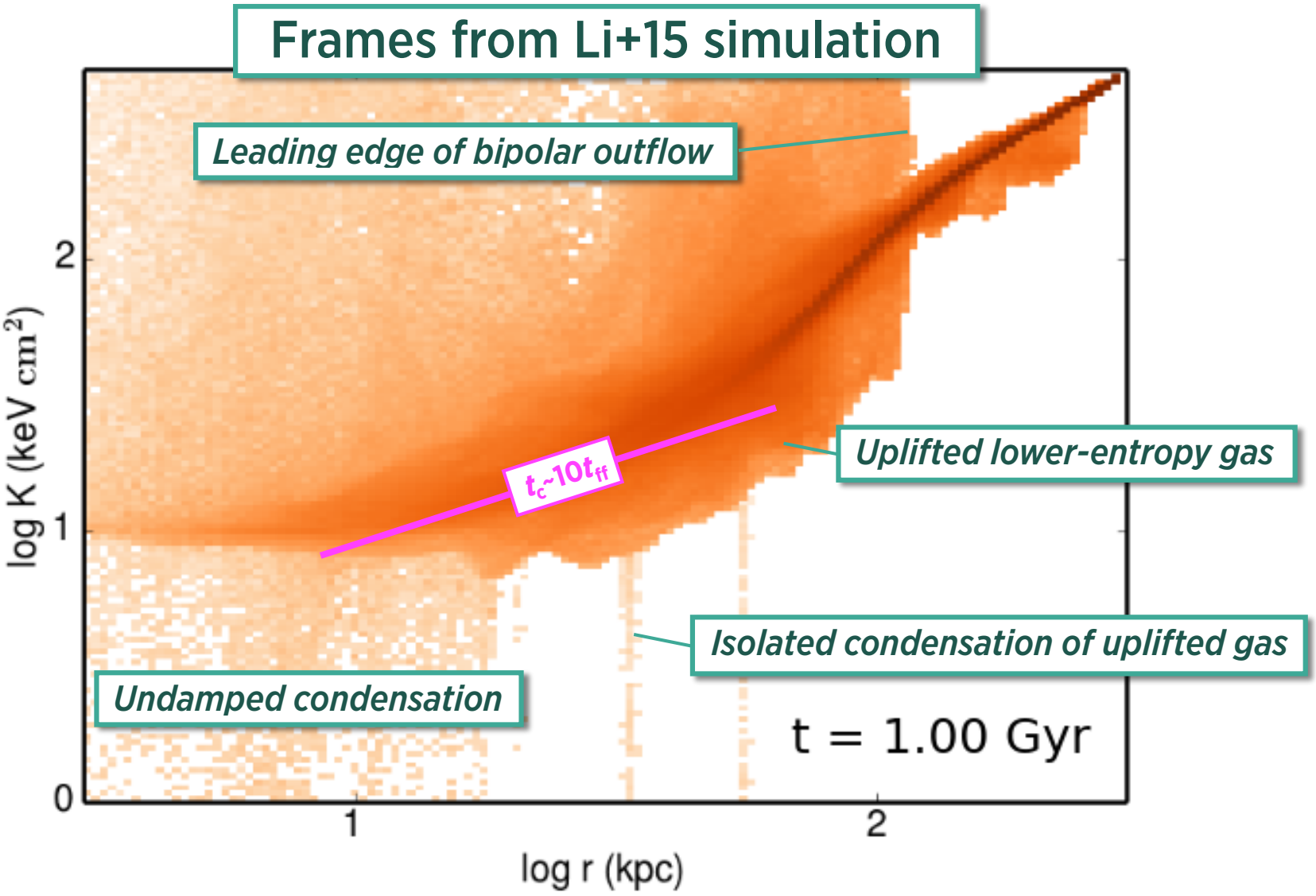




Convective damping suppresses condensation in power-law zone

Entropy & Condensation

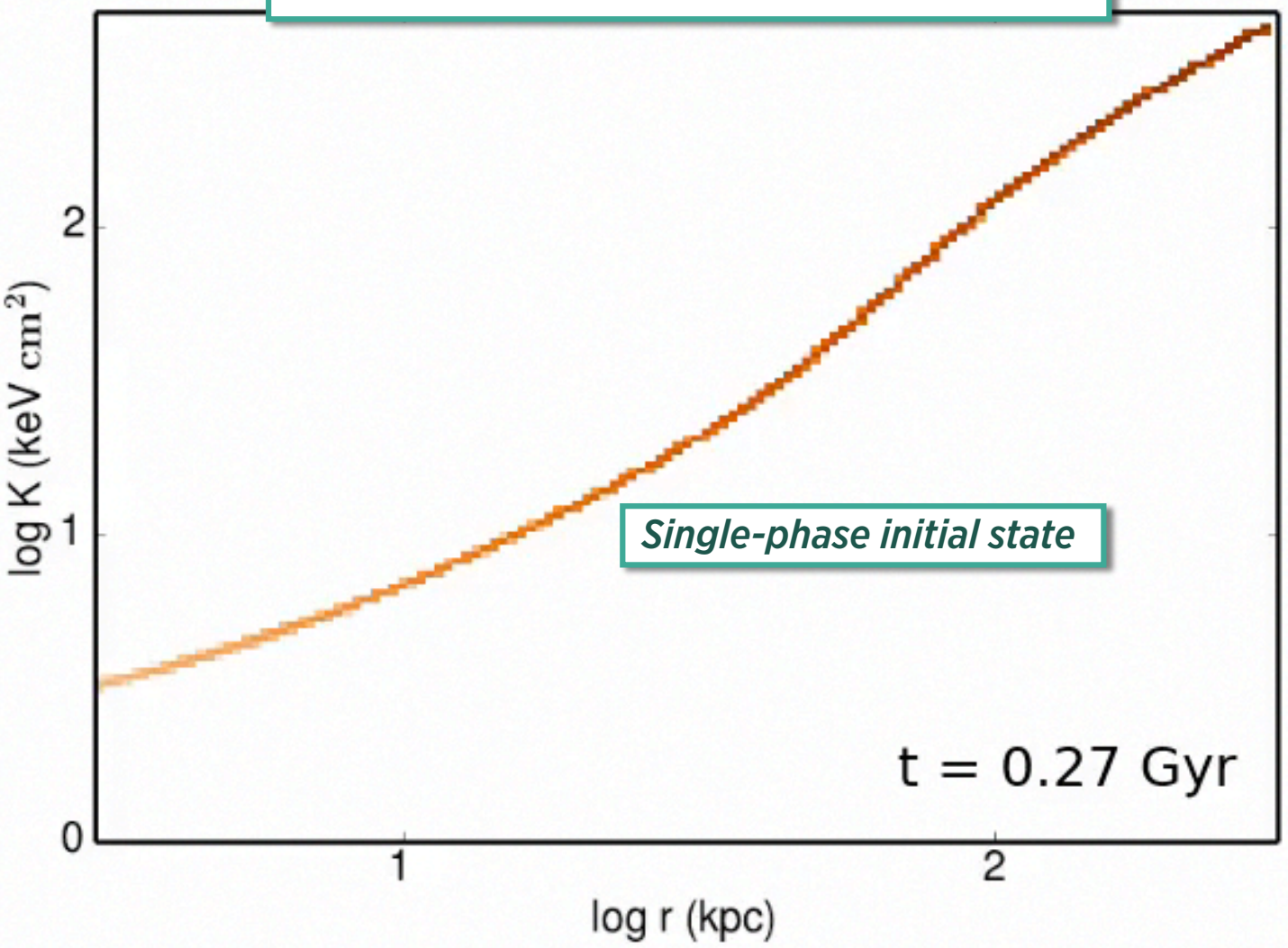
Voit+ 16, arXiv:1607.02212



