Mass quenching, cold flows and gas inflow into galaxies

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Outline

- The stability of virial shocks (recap of 2003 results)
- Application for spherical and filamentary infall
- How people misquote us (or: is the name "cold flows" misleading?)
- K-H stability of cosmic filaments
- The virial shocks of pancakes and filaments

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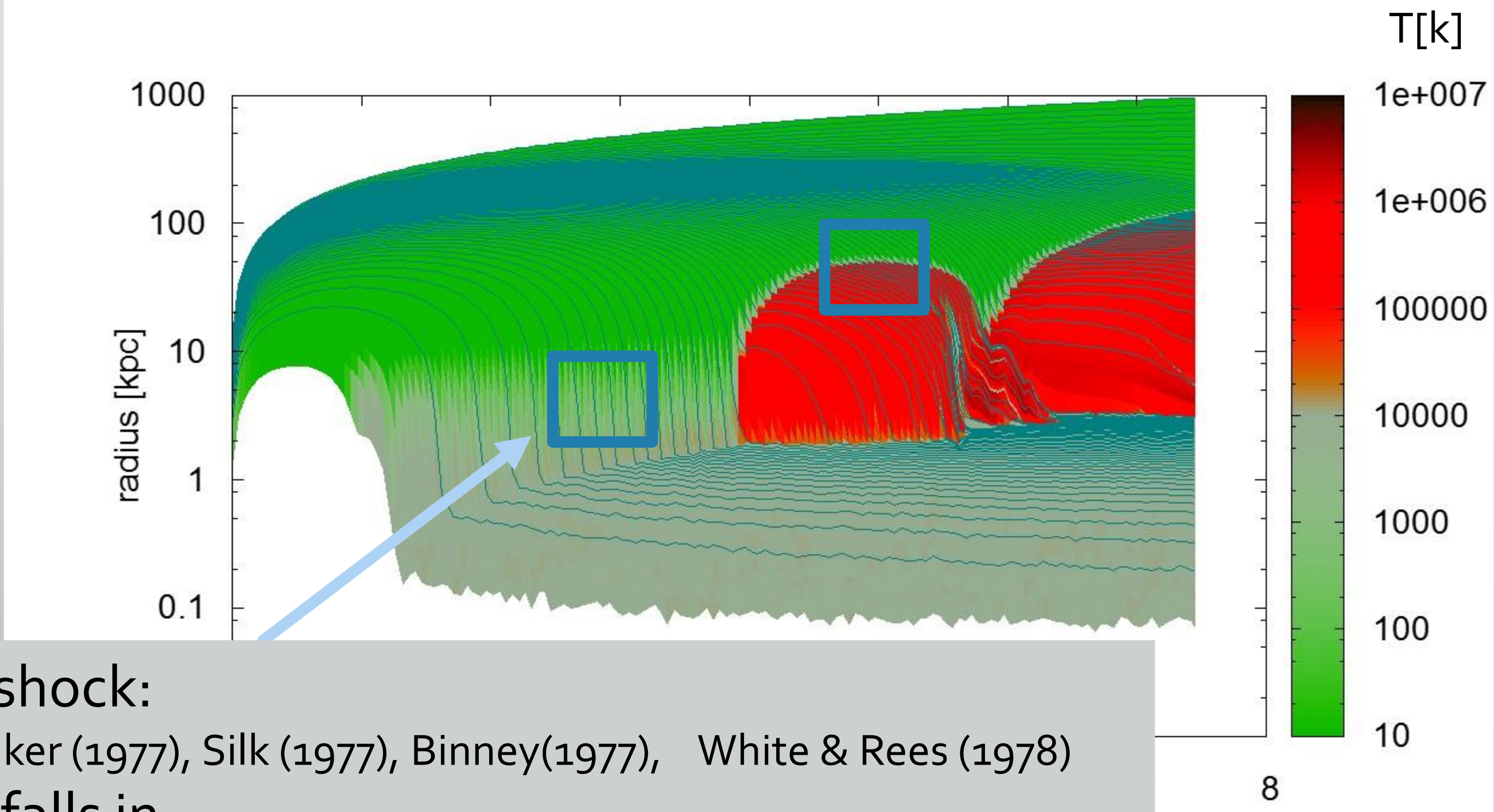
The stability of virial shocks (recap of 2003 results)



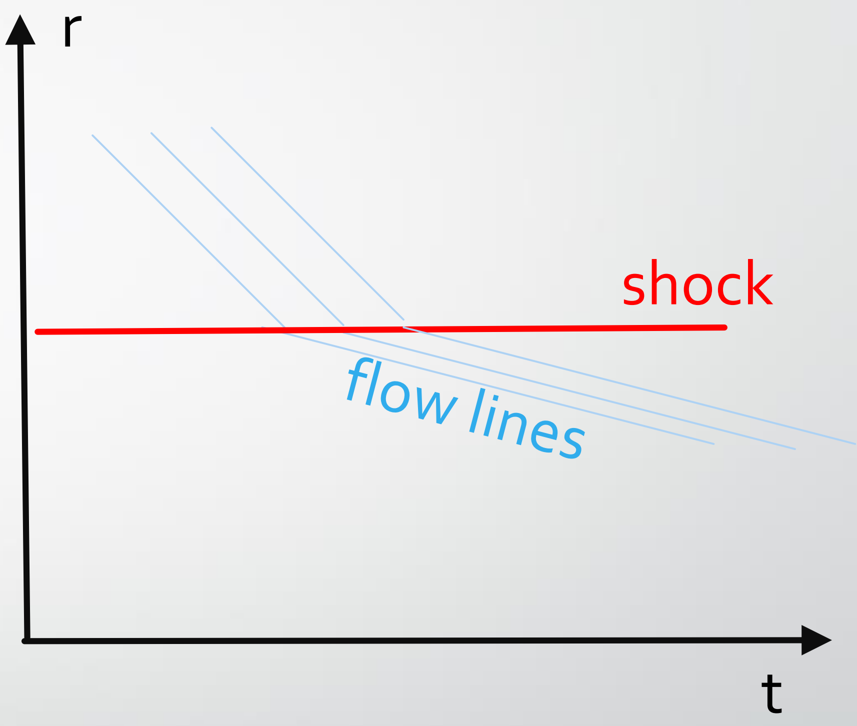
No virial shock:

Rees & Ostriker (1977), Silk (1977), Binney(1977), White & Rees (1978)

Gas free-falls in

Birnboim & Dekel 2003

The stability analysis



Assume:

1. Forces in post-shock gas are initially zero $\ddot{r} = 0$
2. Outwards force => gas stable => shock stable
3. Velocities are non-zero
   I. Homologic $u = \frac{u_s}{r_s} r$
   II. v is NOT small (ie. non-linear) perturbation
   III. v is specific (no ω(k))
4. Perturbation analysis in r-space $r \to r + \delta r = r + u\delta t$; $\mathrm{P} \to P + \delta P$
5. Cooling is important

The stability analysis – effective polytropic index

For ideal gas : $P = (\gamma - 1)\rho e$ with cooling rate q :

$$\gamma = \left(\frac{\partial \ln P}{\partial \ln \rho} \right)_S$$

$$\gamma_{eff} \equiv \frac{d(\ln P)}{d(\ln \rho)} = \frac{\rho}{P}\left(\frac{\dot{P}}{\dot{\rho}} \right)$$

$$\dot{e} = -P\dot{V} - q$$

$$\gamma_{eff} = \gamma - \frac{\rho}{\dot{\rho}} \Big/ \frac{e}{q}$$

Compression time

Cooling time

Do the actual work… …and after some algebra:

$$\delta\ddot{r} = \underbrace{\frac{12\pi r^2 u_1 \delta t P'}{r_s}}_{>0}\left[\gamma - \frac{2}{\gamma_{eff}}(\gamma - \gamma_{eff}) - \frac{4}{3}\right]$$

