Galaxy Buildup by Narrow Streams at High z

Avishai Dekel, HU

June 2008

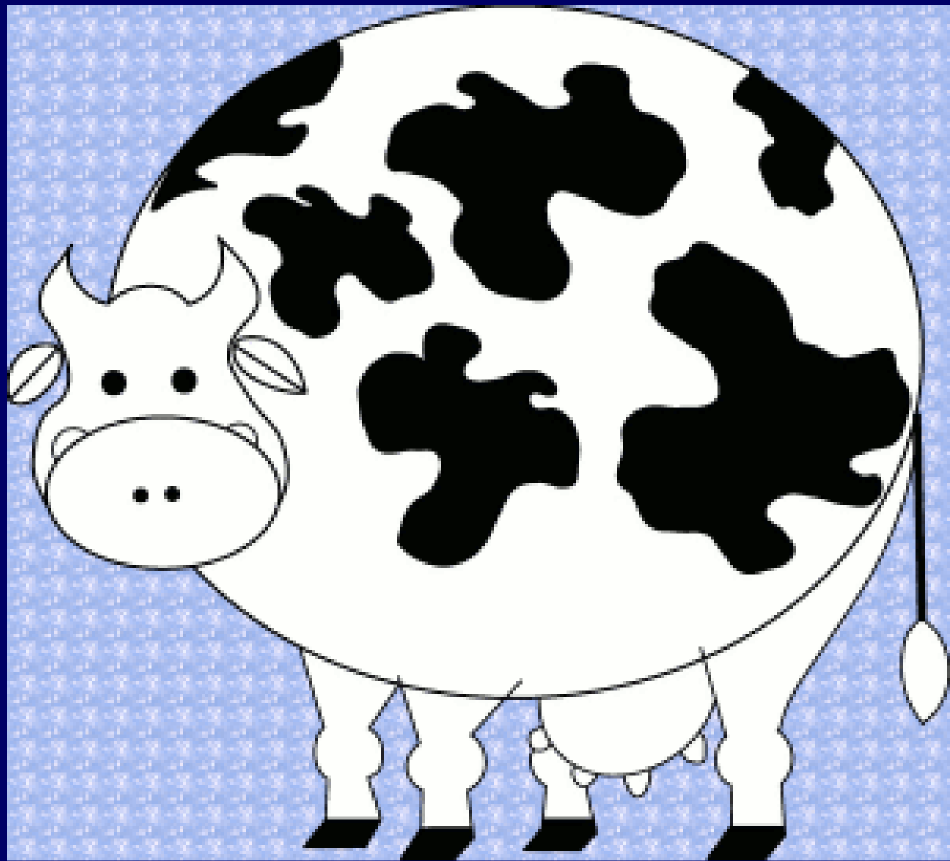
Simulations: Teyssier, Pichon, et al.; Kravtsov et al.

Analysis: Freundlich, Goerdt, Neistein,
Birnboim, Engel, Mumcuoglu, Zinger, Libeskind

Outline

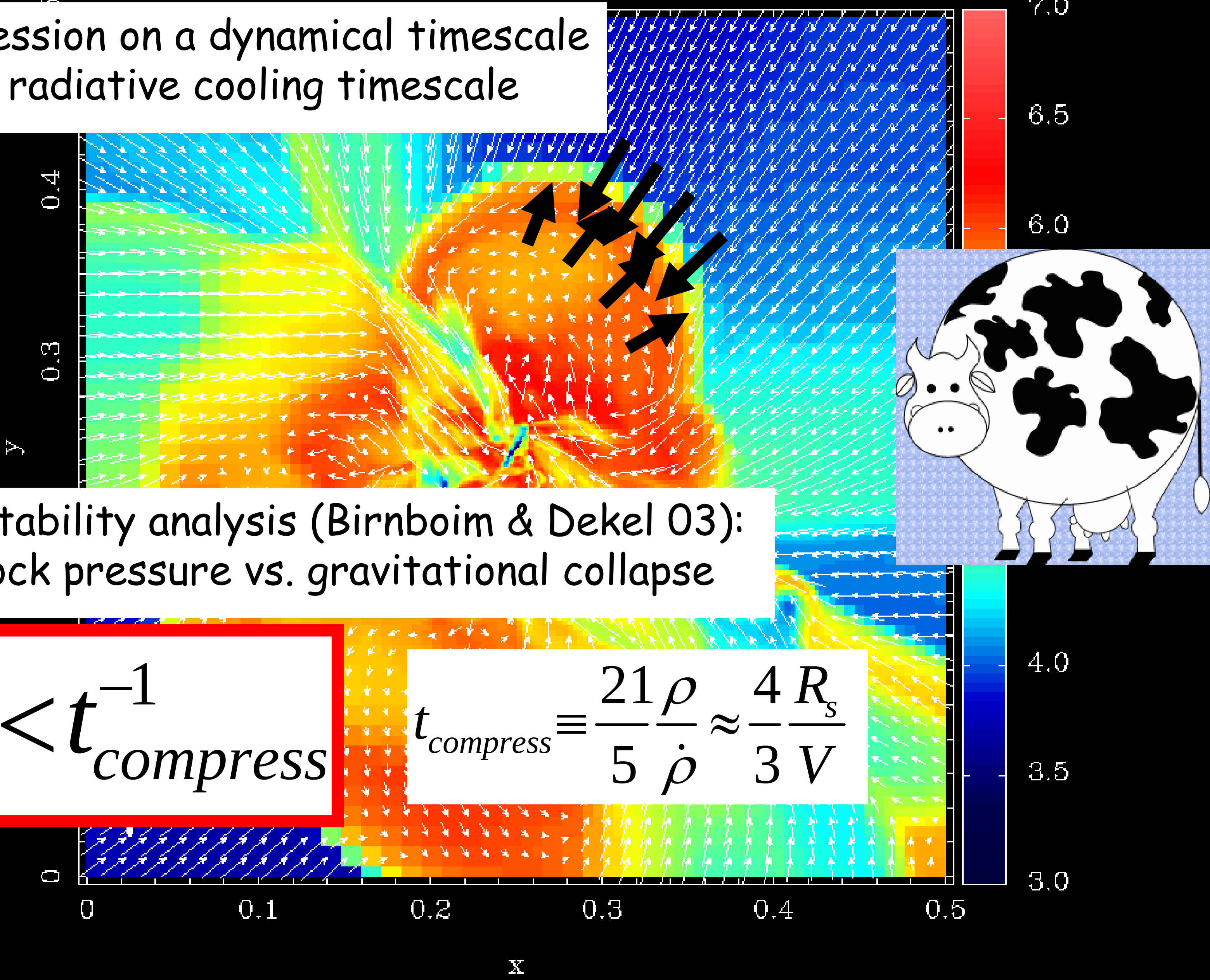
- Virial shock heating
- At high z: cold streams in hot media
- Gas flux into disk vs virial radius
- Mergers vs smooth flows
- High SFR galaxies at z=2-3

Consider a spherical cow…



Gas through shock: heats to virial temperature

compression on a dynamical timescale
versus radiative cooling timescale

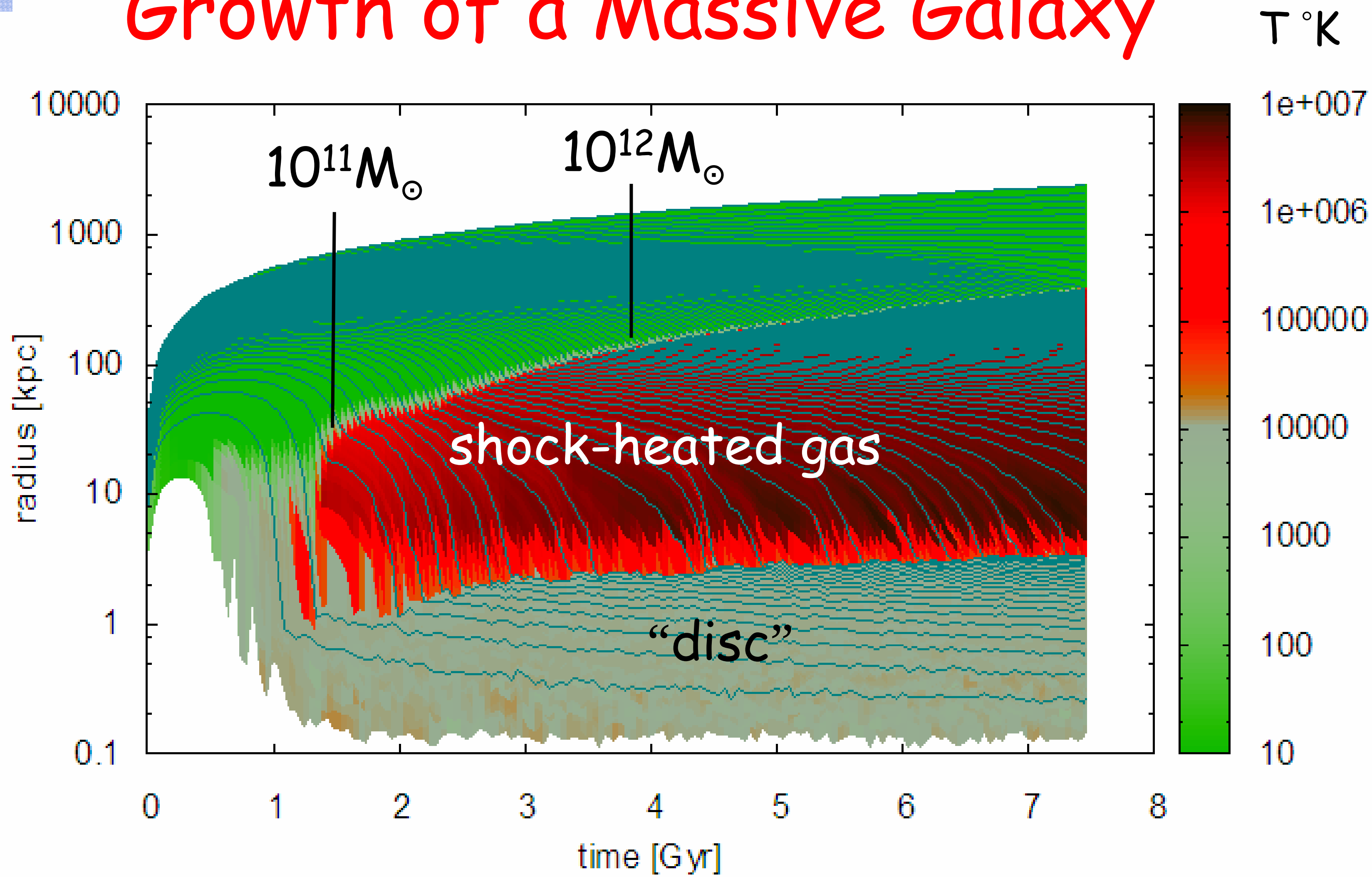


Shock-stability analysis (Birnboim & Dekel 03):
post-shock pressure vs. gravitational collapse

$$t_{cool}^{-1} < t_{compress}^{-1}$$

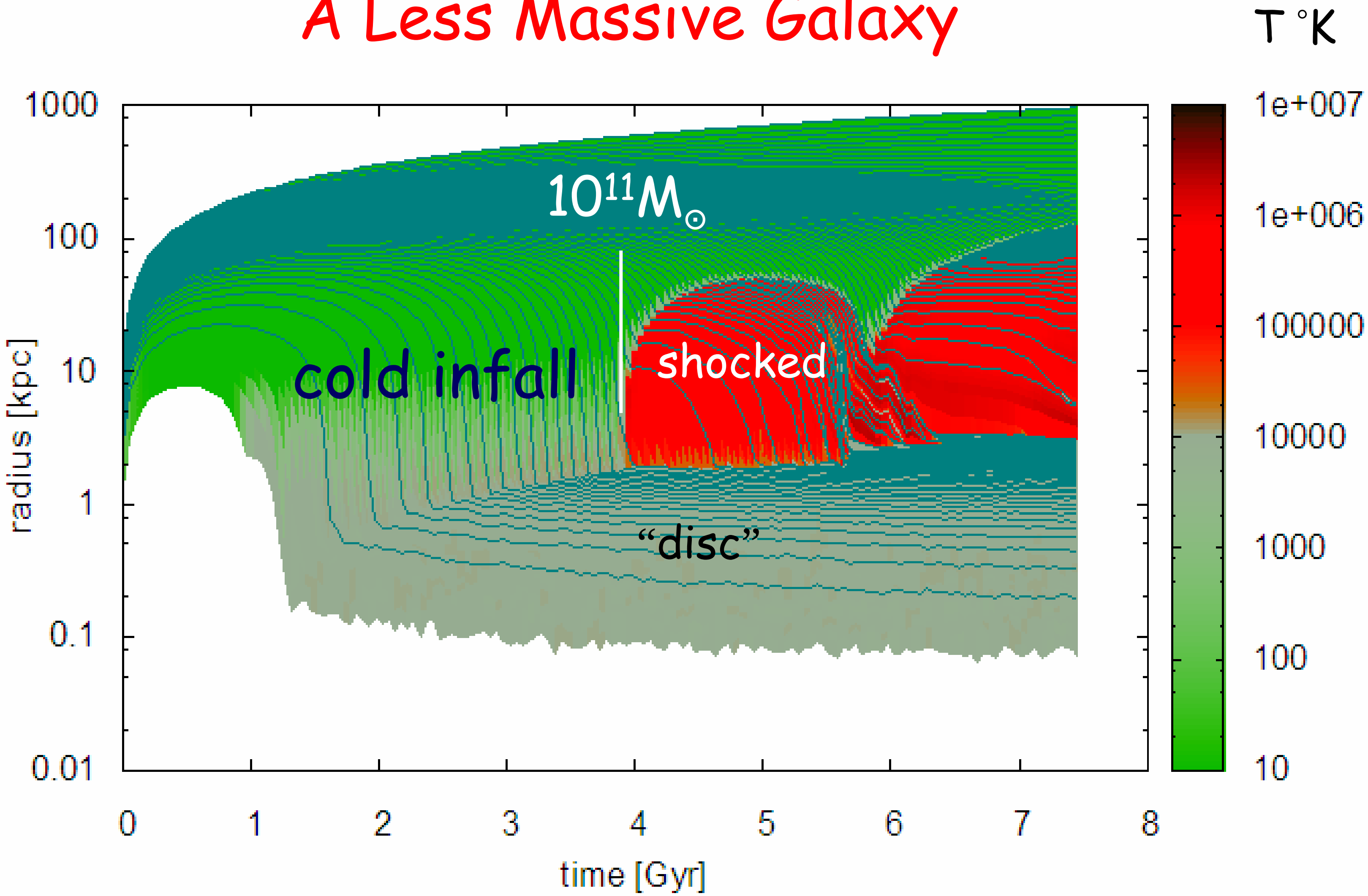
$$t_{compress} \equiv \frac{21}{5}\frac{\rho}{\dot{\rho}} \approx \frac{4}{3}\frac{R_s}{V}$$

Growth of a Massive Galaxy



Spherical hydro simulation Birnboim & Dekel 03

A Less Massive Galaxy



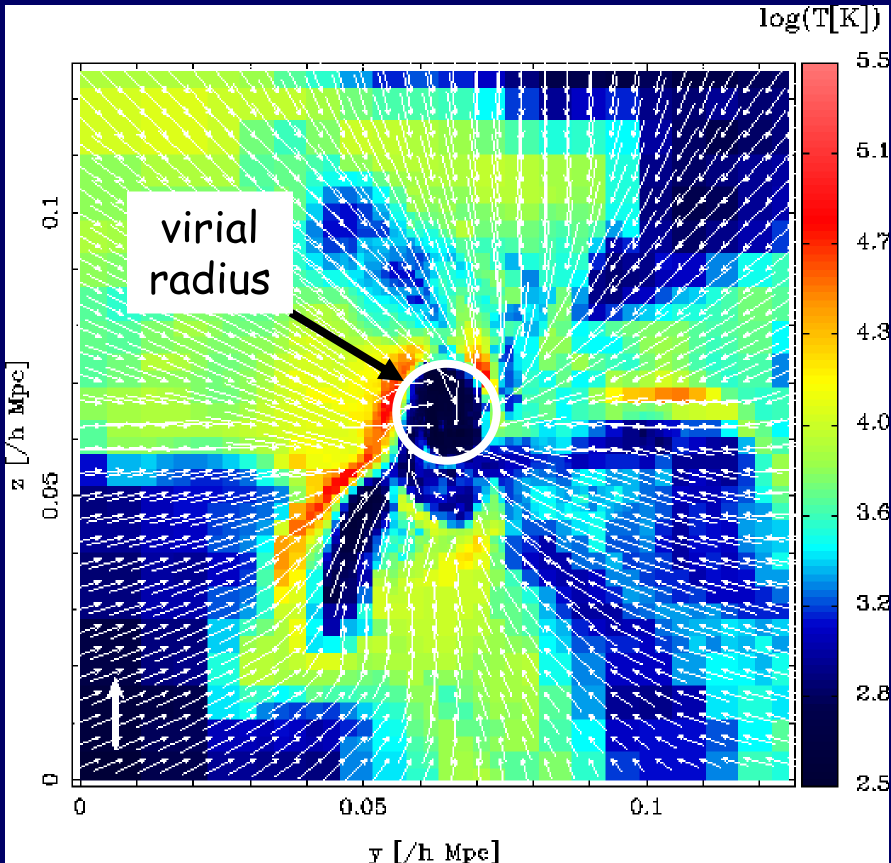
Spherical hydro simulation

Birnboim & Dekel 03

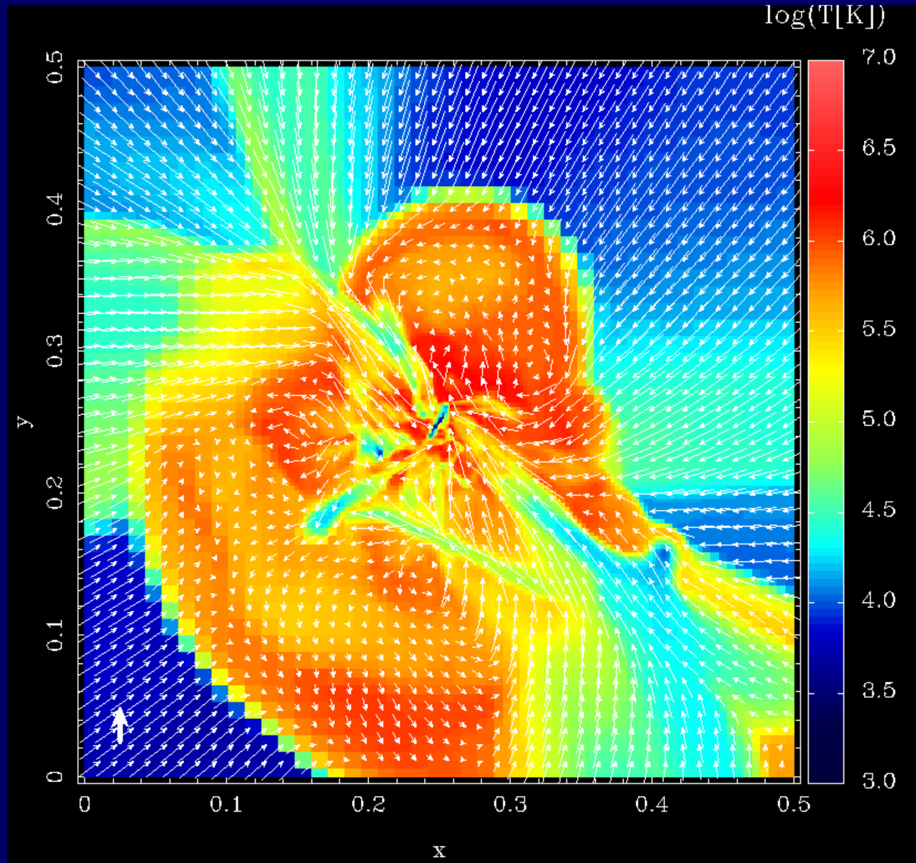
The Critical Mass: Cosmological Simulations

