

Feedback & multiphase gas across halos

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[ICM2019, Budapest]

Outline

- feedback AGN jet-ICM simulations (not using Bondi)
- I-problem & stochastic cold gas at ~ 1 kpc
- ICM vs IGrM
- testing $t_{\text{cool}}/t_{\text{ff}}$ criterion: Mrk 1216
- deprojecting simulation data: can we recover $t_{\text{cool}}/t_{\text{ff}}$?

AGN jet-ICM sims.



Deovrat Prasad
mass

[Prasad et al. 2015]

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \mathbf{v} = S_\rho$$

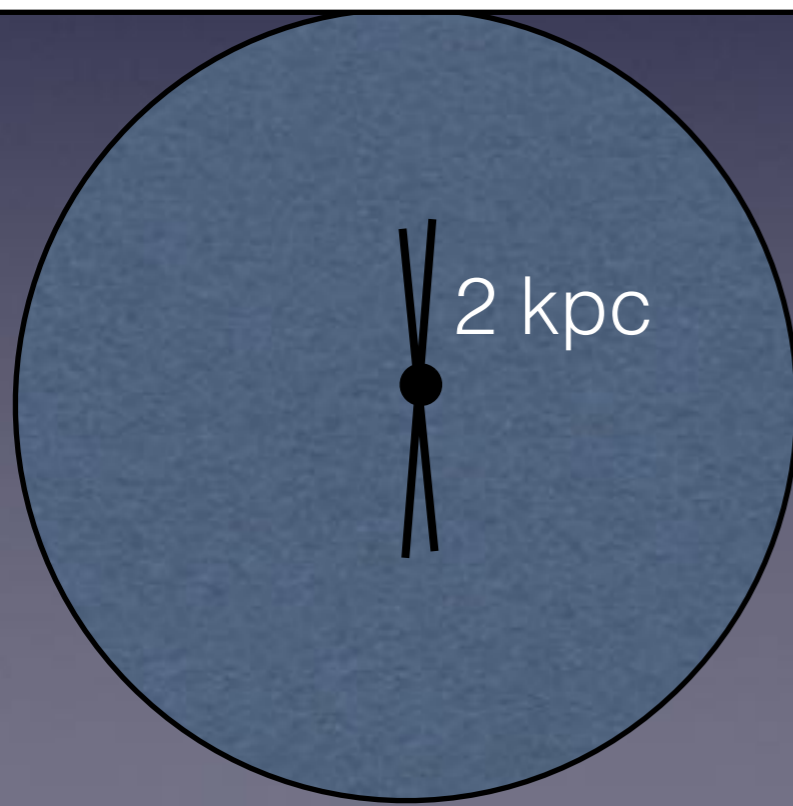
$$\rho \left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} \right) = -\nabla p - \rho \nabla \Phi + S_\rho v_{\text{jet}} \hat{\mathbf{r}}$$

momentum

See also Gaspari+, Li+

$$\frac{p}{\gamma - 1} \frac{d}{dt} \ln(p / \rho^\gamma) = -n^2 \Lambda$$

energy

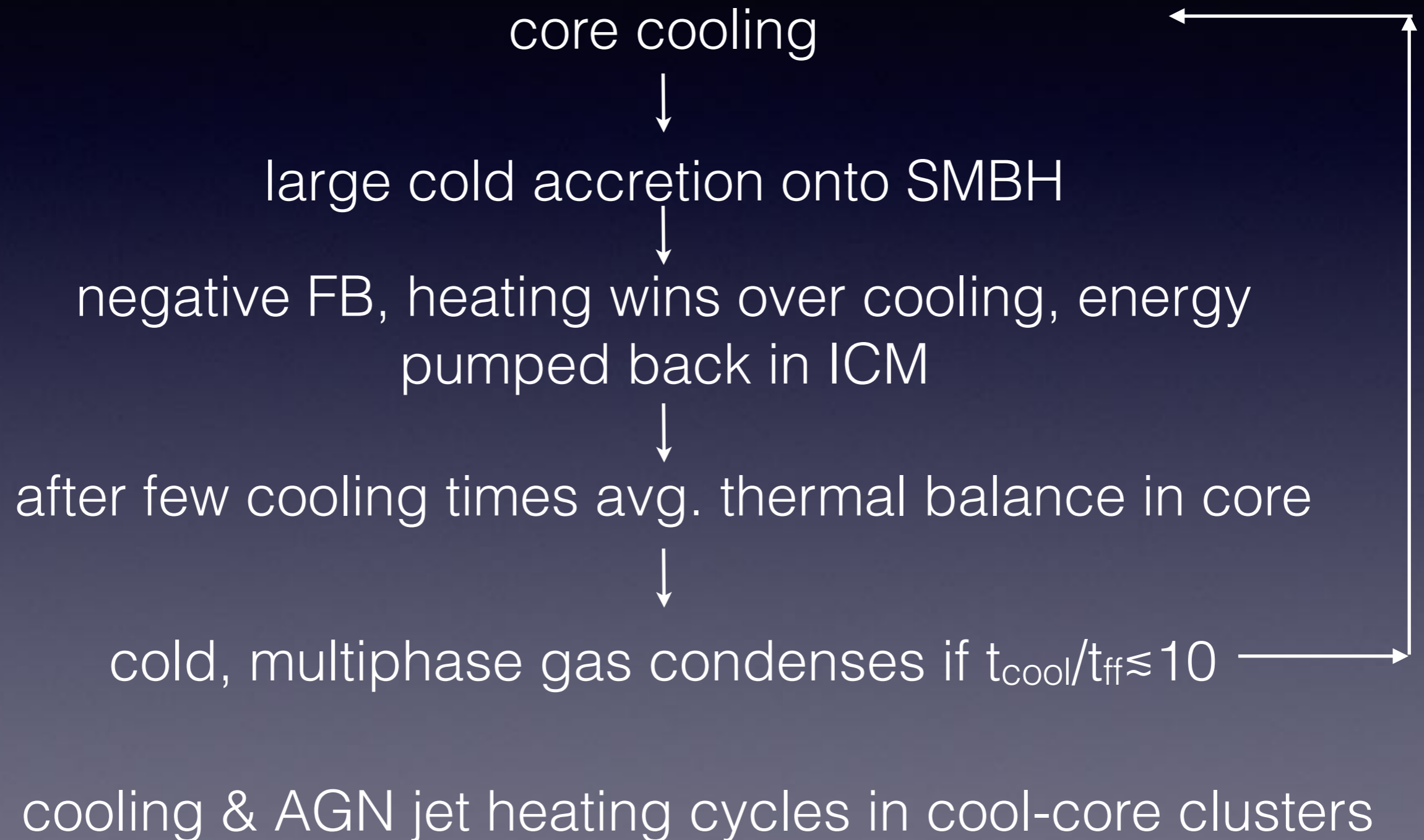


source term applied in a small
bipolar cone at the center:
opening angle of 30° , size 2 kpc

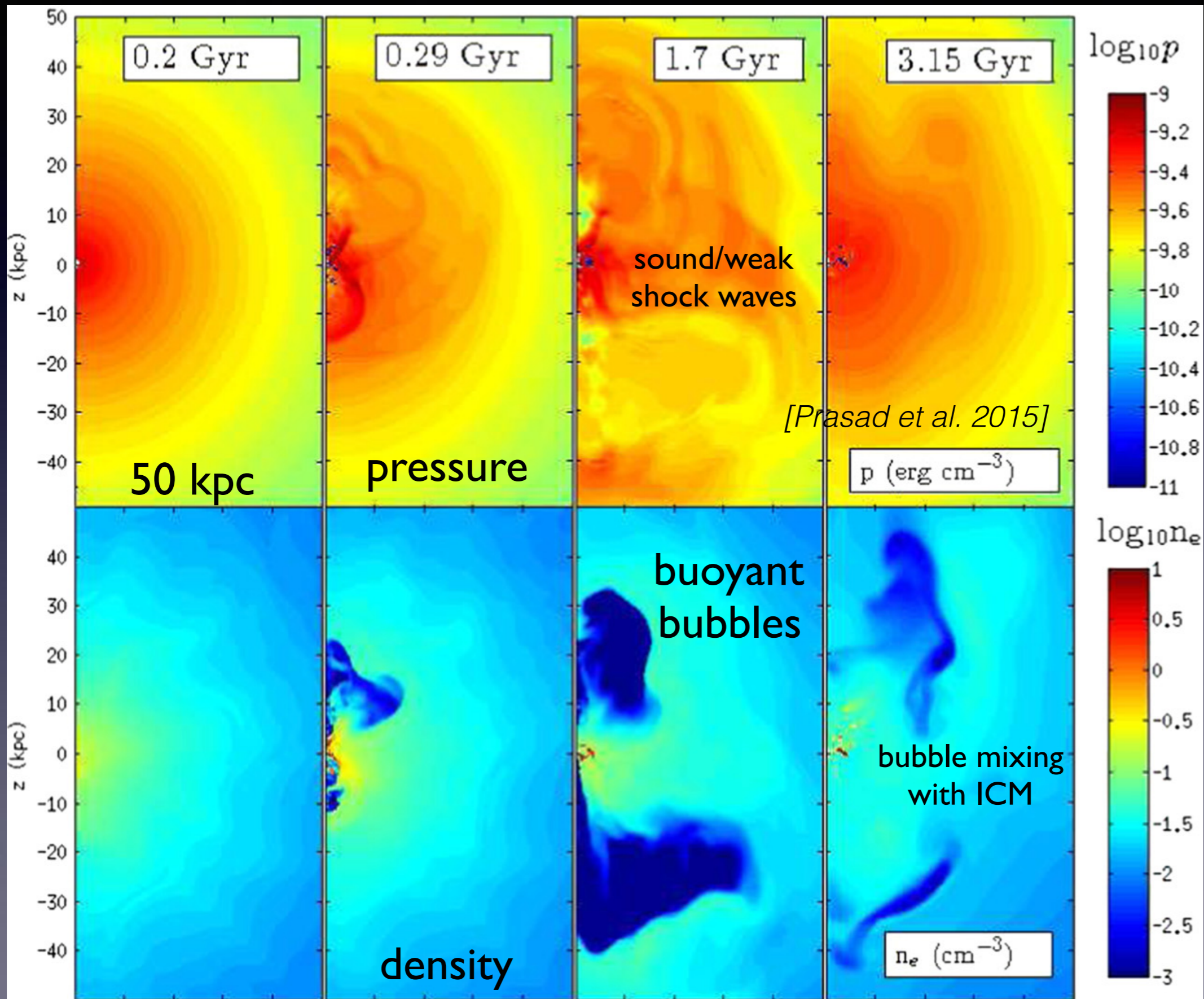
$$\dot{M}_{\text{jet}} v_{\text{jet}}^2 = \epsilon \dot{M}_{\text{acc}} c^2$$

$v_{\text{jet}} = 0.1c$, $\epsilon = 6 \times 10^{-5}$, $r_{\text{in,out}} = 1, 200$ kpc
robust to variations