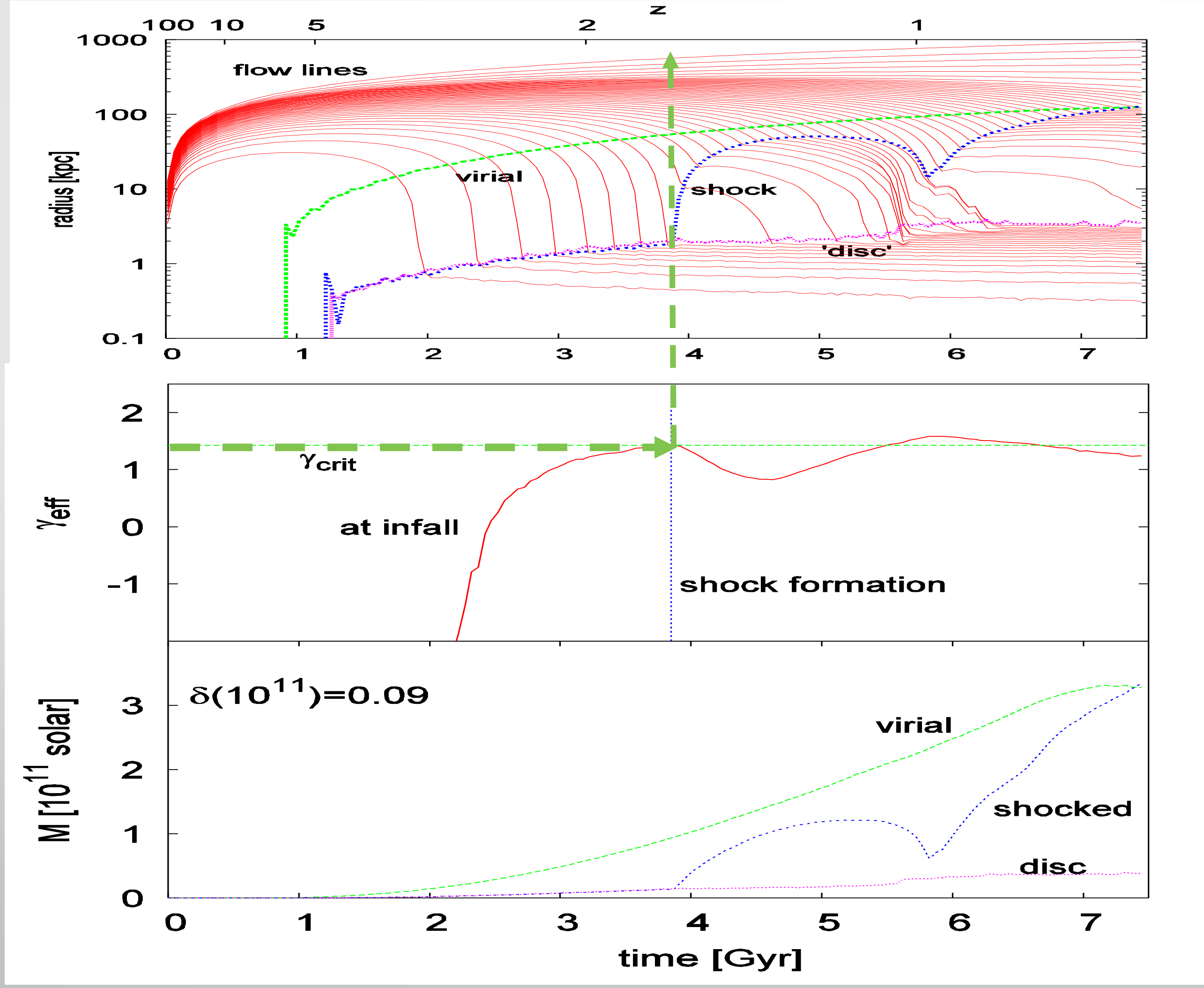
So,

$$\gamma_{crit} = \frac{2\gamma}{\gamma + 2/3} = \frac{10}{7} = 1.43 \quad \text{for } \gamma = 5/3 \text{ gas}$$

$\gamma_{eff} < \gamma_{crit}$ unstable

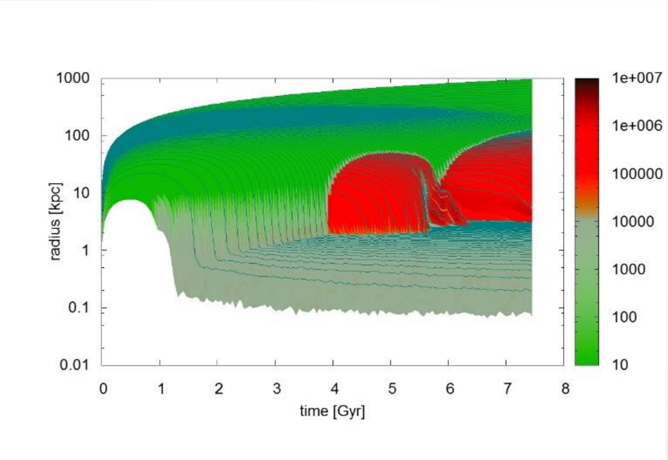
$\gamma_{eff} > \gamma_{crit}$ stable

Simulation confirms analytic model: shock when $\gamma_{eff} > \gamma_{crit}$=1.43



No free parameters, no fudge factors

Important note!



The stability criterion checks if gas can be hydrostatic.

Not if it is hot.

Shocks are expected, but will collapse on a dynamic timescale

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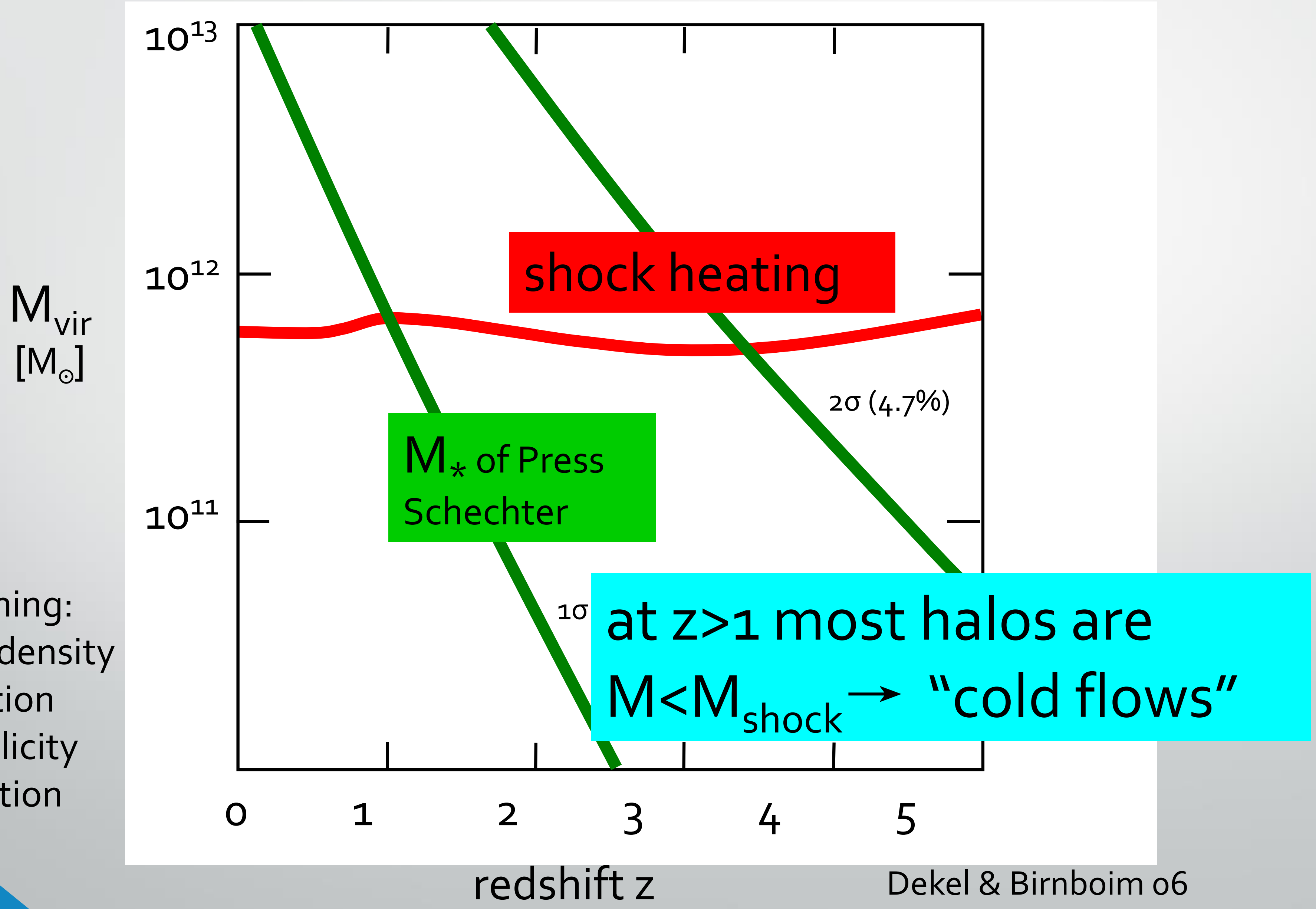
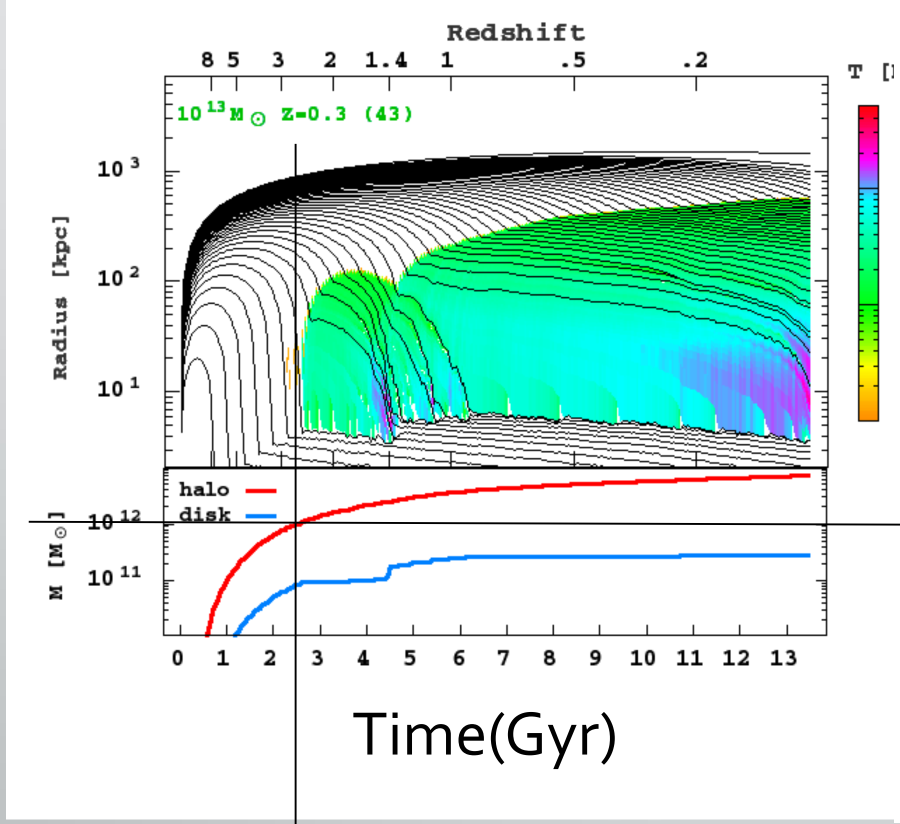
Cold Flows in Spherical Halos

