Cosmological Gas Accretion @ z=2

(with: Hernquist, Kereš, Nelson, Sijacki, Springel, Vogelsberger)

&

Accretion-driven Turbulence in Disks

(with: Cacciato, Dekel)

Shy Genel (ITC-Harvard)

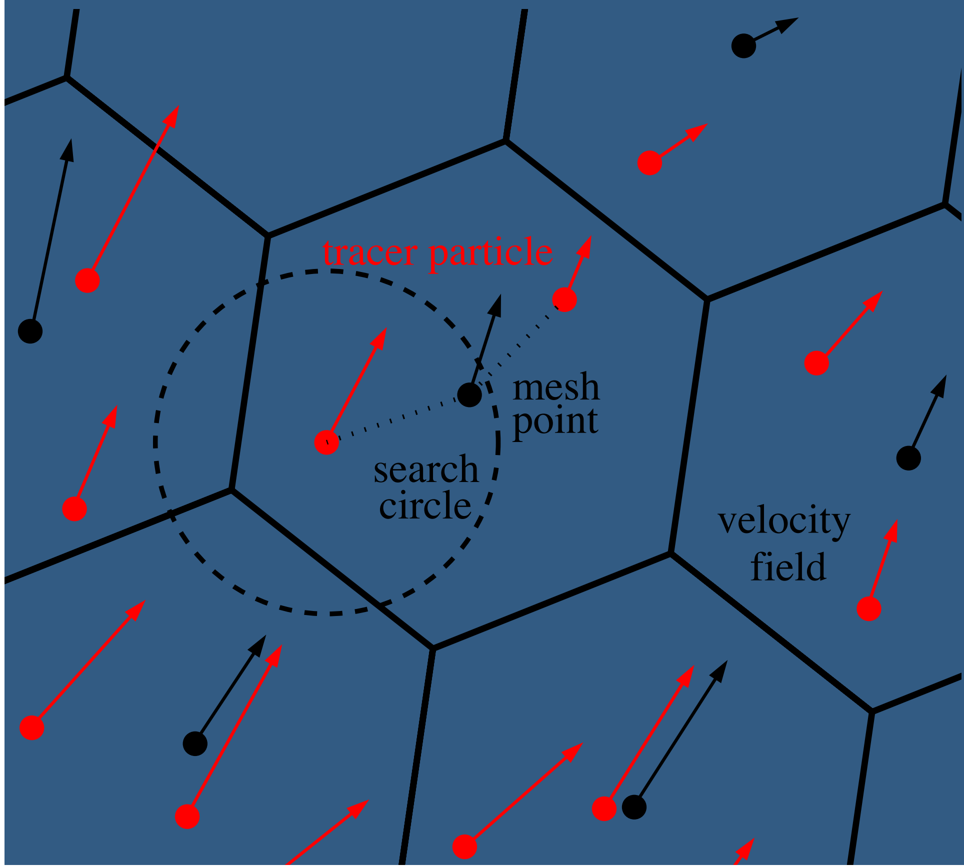
Outline

- Following gas flow in Arepo with tracer particles
- Gas accretion onto galaxies at z=2
- Accretion as a turbulence-driver and implications

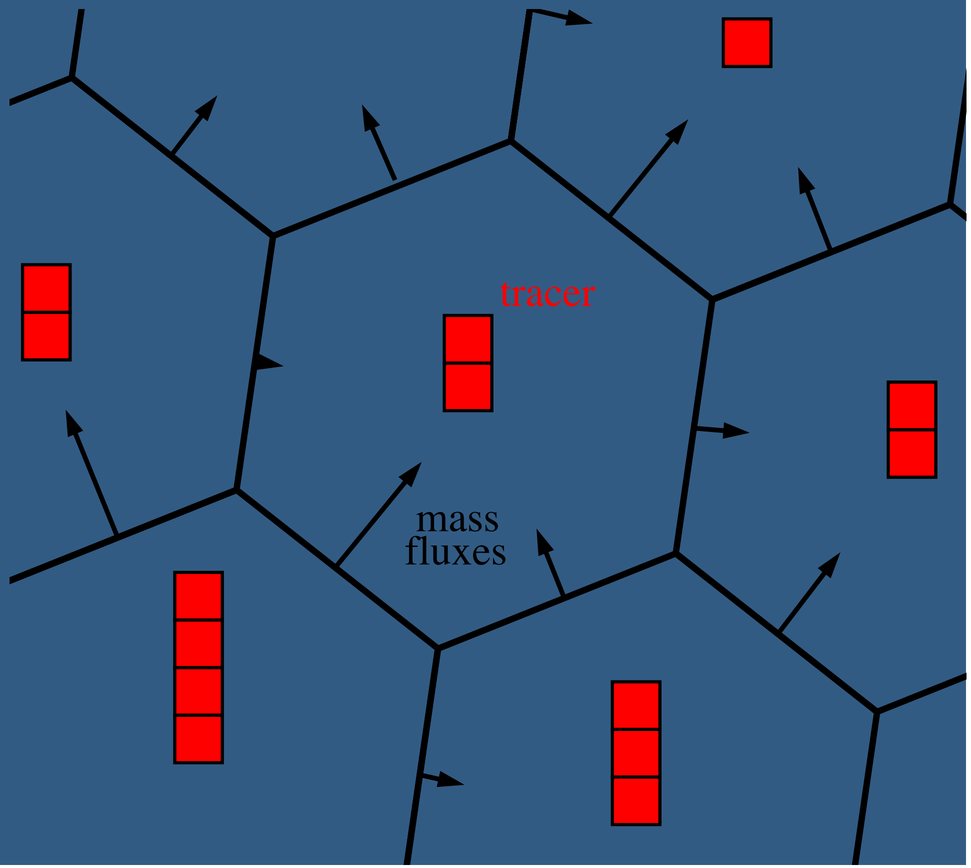
Tracer particles in Arepo

Genel et al. in prep.
Vogelsberger et al. in prep.

Velocity field tracers:



Monte Carlo tracers:



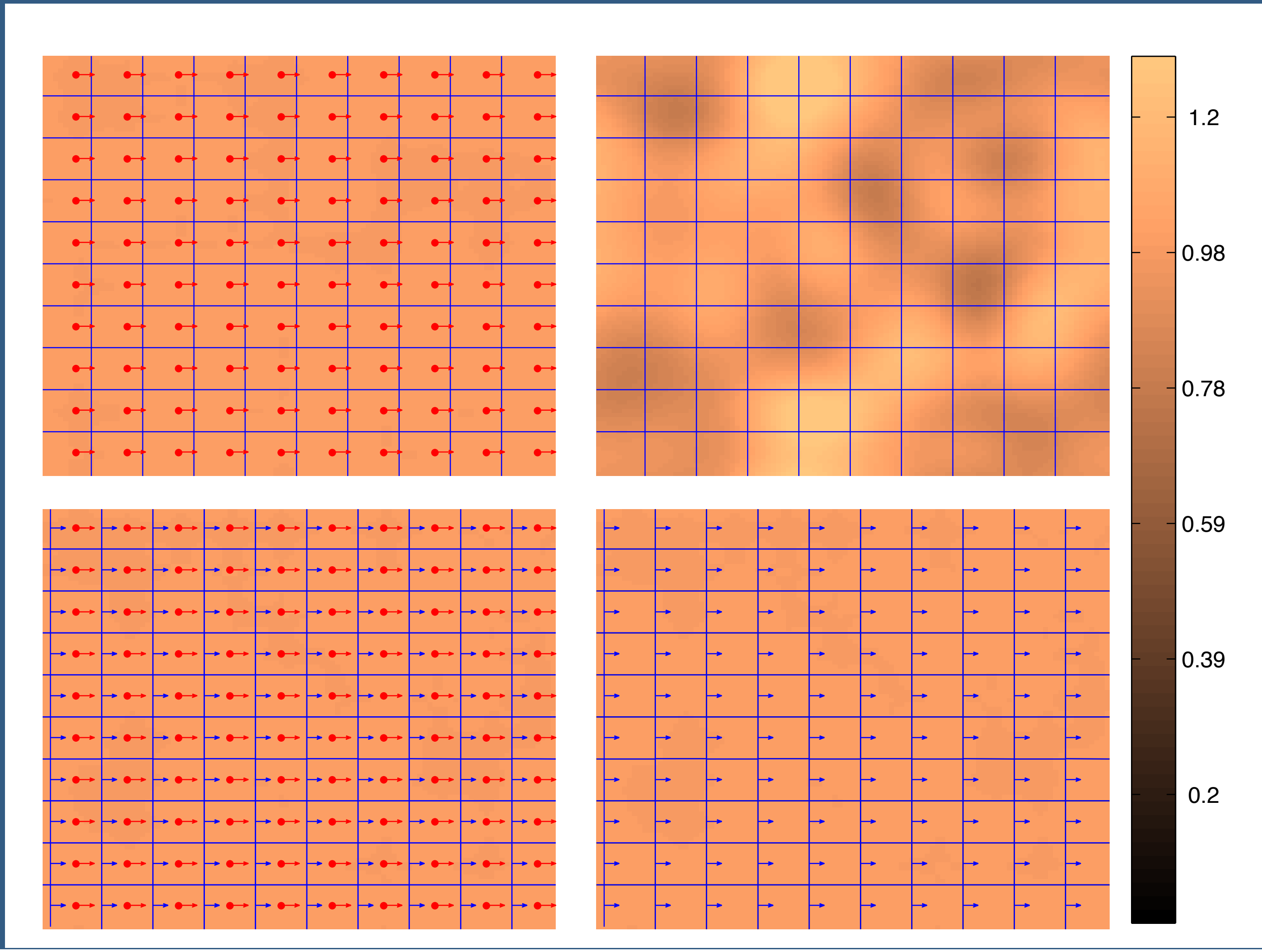
Tracer particles in Arepo – uniform flow