AGN feedback cycles



r- θ slices



Angular momentum problem

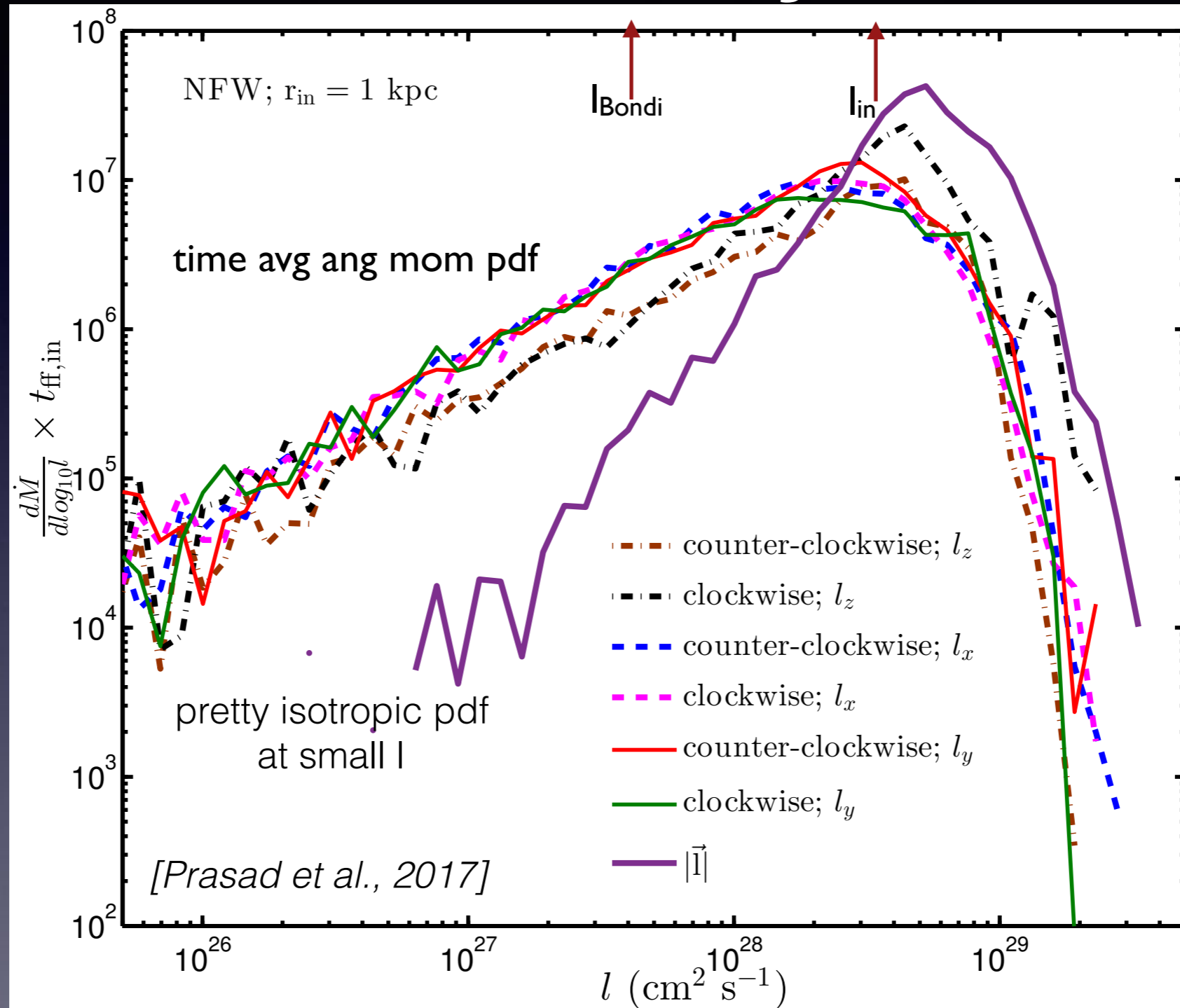
$$t_{\text{visc}} \sim \frac{1}{\alpha (H/R)^2 \Omega_K}$$

too long if $H/R \sim 10^{-3}$,
of standard AGN thin disks
moreover, star formation
where M_d/M_{BH} exceeds H/R

$$t_{\text{visc}} \sim 4.7 \text{ Gyr} \left(\frac{R}{1 \text{ pc}} \right)^{3/2} \left(\frac{H/R}{0.001} \right)^{-2} \left(\frac{\alpha}{0.01} \right)^{-1}$$

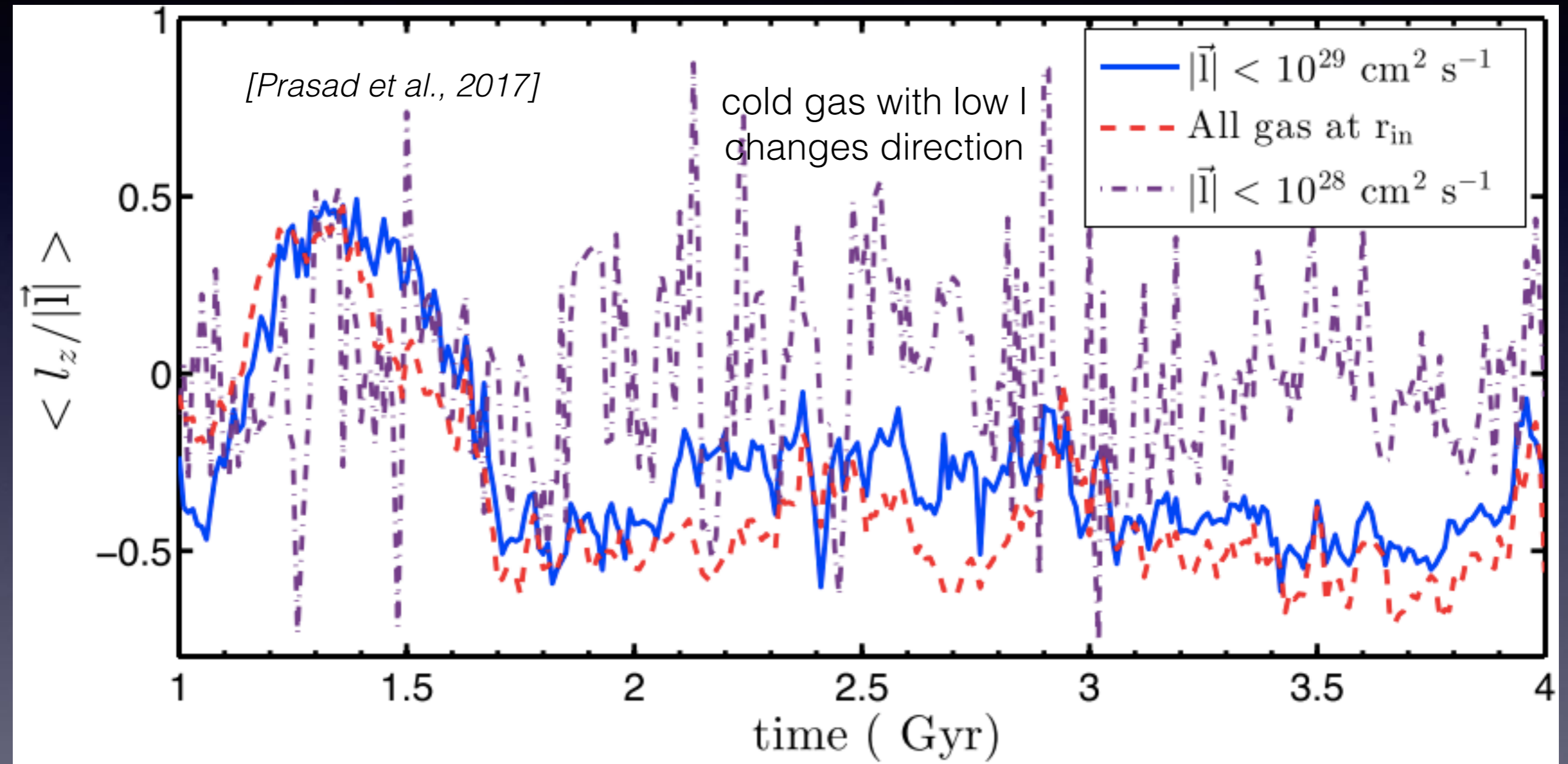
must avoid a large thin disk
 $t_{\text{visc}} < \text{core cooling time}$

cold l-distr in jet sims



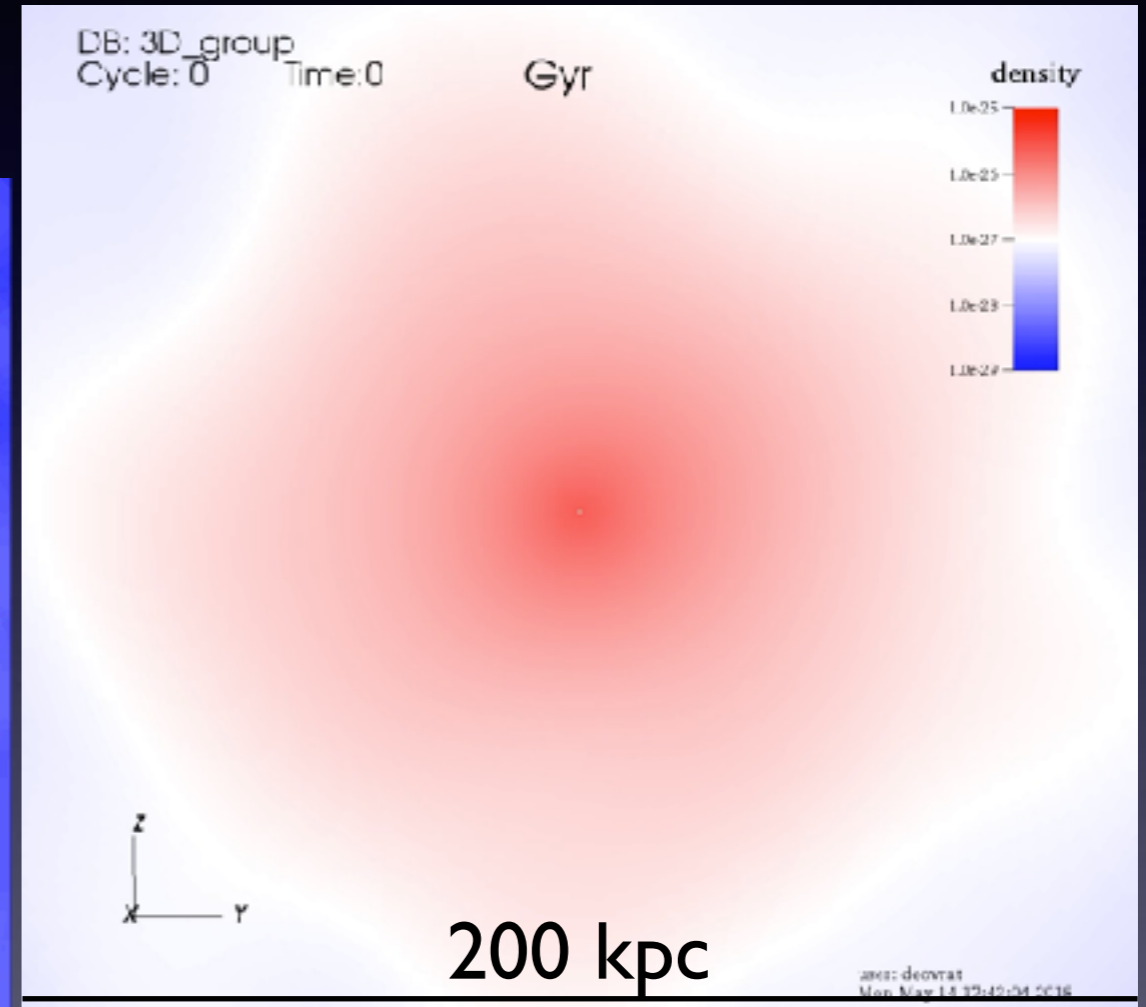
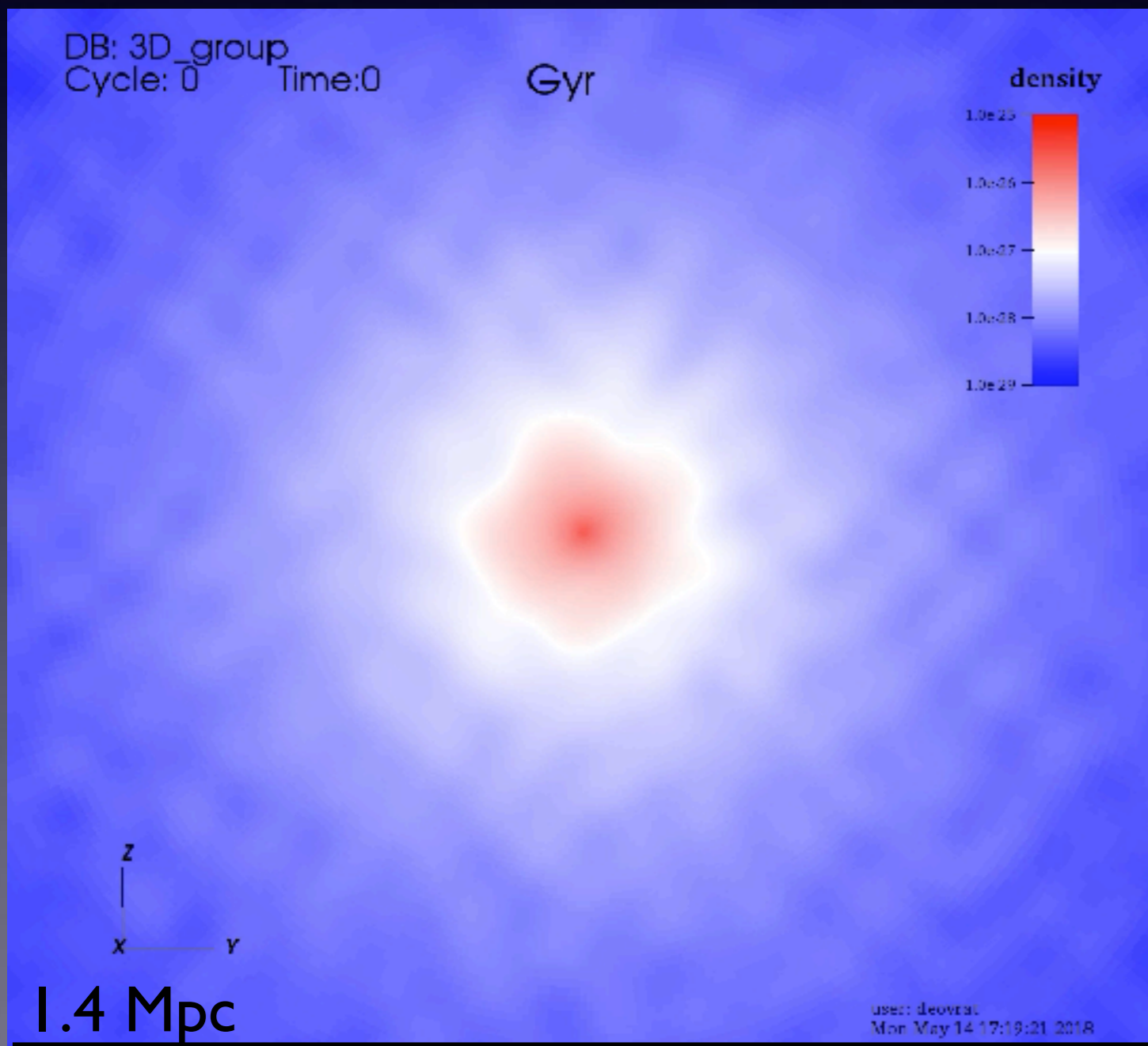
our jet-ICM simulations show that stochastic cold accretion, in which sufficient low l , may be realized