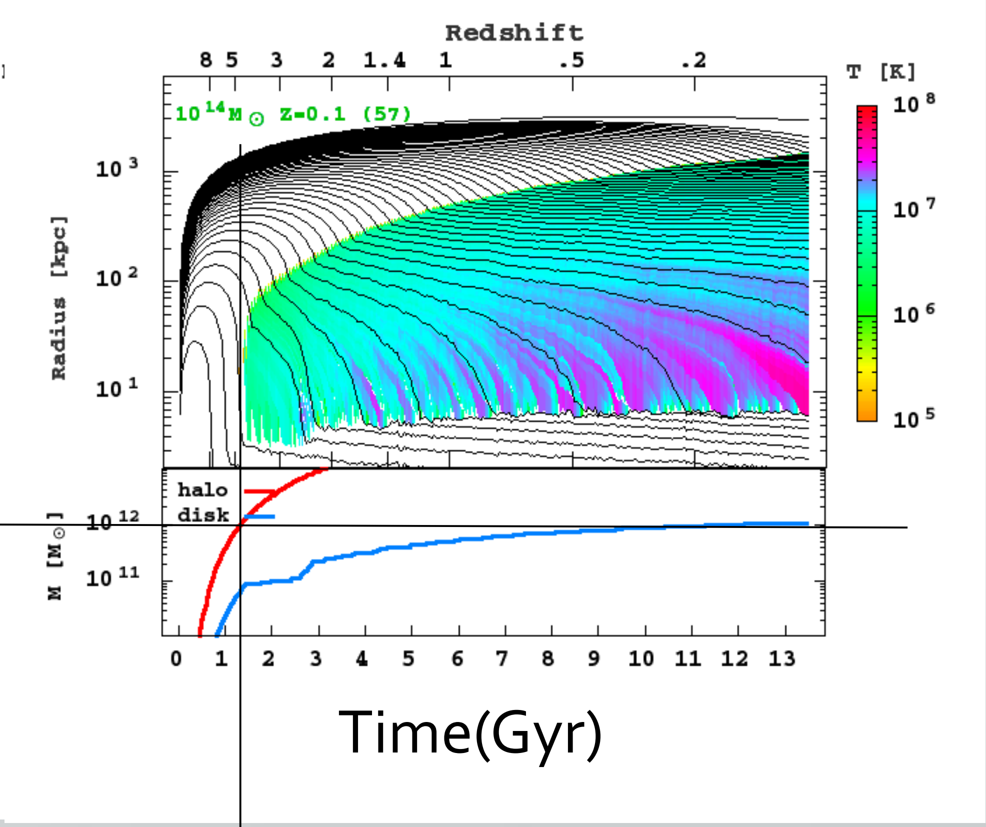


Assuming:
- Overdensity evolution
- Metalicity evolution

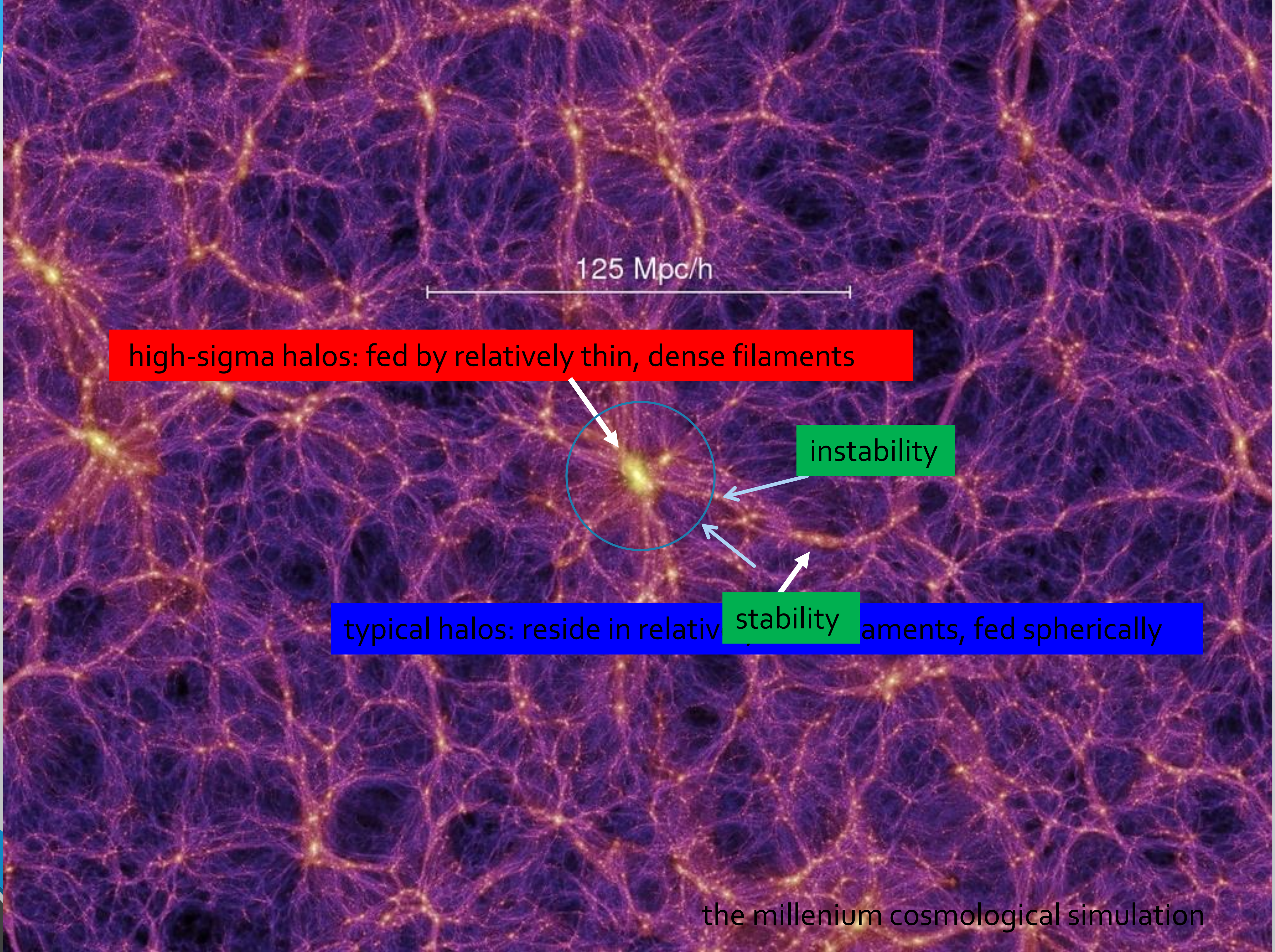
Dekel & Birnboim 06

Shock always forms at same mass



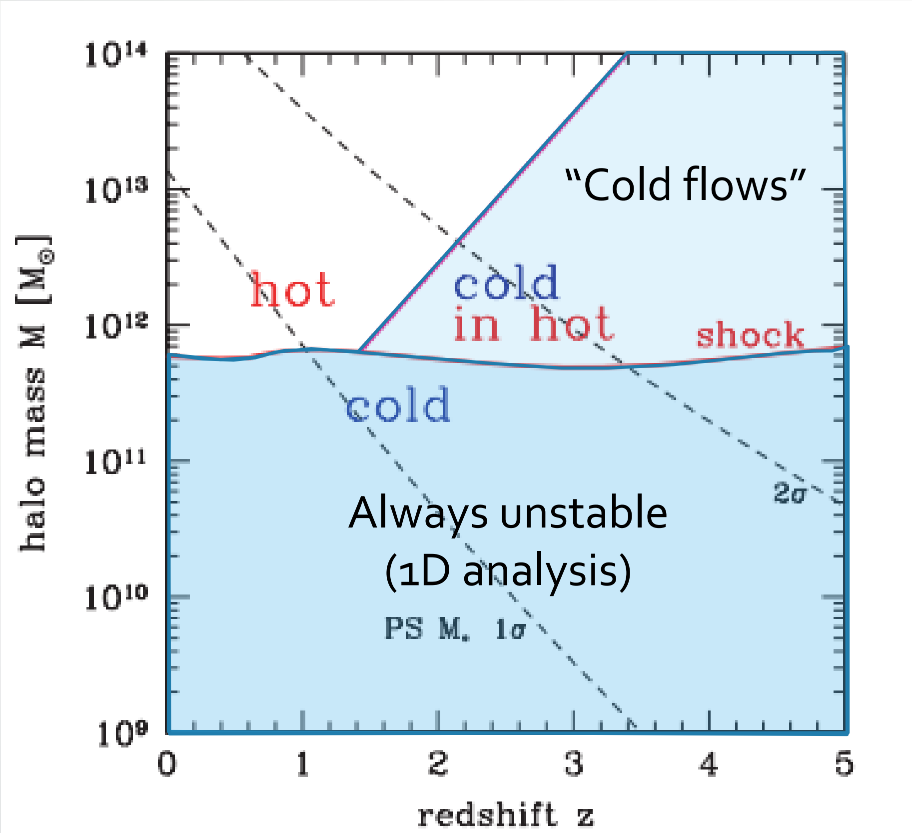


High z vs. Low z
Spherical vs. Filamentary



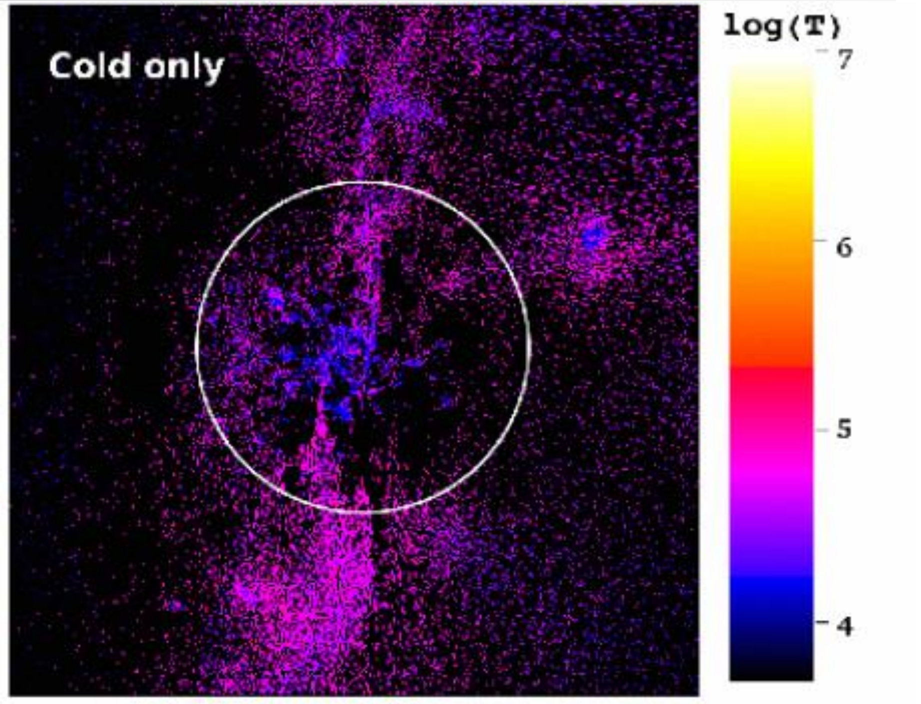
the millenium cosmological simulation

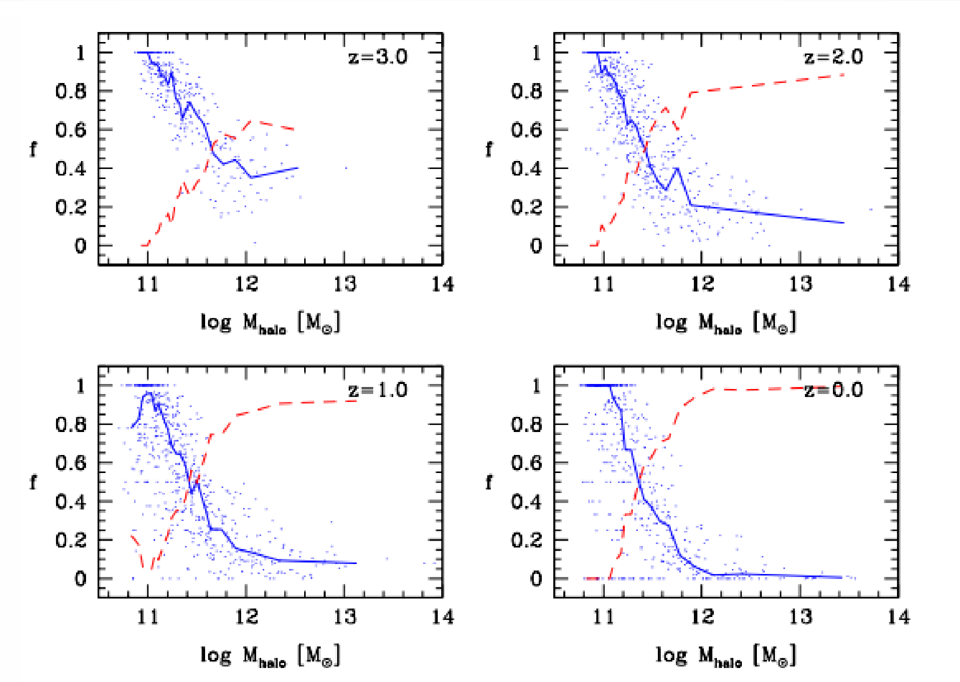
Cosmological Context