Entropy & Condensation

Voit+ 16, arXiv:1607.02212

Frames from Li+15 simulation



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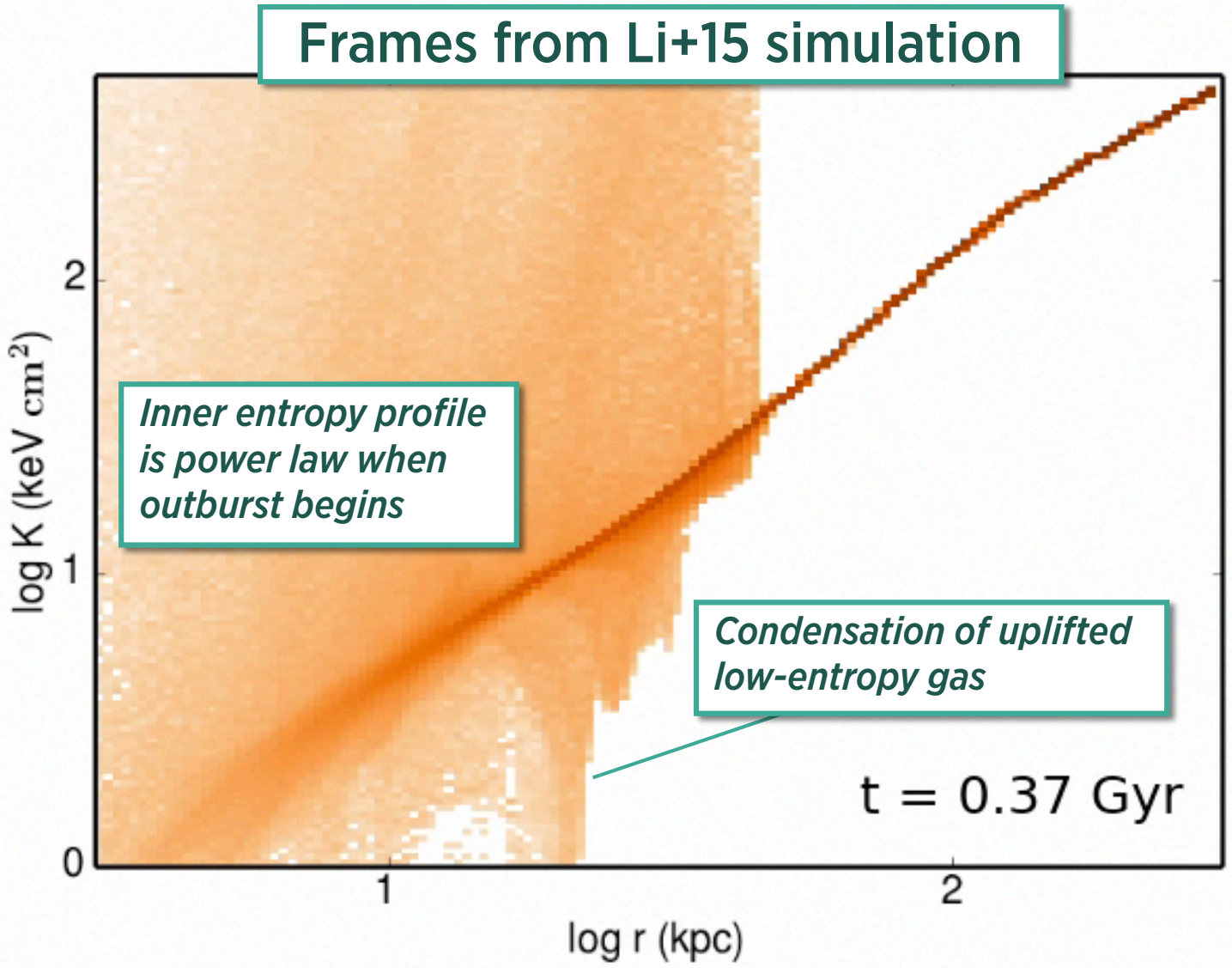