SPH Keres et al 2005, AMR Kravtsov et al

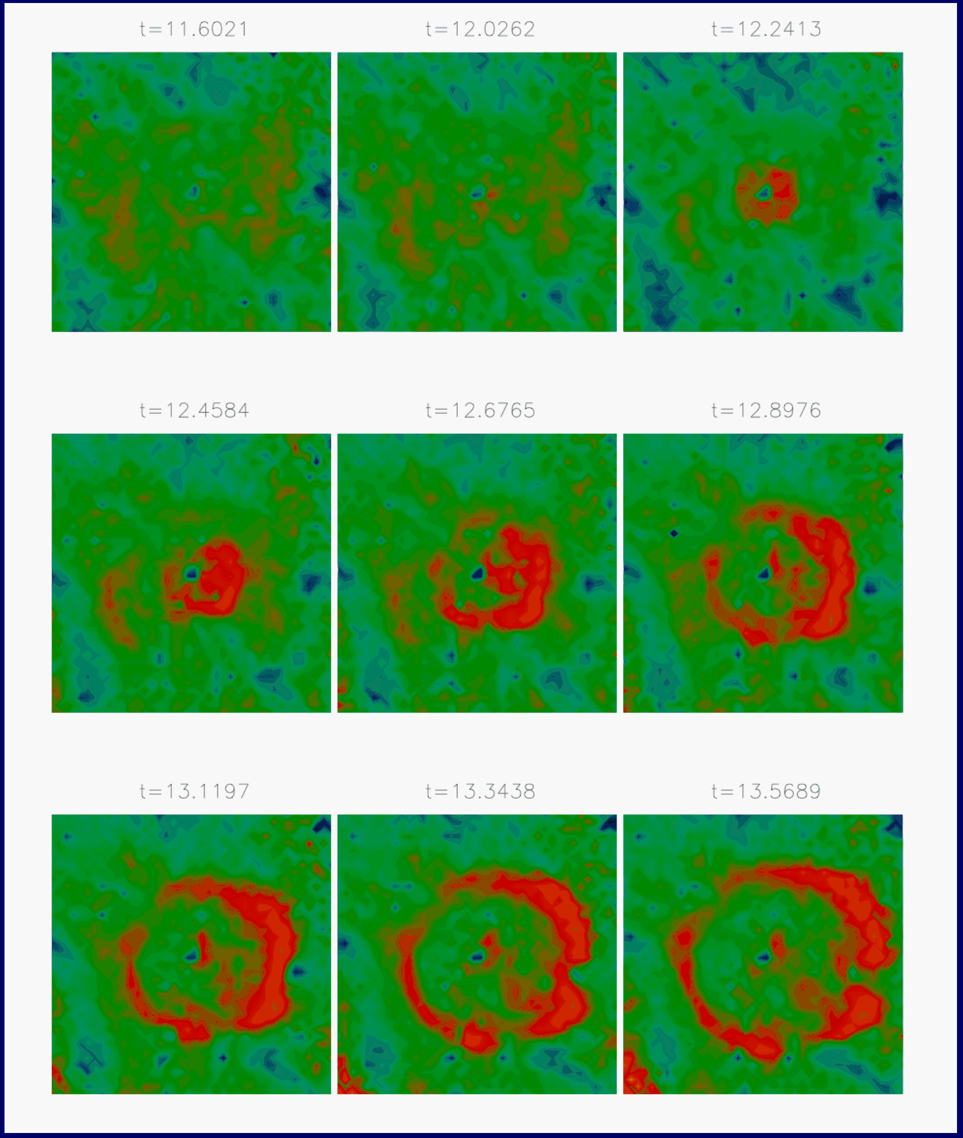
$M \ll 10^{12} M_\odot$ cold flows



$M > 10^{12} M_\odot$ virial shock heating

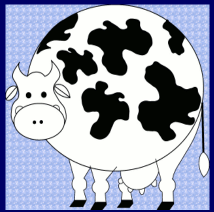


A virial shock in a 3D cosmological simulation:
at M_{crit} – rapid expansion from the inner halo to R_{vir}



d(Entropy)/dt

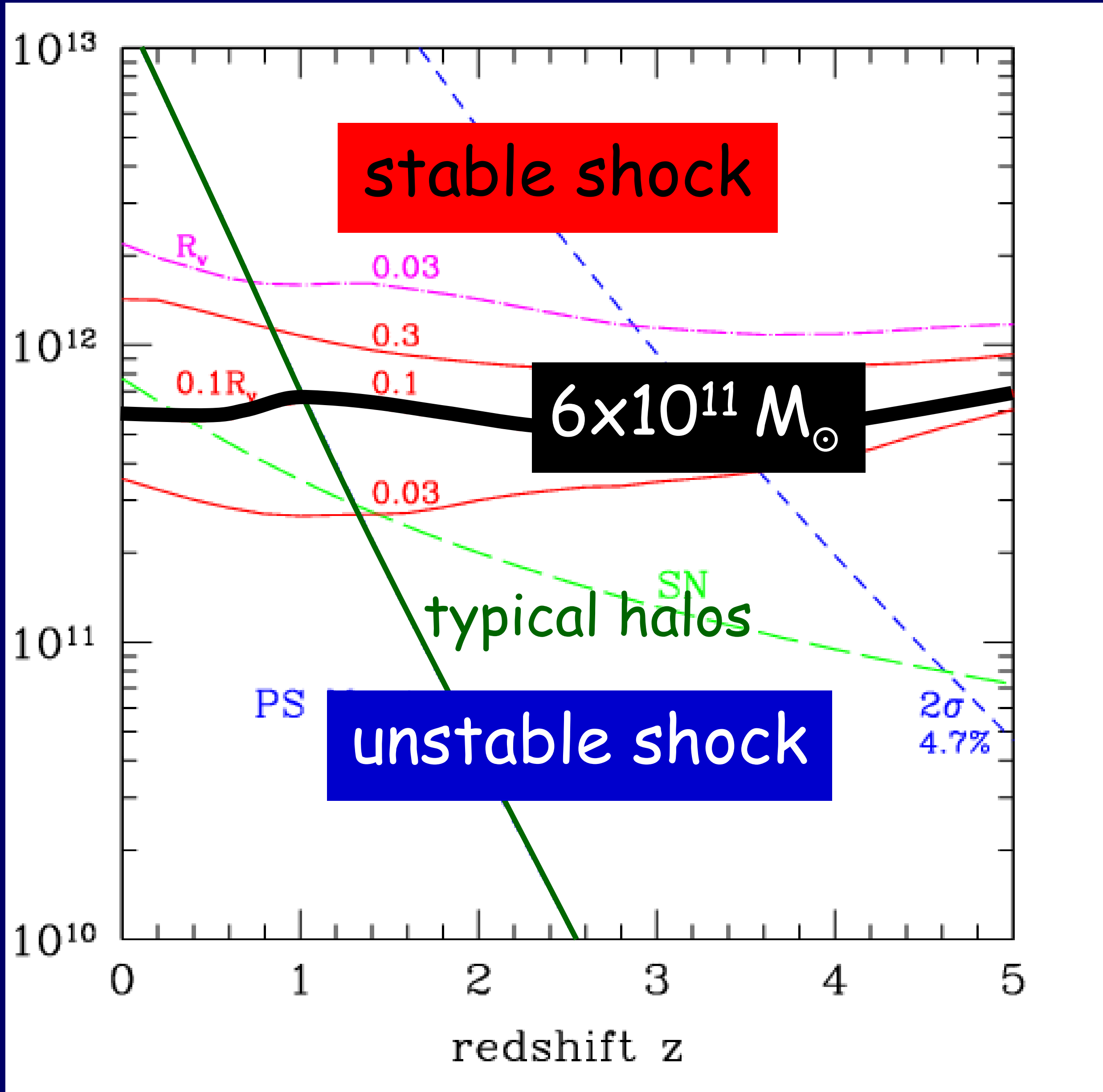
Libeskind, Birnboim, Dekel 08



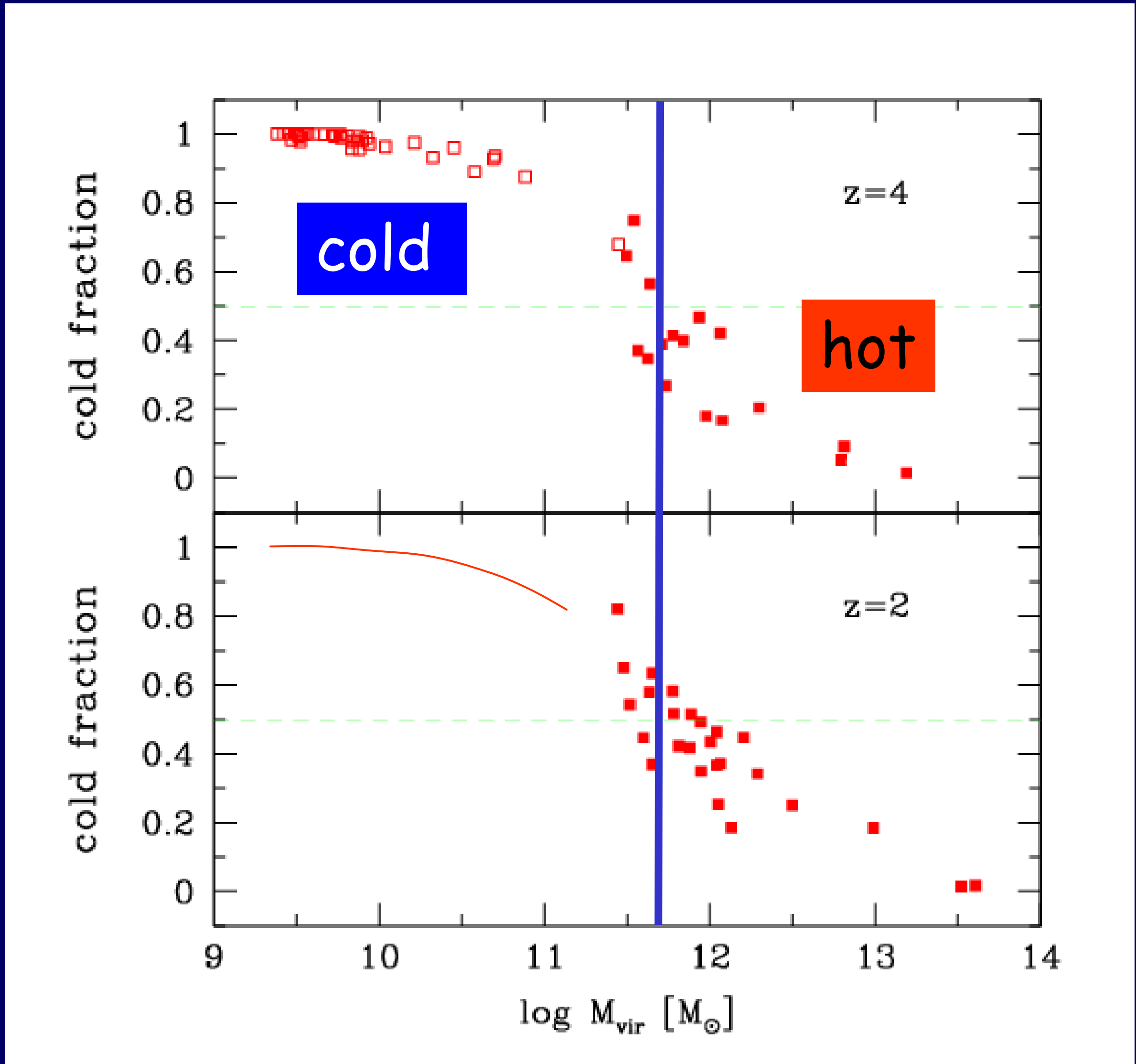
Shock-Heating Scale

Dekel & Birnboim 06

M_{vir} $[M_\odot]$



Fraction of Cold Gas in Halos: Cosmological simulations (Kravtsov)

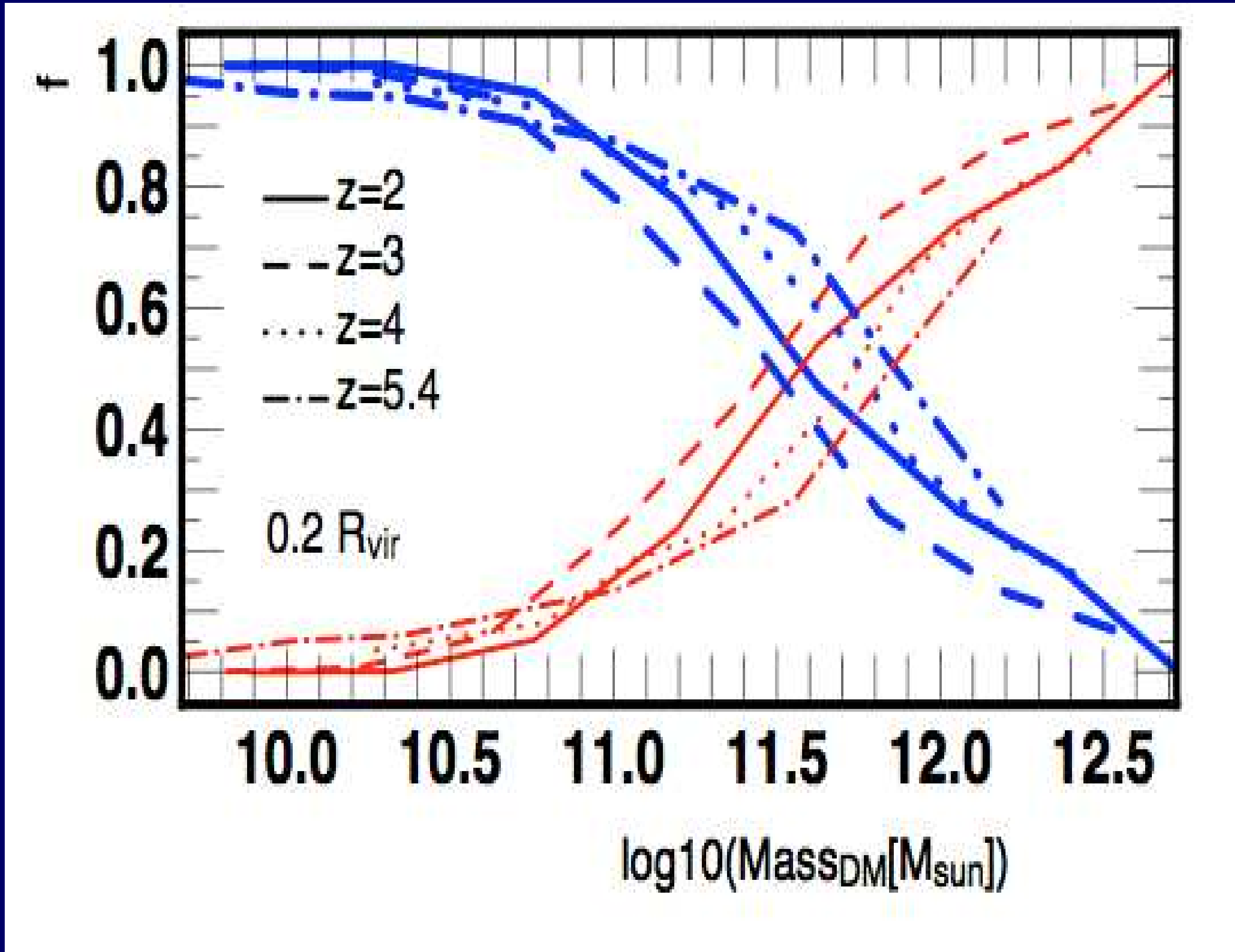


Birnboim, Dekel, Neistein 2007

Zinger, Birnboim, Dekel, Kravtsov

Fraction of cold inward flux at $0.2R_{vir}$: Cosmological Simulations

Ocvirk, Pichon, Teyssier 08



Cold Streams in a Hot Medium at High z

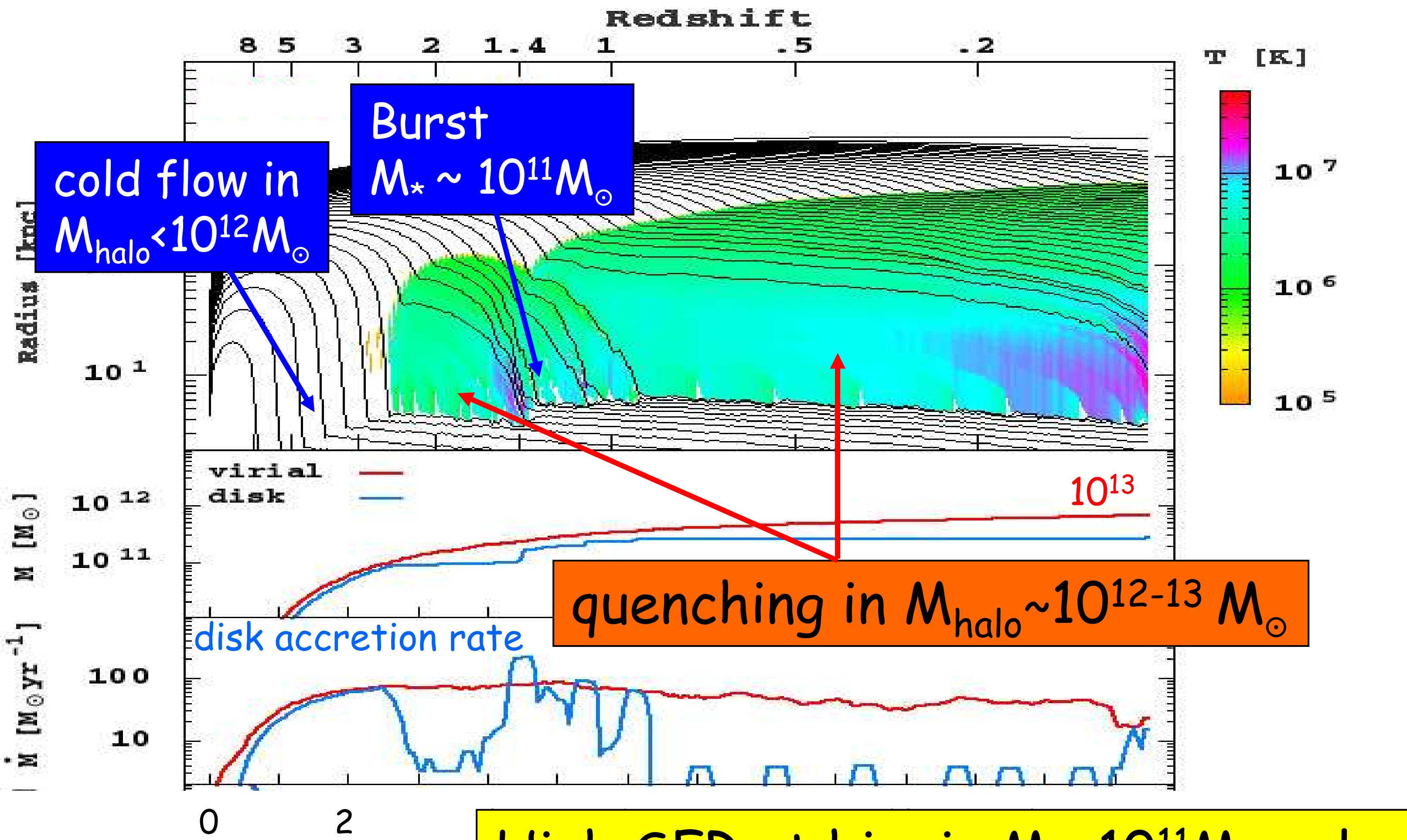
Dekel & Birnboim 2006

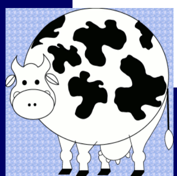
Birnboim, Dekel & Neistein 2007

Dekel et al. 2008, in prep.