Dekel & Birnboim 2006

3D SPH hydro-simulations

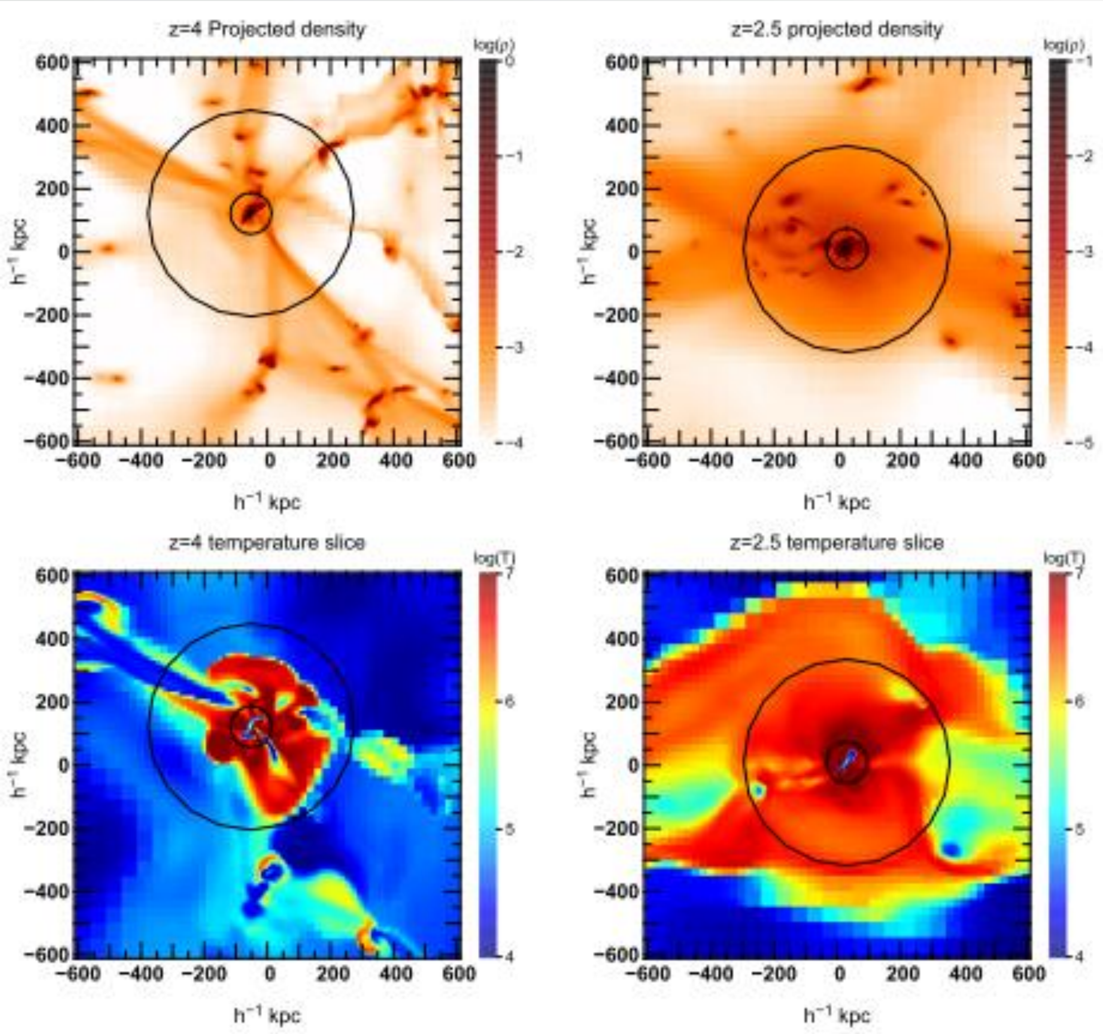


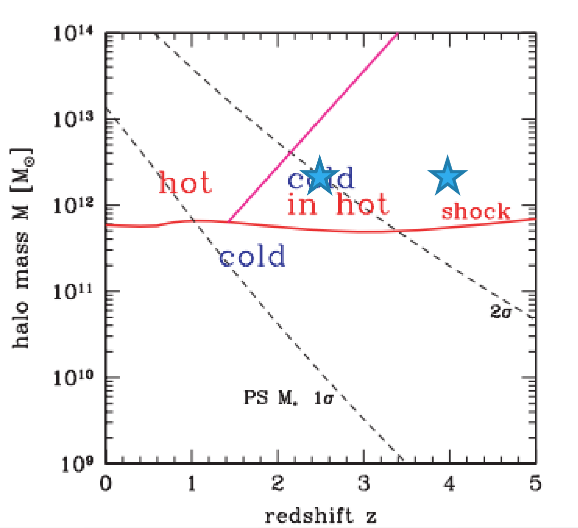


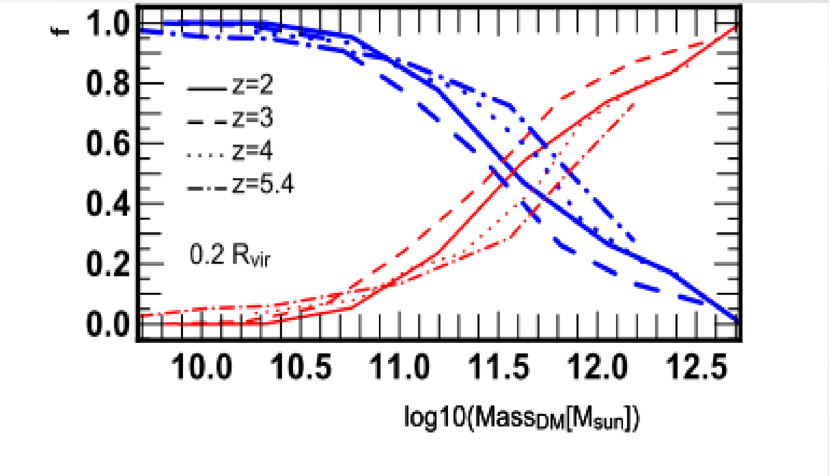
See also, Brooks et al. 09(GASOLINE), ., Schaye et al. …

Kereš et al. 2005
Kereš et al. 2009

3D Eulerian hydro-simulations



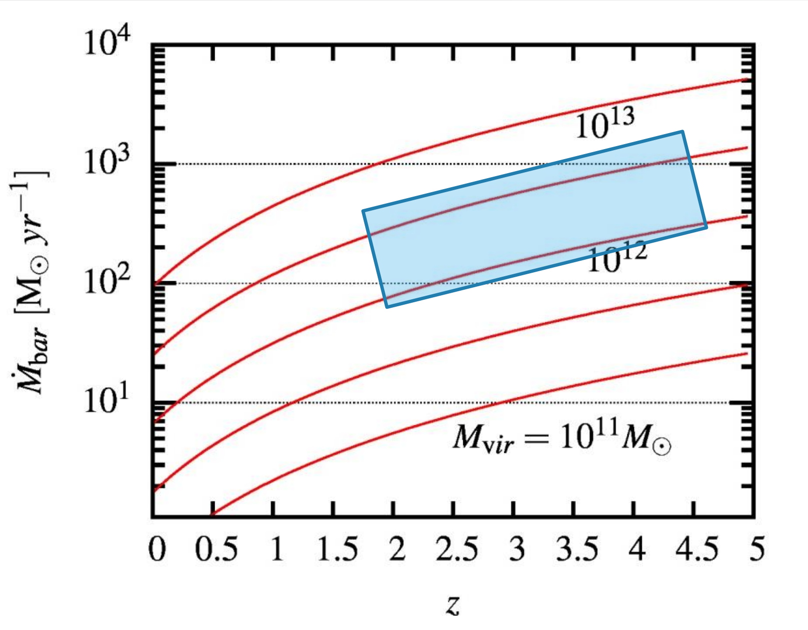




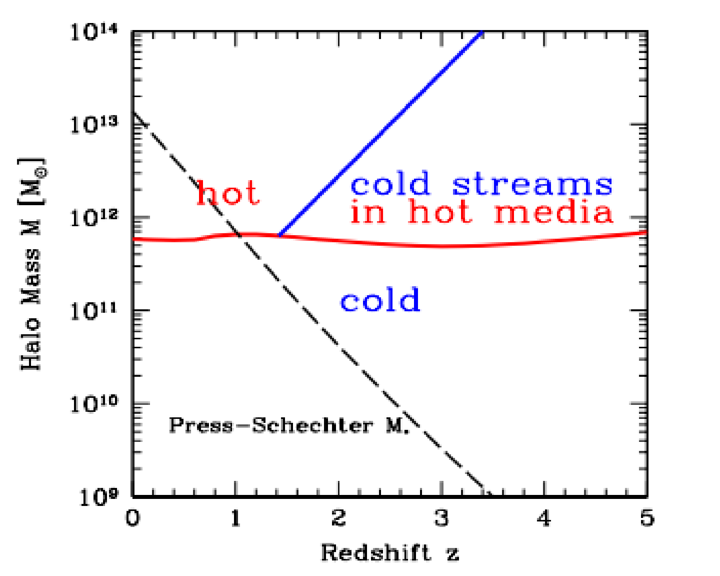
2e12 halo, z=4 2e12 halo, z=2.5 Ocvirk et al. 2008