time variability of l



low l gas angular momentum changes on $<$ core cooling time

Density cut: group

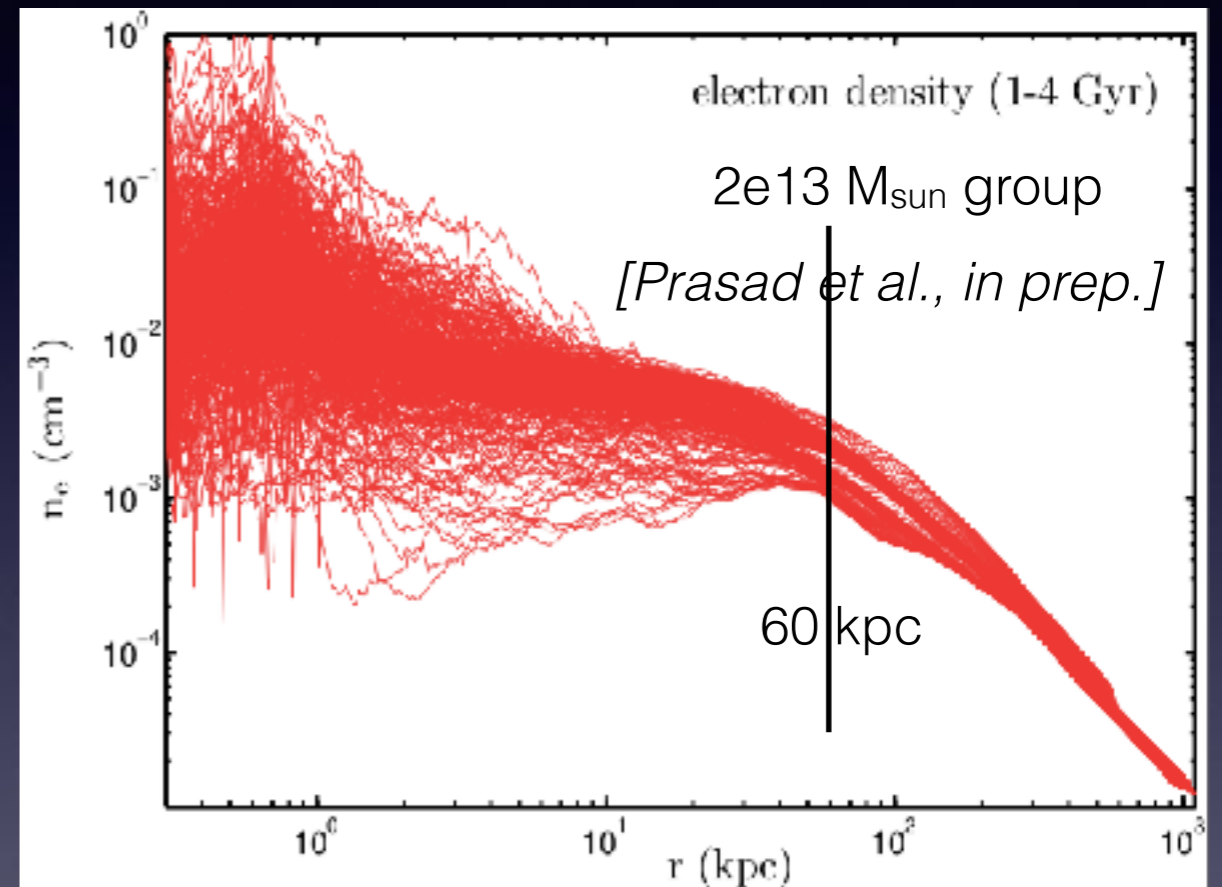
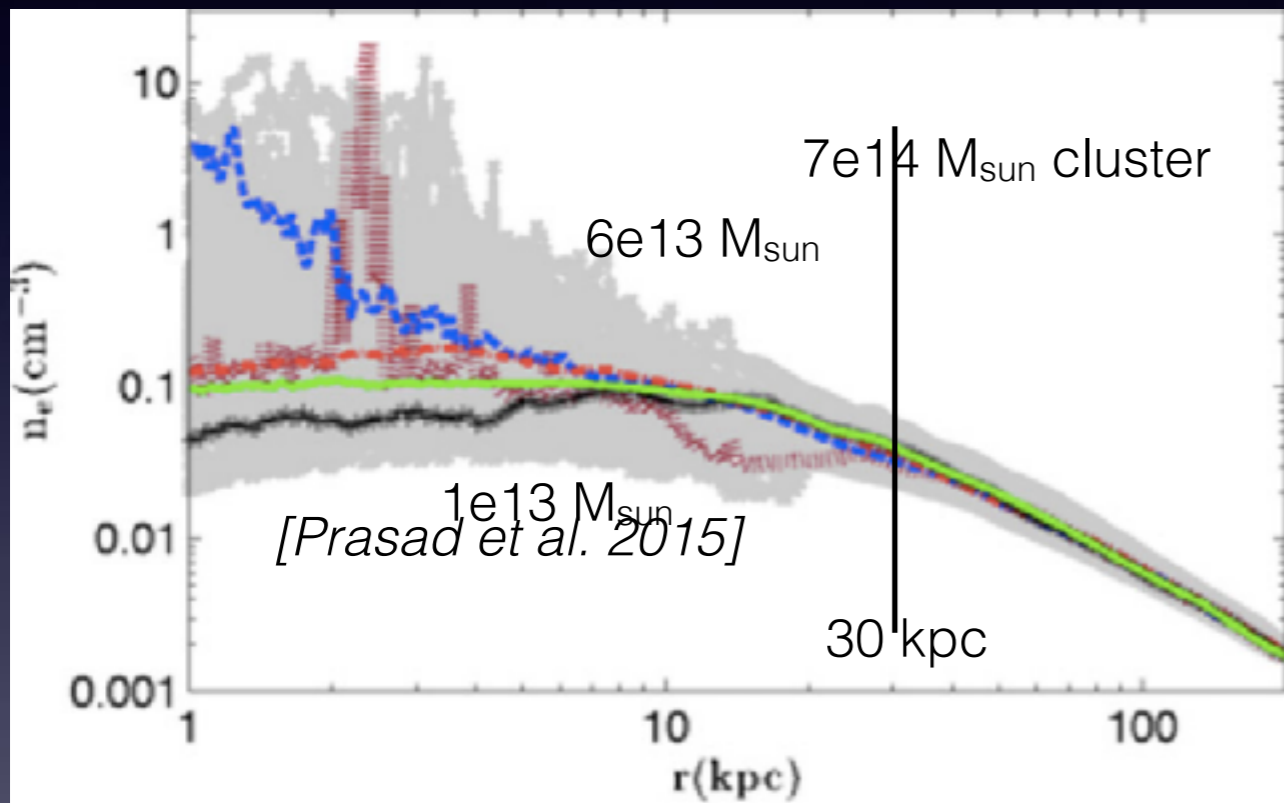


PLUTO hydro code:
NFW; $\epsilon=5 \times 10^{-5}$, $2e13 M_{\text{sun}}$
500x240x40 in $(\log r, \theta, \phi)$
 $r_{\text{min}}=0.3$ kpc, $r_{\text{max}}=1.1$ Mpc
made by Deovrat Prasad

ICM vs IGrM



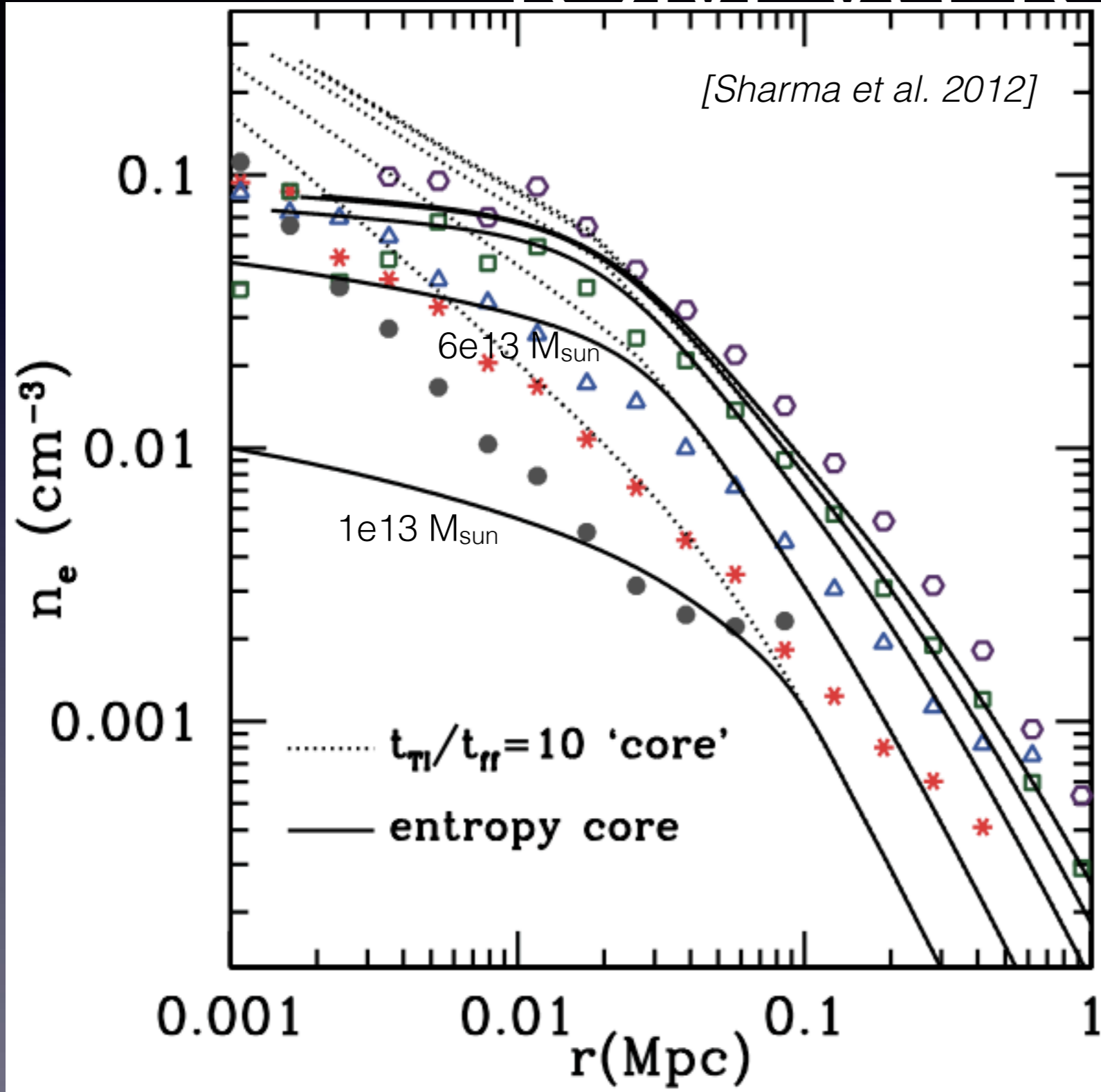
3-D AGN jet-ICM/CGM simulations with kinetic jet feedback