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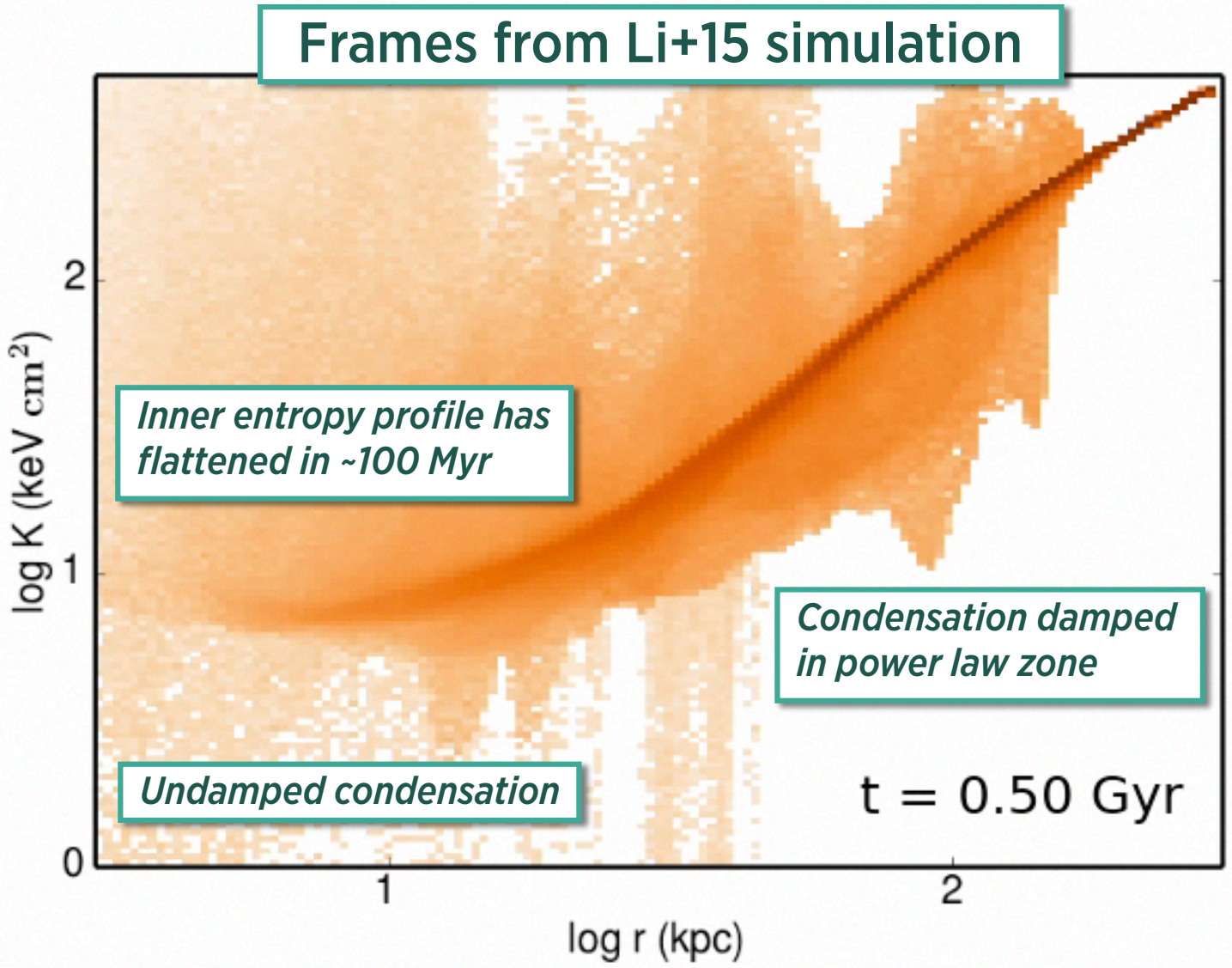