See also, Kravtsov et al. (ART), Agertz et al. …

Most stars in the universe form through unstable accretion

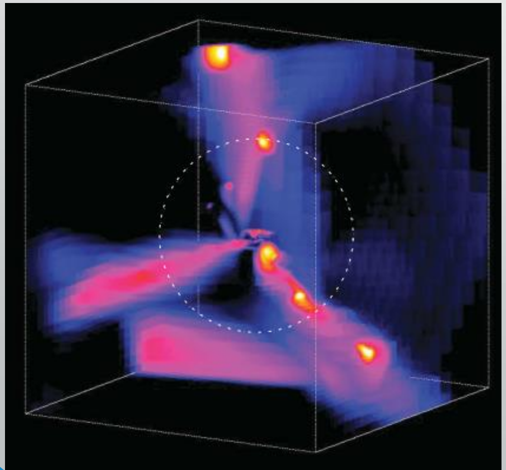


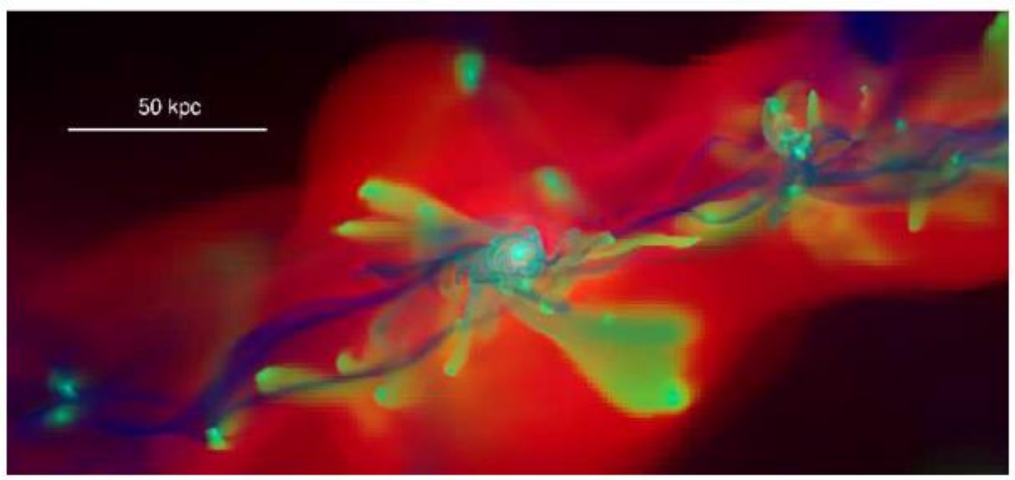
Wechsler et al 2002, Dekel et al. 2009



Dekel & Birnboim 2006
Keres et al. 05-09

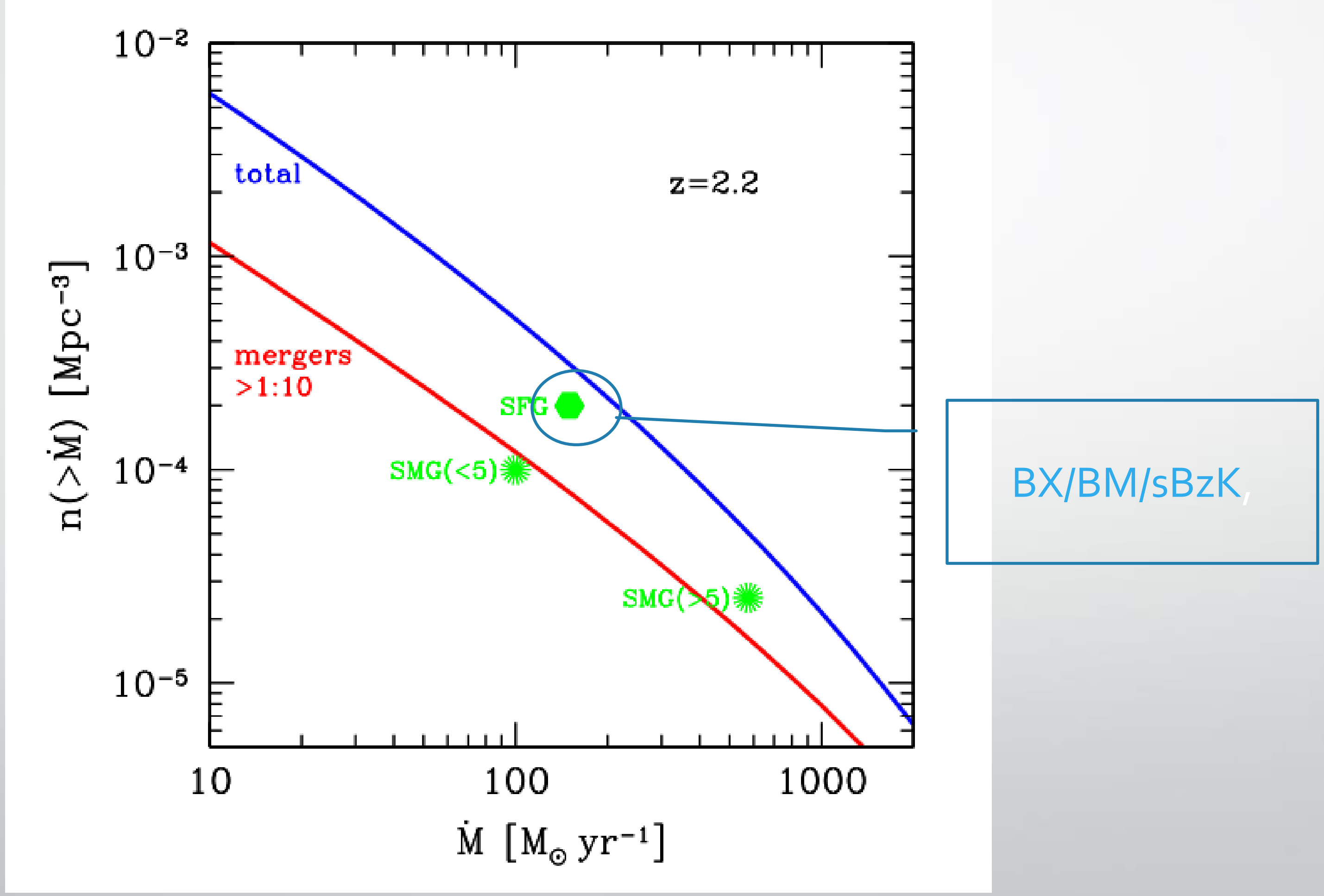
Agertz et al. 2009





Star forming galaxies

Cold accretion vs. Merger induced star bursts



Dekel, Birnboim et al. 2009, Nature

How people misquote us
(or: is the name "cold flows" misleading?)