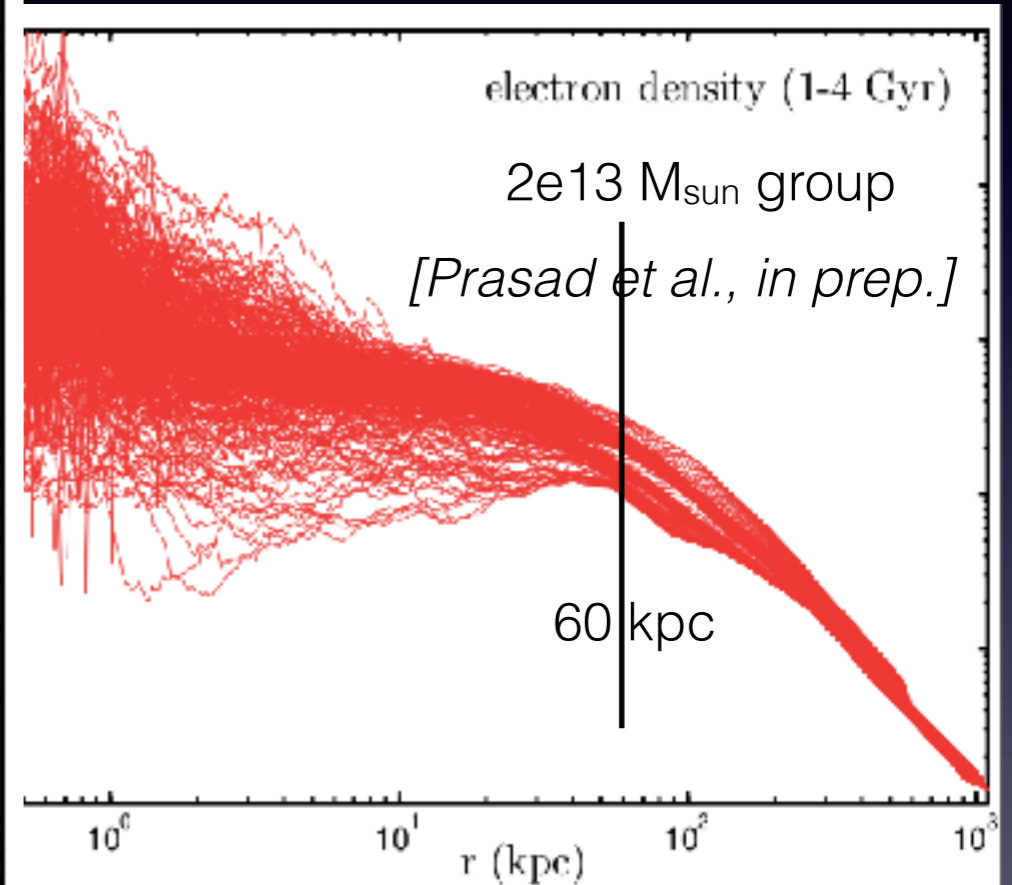
core size is smaller in clusters compared to groups
&
core density higher in clusters compared to groups

roughly consistent with $t_{\text{TII}}/t_{\text{ff}}$ models; can we extrapolate to MW CGM?

ICM vs IGrM



etic jet feedback



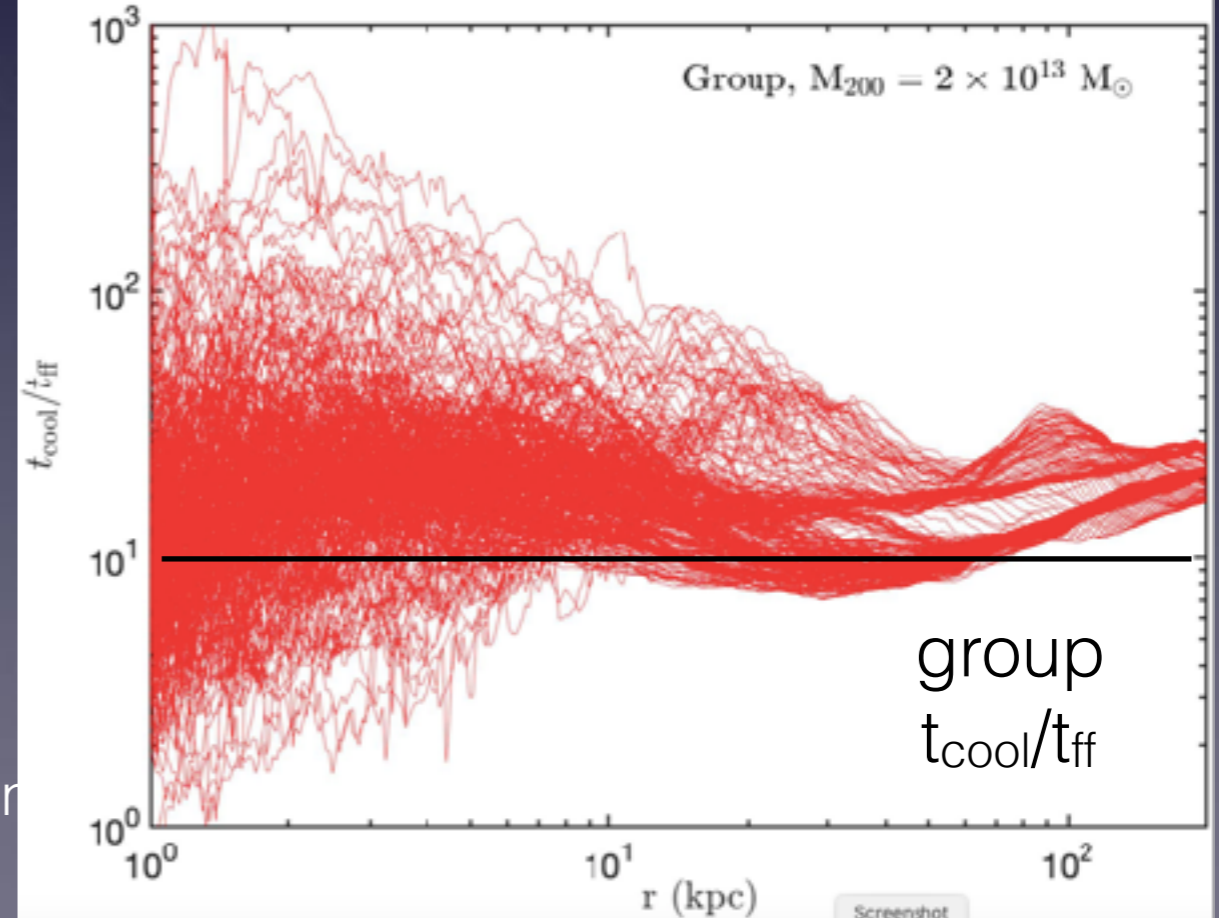
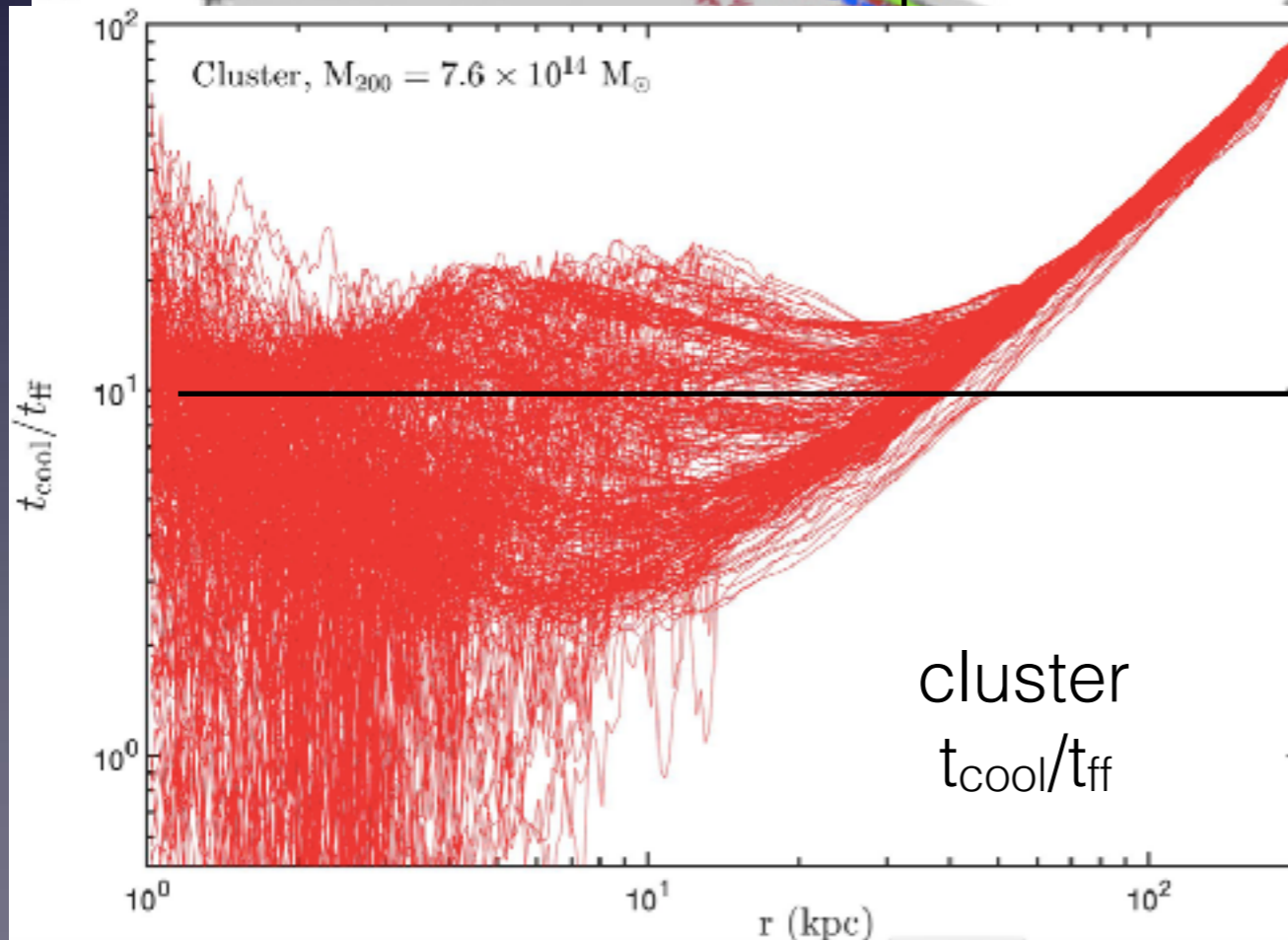
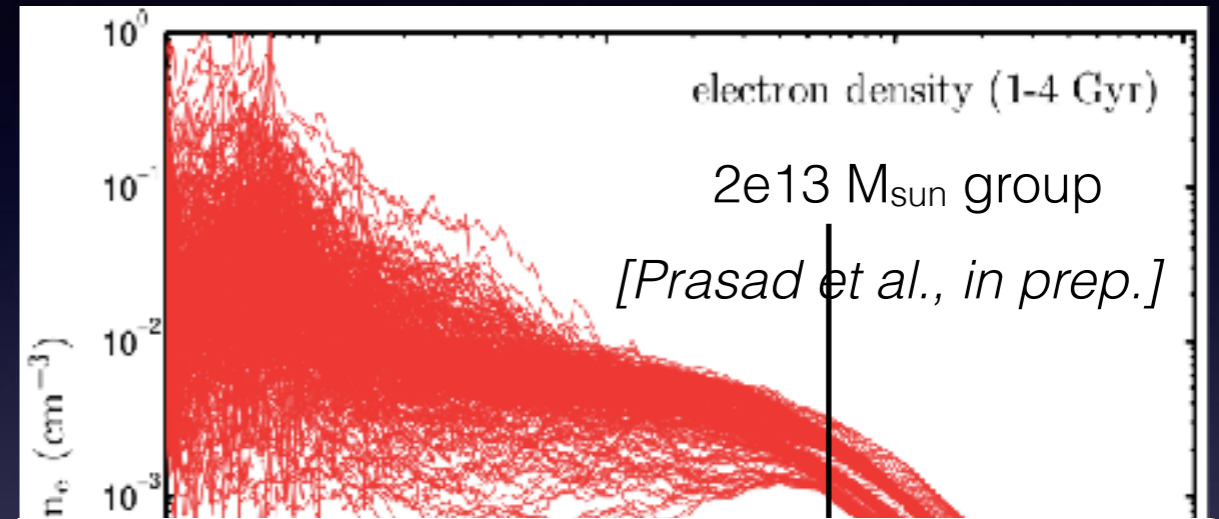
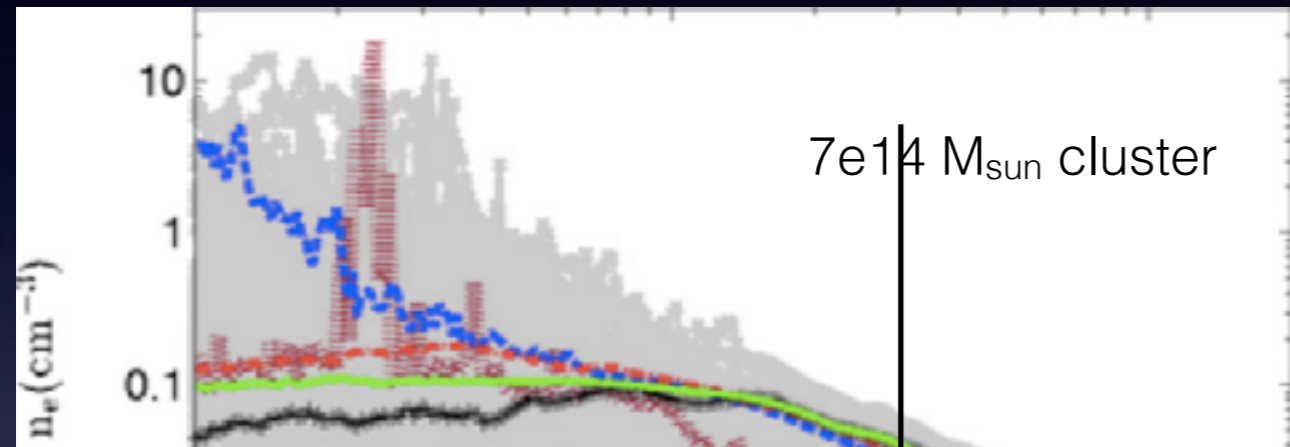
ed to groups