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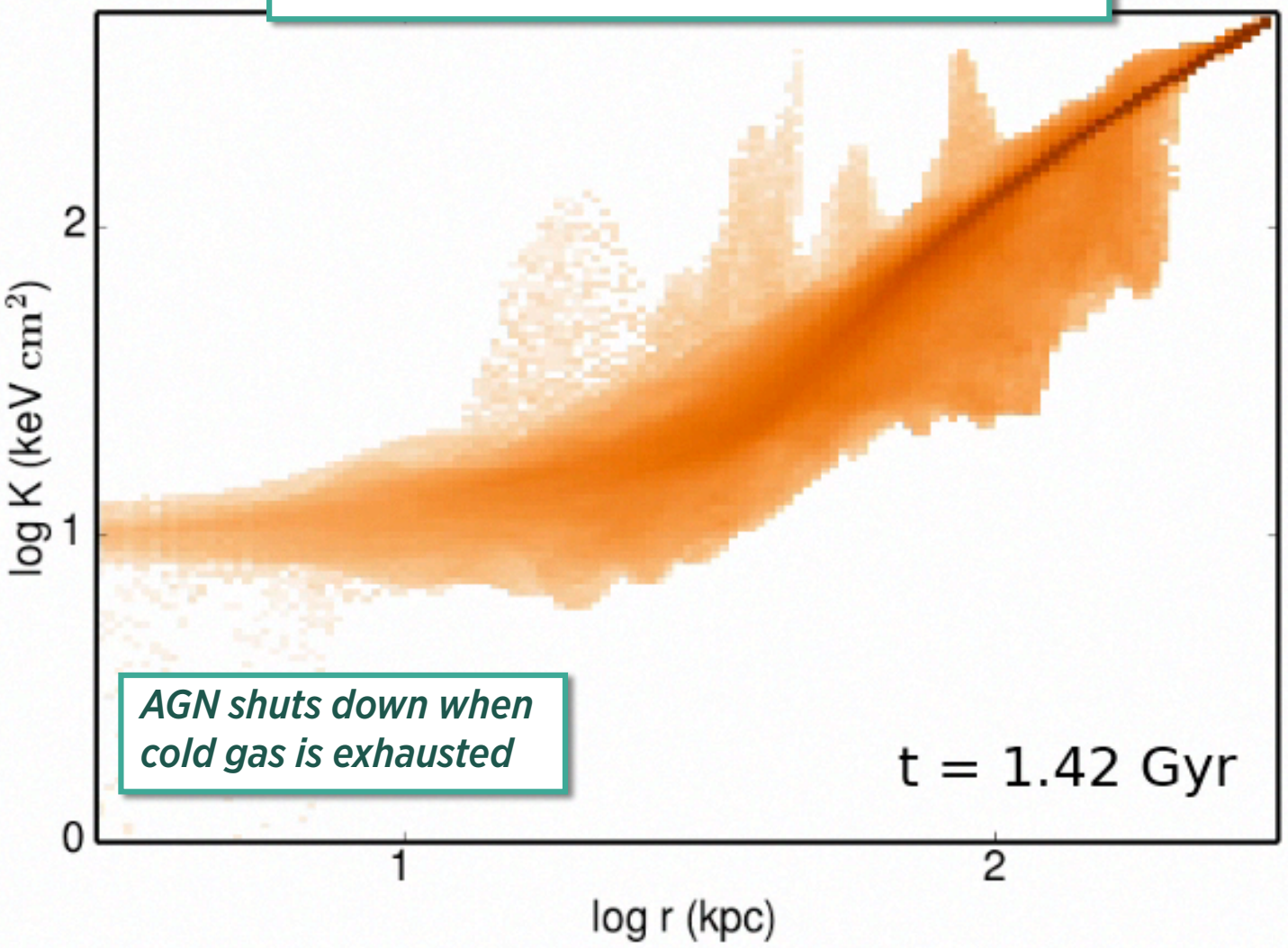

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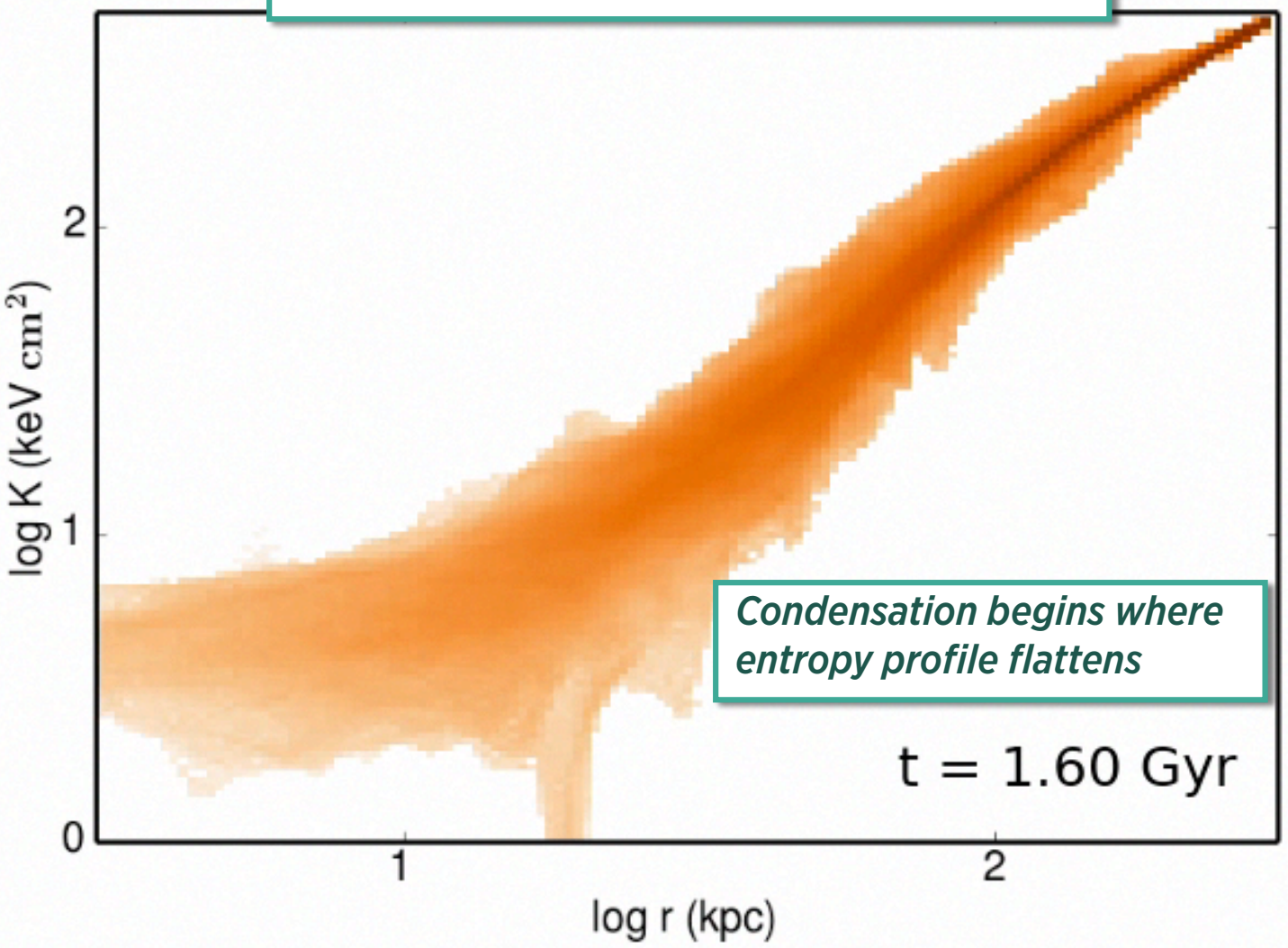