cold flows (*noun*): Dusan Kereš 2005

"Cold flow" definition	application
Gas is never hydrostatic	good for gas accretion rates
Gas is cold within R_{vir} (Ocvirk 08, Agartz 09, Dekel 09)	good for observability of cold flows
Gas never heated (Kereš 05, Nelson 13)	good for analyzing Lagrangian sims

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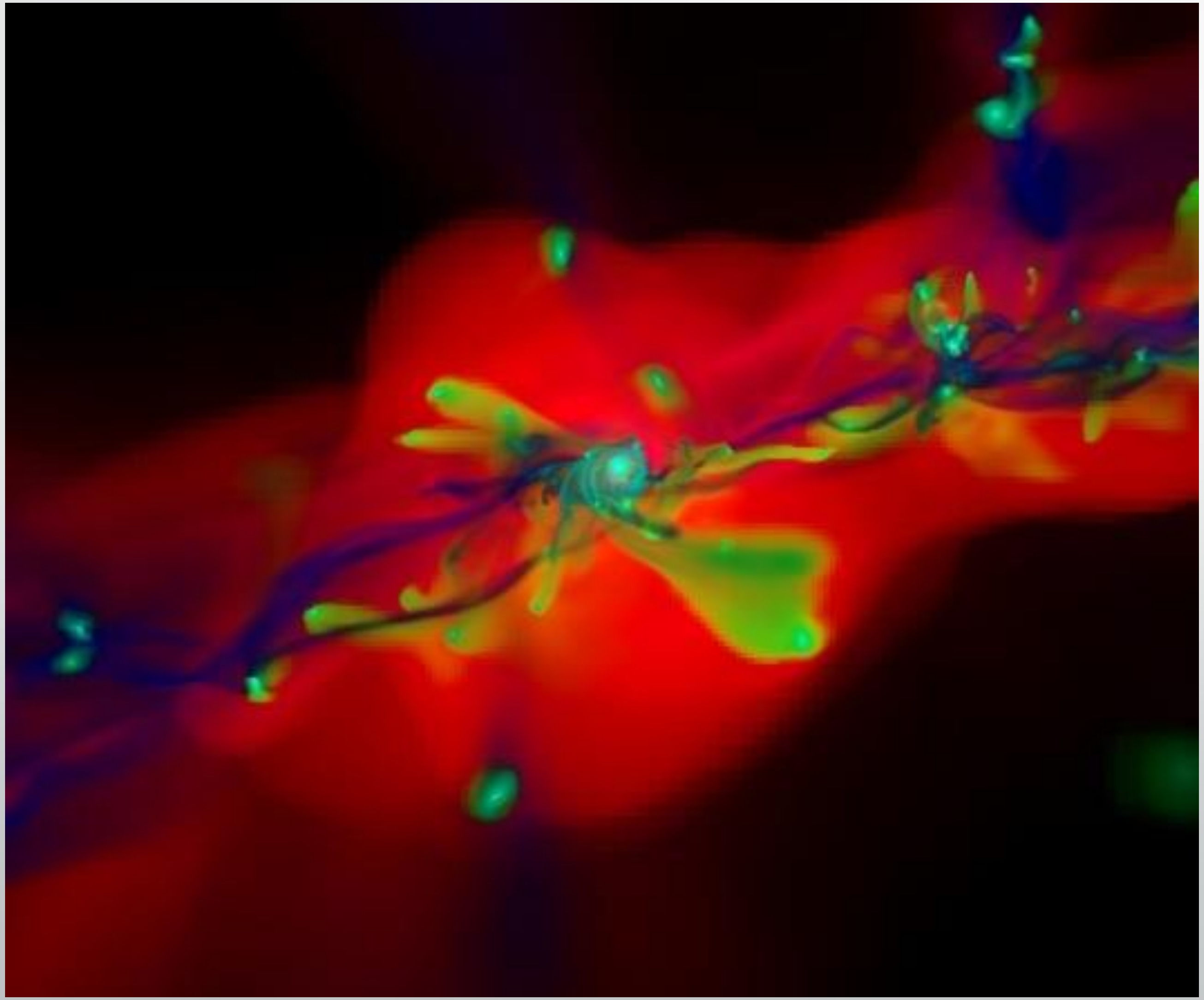
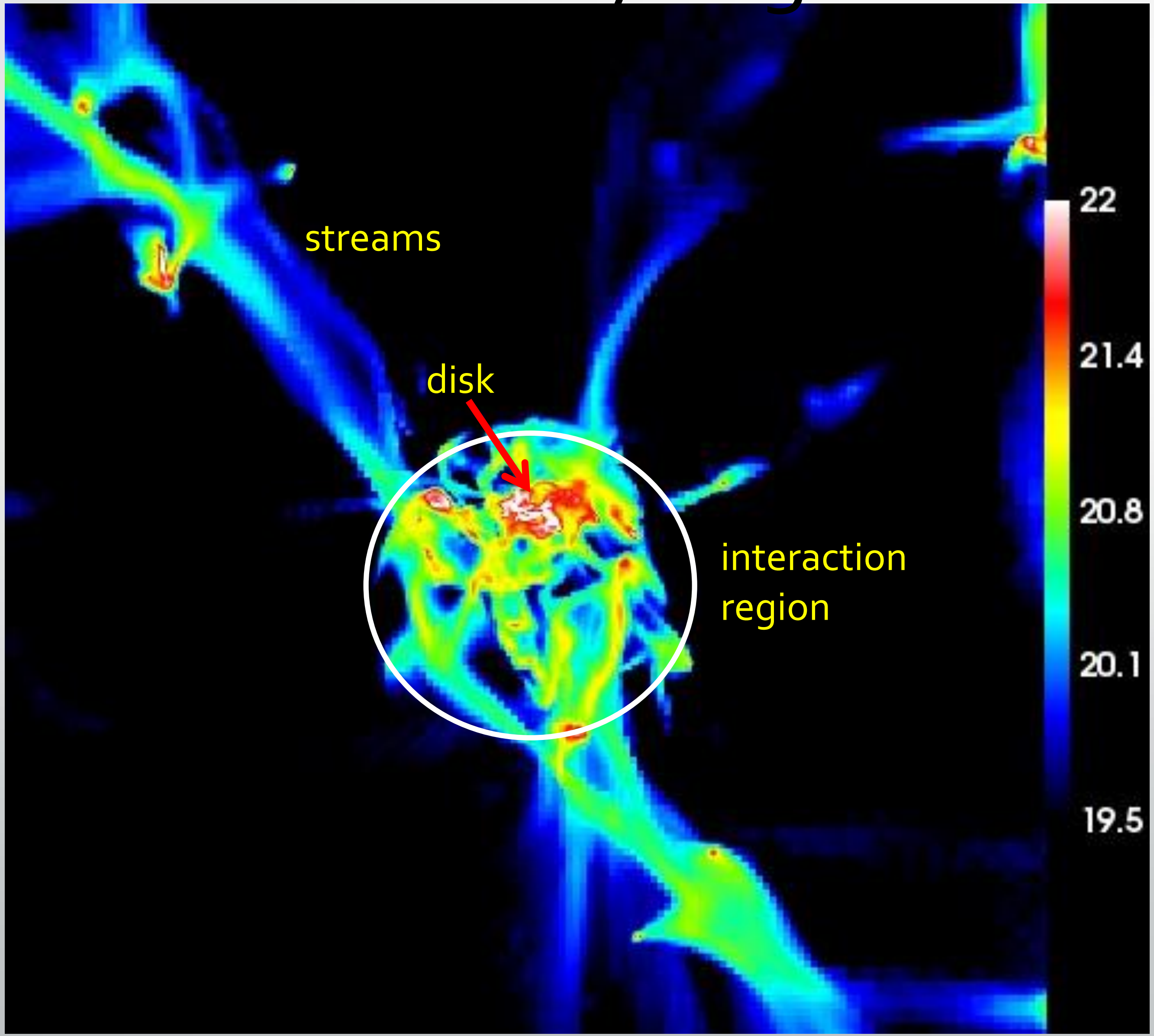
Kelvin Helmholtz instability of infalling streams