Shocked Accretion: cold flows and quenching

Birnboim, Dekel, Neistein 07



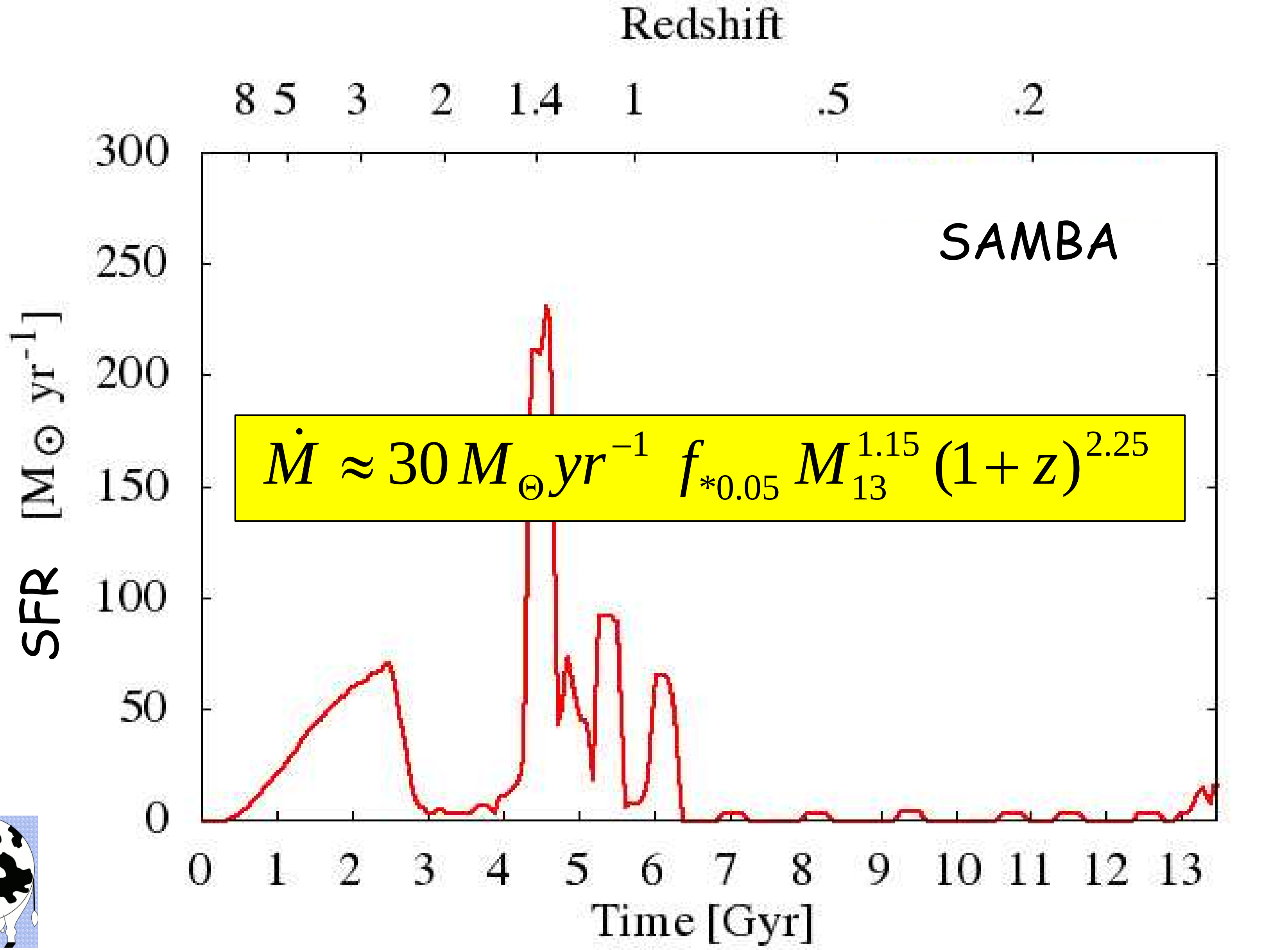


High SFR at hi z in $M_{*}=10^{11}M_{\odot}$ galaxies

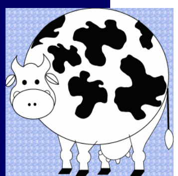
Suppressed SFR in half the galaxies

Galaxies can switch blue-red-blue-…

Shocked-Accretion Massive Burst And Shutdown



$$\dot{M} \approx 30\, M_{\Theta} yr^{-1}\; f_{*0.05}\, M_{13}^{1.15} (1+z)^{2.25}$$

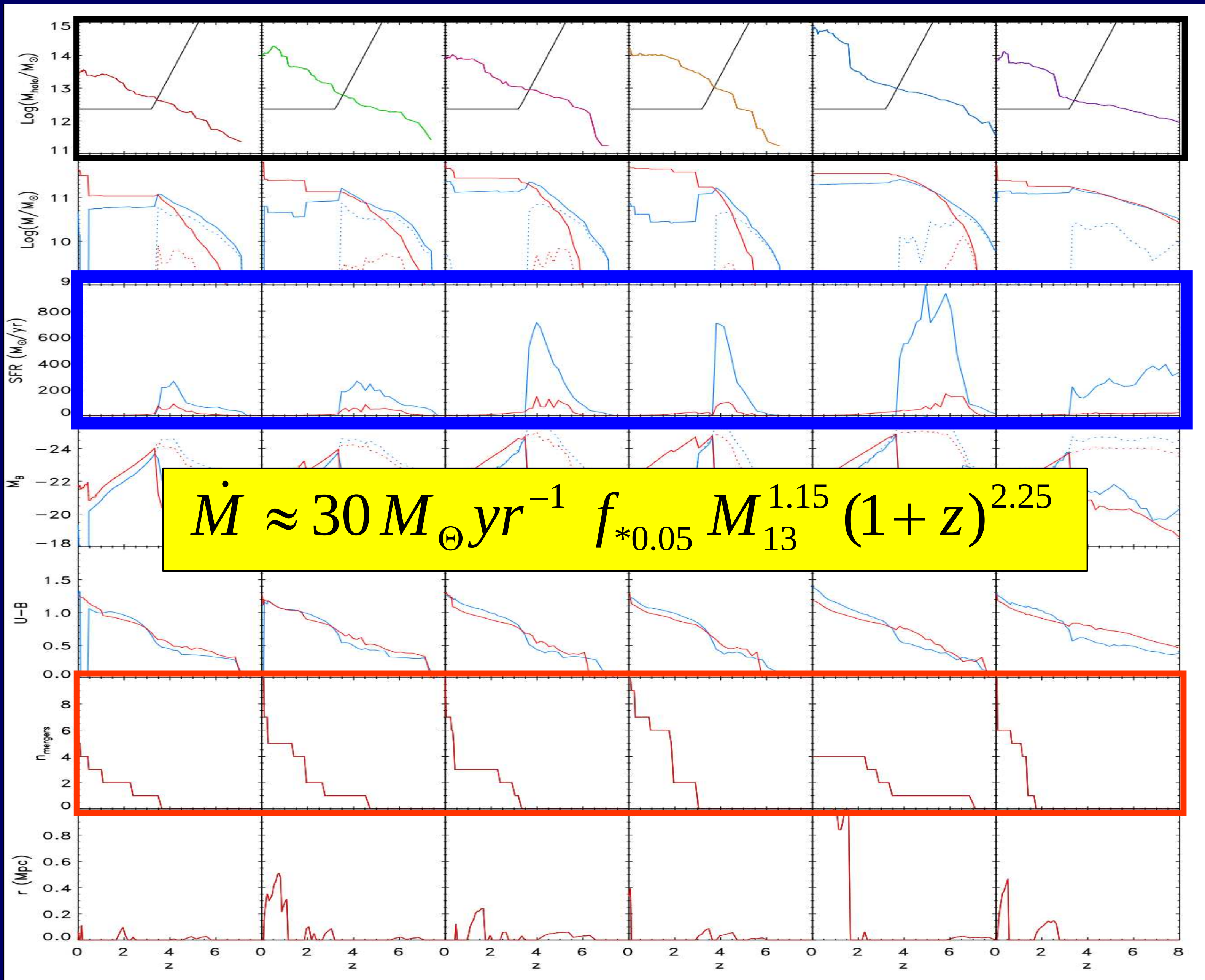


SAM: Massive Starbursts at high z

M_{halo}

SFR

mergers



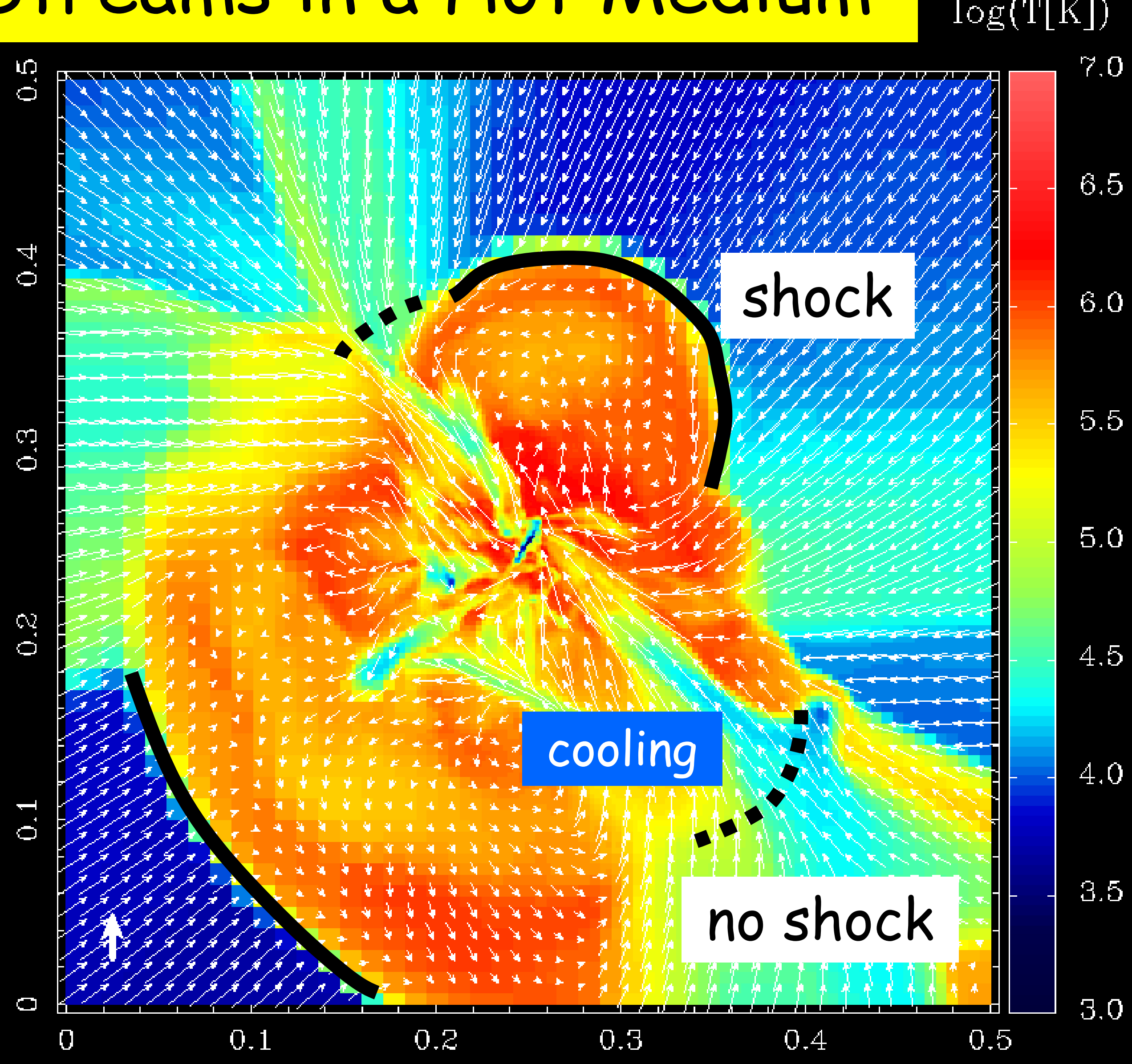
$$\dot{M} \approx 30\, M_{\Theta} yr^{-1} \; f_{*0.05}\, M_{13}^{1.15} (1+z)^{2.25}$$