Condensation begins where entropy profile flattens

Entropy & Condensation

Voit+ 16, arXiv:1607.02212

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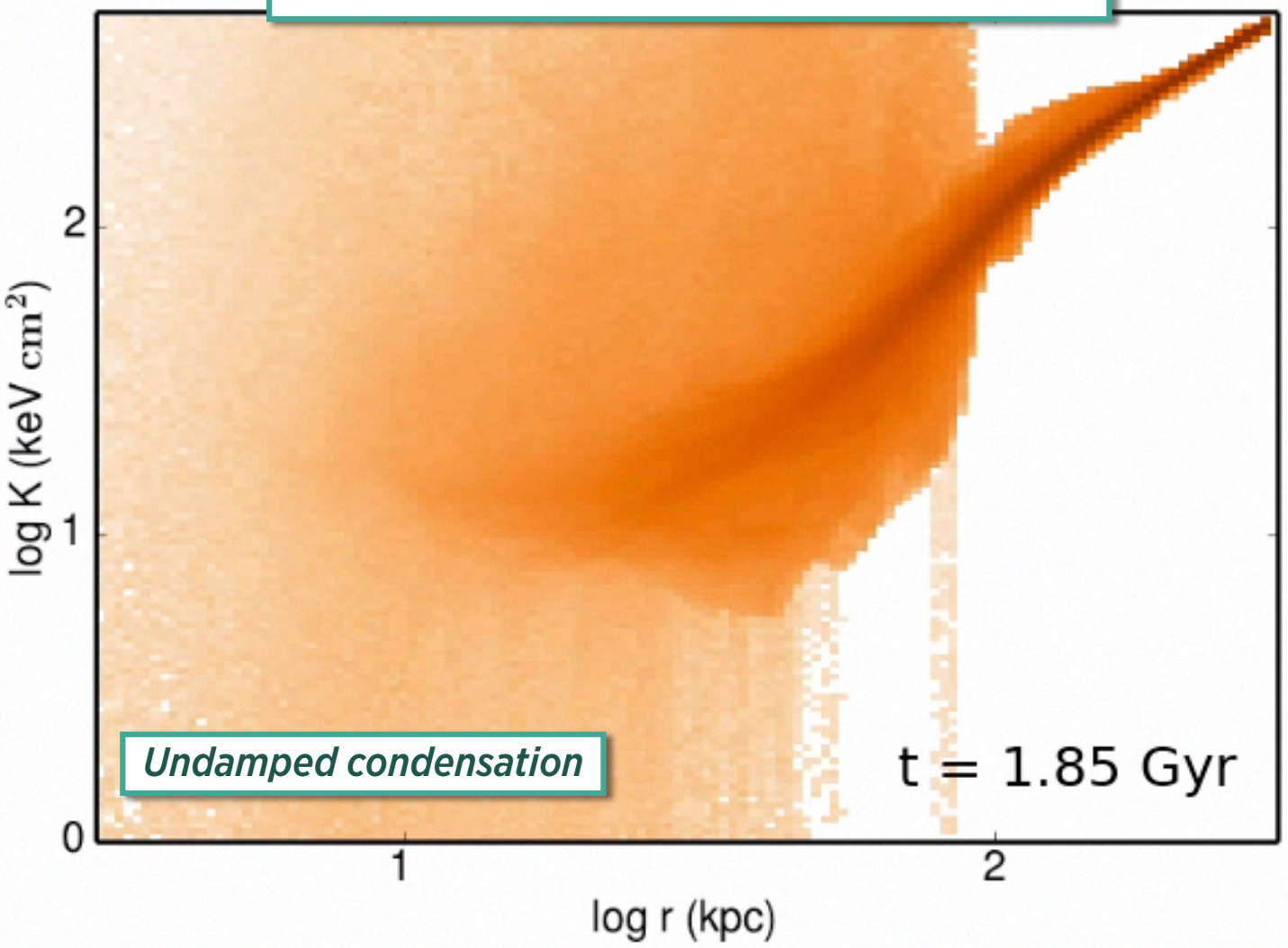