Agertz et al 2009
RAMSES

What happens to the flow near the galaxy?
The 'messy' region



Ceverino, Dekel, Bournaud 2010
ART 35-70pc resolution

Typical numbers for streams

Stream temperature: $T_c \sim 10^4 - 10^5\ K$

Surrounding temperature: $T_h \geq 10^6\ K\ \left(\mathrm{M_h} \geq 10^{12} M_\odot\right)$

Pressure equilibrium: $P_h \simeq P_c$

Density contrast: $\frac{\rho_c}{\rho_h} \simeq 10 - 100$

Stream velocity: $V \simeq V_{vir} \sim \sqrt{\frac{K_B T_{vir}}{m}} \sim C_{s,\mathrm{hot}}$

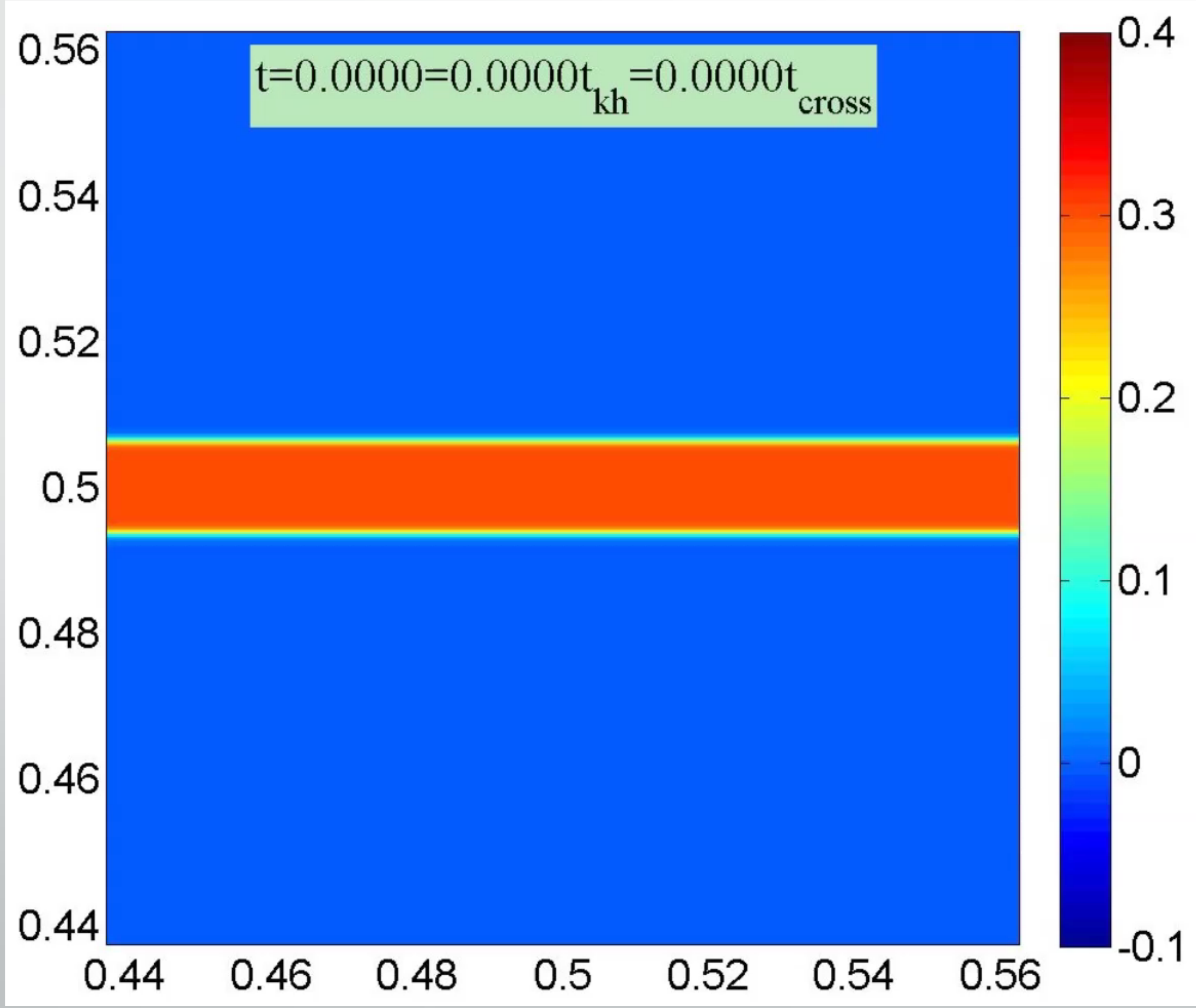
Mach number: $\mathrm{M_{hot}} \equiv \frac{V}{C_{s,hot}} \sim 1 - 1.5, M_{cold} = 3 - 15$

Stream radius: $\mathrm{R_s} \leq 10\ kpc \sim 0.1\ R_{vir}$

Size ratio: $\frac{R_s}{R_{vir}} \sim 0.05 - 0.1$

Mandelker, Padnos, Dekel, Birnboim; in prep.

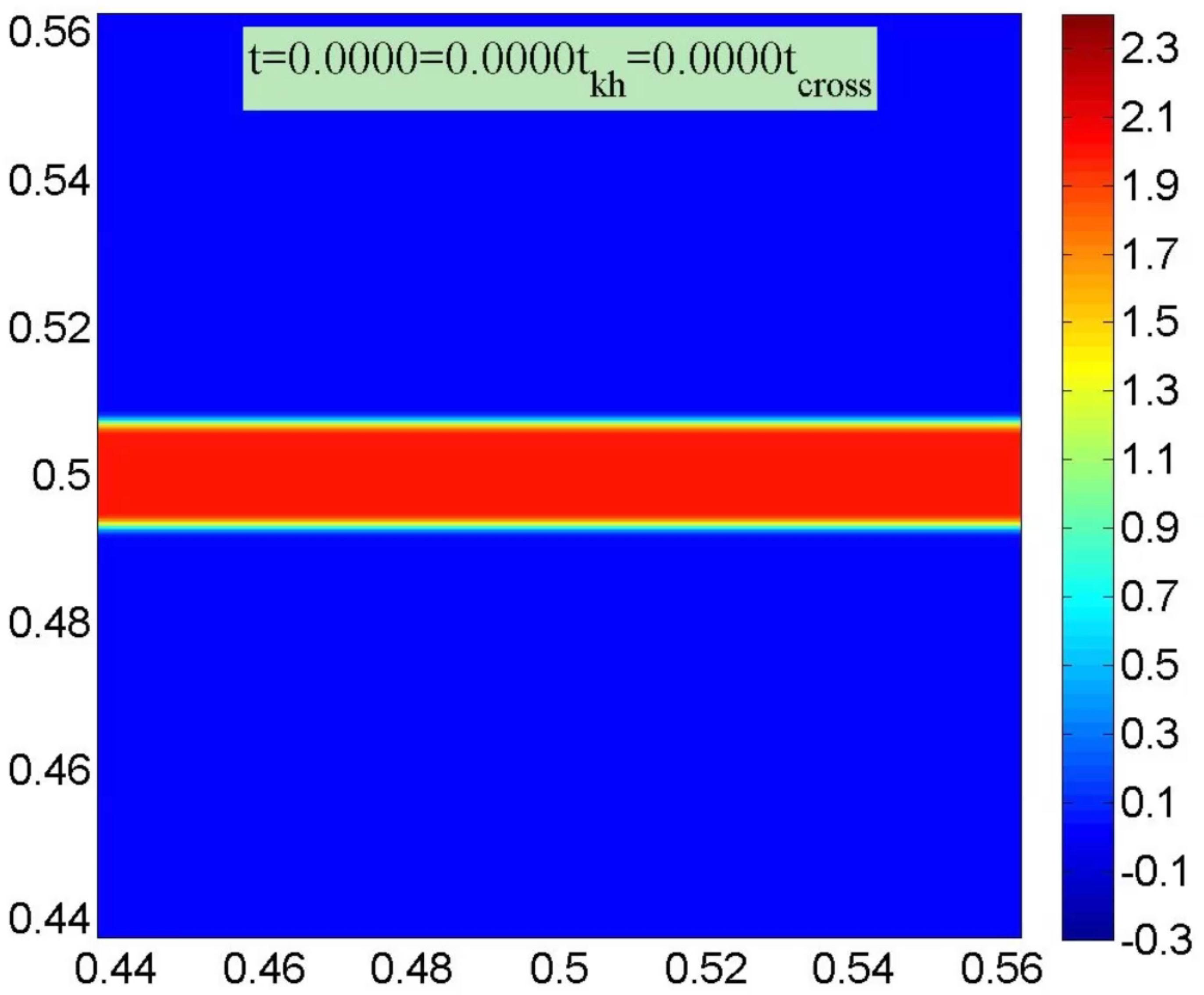
$M = 0.5 \;\; \delta_\rho = 2$



Mandelker, Padnos, Dekel, Birnboim; in prep.