Velocity field tracers

Monte Carlo tracers

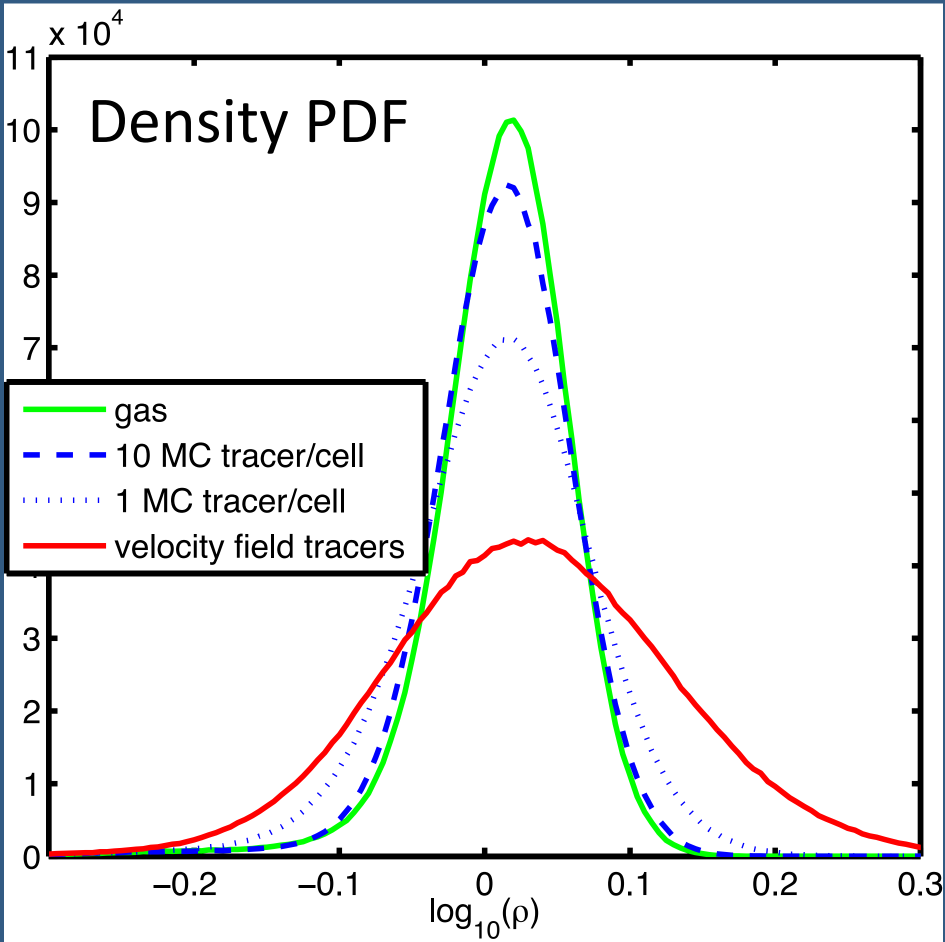
Fixed mesh:

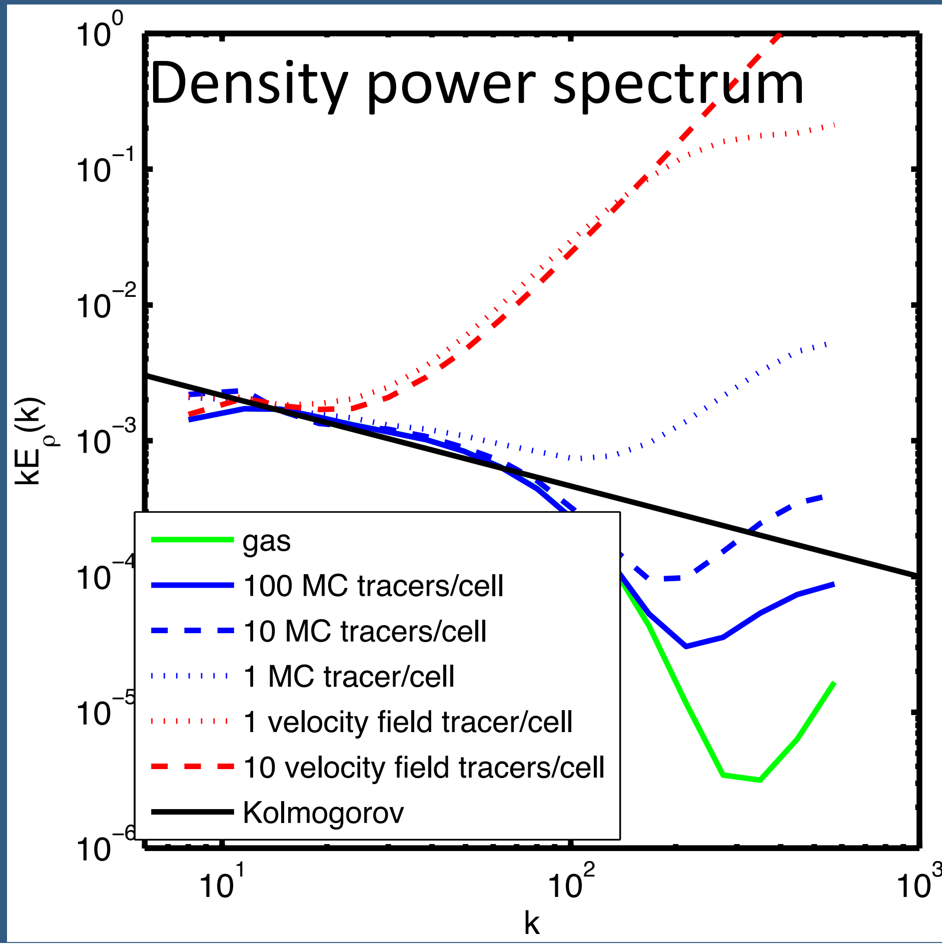
Moving mesh:



Tracer particles in Arepo – turbulence

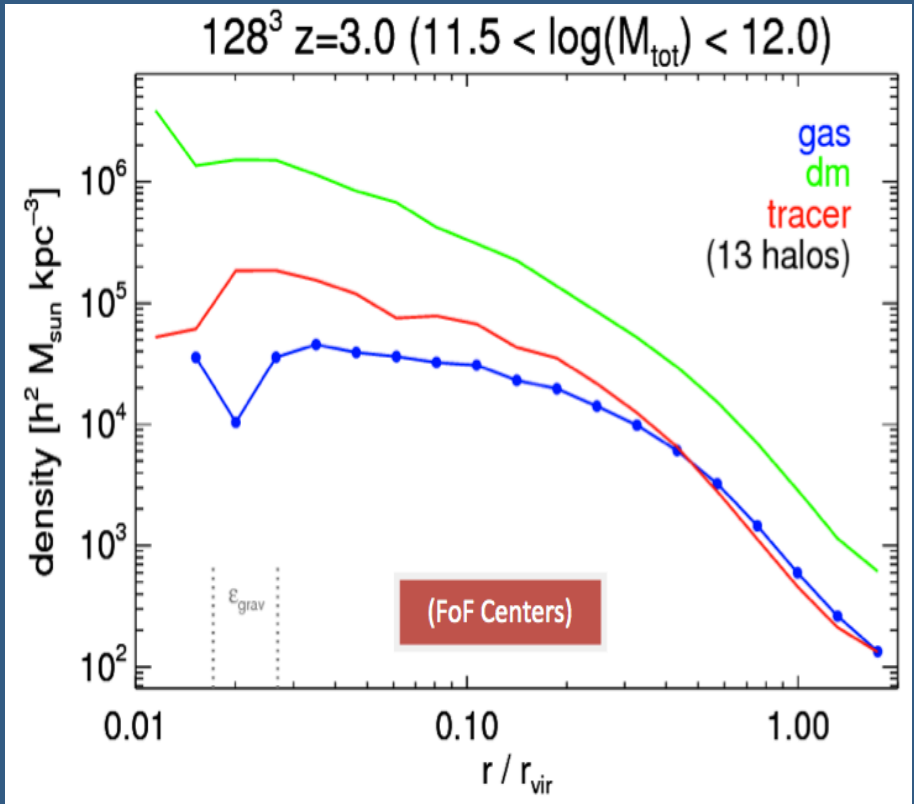
Driven isothermal turbulence (Bauer & Springel 2012), 128^3 cells