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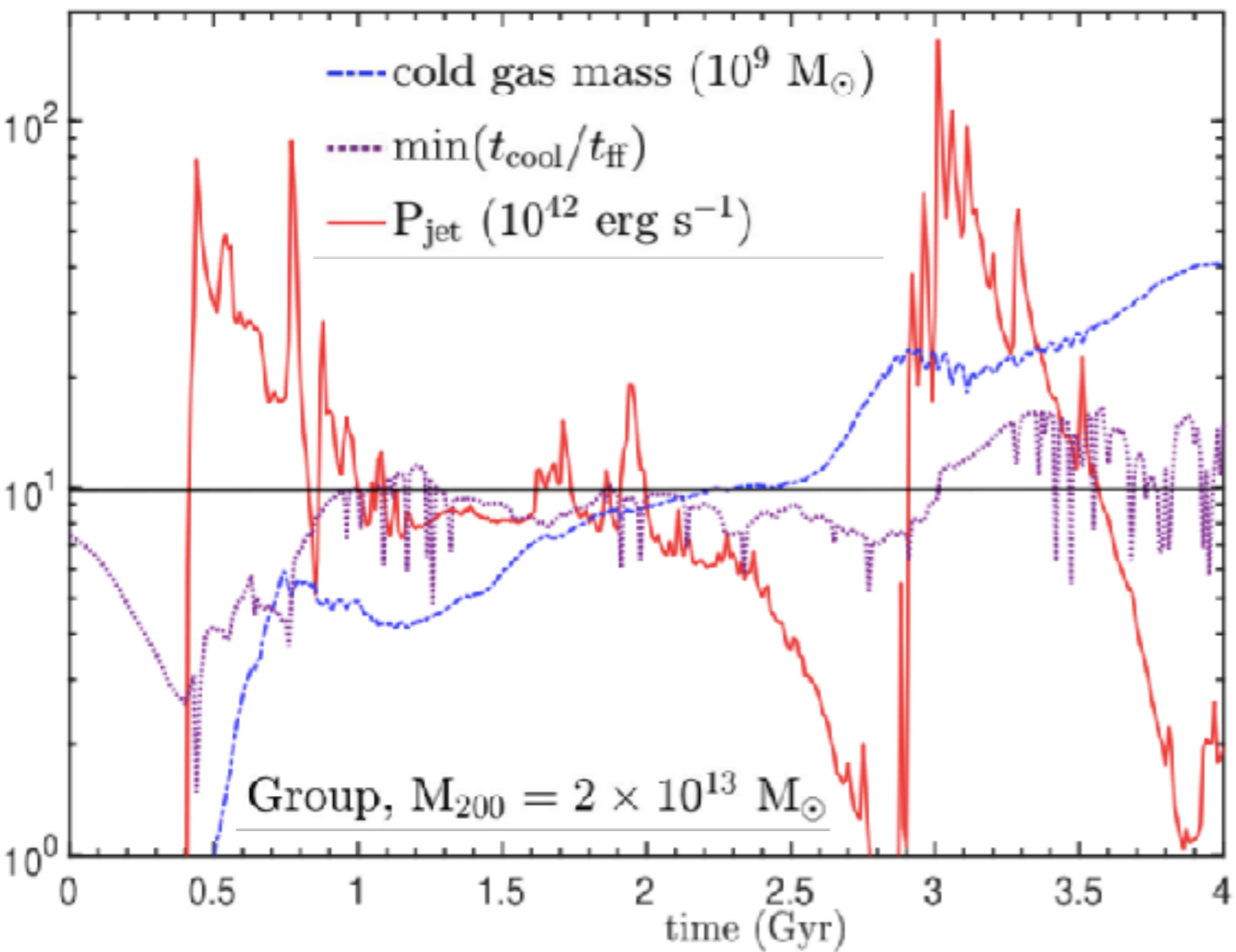
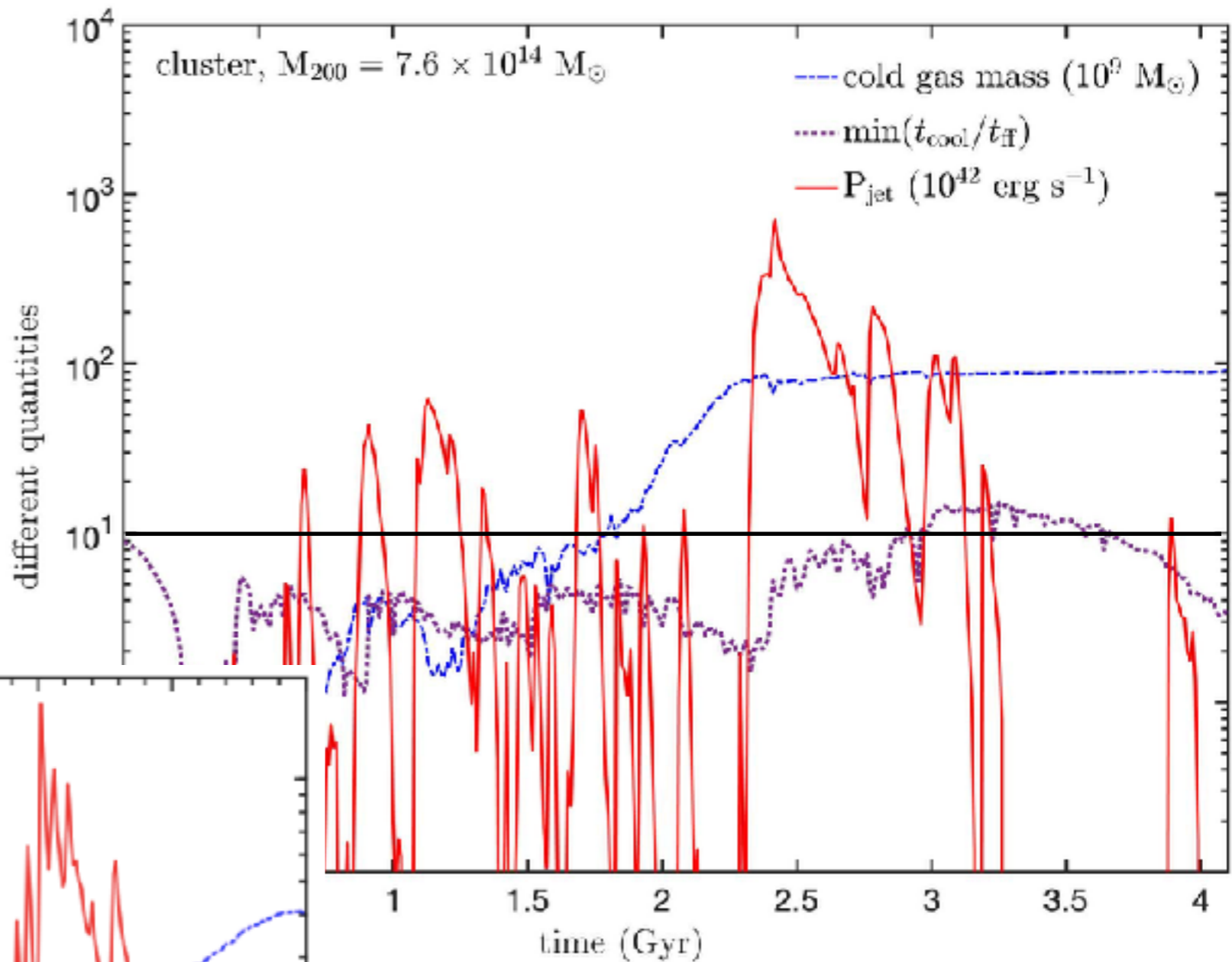
apolate to MW CGM?