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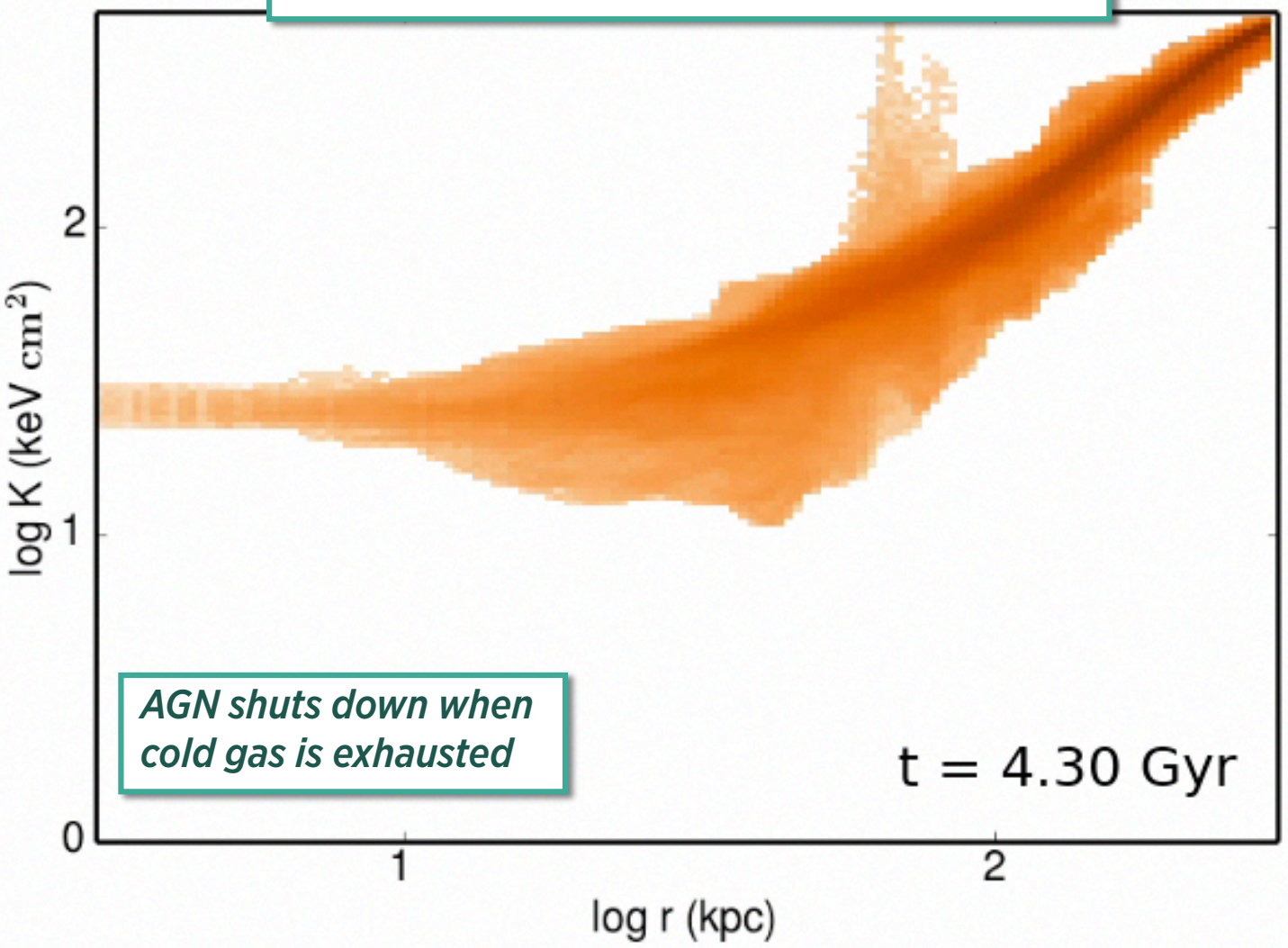