At High z, in Massive Halos: Cold Streams in a Hot Medium

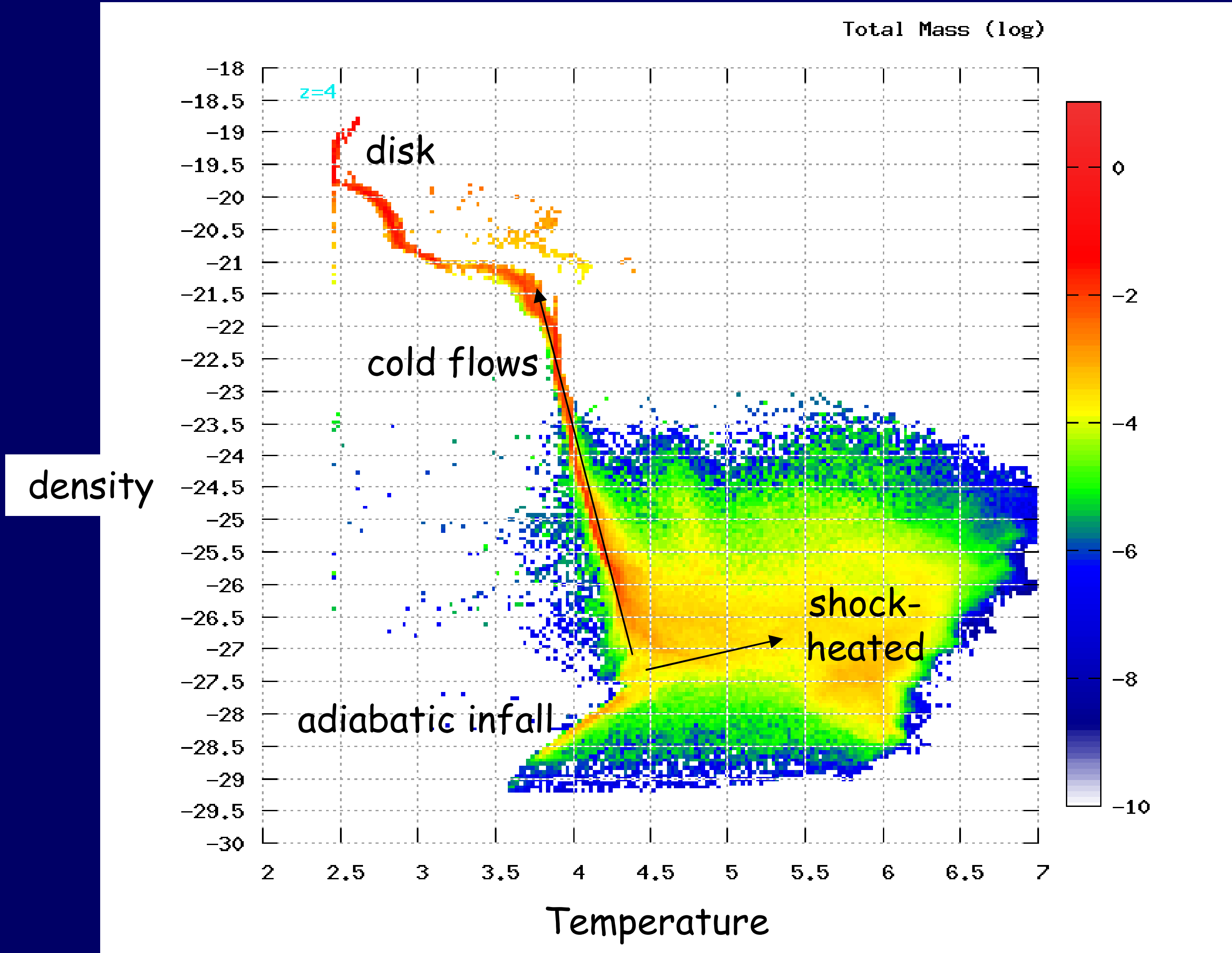
in $M > M_{shock}$

Totally hot at z<1

Cold streams at z>2

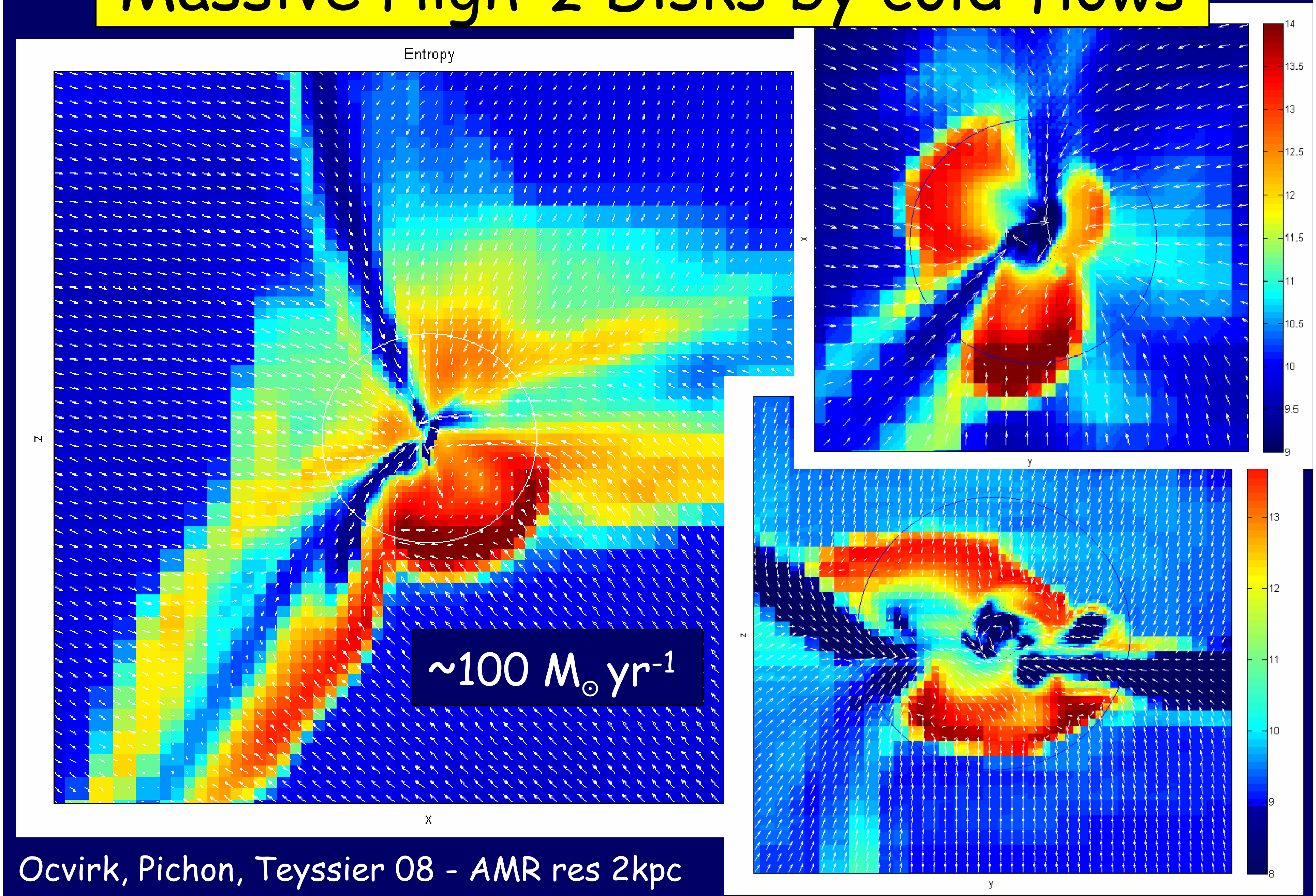


Mass Distribution of Halo Gas



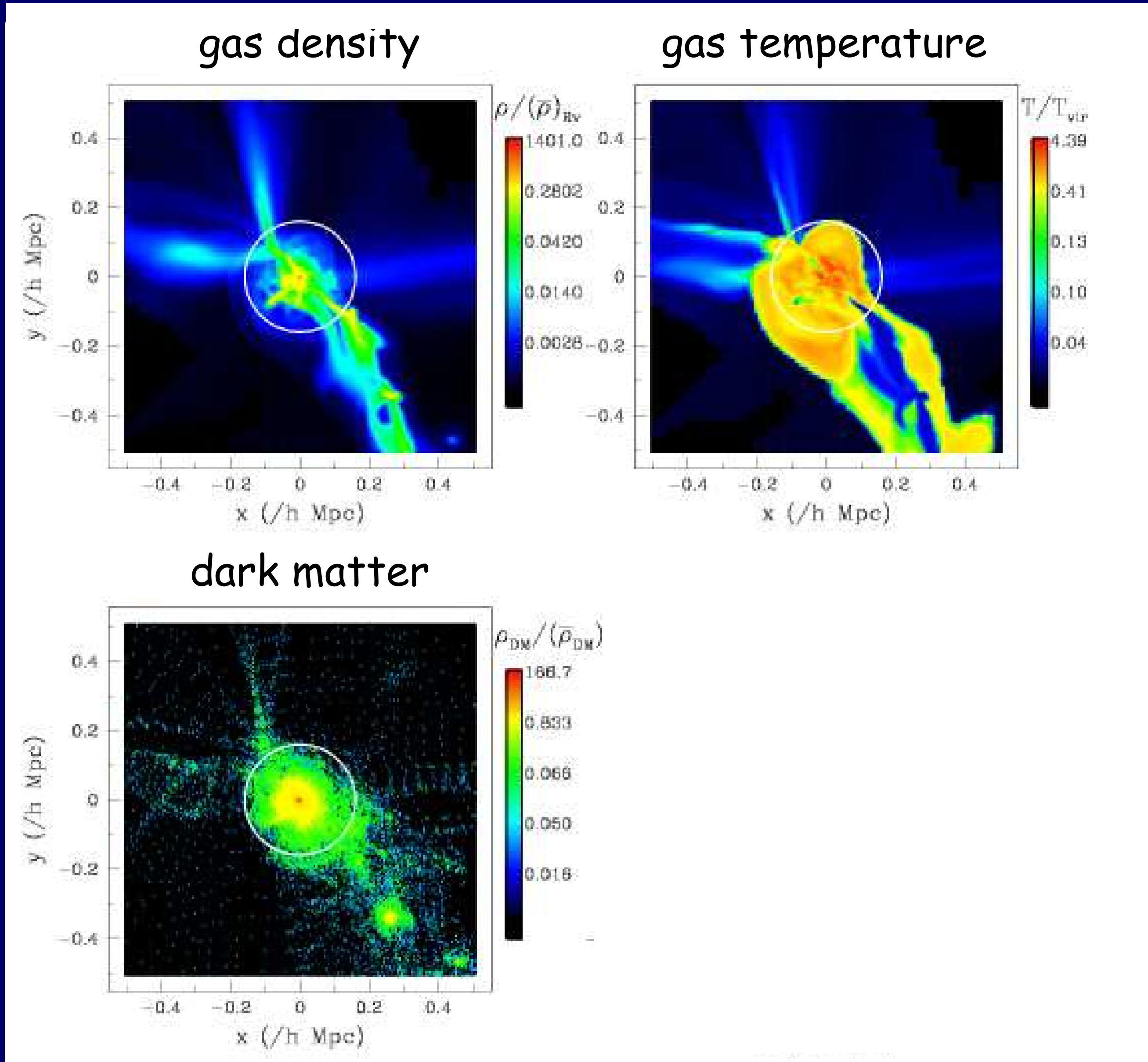
Analysis of Eulerian hydro simulations by Birnboim, Zinger, Dekel, Kravtsov

Massive High-z Disks by cold flows

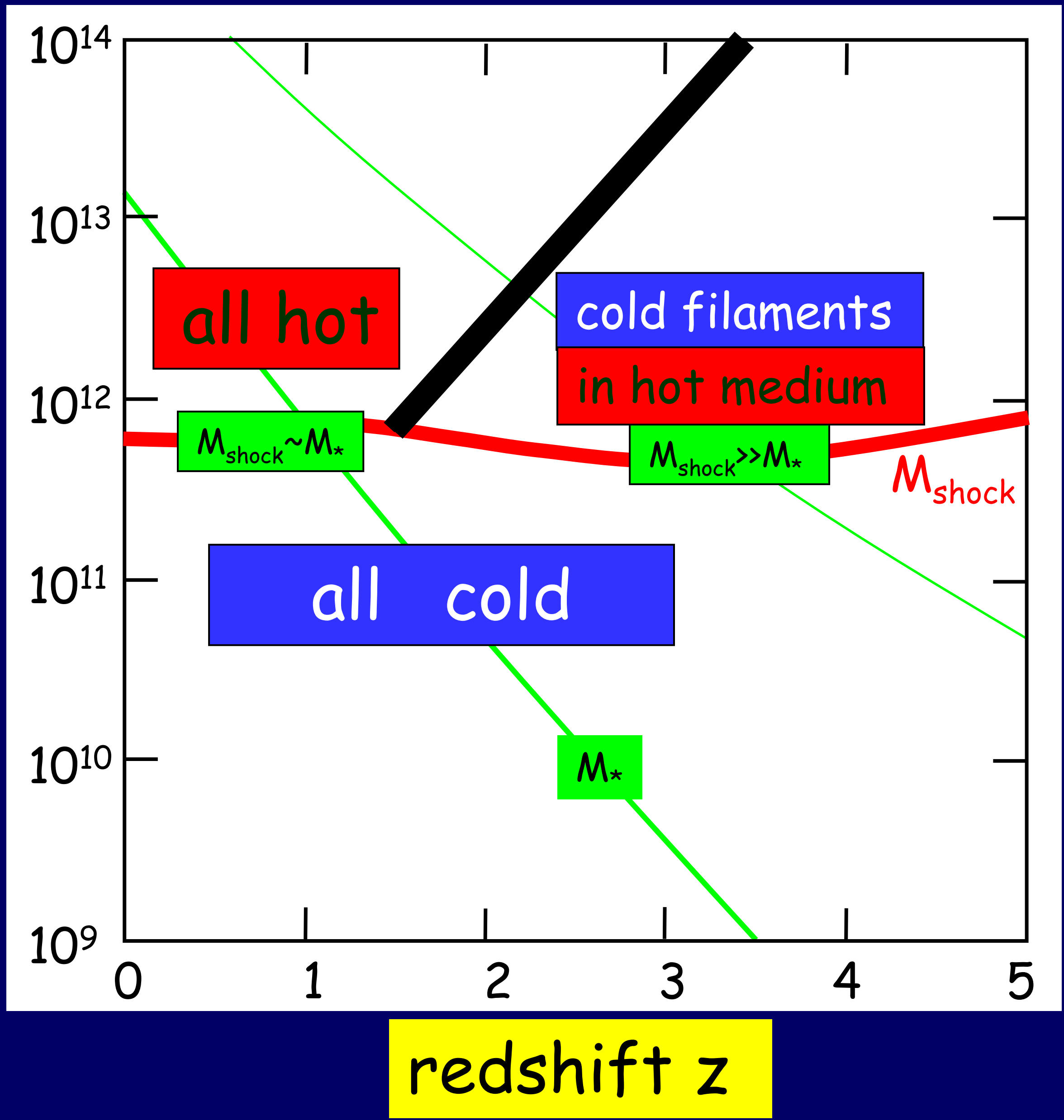


Ocvirk, Pichon, Teyssier 08 - AMR res 2kpc

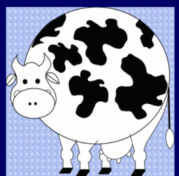
Cold flows riding dark-matter filaments

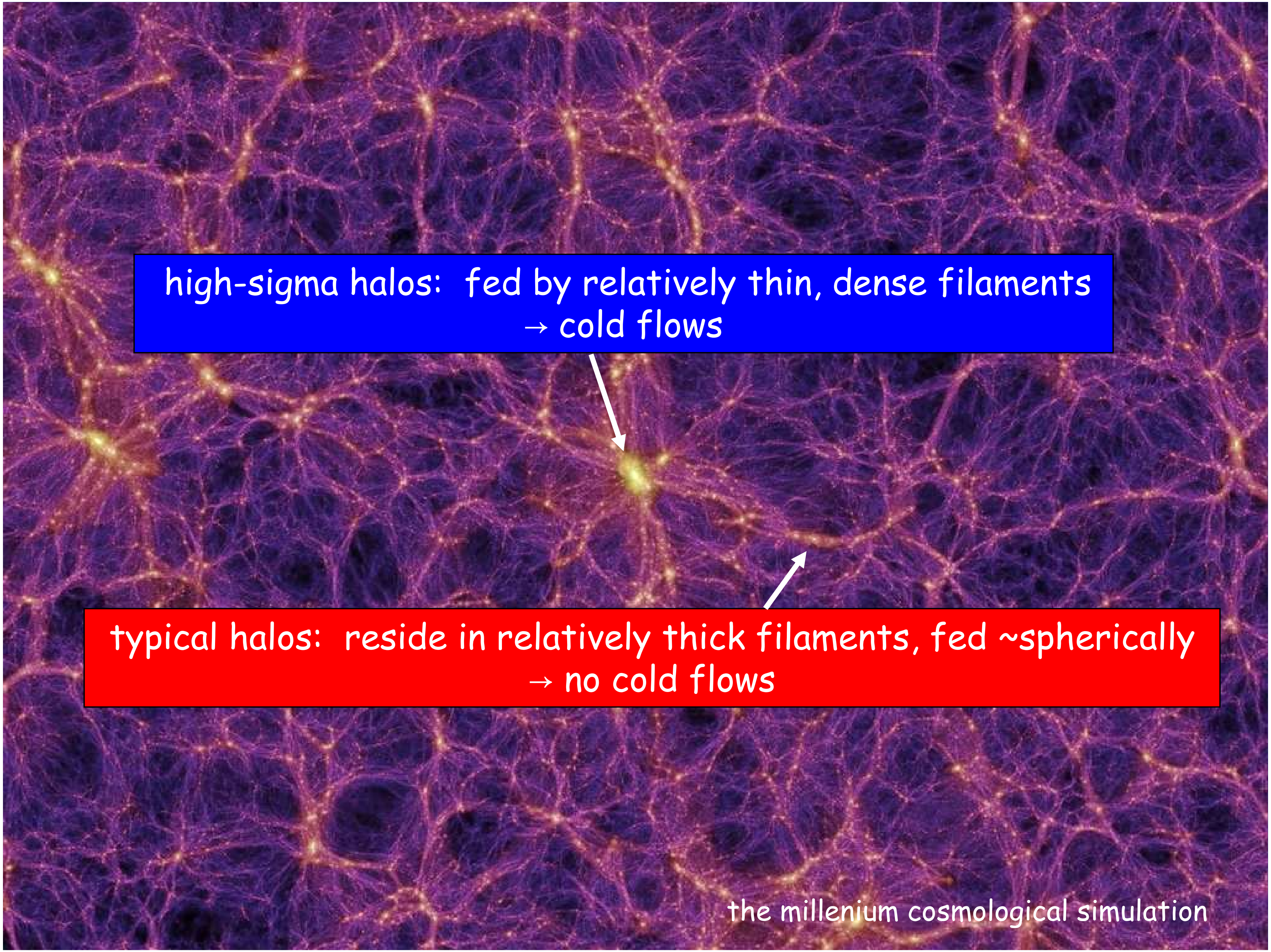


Cold Streams in Big Galaxies at High z

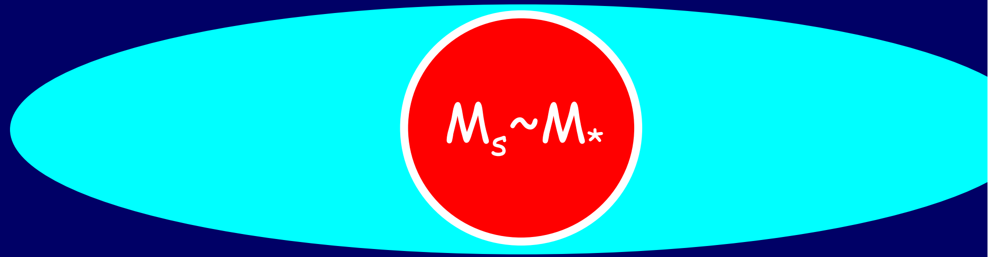


Dekel & Birnboim 06 Fig. 7



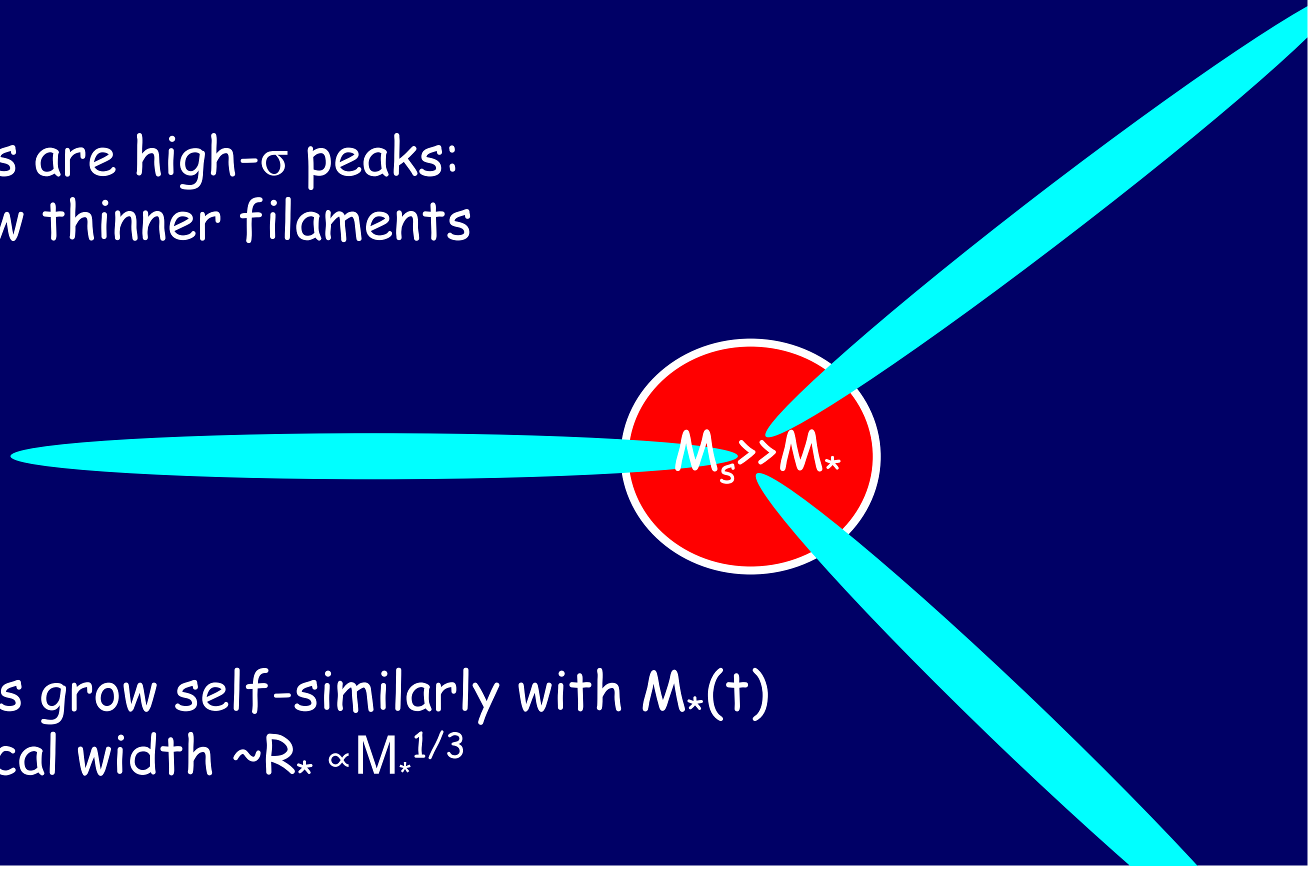

high-sigma halos: fed by relatively thin, dense filaments
→ cold flows
typical halos: reside in relatively thick filaments, fed ~spherically
→ no cold flows
the millenium cosmological simulation