ICM vs IGrM

3-D AGN jet-ICM/CGM simulations with kinetic jet feedback

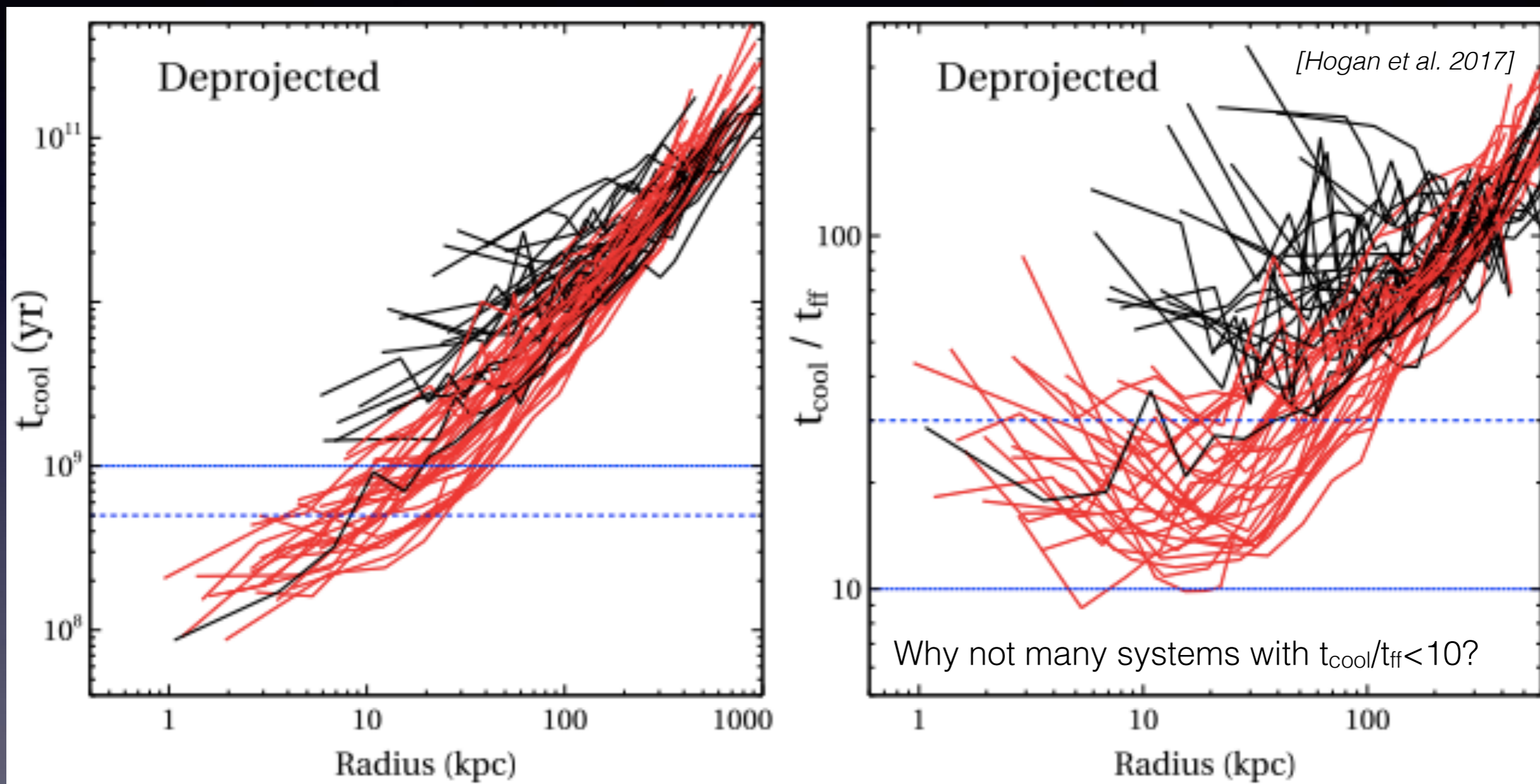


ICM vs IGrM



lower cold gas mass, jet power,
duty cycle for groups for same ϵ

$t_{\text{cool}}/t_{\text{ff}}$, t_{cool} , K_0 Or $t_{\text{cool}}/t_{\text{eddy}}$?



Why does t_{ff} in the denominator not matter? Because halos are self similar!

$$t_{\text{ff}} = \sqrt{\frac{2r^3}{GM(r)}}$$

essentially independent of halo mass, high-z CCs consistent with $t_{\text{cool}}/t_{\text{ff}}$

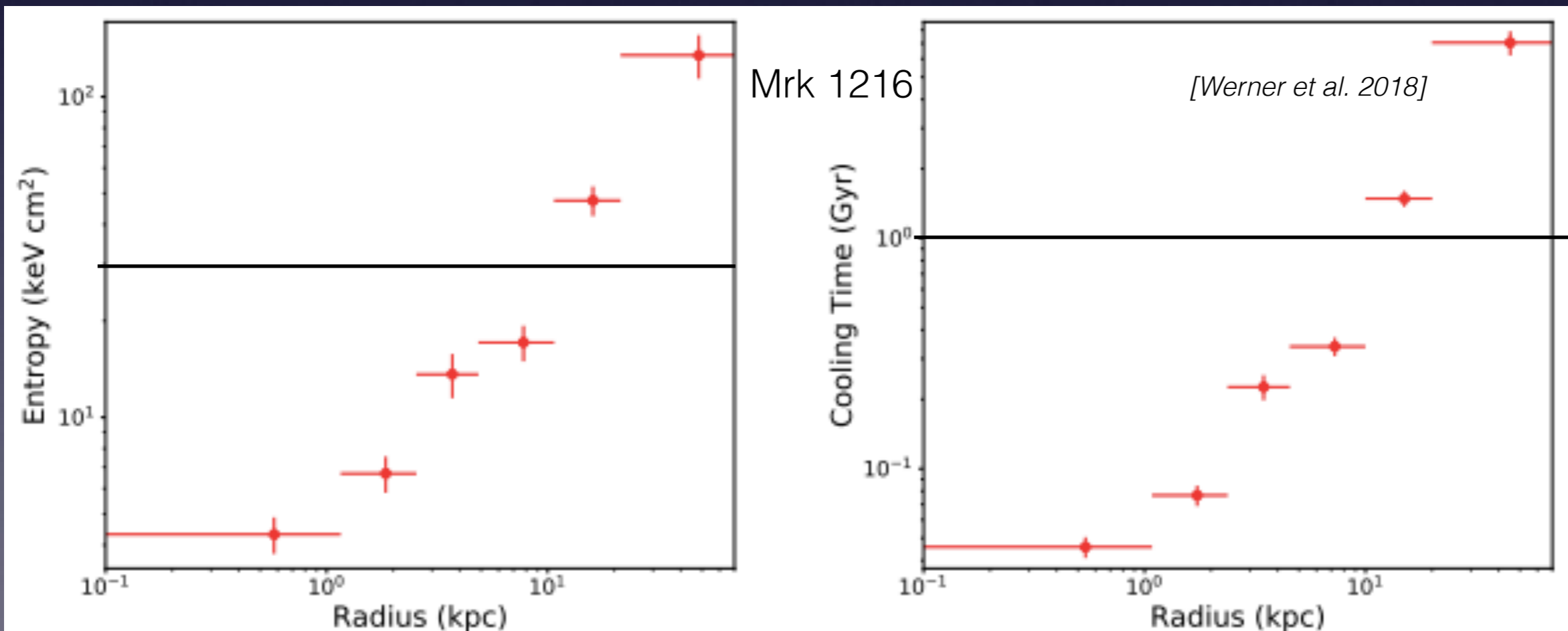
why should t_{eddy} be $\propto t_{\text{ff}}$ when P_{jet} varies so much?

Compact elliptical galaxies

Digging for red nuggets: discovery of hot haloes surrounding massive, compact, relic galaxies

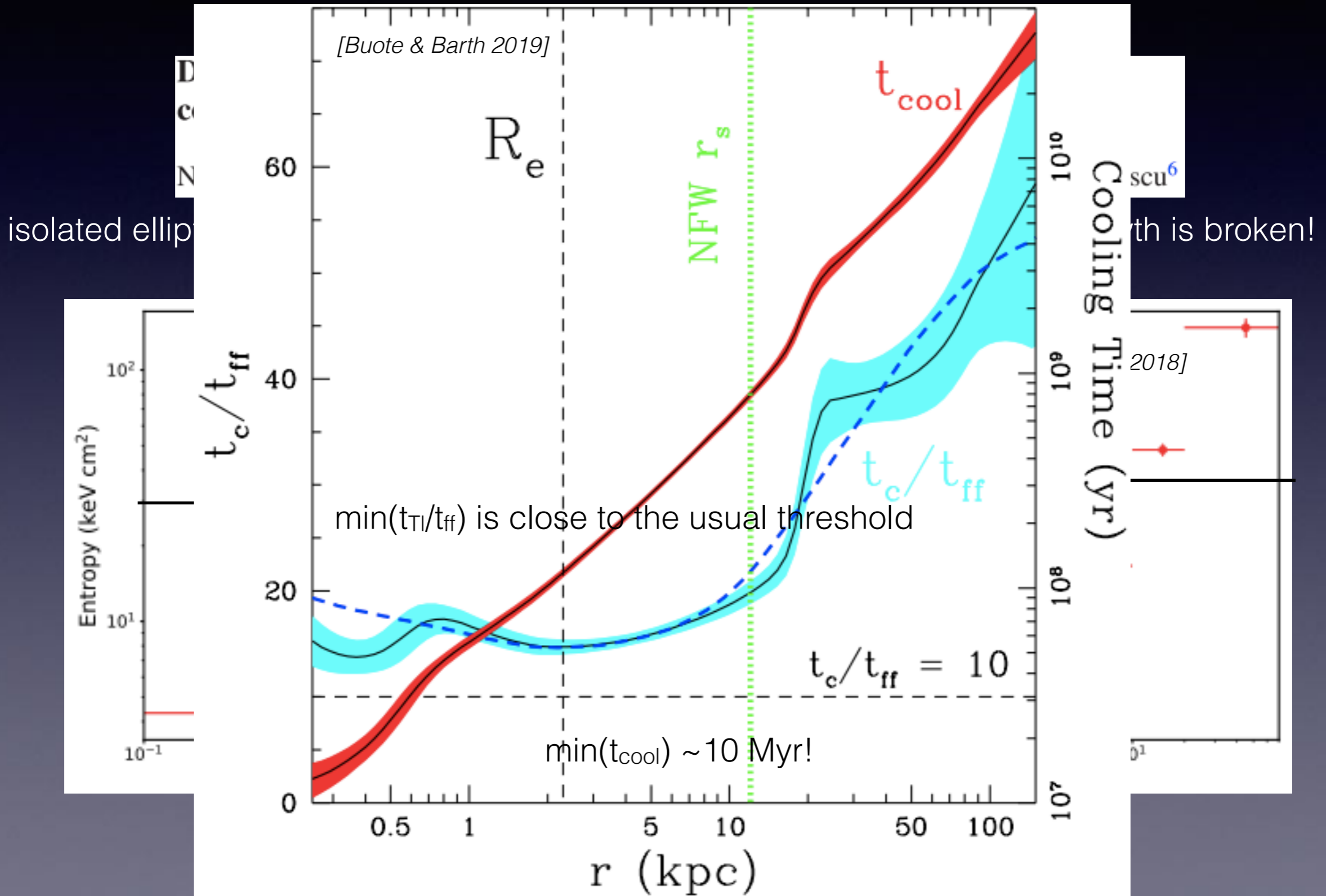
N. Werner,^{1,2,3★} K. Lakhchaura,¹ R. E. A. Canning,^{4†} M. Gaspari^{5‡} and A. Simionescu⁶

isolated elliptical galaxies with no late time growth! self-similarity of DM growth is broken!
Can test t_{cool} vs $t_{\text{cool}}/t_{\text{ff}}$ vs K_0



more than 10x lower than standard K_0 and t_{cool} thresholds!