AGN shuts down when cold gas is exhausted

Entropy & Condensation

Voit+ 16, arXiv:1607.02212

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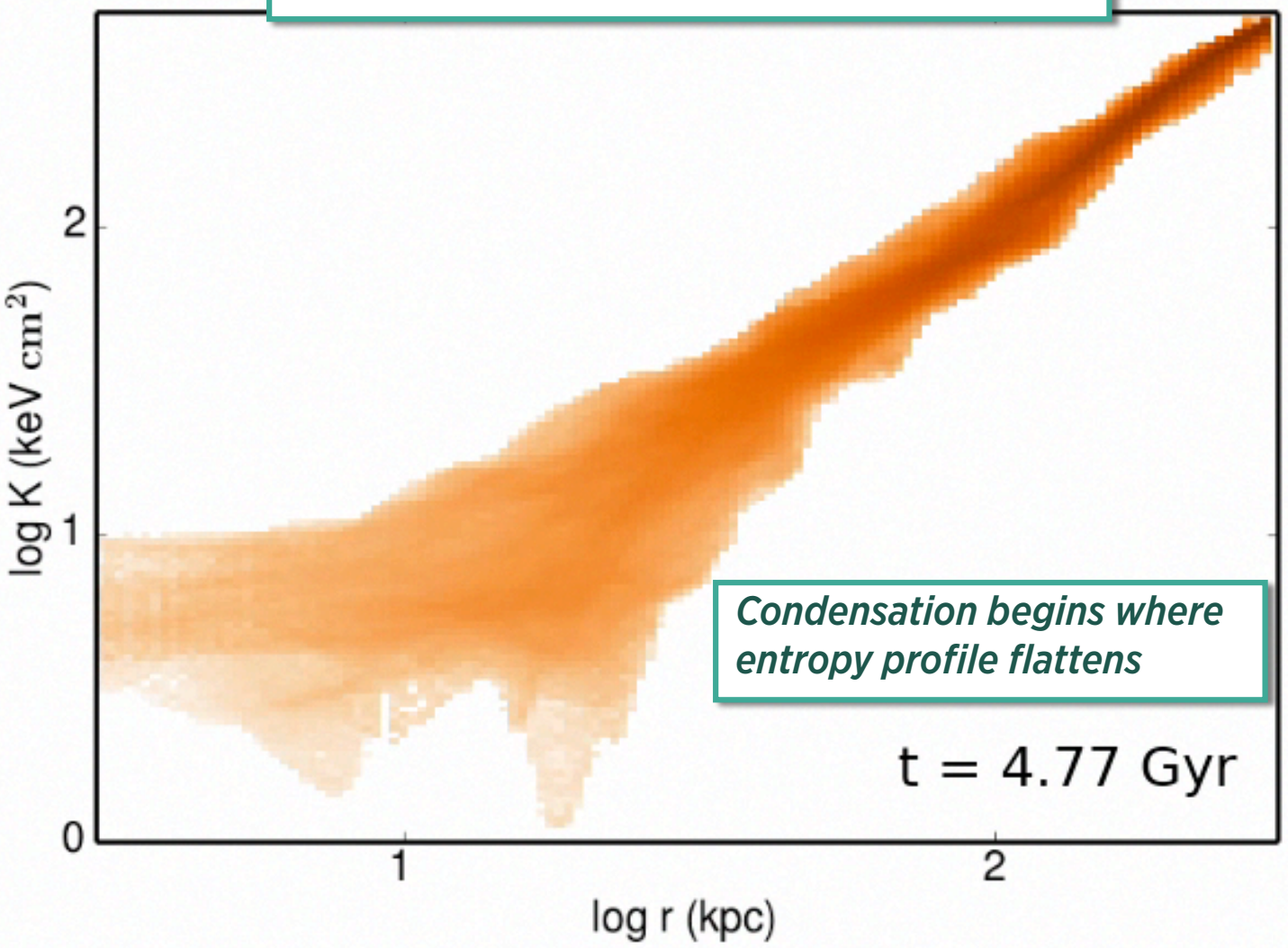

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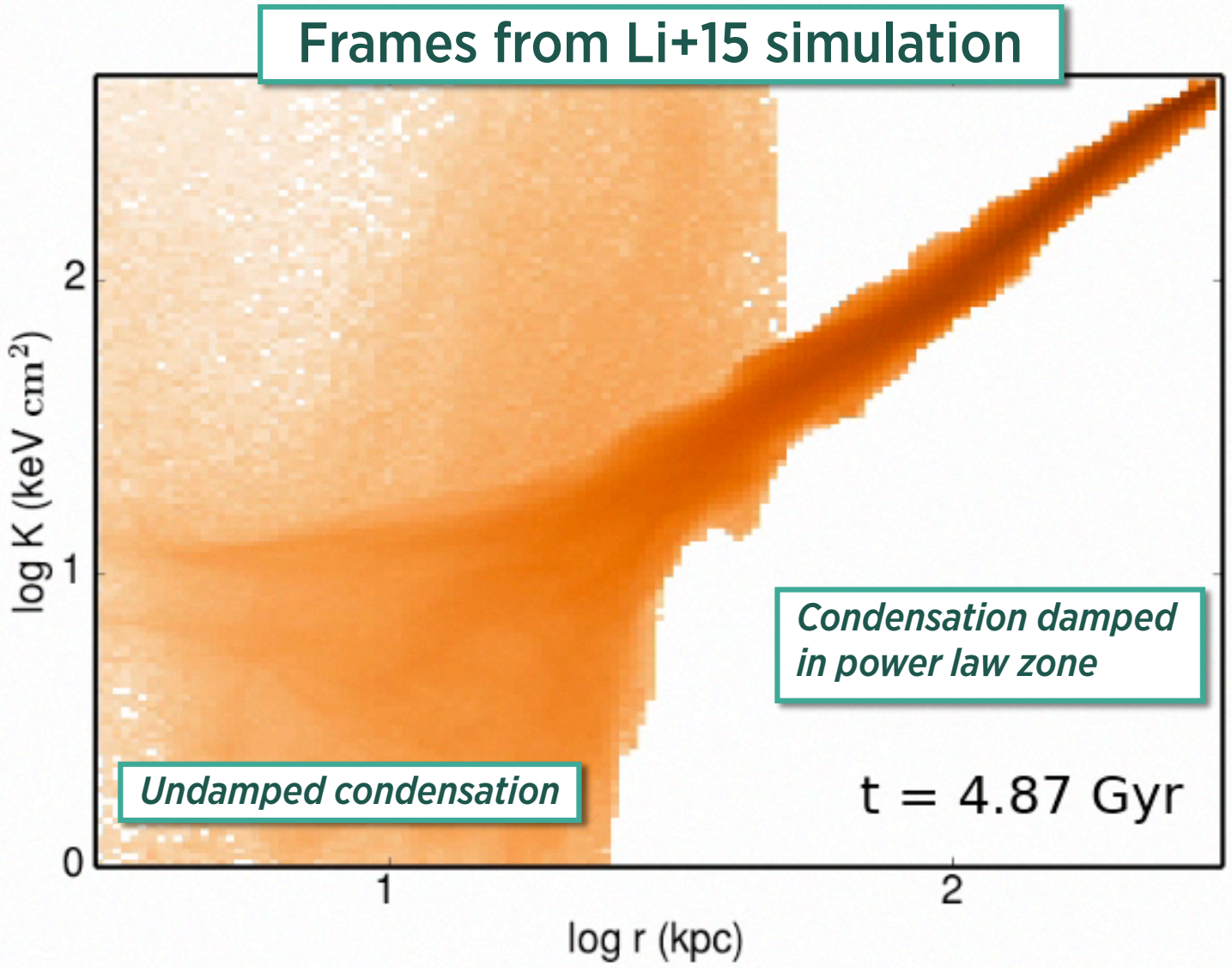