Origin of dense filaments in hot halos ($M \geq M_{shock}$) at high z



At low z, M_{shock} halos are typical:
they reside in thicker filaments
of comparable density

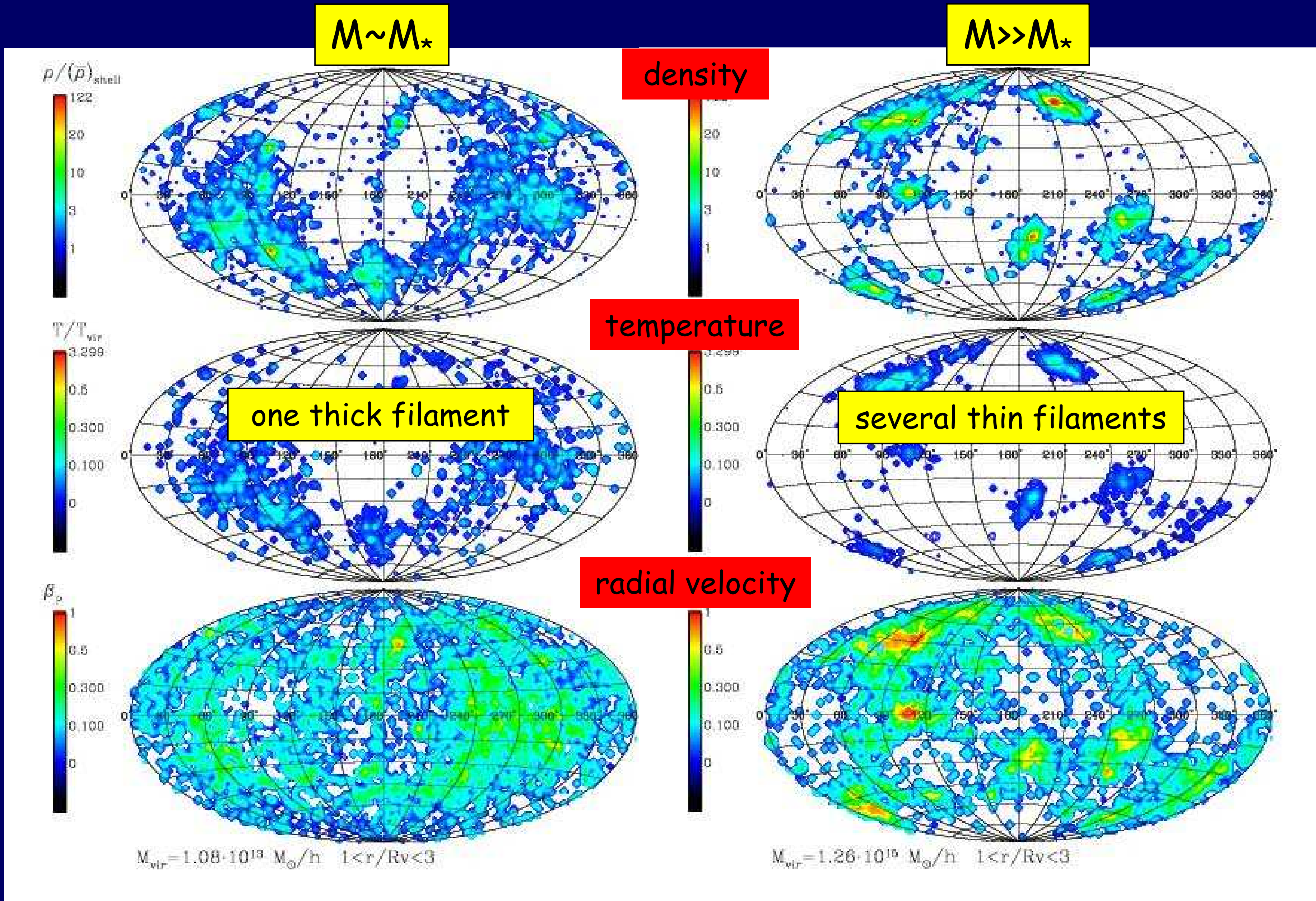
At high z, M_{shock} halos are high-σ peaks:
they are fed by a few thinner filaments
of higher density



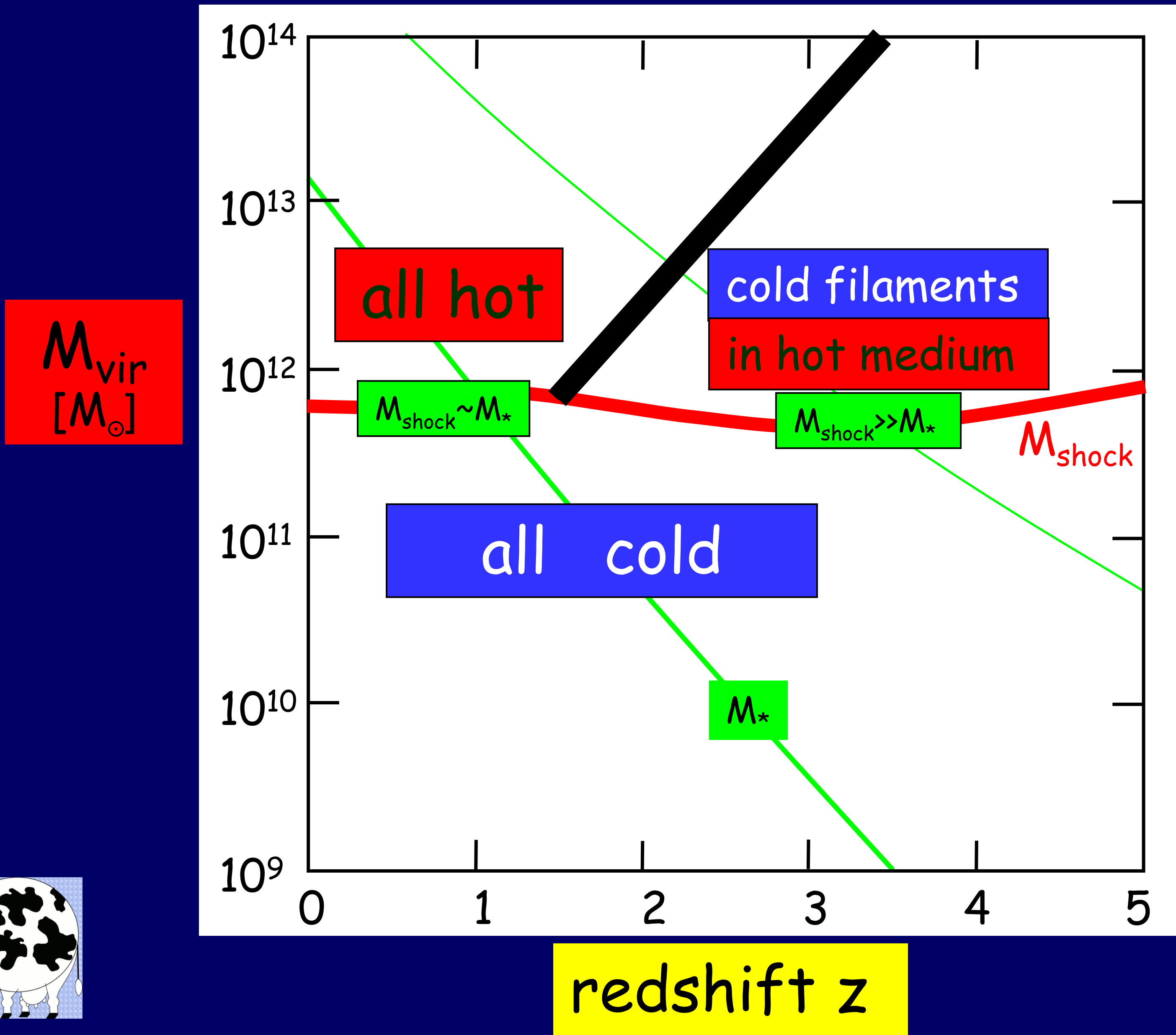
Large-scale filaments grow self-similarly with $M_*(t)$
and always have typical width $\sim R_* \propto M_*^{1/3}$

Dark-matter inflow in a shell 1-3R_{vir}

Seleson & Dekel

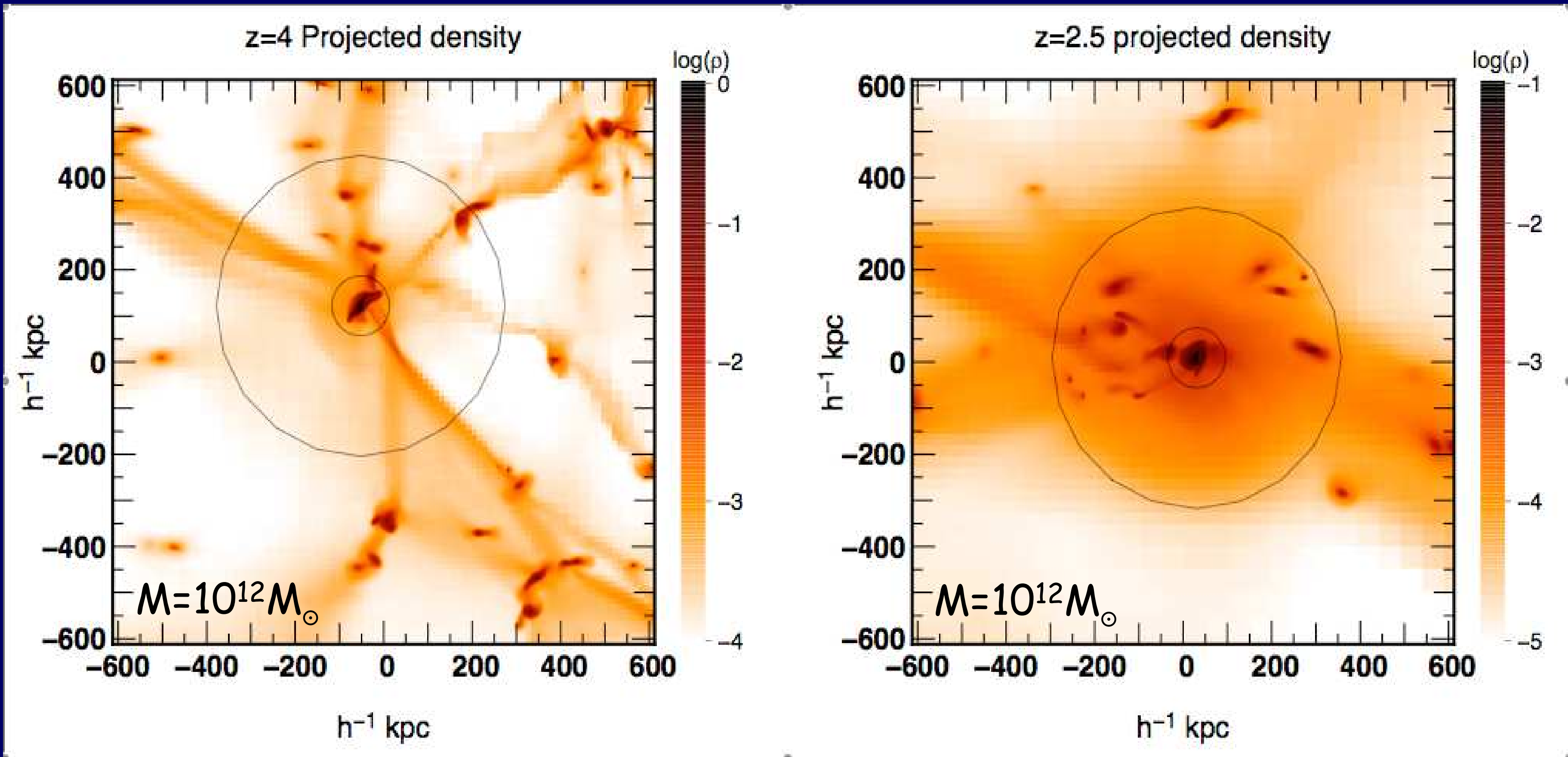


Cold Streams in Big Galaxies at High z



Gas Density in Massive Halos $2 \times 10^{12} M_\odot$

high z low z



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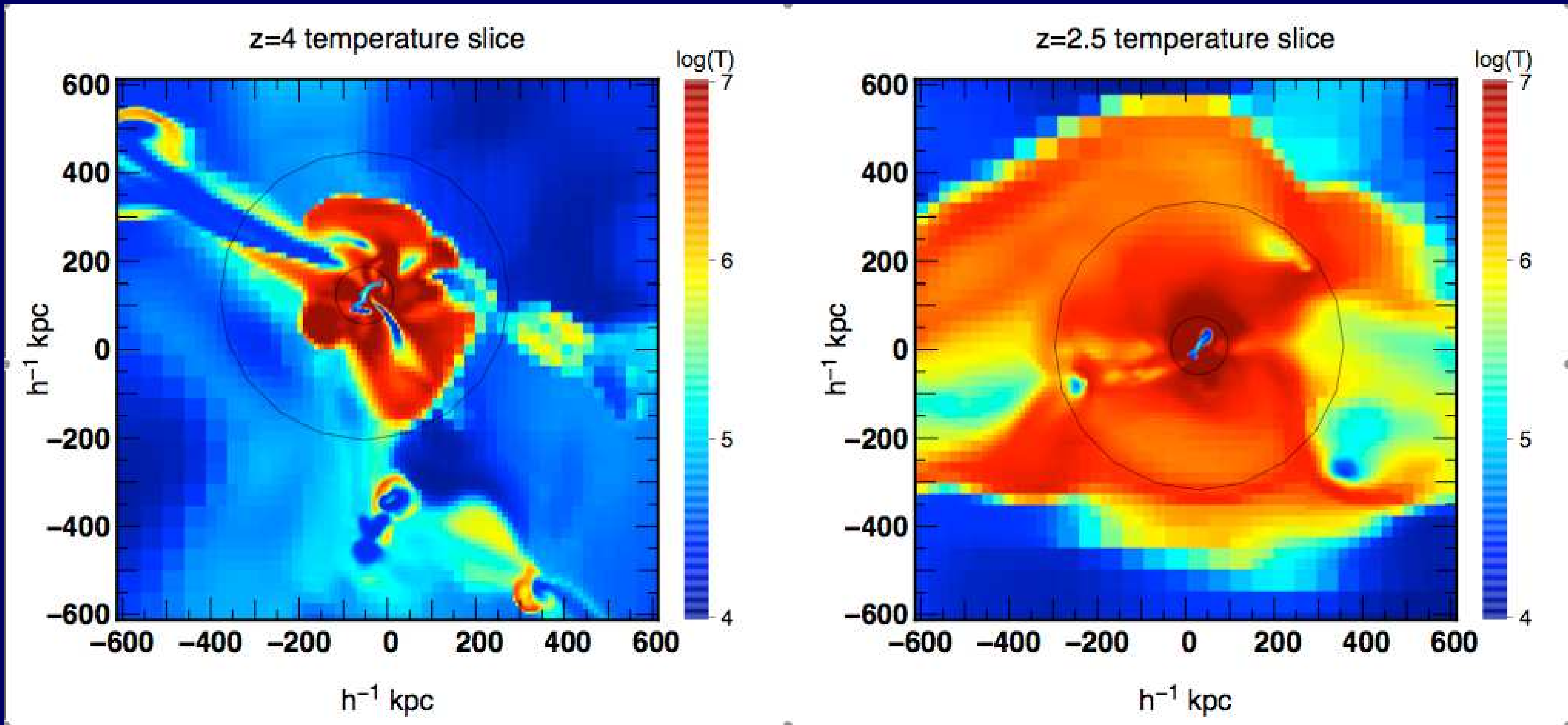
Temperature in Massive Halos $2 \times 10^{12} M_{\odot}$