Compact elliptical galaxies

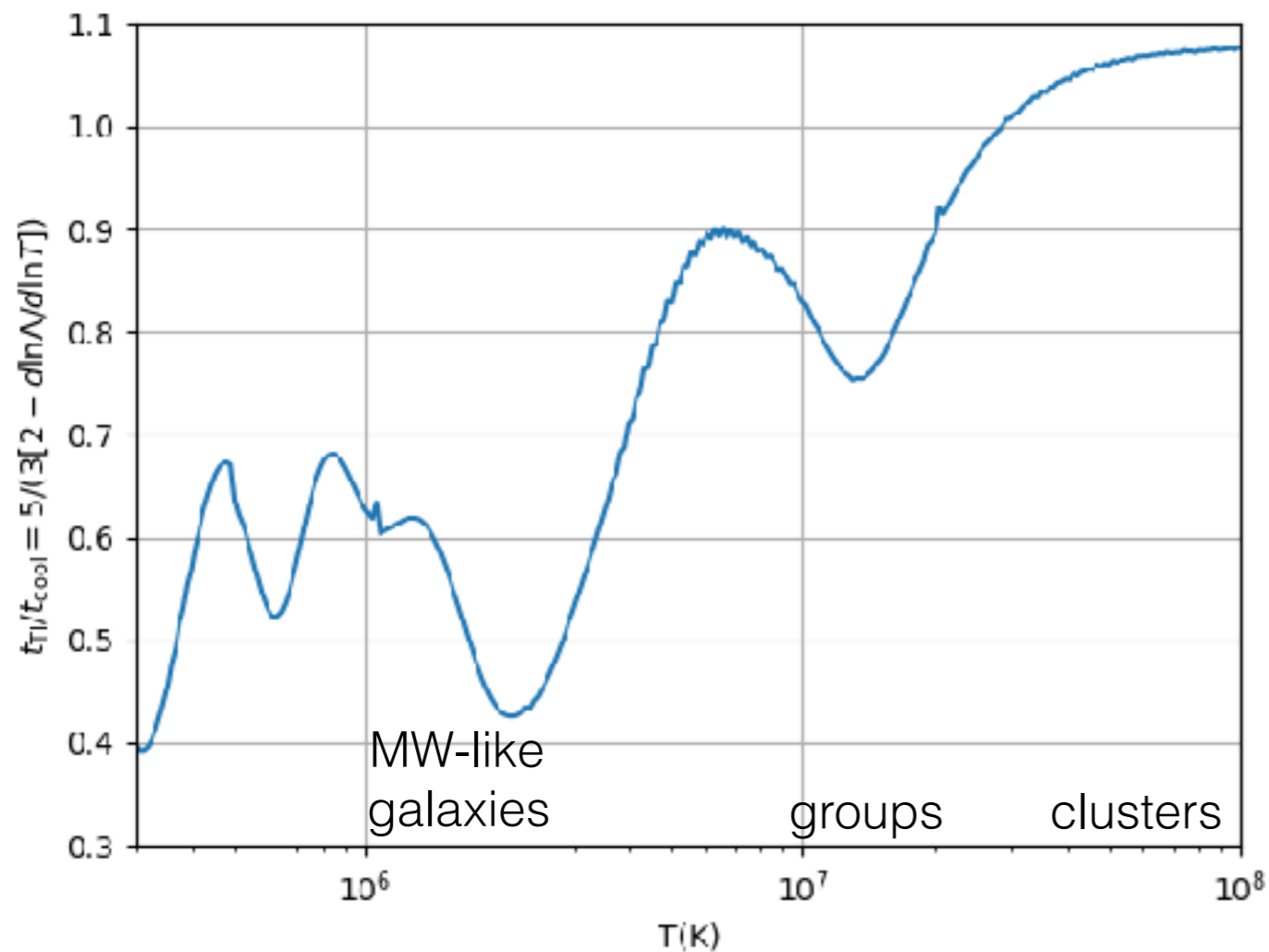


t_{TI} , not t_{cool}

$$t_{\text{TI}} = \frac{5}{3} \frac{t_{\text{cool}}}{(2 - d \ln \Lambda / d \ln T)} = \frac{10}{9} t_{\text{cool}} \text{ for } \Lambda \propto T^{1/2} \text{ for clusters}$$

$$= \frac{5}{9} t_{\text{cool}} \text{ for } \Lambda \propto T^{-1}$$

distinction between t_{cool} and t_{TI} quantitatively important!



for CGM in lower mass halos

t_{TI} more appropriate
for CGM, IGrM!

Deprojection bias

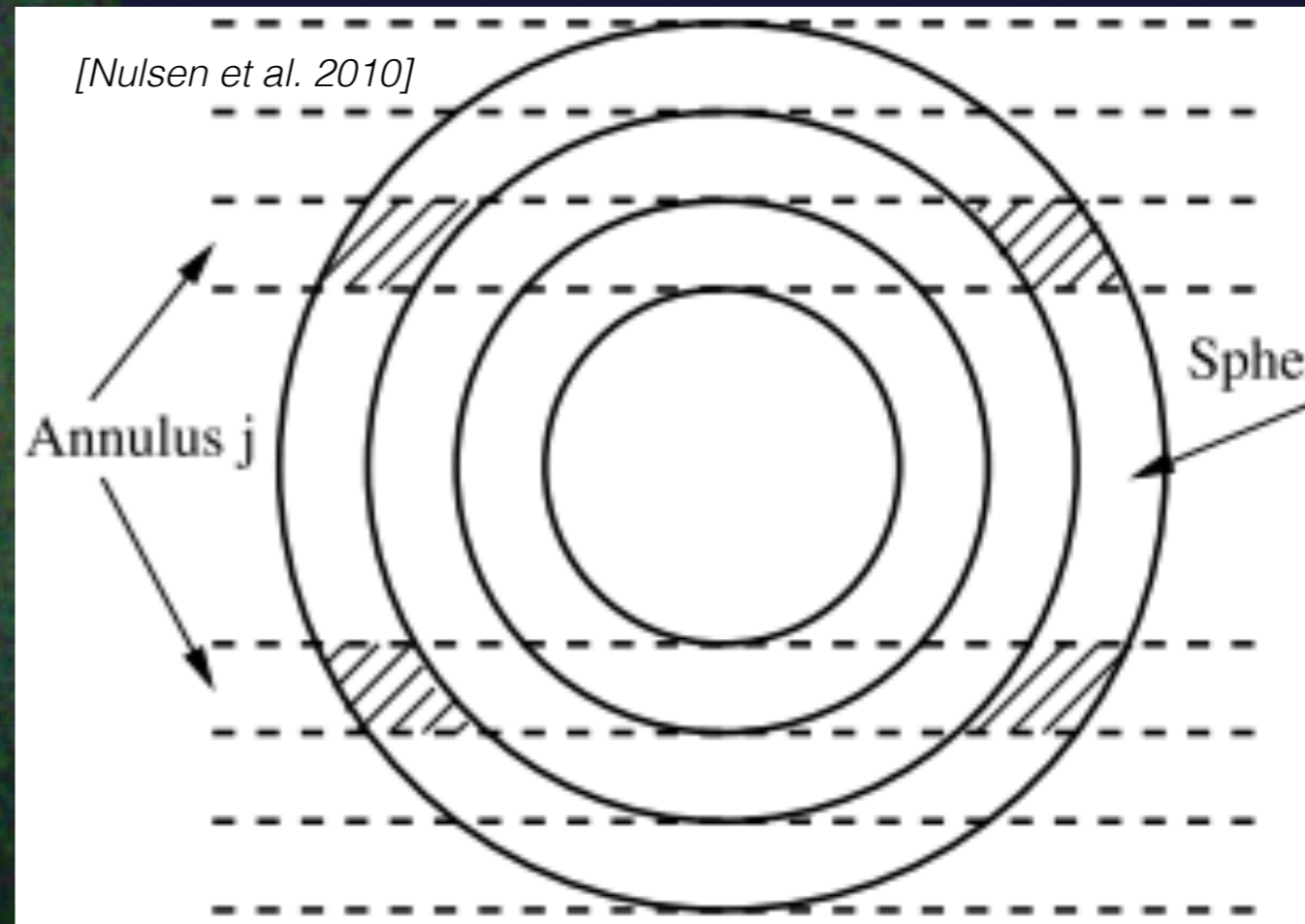
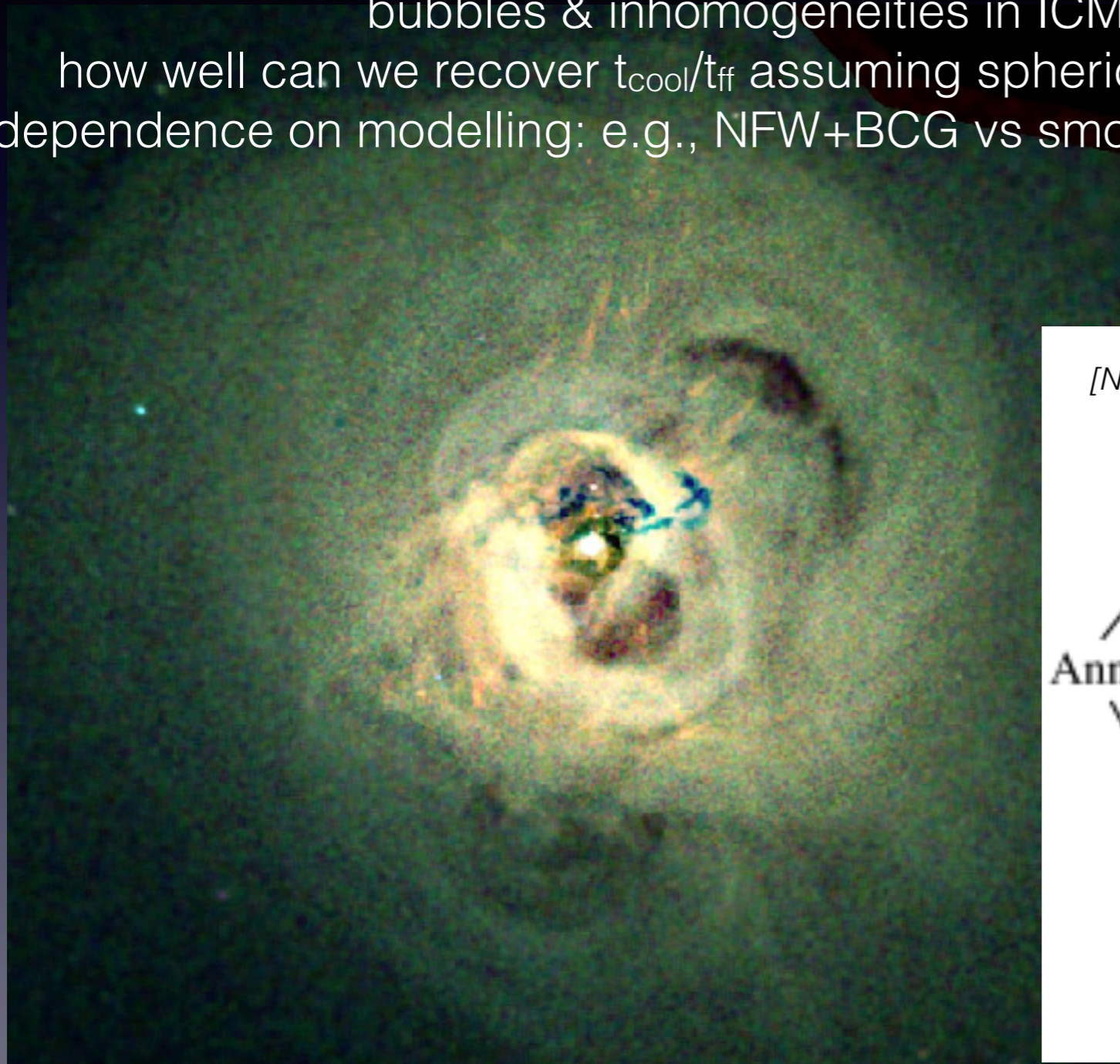
bubbles & inhomogeneities in ICM

how well can we recover $t_{\text{cool}}/t_{\text{ff}}$ assuming spherical symmetry?

dependence on modelling: e.g., NFW+BCG vs smooth p-fit (2 ways)