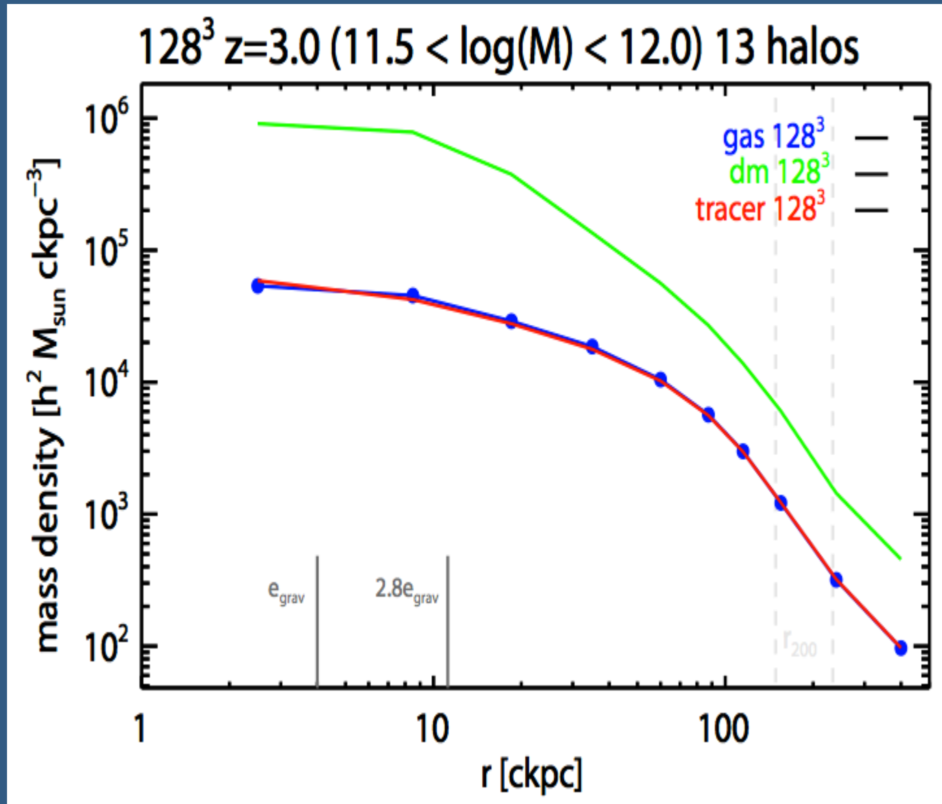


Tracer particles in Arepo – halo centers

Velocity field tracers

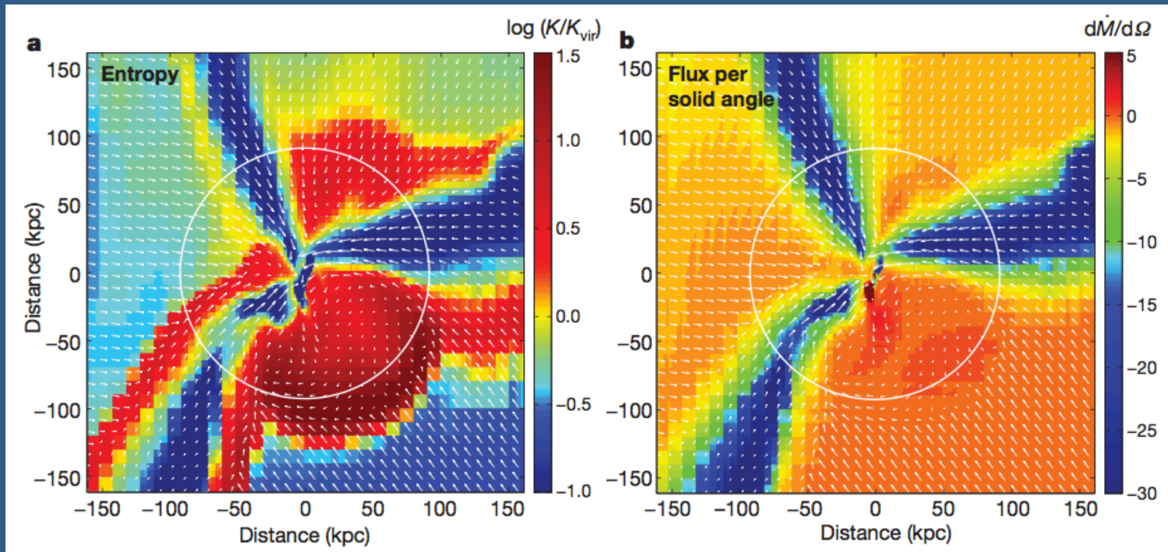


Monte Carlo tracers

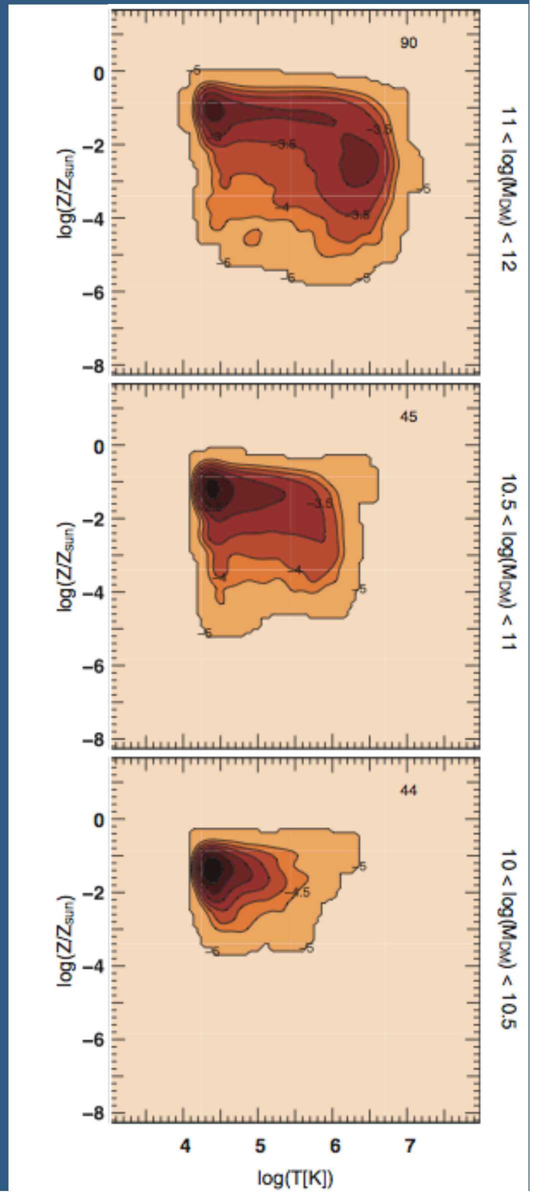


Accretion bimodality?