high z

low z

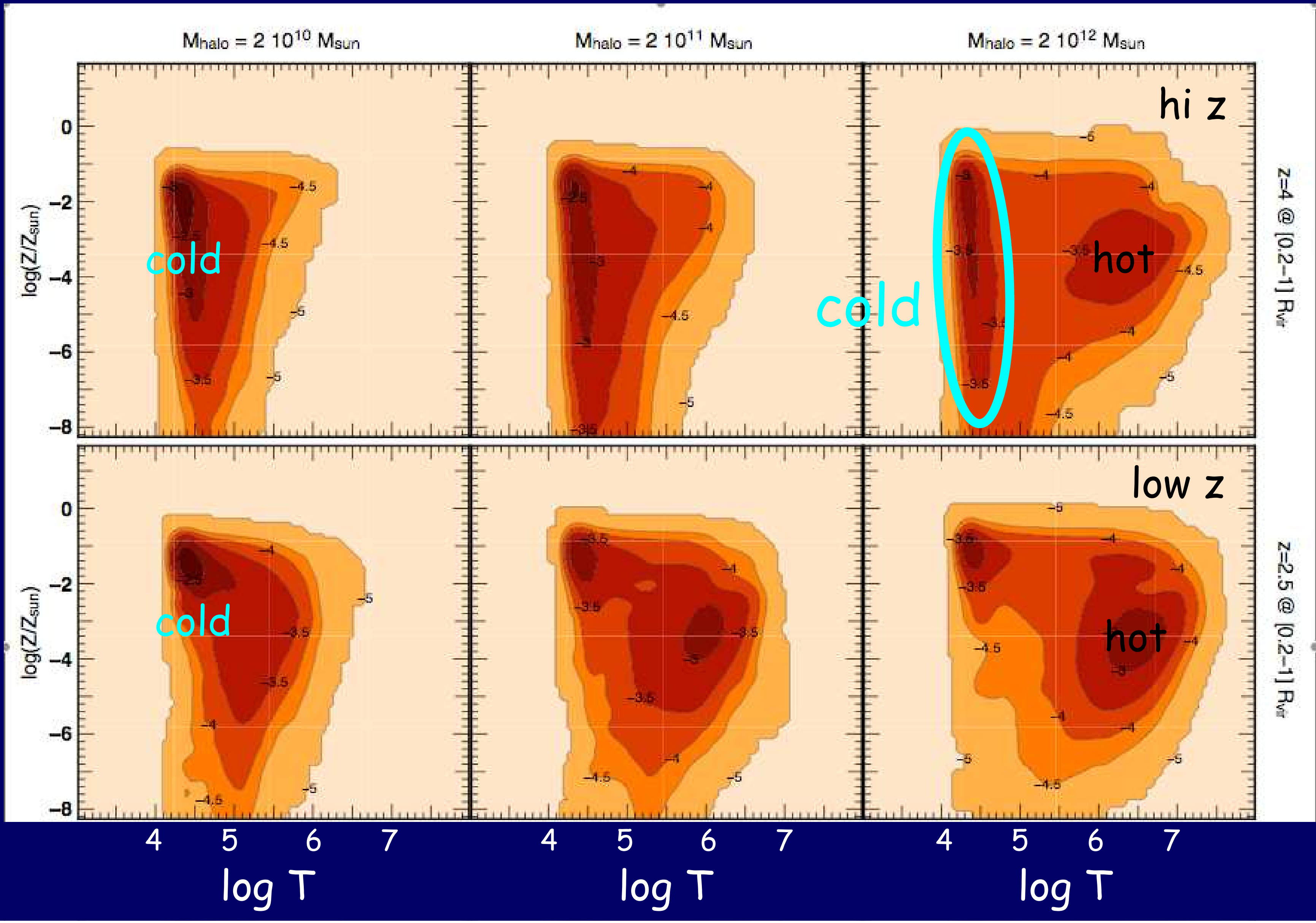


Ocvirk, Pichon, Teyssier 08

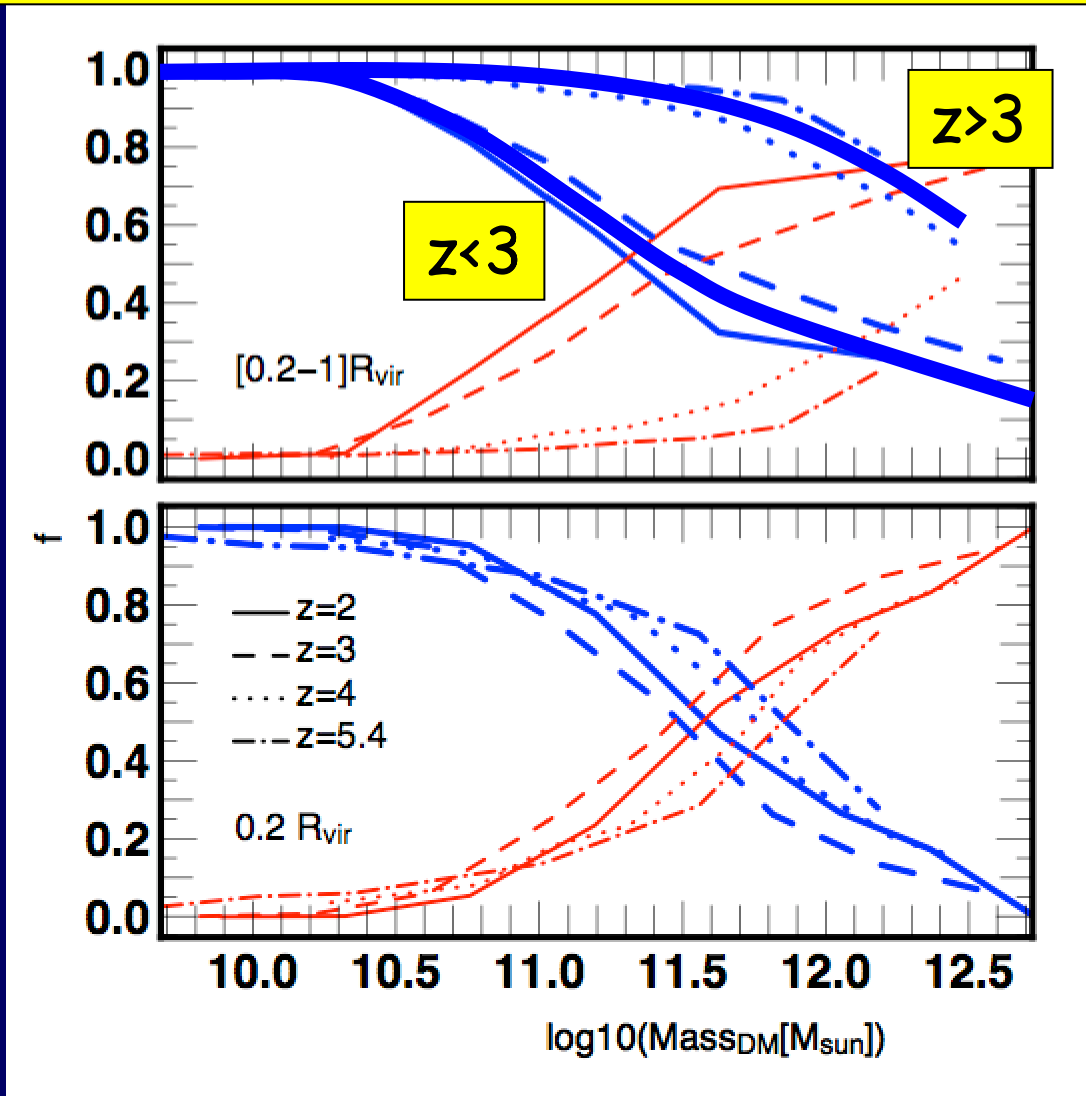
Flux Weighted Temperature Distribution

Halo Mass →

Ocvirk, Pichon, Teyssier 08



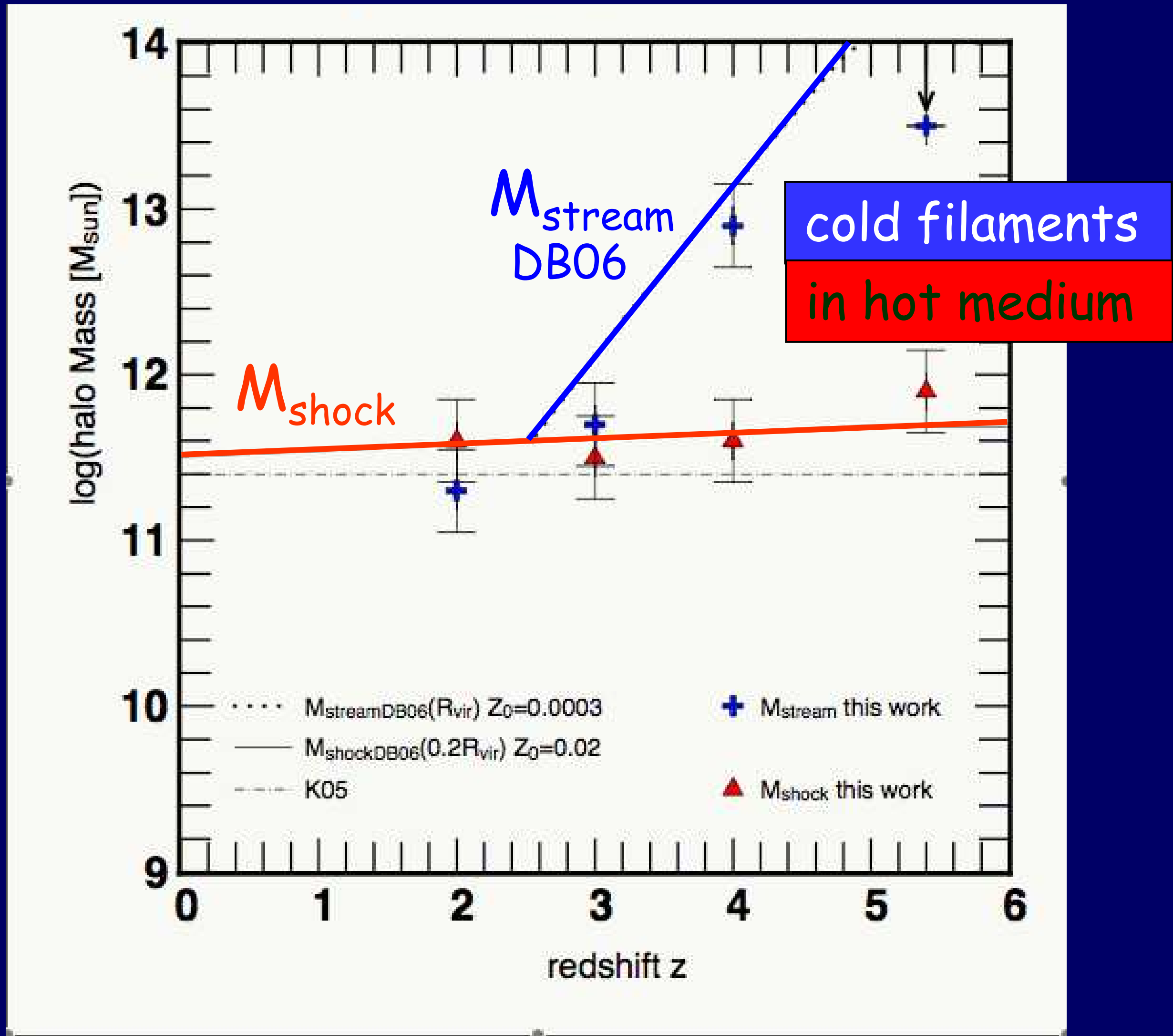
Cold Fraction of Inward Flux



Ocvirk, Pichon, Teyssier 08

Critical Mass in Cosmological Simulations

Ocvirk, Pichon, Teyssier 08

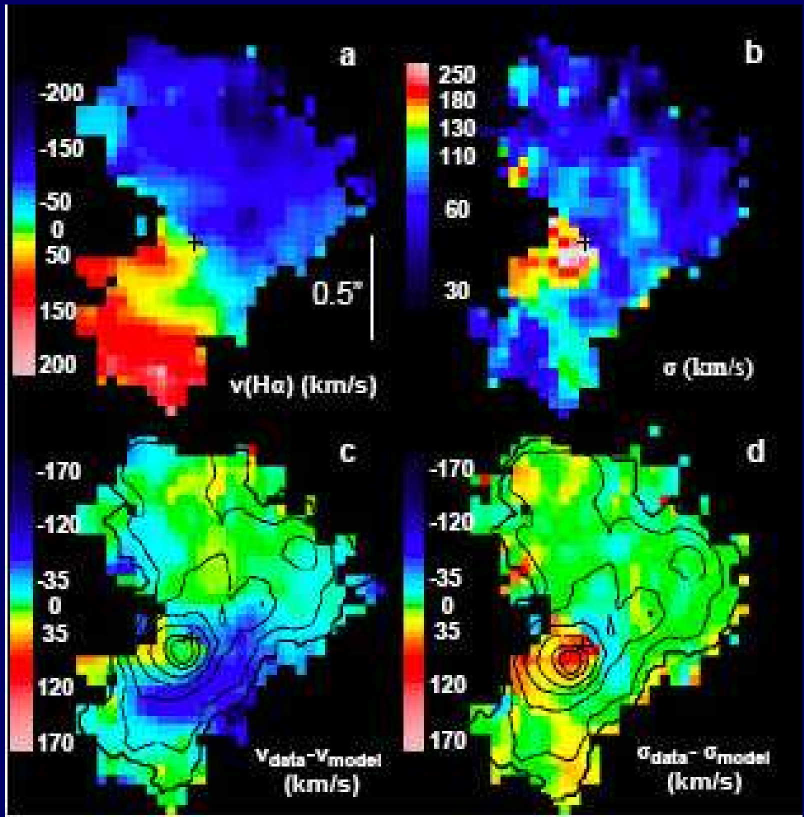


Observed Maximum Bursts

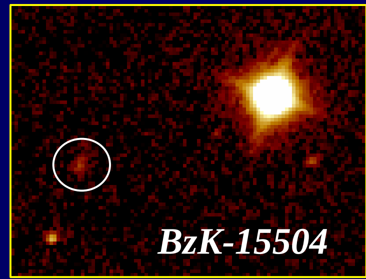
Genzel et al. 2006, …

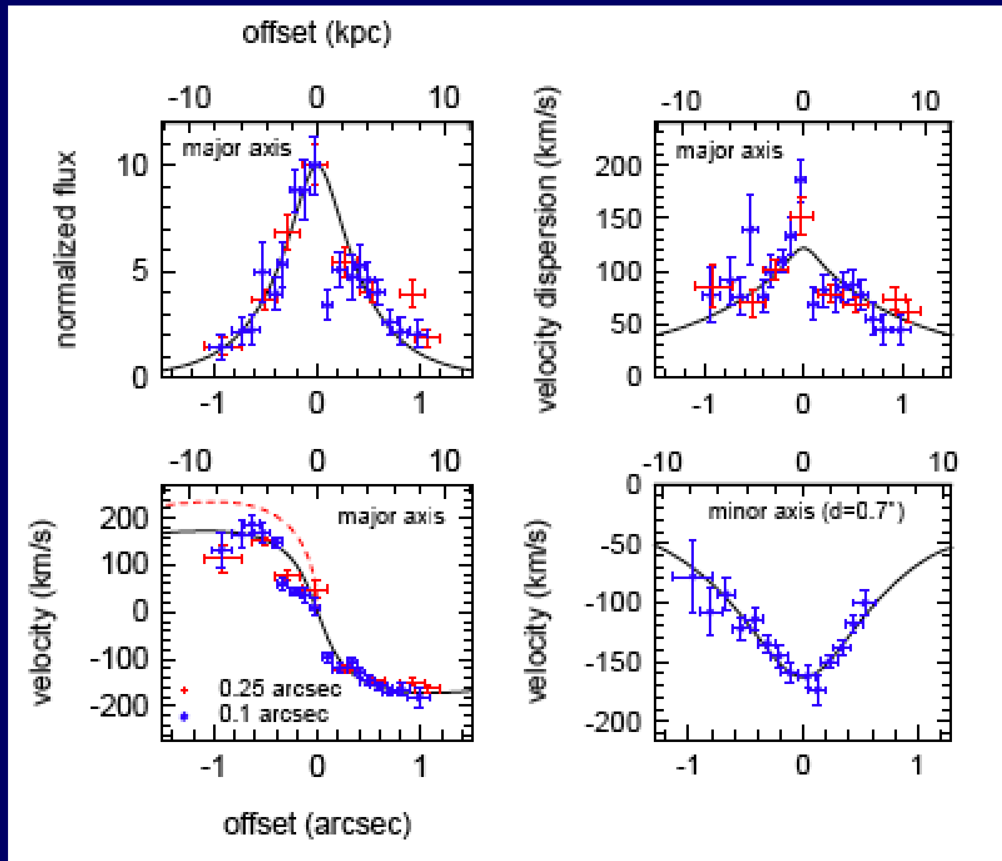
- Optical/UV-selected galaxies at z~2-2.5
- $M_{star} \sim 10^{11} M_\odot$ SFR ~ 200 $M_\odot\, yr^{-1}$
- Most of the mass is bursting -> gaseous input
- Very rapid SFR: burst ~0.5 Gyr
  $t_{SFR} < R_{vir}/V_{vir} \sim t_{cool} \ll t_{Hubble}$
- Disk morphology & kinematics: no major mergers