AGN Feedback & IGM Regulation

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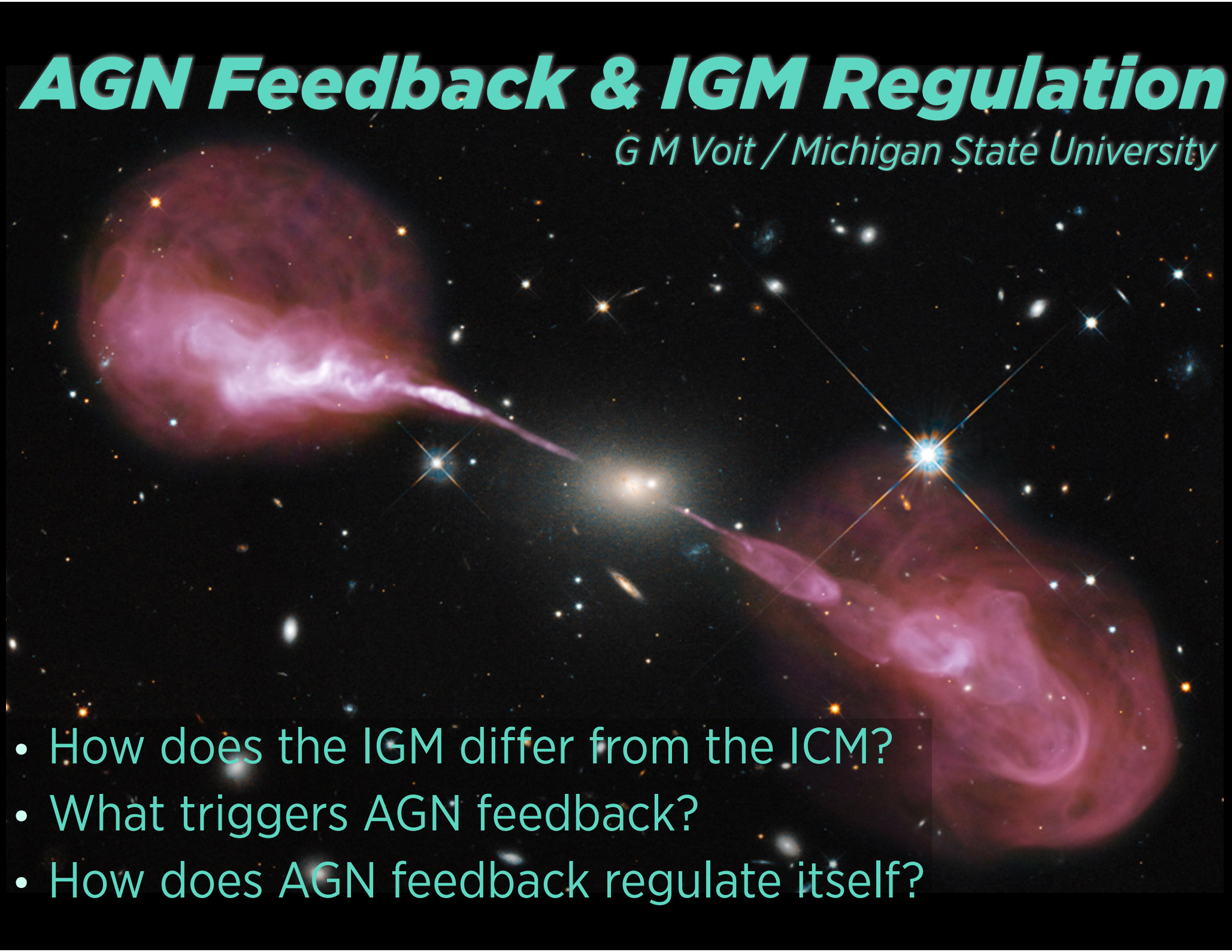

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