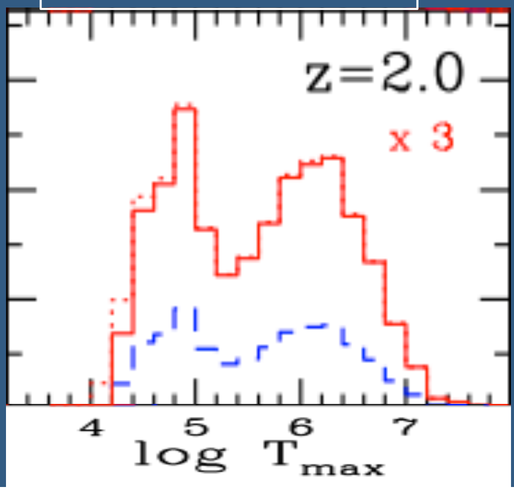
Dekel et al. 2009

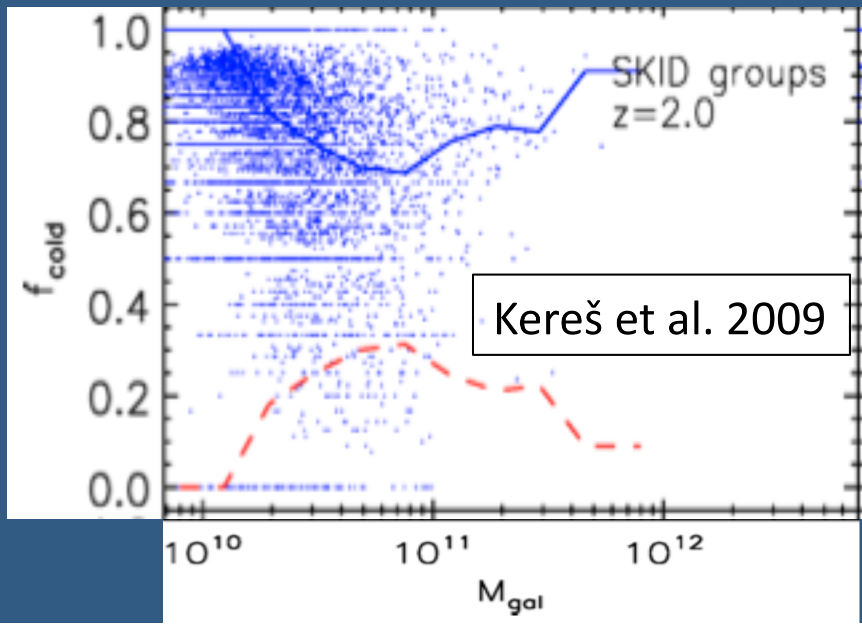


Ocvirk et al. 2008



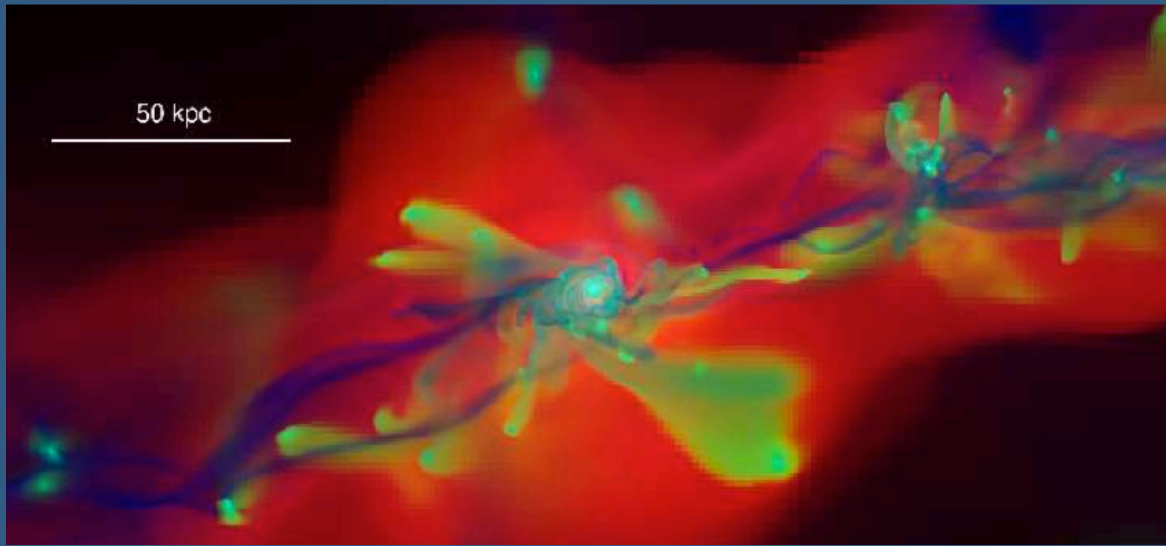
Kereš et al. 2005



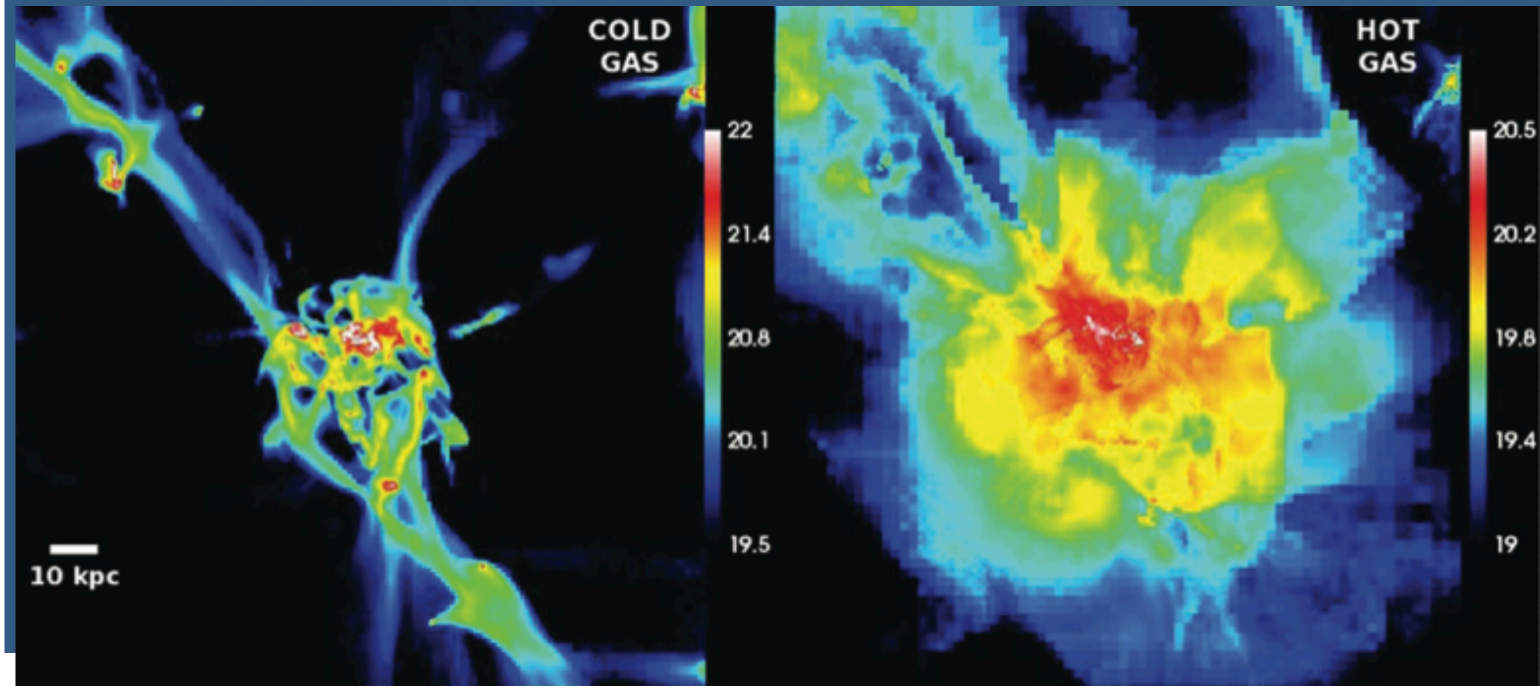


Kereš et al. 2009

Do cold streams reach the galaxy?