Maximum Burst: BzK-15507 (Genzel et al 2006)



z=2.4





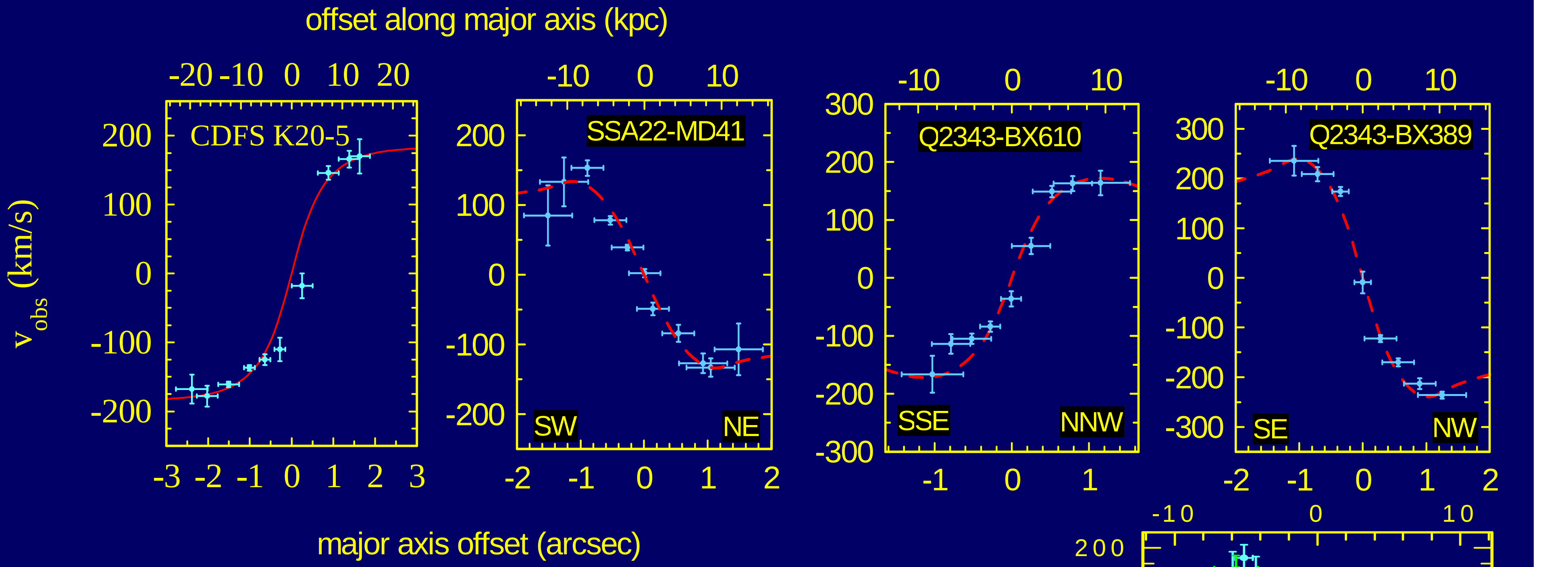
M_{star}~$0.8\times10^{11}M_{\odot}$

M_{gas}~$0.4\times10^{11}M_{\odot}$

SFR~150 $M_{\odot}\,yr^{-1}$

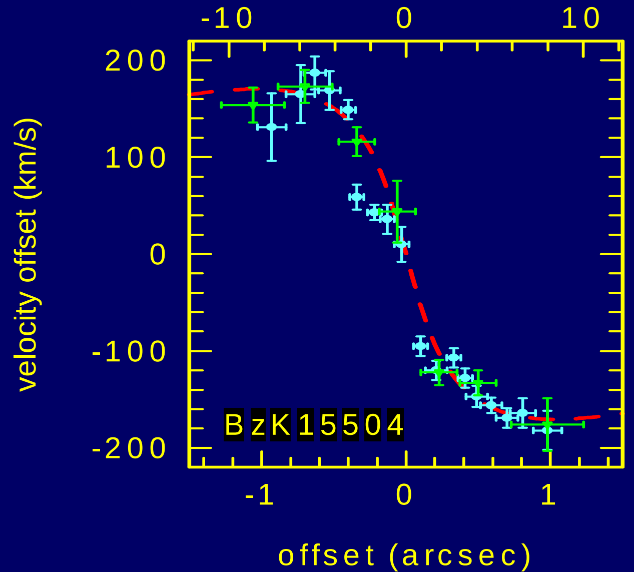
Δt~0.5 Gyr

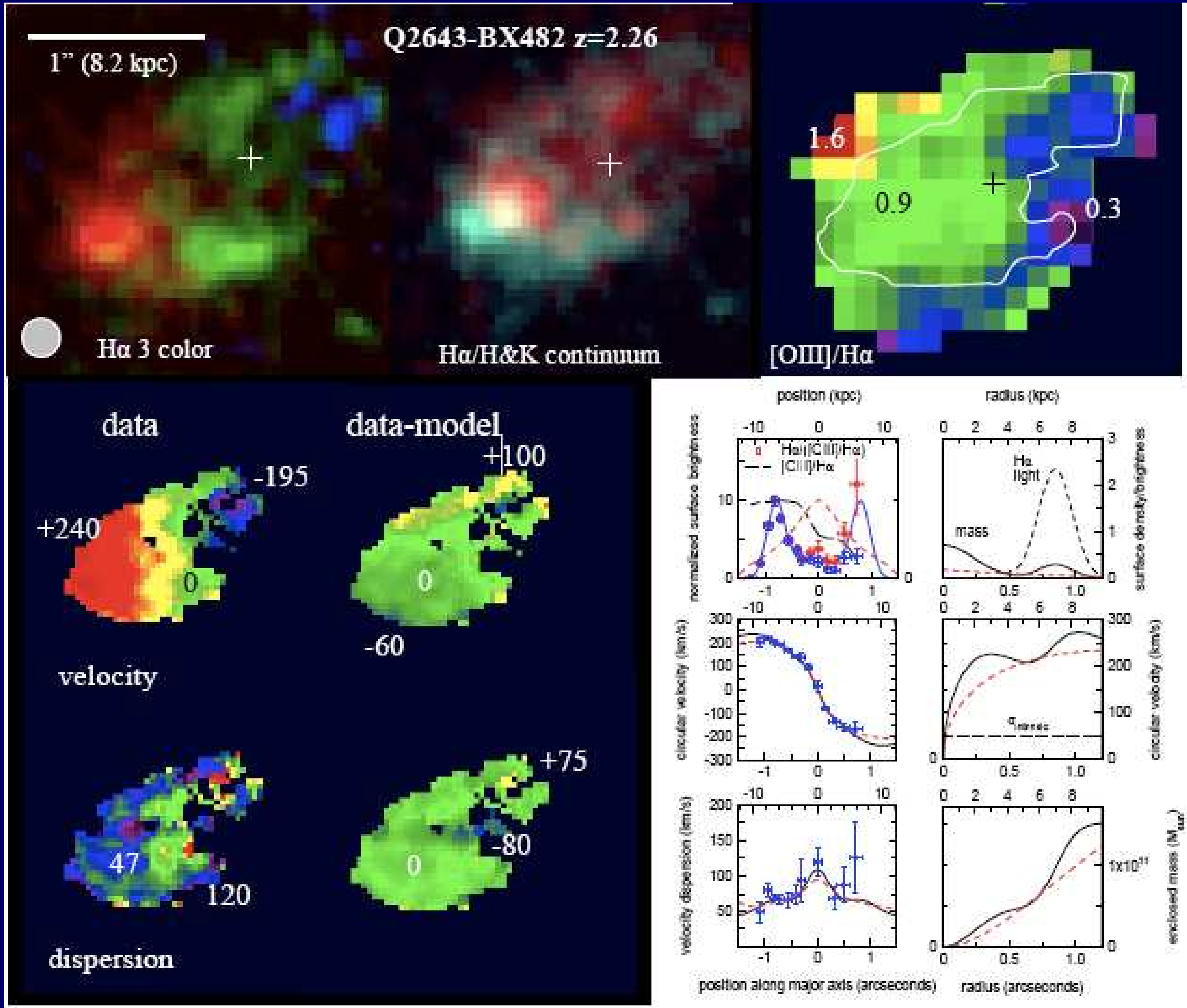
Rotation curves to R>10 kpc



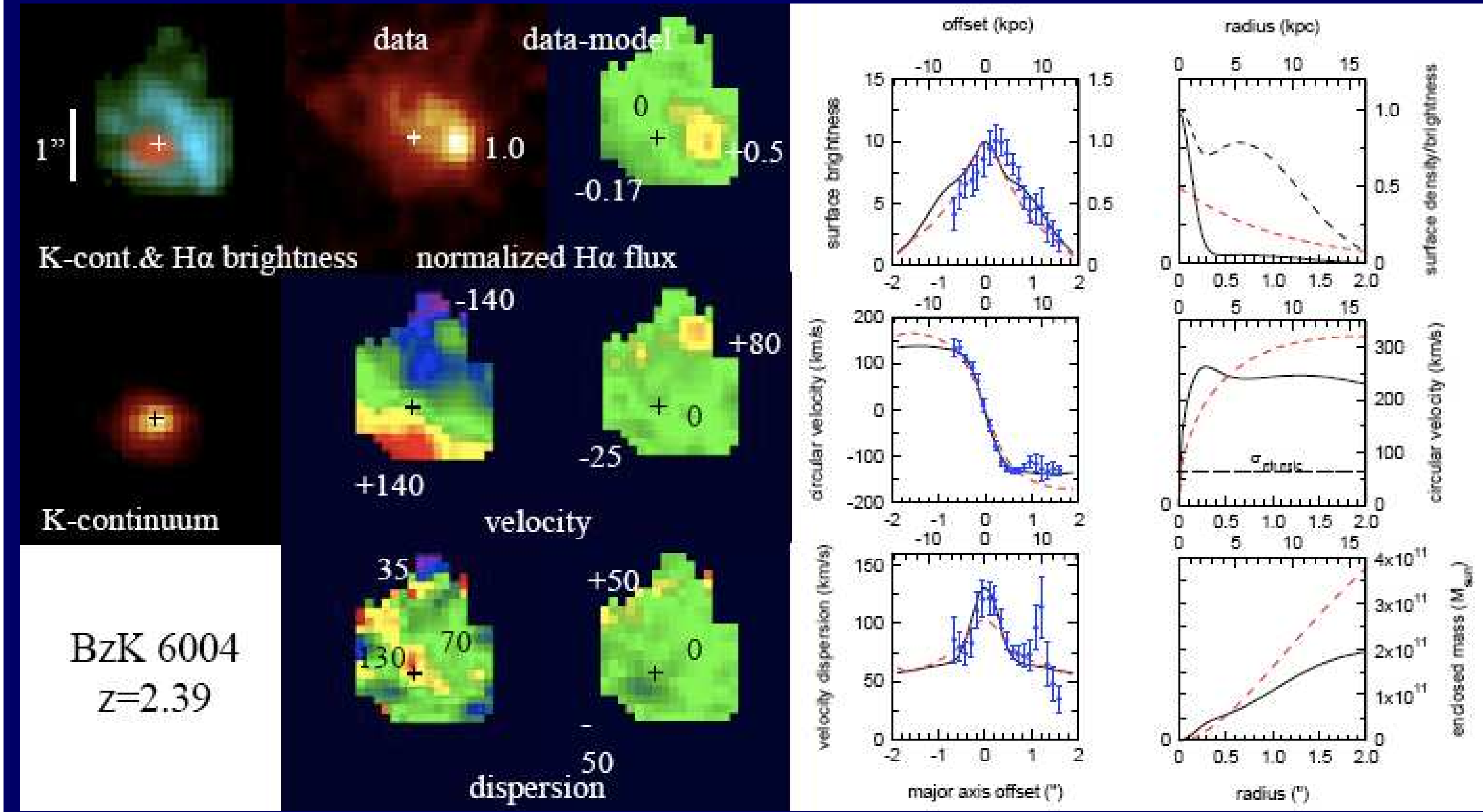
$<r_{1/2}>=3.7(1.6)$ kpc,
$<v_c>=180(90)$ km/s,
$M_{dyn}=0.5\text{-}25\times10^{10}\ M_\odot$

Förster Schreiber et al. 2006, ApJ 645, 1062
Genzel et al. 2006, Nature, Aug 17th





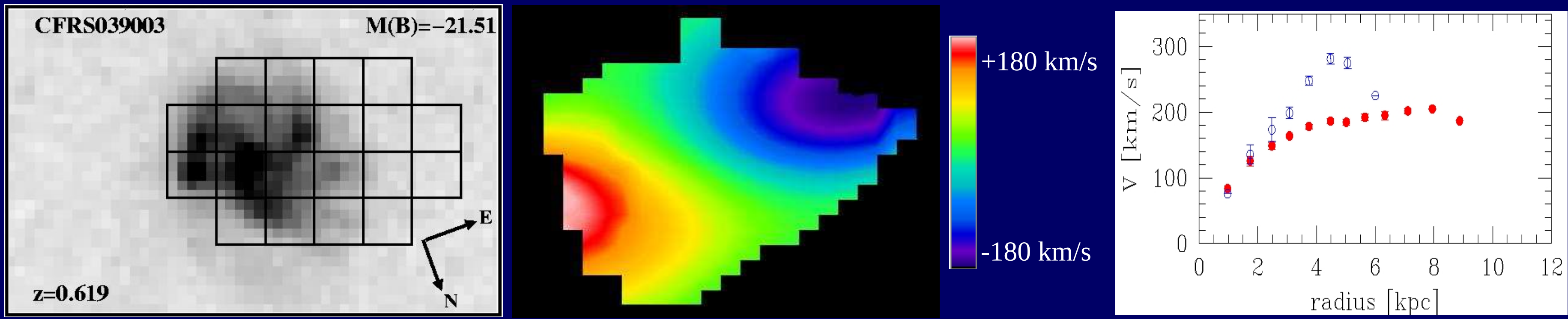
Q2643-BX482 z=2.26
1" (8.2 kpc)
Hα 3 color
Hα/H&K continuum
1.6
0.9
0.3
[OIII]/Hα
data
data-model
+240
-195
0
+100
0
-60
velocity
47
120
+75
0
-80
dispersion
position (kpc)
radius (kpc)
normalized surface brightness
surface density/brightness
mass
Hα light
circular velocity (km/s)
velocity dispersion (km/s)
enclosed mass
position along major axis (arcseconds)
radius (arcseconds)

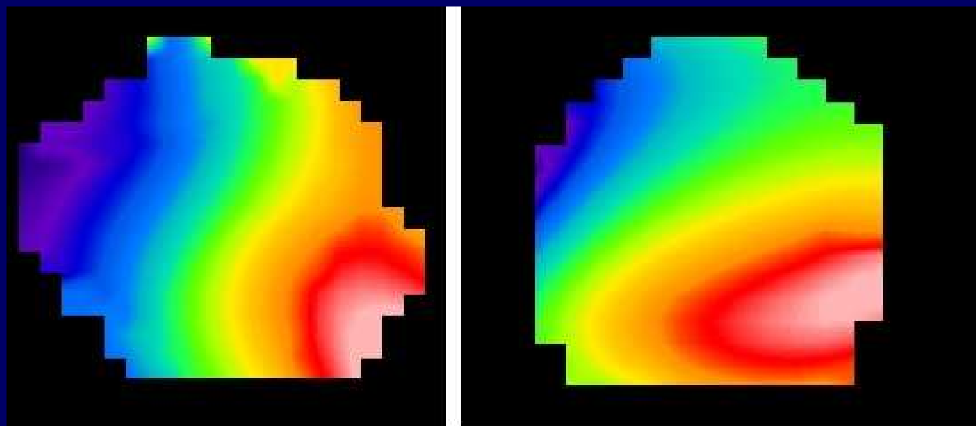


K-cont.& Hα brightness
1"
data
1.0
data-model
0
+0.5
-0.17
normalized Hα flux
K-continuum
-140
+140
+80
0
-25
velocity
35
70
130
+50
0
-
50
dispersion
BzK 6004
z=2.39
offset (kpc)
surface brightness
circular velocity (km/s)
velocity dispersion (km/s)
major axis offset (")
radius (kpc)
surface density/brightness
circular velocity (km/s)
enclosed mass (M_sun)
radius (")

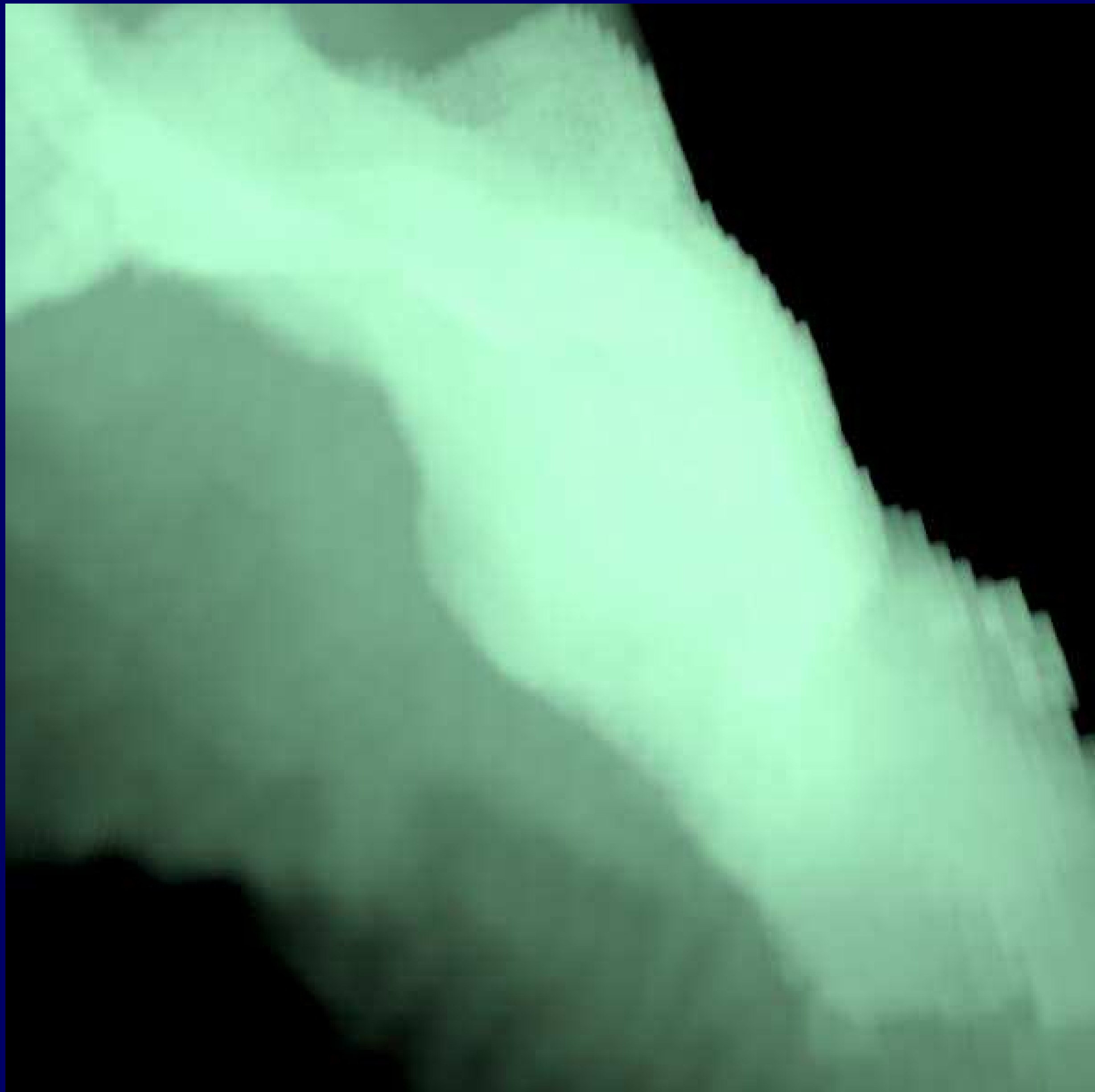
LIRGS at z~0.7
High SFR in Massive Rotating Disks