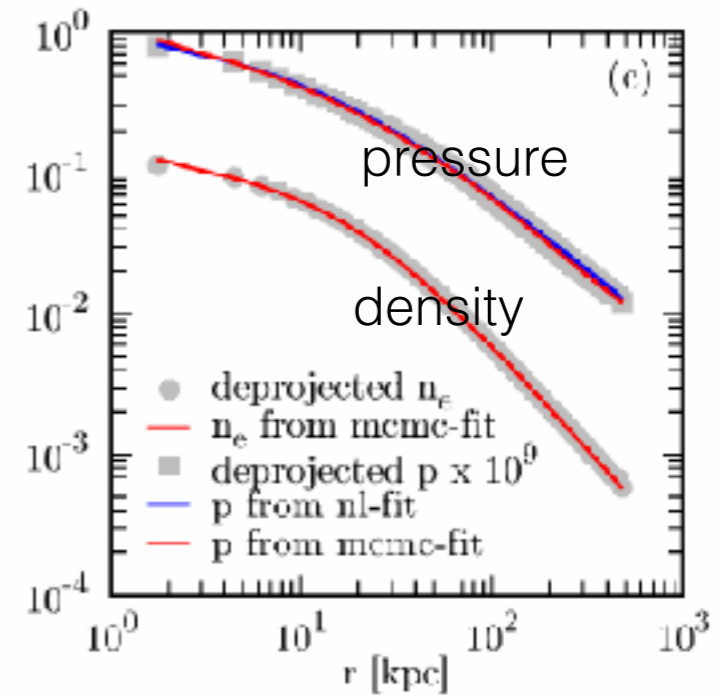
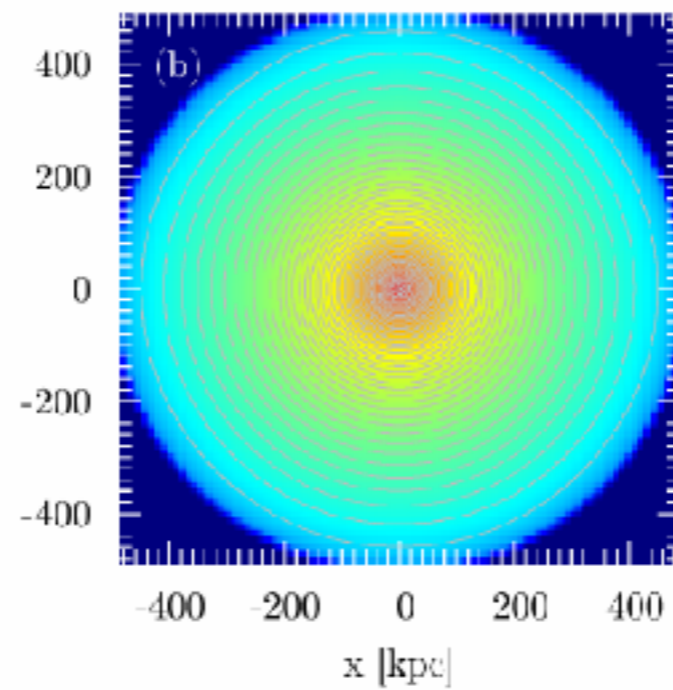
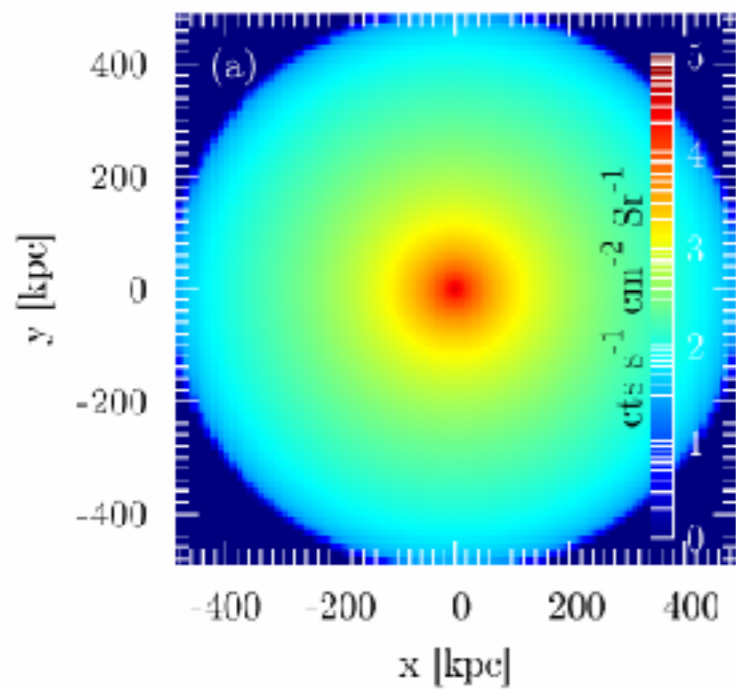
Kartick Sarkar



Deprojection bias

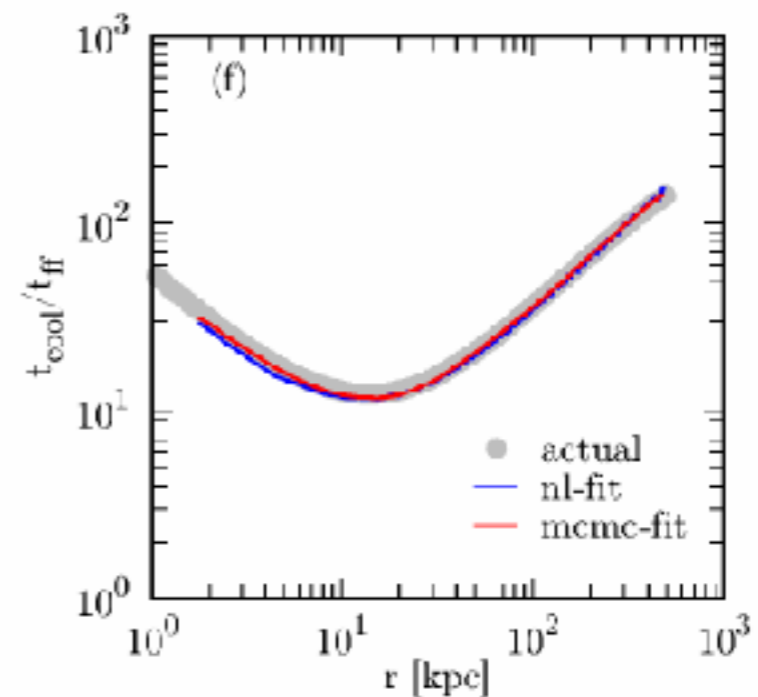
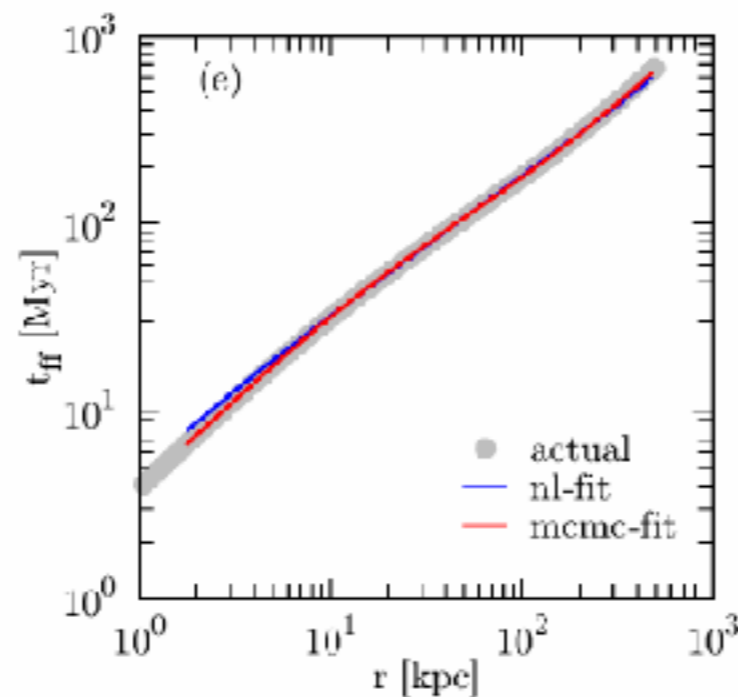
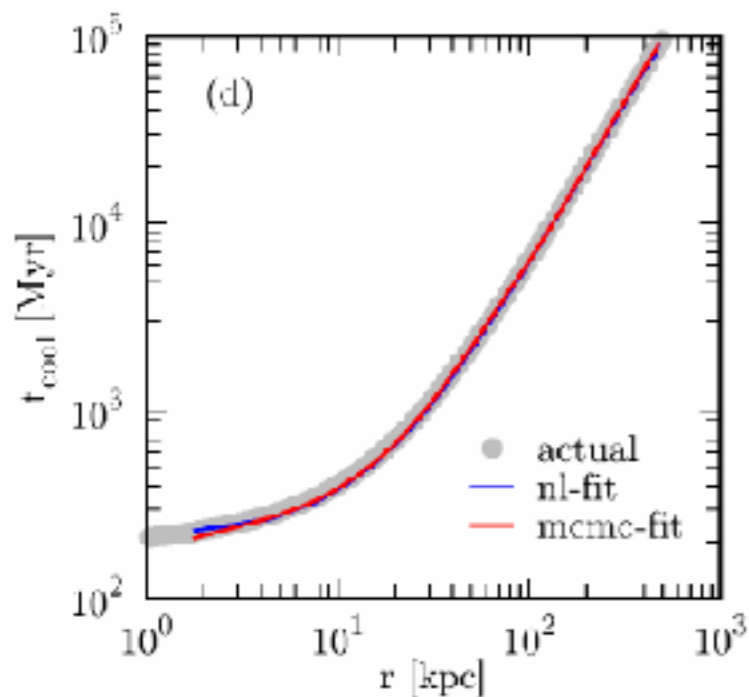


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recovery perfect if profiles spherically symmetric

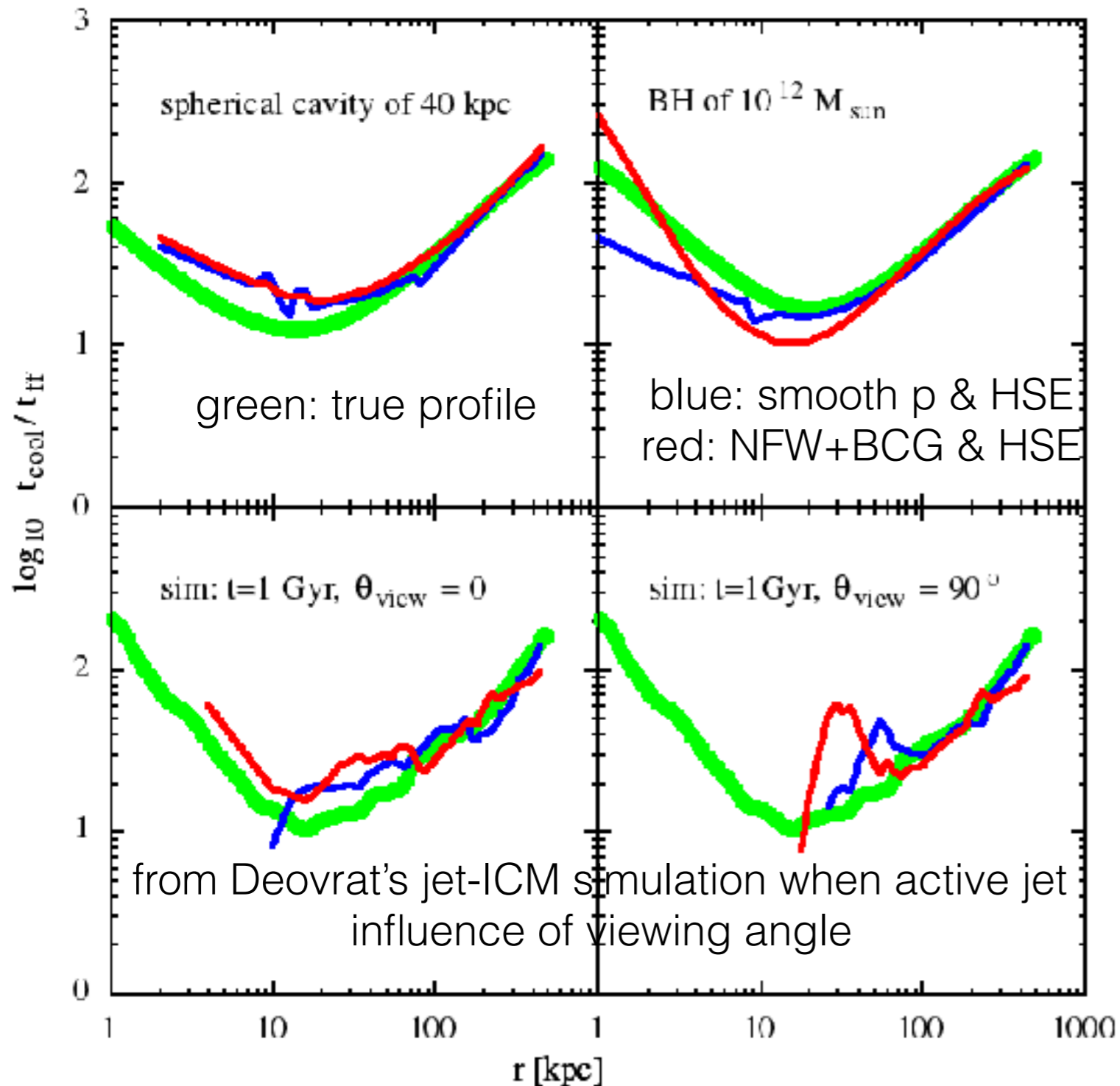
[Sarkar et al., in prep.]



Deprojection bias



Kartick Sarkar



- Summary:
- cavities raise $t_{\text{cool}}/t_{\text{ff}}$, as expected
 - imposed form of g over-constraining
 - $t_{\text{cool}}/t_{\text{ff}}$ recovered at most times
 - c-M200 degeneracy in spectral analysis

In progress

Summary

- IGrM, ICM similar; consistent with $t_{\text{TI}}/t_{\text{ff}}$ models
- angular momentum problem & low- l cold gas
- CEGs (e.g., Mrk 1216) ideal laboratories
- quantifying projection effects using simulations

Thank you!