Agertz et al. 2009

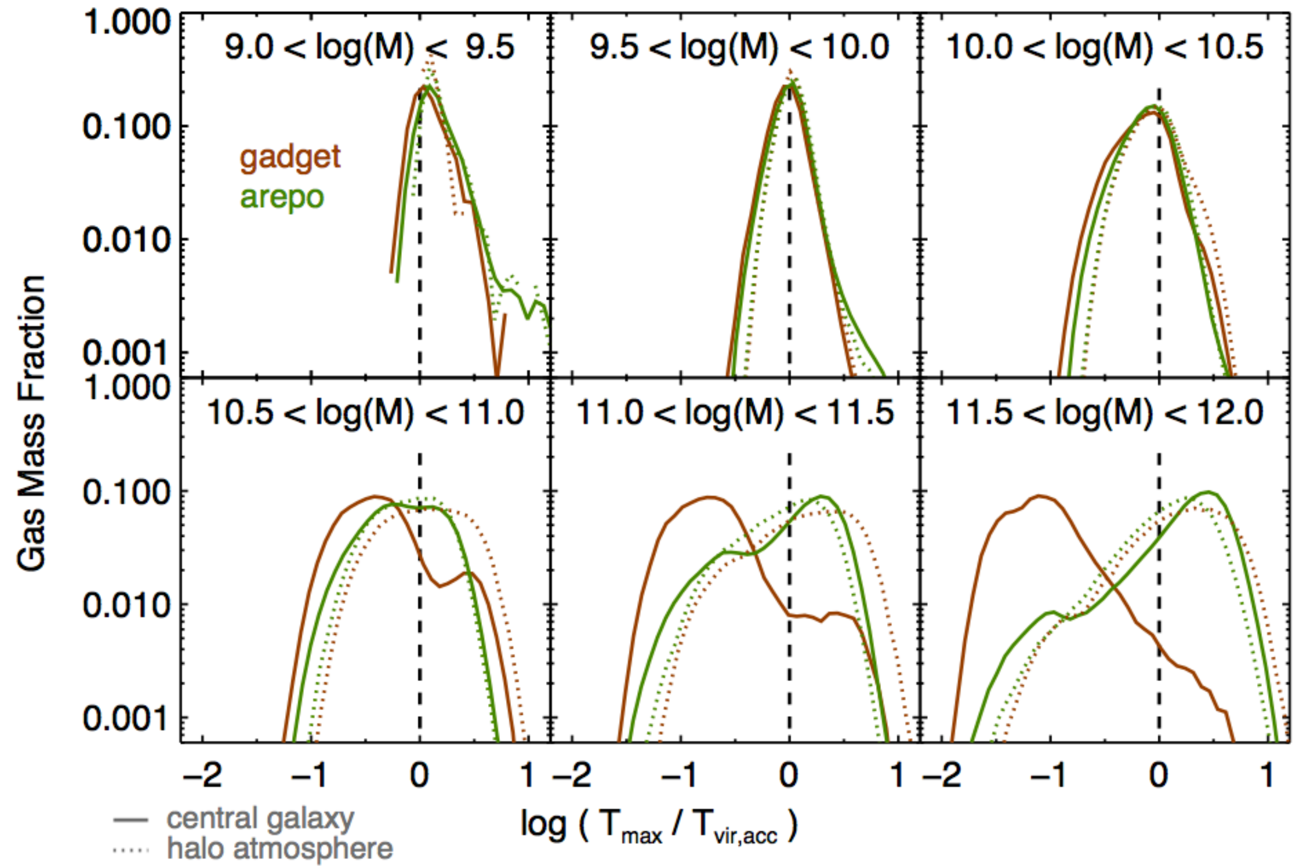


Ceverino et al. 2009

Maximum past temperature of galaxy gas

- Agreement at $M<10^{10.5}M_{sun}$: $T_{max} \approx T_{vir}$
- At $M>10^{10.5}M_{sun}$:
- Both codes show bimodality
- With Gadget, 'cold mode' dominates
- With Arepo, 'hot mode' dominates

Nelson, Vogelsberger, SG et al. in prep.

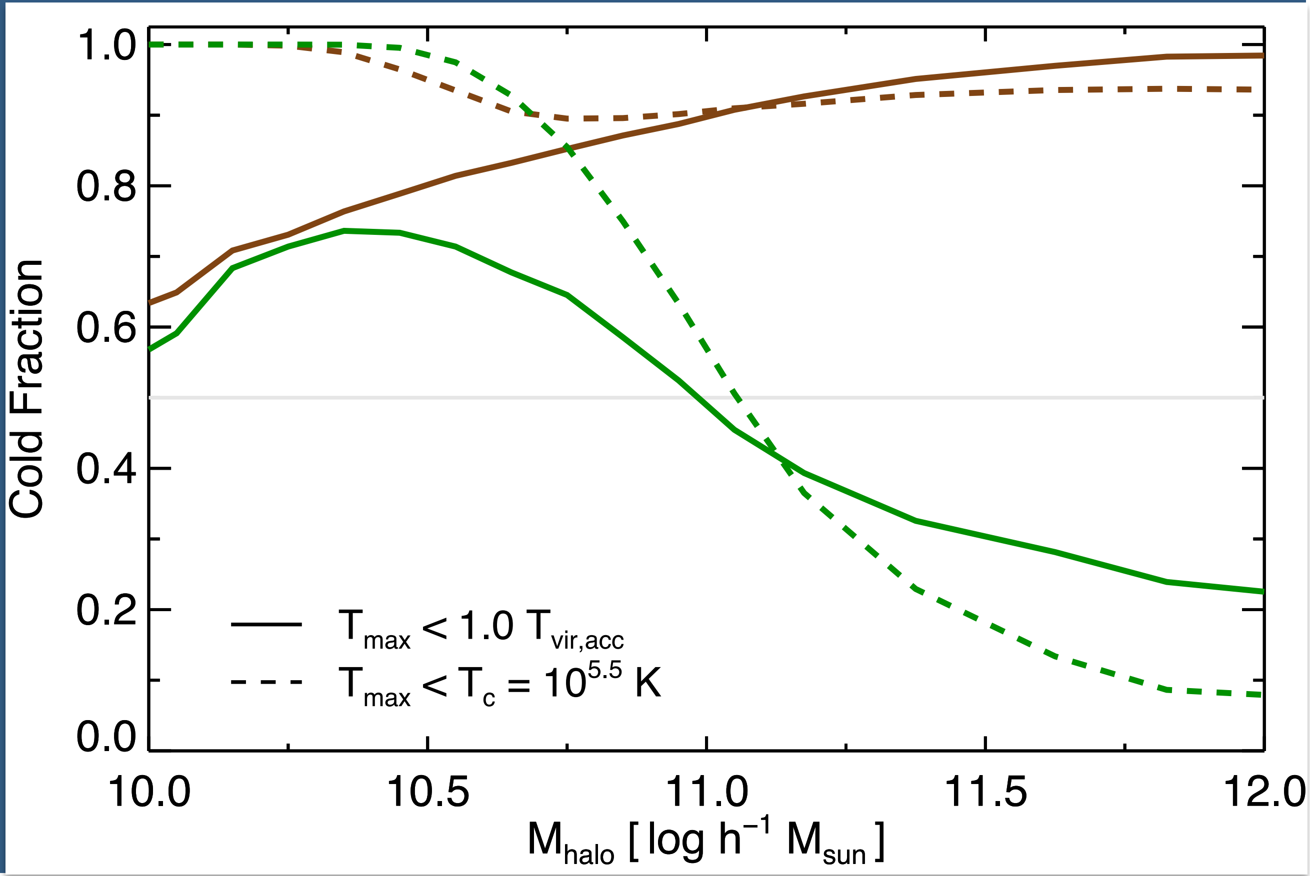


Cold mode fraction of galaxy gas

- For a hot/cold cut at Tvir: gradual transition from cold-dominated to hot-dominated at $10^{10}<M[M_{sun}]<10^{12}$

- For a fixed $T_c=10^{5.5}$K cut: 'transition mass' where $T_{vir}(M)\approx T_c$ – no 'cold accretion' where $T_{vir}>>T_c$

Nelson, Vogelsberger, SG et al. in prep.

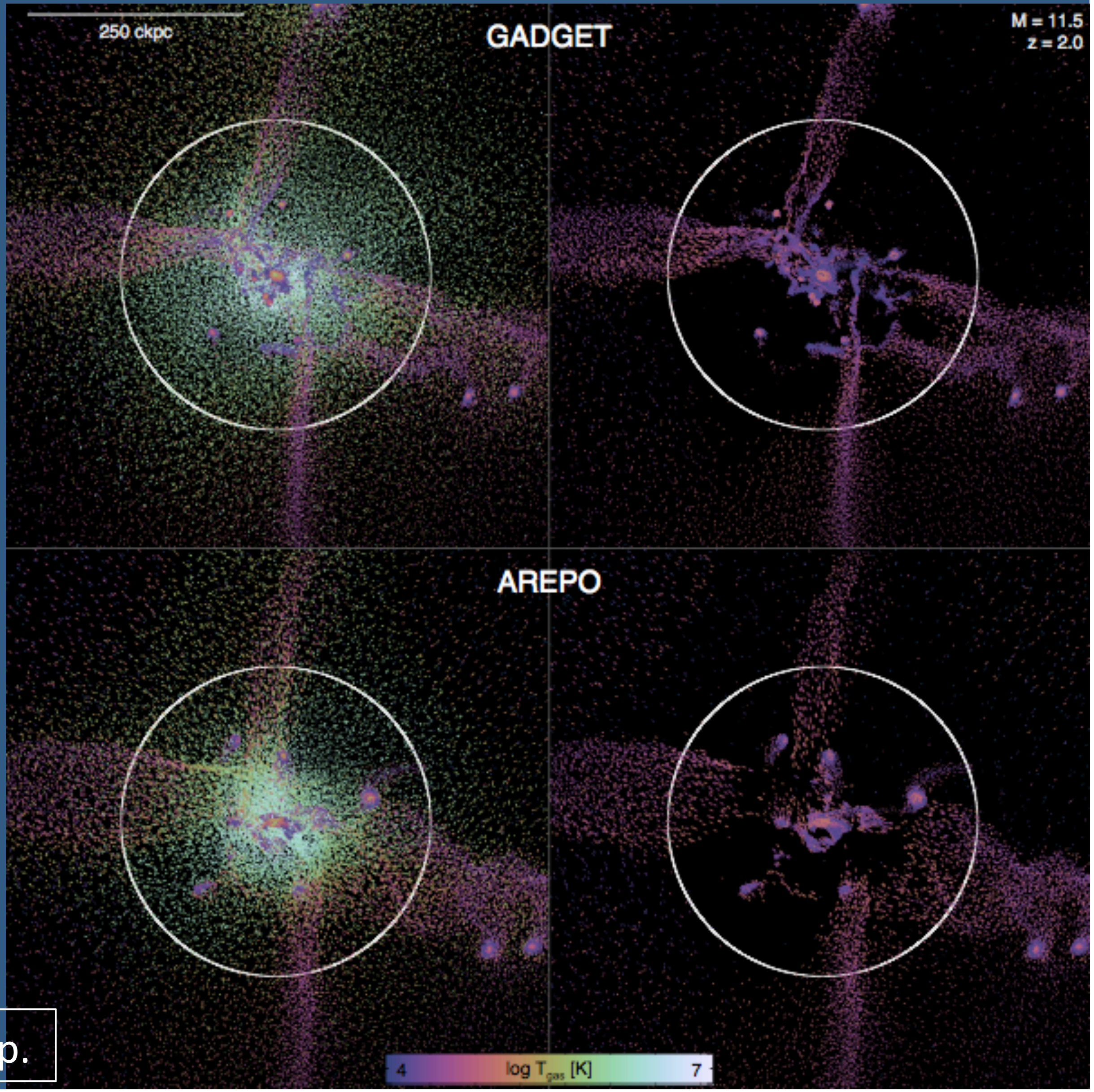


Possible origins of differences

- With Arepo, some streams heat up

- SPH 'cold blobs/ drizzle'