RAMSES (teyssier 02)

$M = 1.5 \;\; \delta_\rho = 100$



Goal: An Analytic dispersion relation for super-sonic KH for cylinder, slab or plane

Analysis performed by two bright students: Nir Mandelker, Dan Padnos

	Planar	Slab	Cylinder
Non-compressible	‘Classical’	Sheet instability	
compressible			Filaments, relativistic jets

Initial results:
For M>>1 flow is stable.
What happens for M1~1, M2>>1?
Stability against tangent perturbation?

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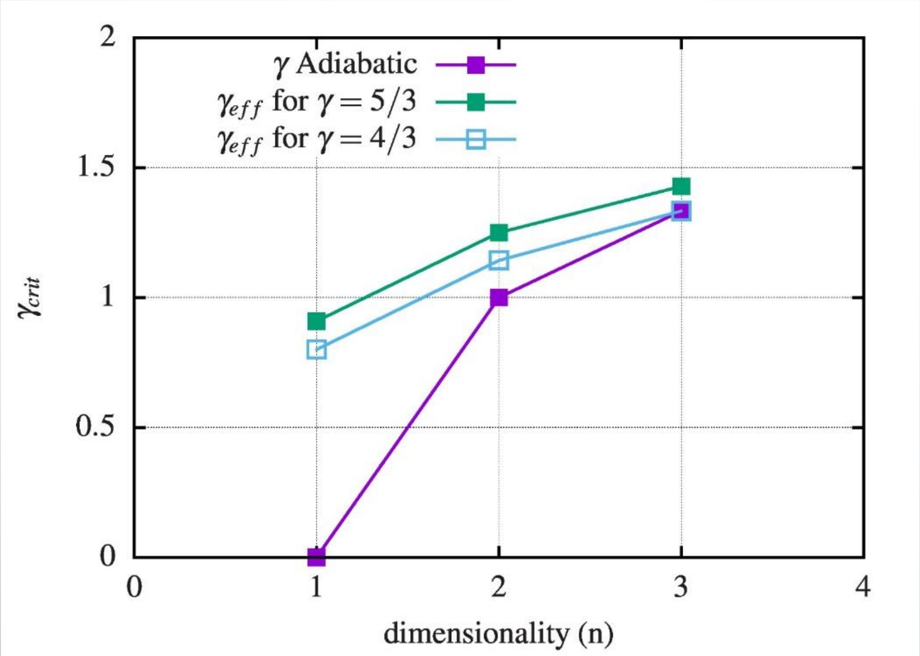
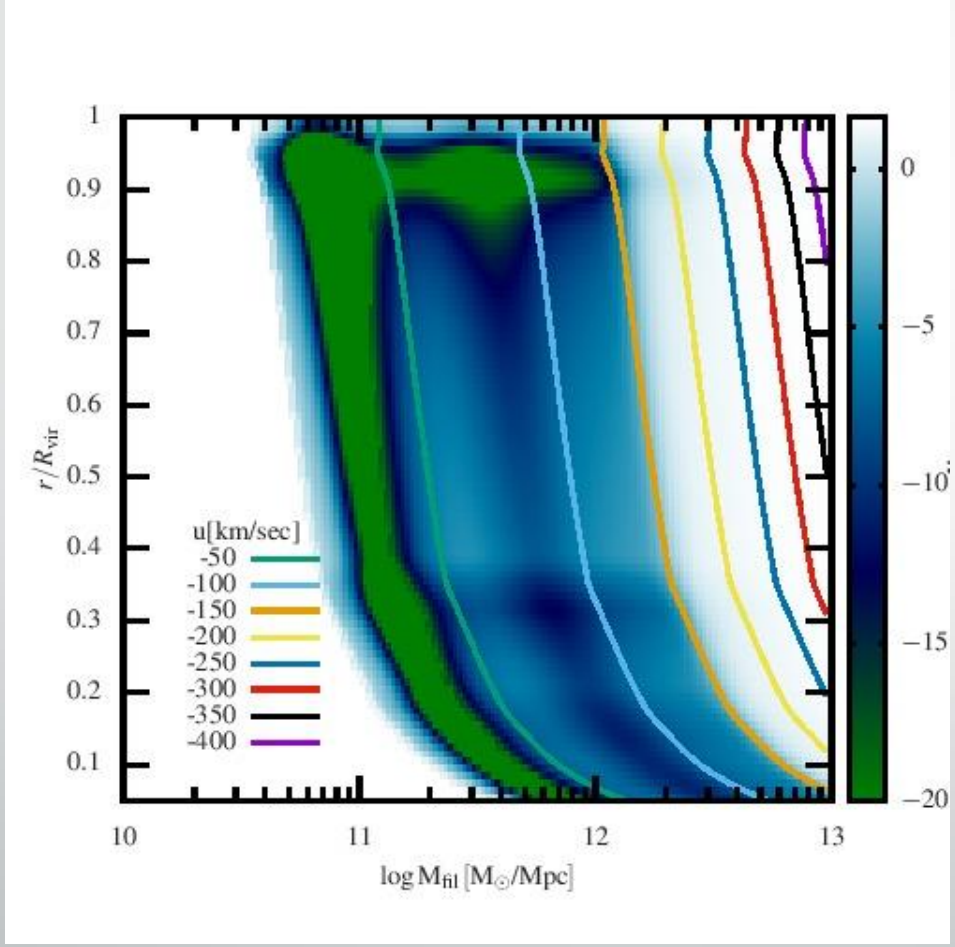
Stability criteria for virial shocks of pancakes, filaments and halos

$$\gamma_{eff} \equiv \frac{d(\ln P)}{d(\ln \rho)} = \frac{\rho}{P}\left(\frac{\dot{P}}{\dot{\rho}}\right)$$

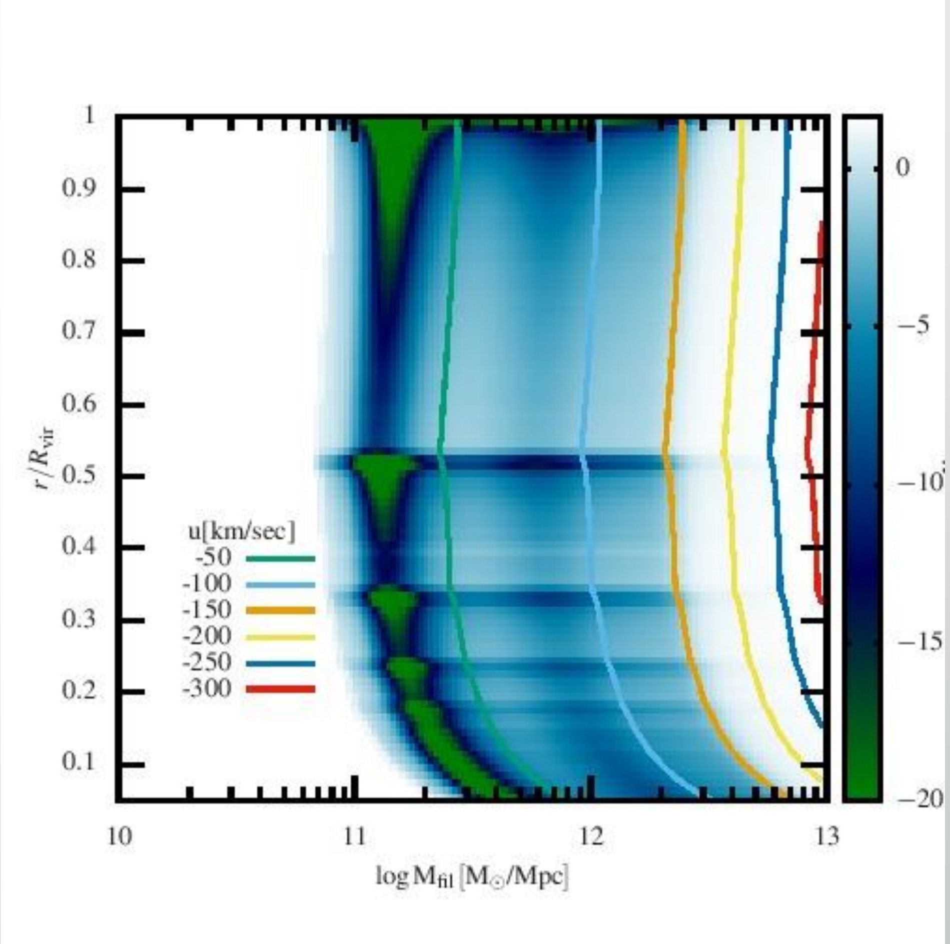


Birnboim, Hahn, Padnos 2014 (in prep.)

Stability of filaments



ε=0.2



ε=0.99

Birnboim, Hahn, Padnos 2014 (in prep.)
Based on similarity solutions of Fillmore_Goldreich 84

Summary

- Mass threshold is for the stability of gas.

  Below threshold - if gas shocks, the shocks will fall in of free-fall timescales
- Transition occurs at ~$10^{12} M_{\odot}$ with unstable filaments penetrating

  stable halo at high-z
- Gaseous filaments are (probably) KH stable because of supersonic flow – stay tuned
- Virial shocks for filaments/sheets are not always stable either

Thank you