- Spurious heating by dissipation of turbulence in SPH



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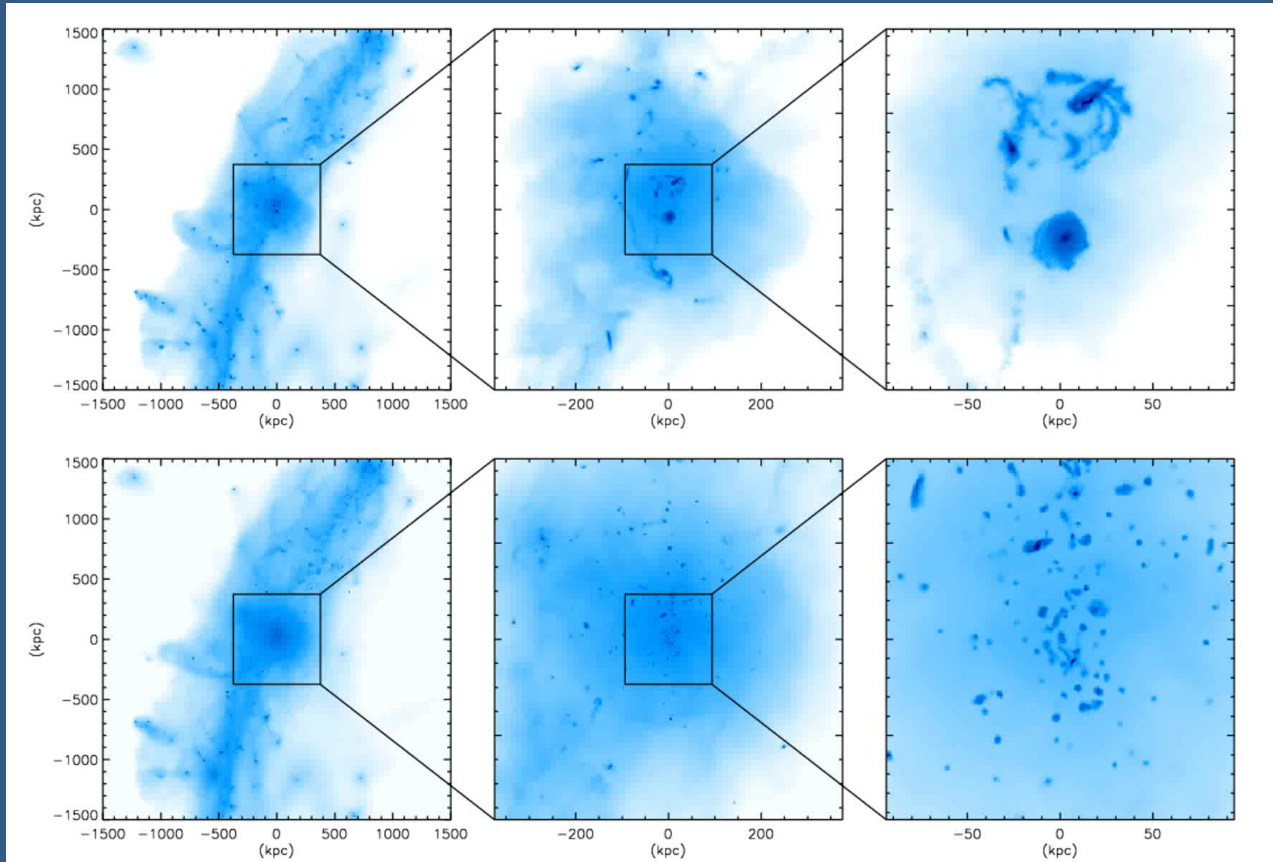
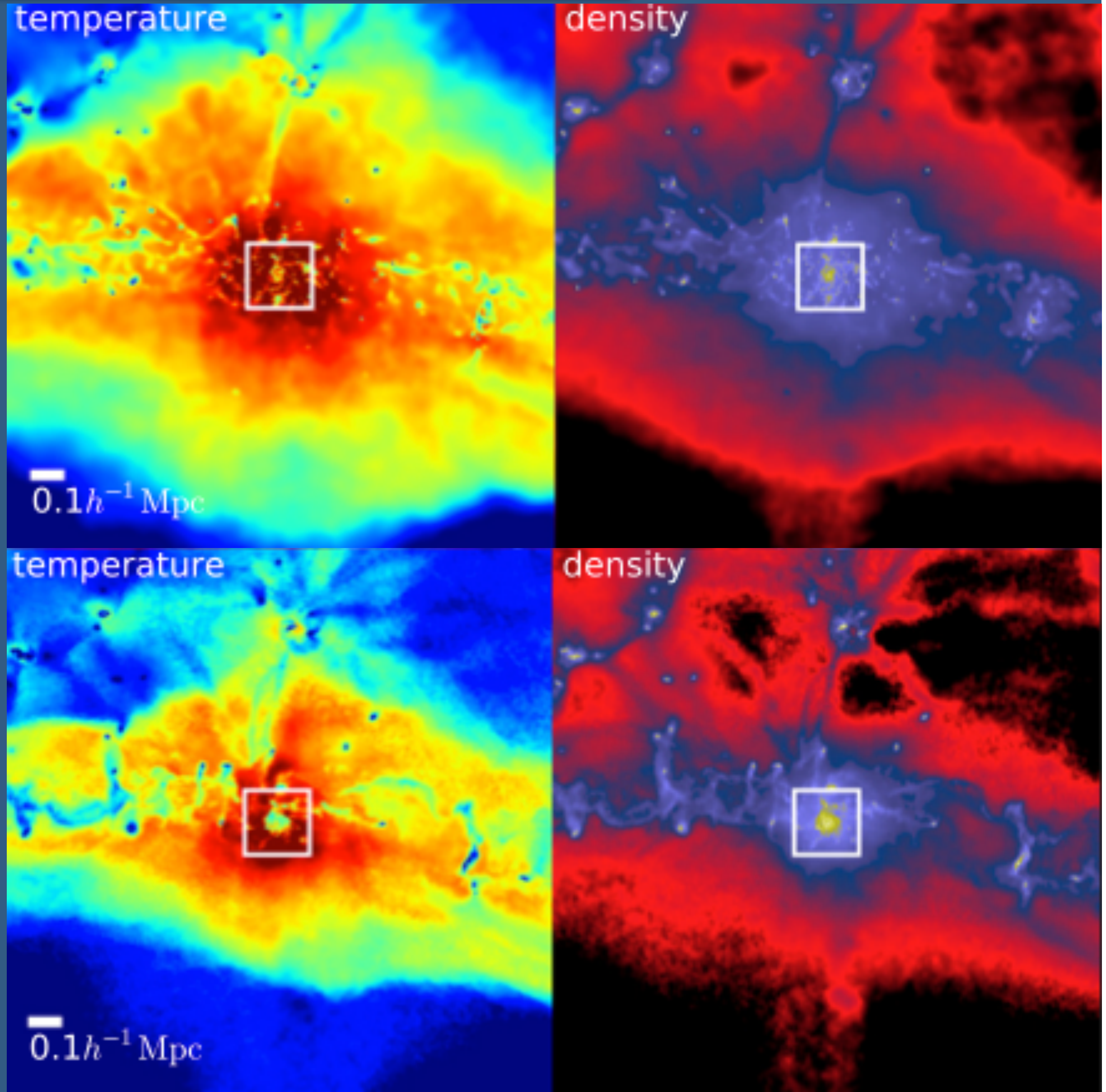


Torrey et al. in prep.

Possible origins of differences

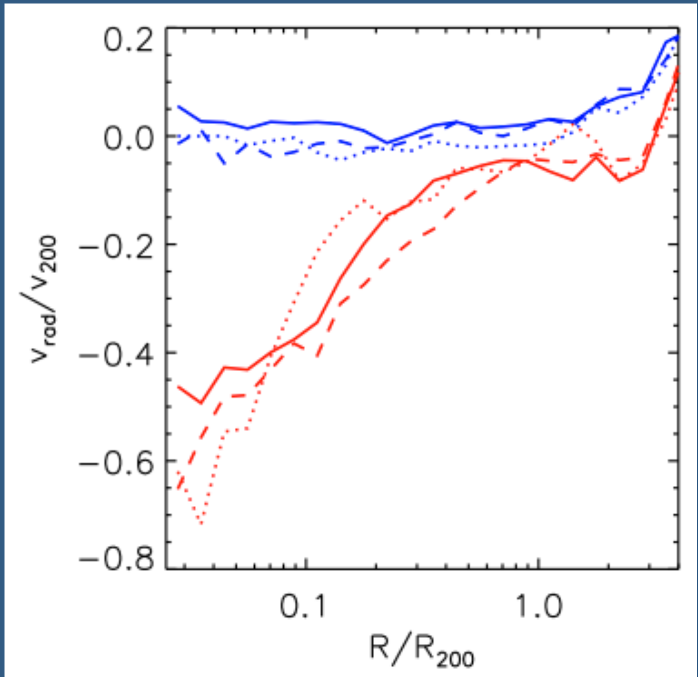
- With Arepo, some streams heat up
- SPH 'cold blobs/ drizzle'
- Spurious heating by dissipation of turbulence in SPH (Bauer & Springel 2012)



Vogelsberger et al. 2012

Possible origins of differences

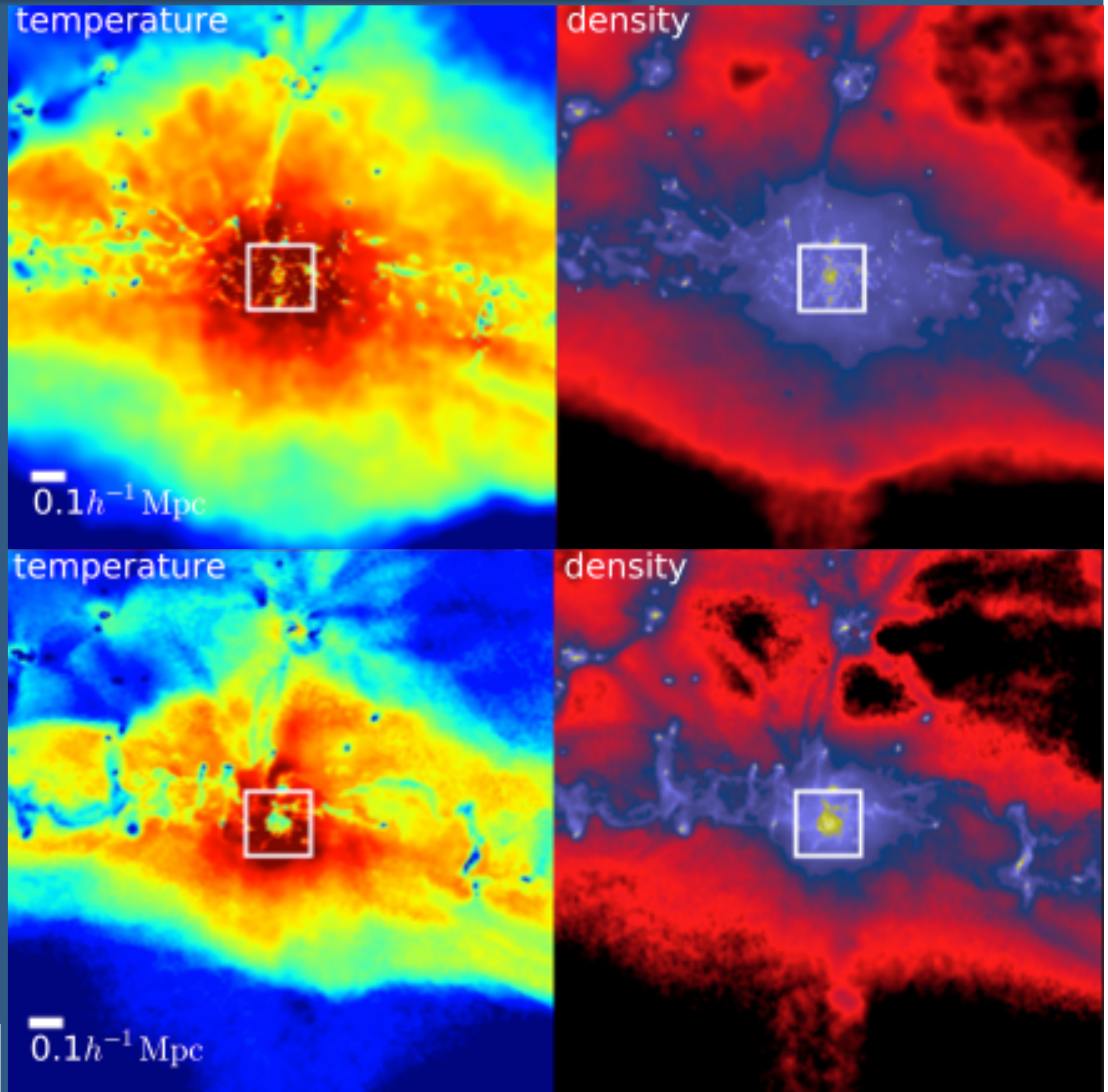
Kereš et al. 2012



by dissipation of turbulence in SPH

(Bauer & Springel 2012)

Vogelsberger et al. 2012



Does temperature even matter?

- Accretion rate remains high(er)
- Issues possibly more important than temperature are:
  - Shocked / non-shocked?
  - Collimated / spherical?
  - Clumpy / smooth?
  - How much angular momentum?

http://www.cfa.harvard.edu/itc/research/movingmeshcosmology/

Moving Mesh Cosmology

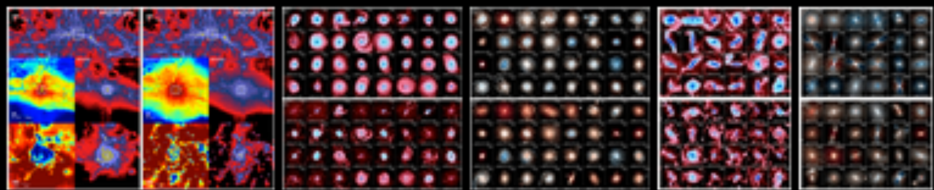
This website presents online material related to the first cosmological simulations of galaxy formation with the new moving mesh code AREPO.

Contact: Mark Vogelsberger

Moving mesh cosmology: numerical techniques and global statistics

Mark Vogelsberger, Debora Sijacki, Dusan Keres, Volker Springel, Lars Hernquist

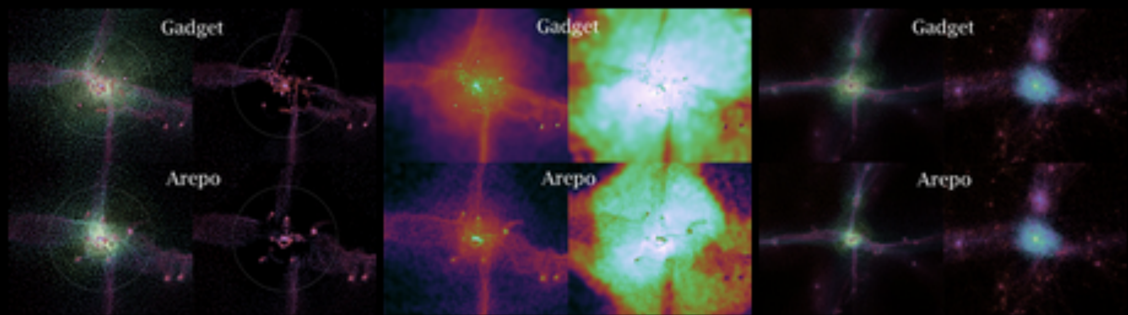
Abstract | arXiv | Images | Movies



Moving mesh cosmology: tracing cosmological gas accretion

Dylan Nelson, Mark Vogelsberger, Shy Genel, Debora Sijacki, Volker Springel, Lars Hernquist

Gadget/Arepo Halo Comparison Project

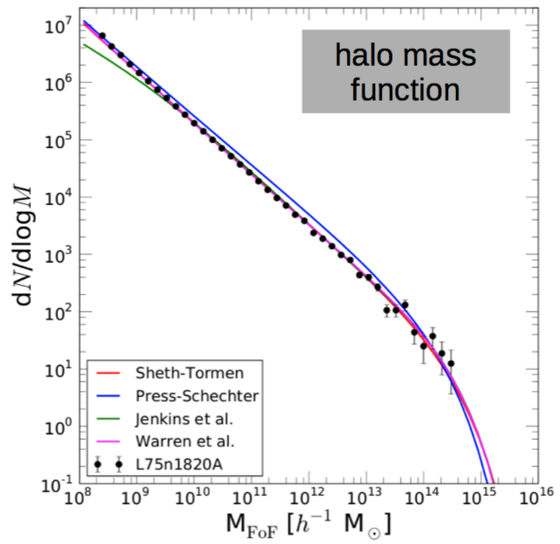


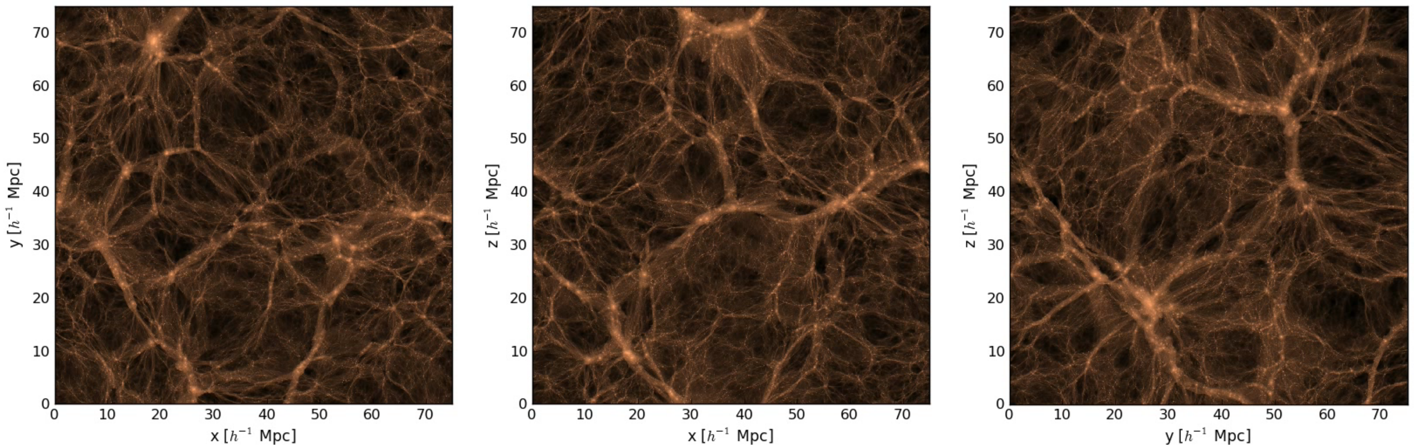
The Illustris Project

- (75Mpc/h)^3 box with 2*1820^3 resolution elements
- $M > 10^{14} M_{sun}$ halos @ z=0, resolving down to $M \approx 10^{8} M_{sun}$
- WMAP-7 cosmology

✓ DM-only run: done

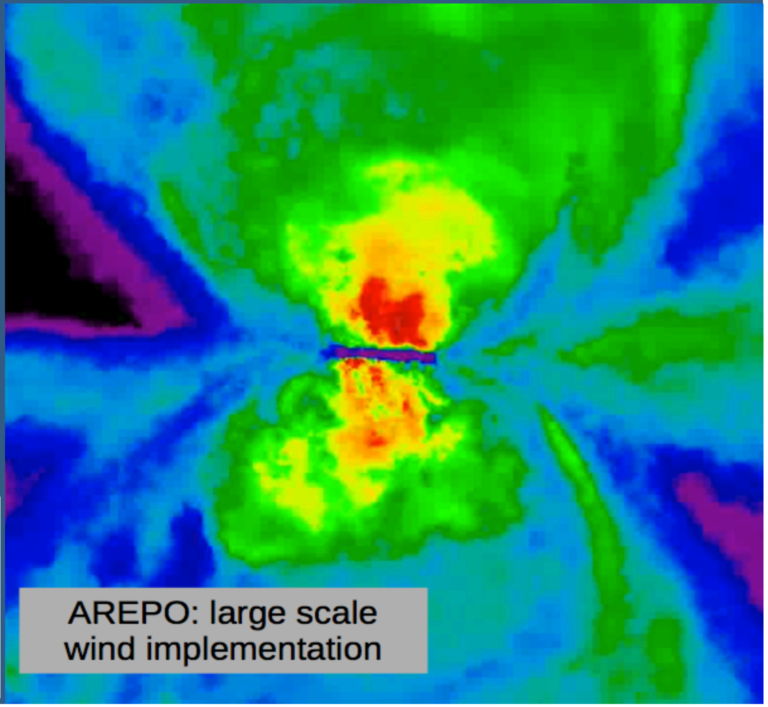
Genel et al. in prep.
Sijacki et al. in prep.
Vogelsberger et al. in prep.





Illustris galaxy formation physics

- Star formation and evolution: mass loss, SN rates
- Chemical enrichment following 9 elements
- Primordial + metal line cooling
- UV/X-ray cosmic background + AGN proximity effects
- Galactic winds
- BH growth, quasar & radio-mode feedback



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Quasi-steady state disks

Self-regulation to a mass quasi-steady state driven by cosmological accretion:

$$\left\{ \begin{aligned} \dot{M}_{\rm g} &= \dot{M}_{\rm cosmo} - \dot{M}_{\rm sink} \\ \dot{M}_{\rm sink} &= M_{\rm g}\tau^{-1} \end{aligned} \right\} \Rightarrow \left\{ \begin{aligned} \dot{M}_{\rm g} &\approx 0 \\ M_{\rm g} &\approx \dot{M}_{\rm cosmo}\tau \end{aligned} \right\}$$

$$\downarrow$$

$$\dot{M}_{\rm SFR} = M_{\rm g} t_{\rm SF}^{-1} \longrightarrow M_{\rm g} = \dot{M}_{\rm cosmo} t_{\rm SF}$$

and:

$$\dot{M}_{\rm SFR} = \dot{M}_{\rm cosmo}$$

See also Bouché+ 2010; Elmegreen & Burkert 2010; Davé+ 2011

Quasi-steady state disks

Self-regulation to a turbulent energy quasi-steady state driven by cosmological accretion:

$$\left\{ \begin{aligned} \dot{E}_\sigma &= \dot{E}_{\rm cosmo} - \dot{E}_{\rm sink} \\ \dot{E}_{\rm sink} &= E_\sigma \tau^{-1} \end{aligned} \right\} \longrightarrow \left\{ \begin{aligned} \dot{E}_\sigma &\approx 0 \\ E_\sigma &\approx \dot{E}_{\rm cosmo}\tau \end{aligned} \right\}$$

$$\downarrow$$

$$\dot{E}_{\rm dis} = E_\sigma t_{\rm dis}^{-1} \longrightarrow E_\sigma = \dot{E}_{\rm cosmo} t_{\rm dis}$$

and:

$$\dot{E}_{\rm dis} = \dot{E}_{\rm cosmo}$$

Gravitationally-driven turbulence

- Writing $E_\sigma \approx M_{\rm g}\sigma^2$ and $\dot{E}_{\rm cosmo} \approx \dot{M}_{\rm cosmo} V_{\rm rot}^2$, and combining the steady state results:

$$\frac{\sigma}{V_{\rm rot}} = \sqrt{\frac{t_{\rm dis}}{t_{\rm SF}}}$$

- Taking

$$t_{\rm dis} \equiv \gamma_{\rm dis} t_{\rm dyn} \approx (1-3)t_{\rm dyn} \quad ; \quad t_{\rm SF} \equiv \frac{t_{\rm dyn}}{\epsilon_{\rm SF}} \approx \frac{t_{\rm dyn}}{0.02} \,,$$

we obtain a fiducial value:

$$\frac{\sigma}{V_{\rm rot}} = \sqrt{\epsilon_{\rm SF}\gamma_{\rm dis}} \approx 0.2 \longrightarrow Q \approx \sqrt{2}\delta^{-1}\frac{\sigma}{V_{\rm rot}} \approx 0.3\delta^{-1}$$

Genel, Dekel & Caciatto, MNRAS, 2012

Gravitationally-driven turbulence

$$\frac{\sigma}{V_{\rm rot}} = \sqrt{\epsilon_{\rm SF}\gamma_{\rm dis}} \approx 0.2 \longrightarrow Q \approx \sqrt{2}\delta^{-1}\frac{\sigma}{V_{\rm rot}} \approx 0.3\delta^{-1}$$

In the local Universe:

- Gas velocity dispersions of $\sigma \approx 10{\rm km/s}$, and $\frac{\sigma}{V_{\rm rot}} \approx 0.05$
- Gas fraction $\delta \sim 0.03$

At high redshift (z~2):

- Gas velocity dispersions of $\sigma \approx 40 - 80{\rm km/s}$, and $\frac{\sigma}{V_{\rm rot}} \approx 0.25$
- Gas fraction $\delta \sim 0.3$

x5 (velocity dispersion ratio), x10 (gas fraction)

$$Q \approx \sqrt{2}\delta^{-1}\frac{\sigma}{V_{rot}} \sim 2-3 \xrightarrow{/2} Q \approx \sqrt{2}\delta^{-1}\frac{\sigma}{V_{rot}} \sim 1$$

Genel, Dekel & Caciatto, MNRAS, 2012