Hammer et al 2004



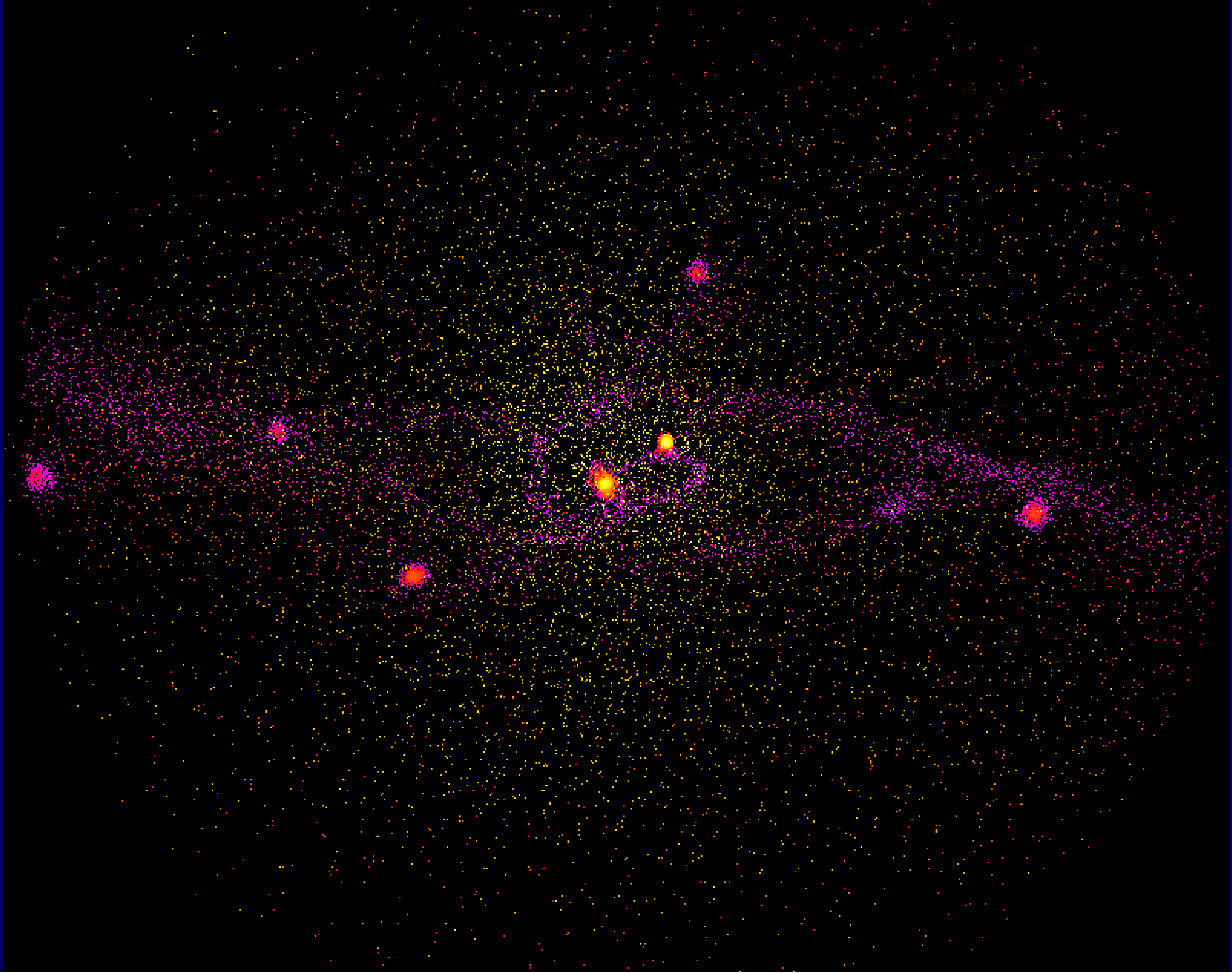


A disk fed by streams at high z

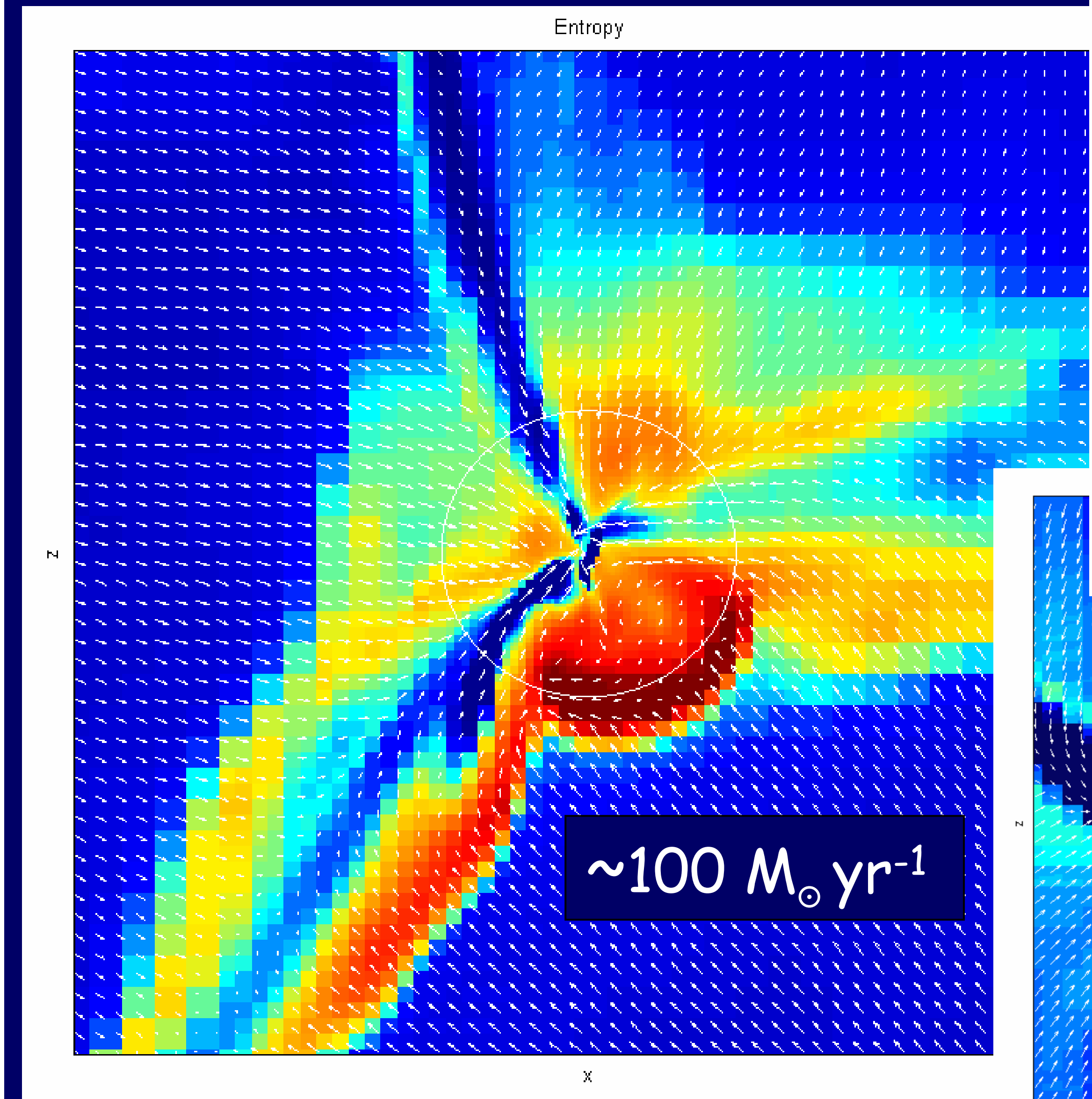


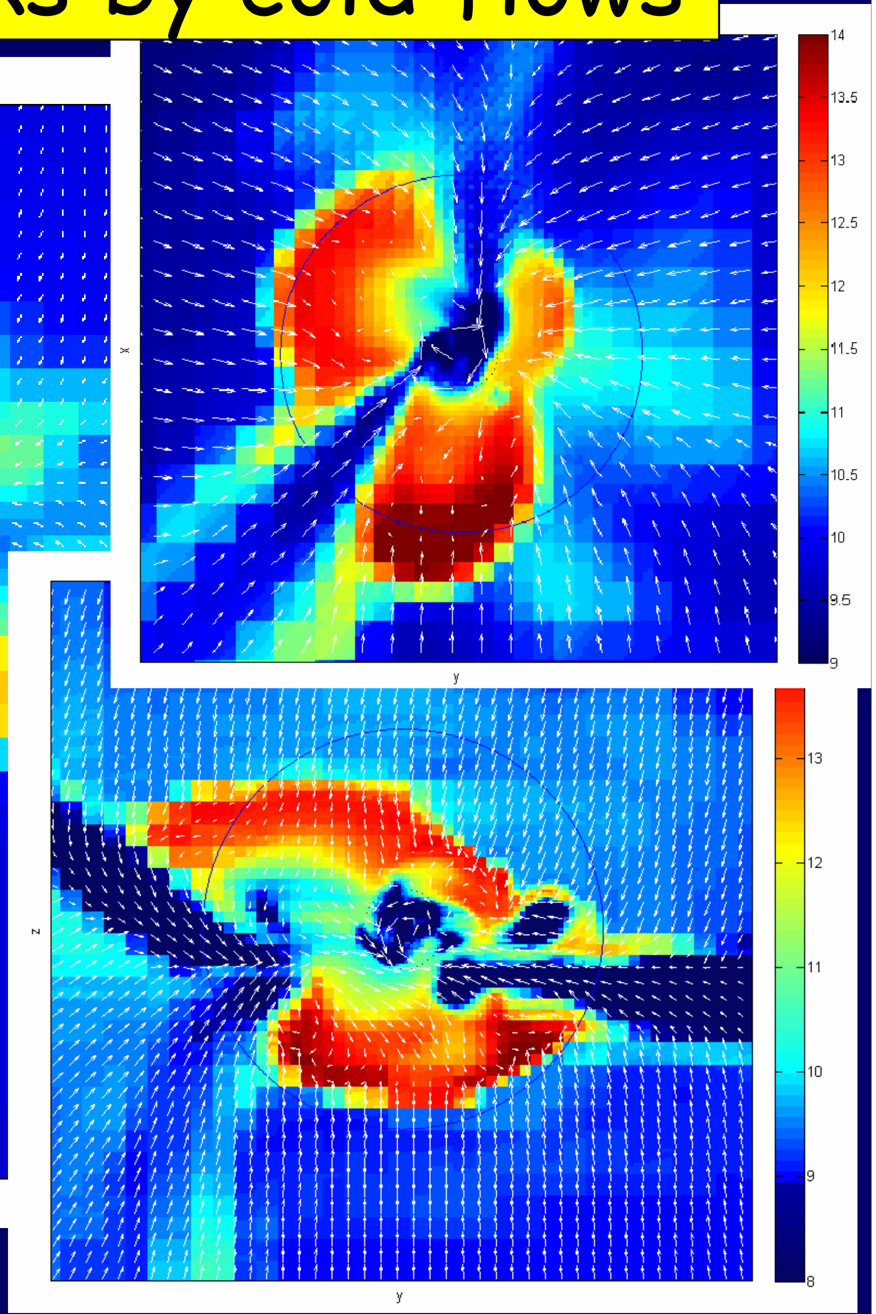
Governato et al.

Cold Streams at z=3 (SPH, Katz et al.)



Massive High-z Disks by cold flows



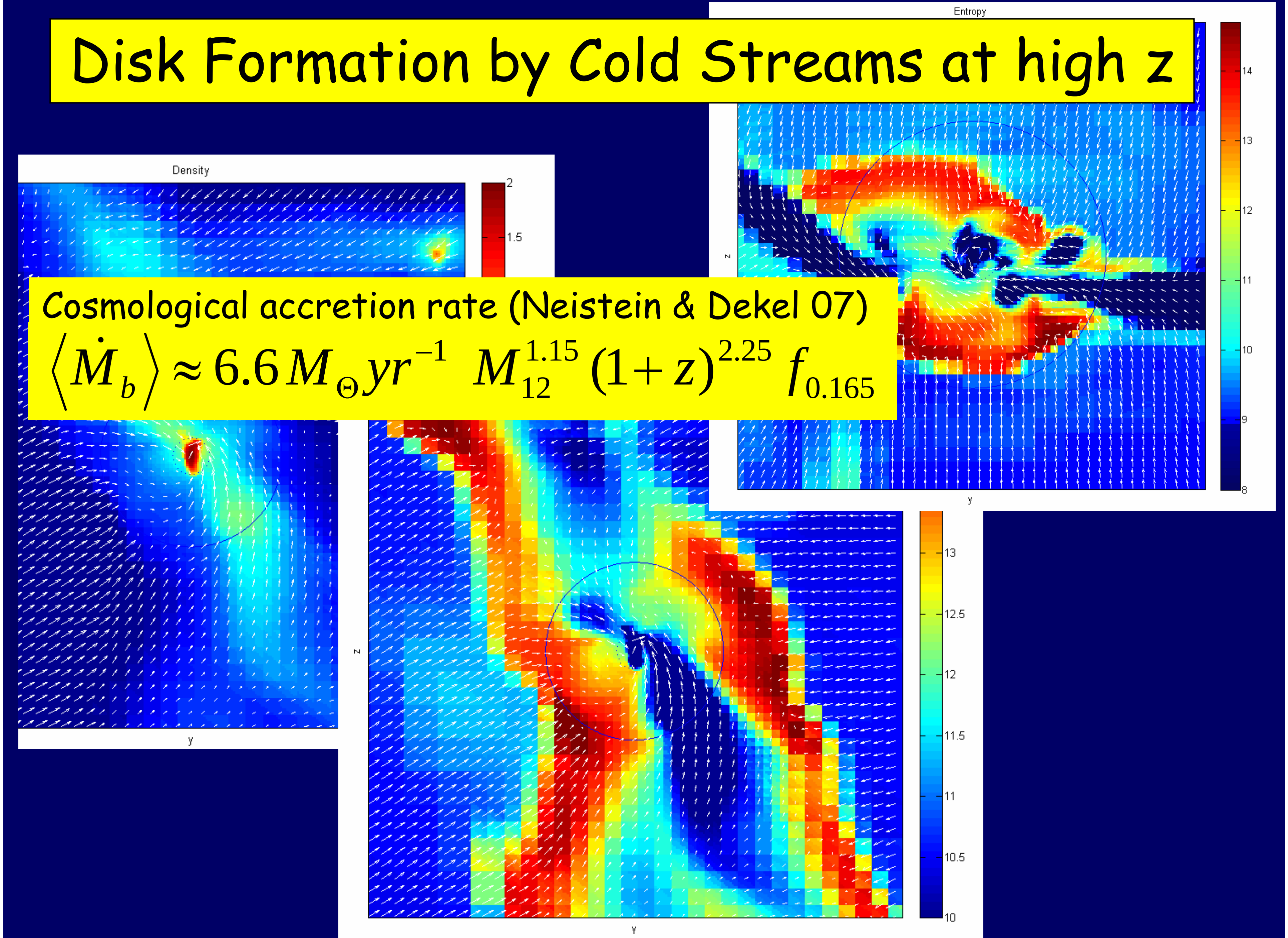


Ocvirk, Pichon, Teyssier 08 - AMR res 2kpc

Disk Formation by Cold Streams at high z

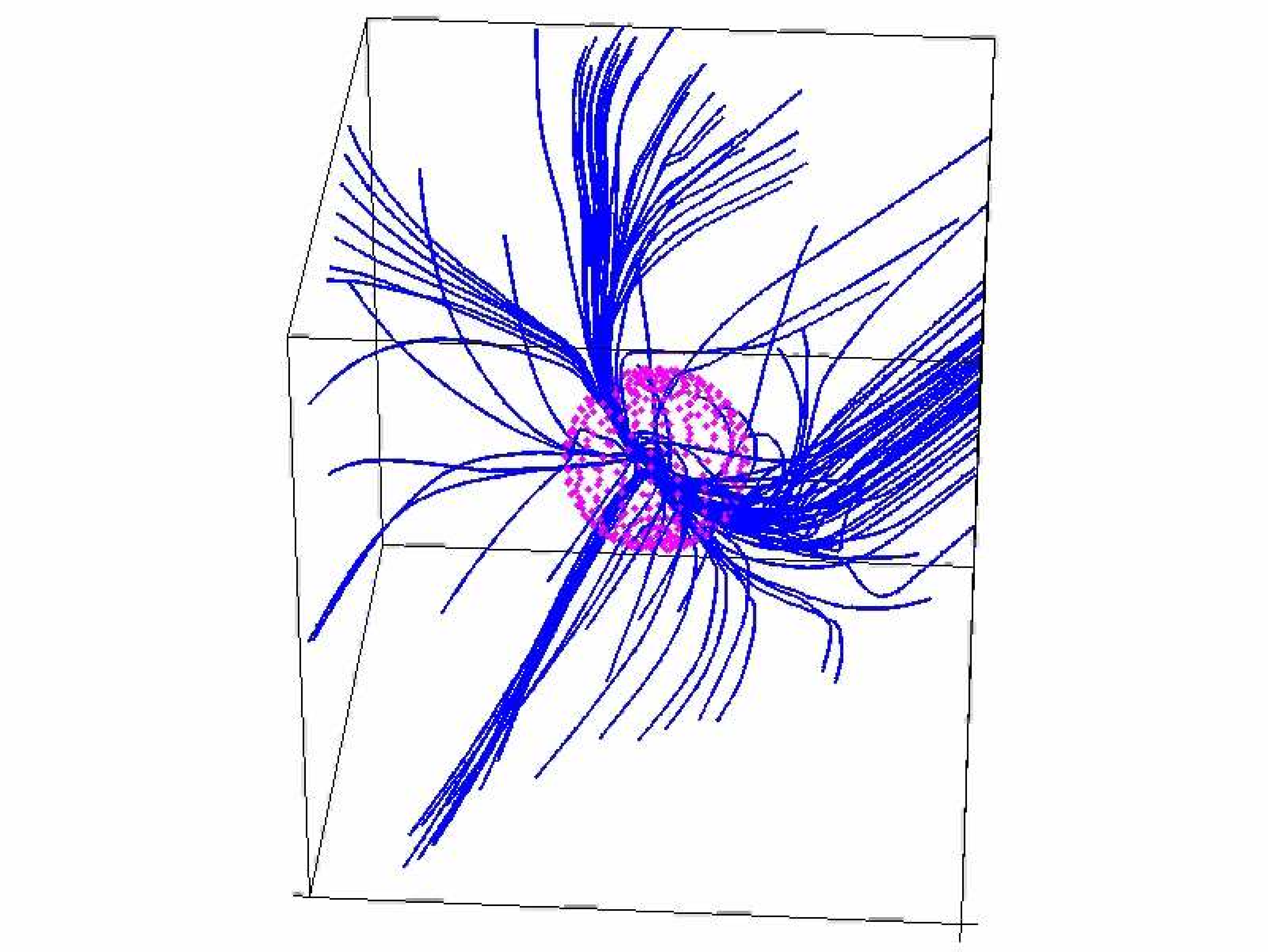
Cosmological accretion rate (Neistein & Dekel 07)

$$\left\langle \dot{M}_b \right\rangle \approx 6.6\, M_{\Theta} yr^{-1}\;\; M_{12}^{1.15}\,(1+z)^{2.25}\, f_{0.165}$$



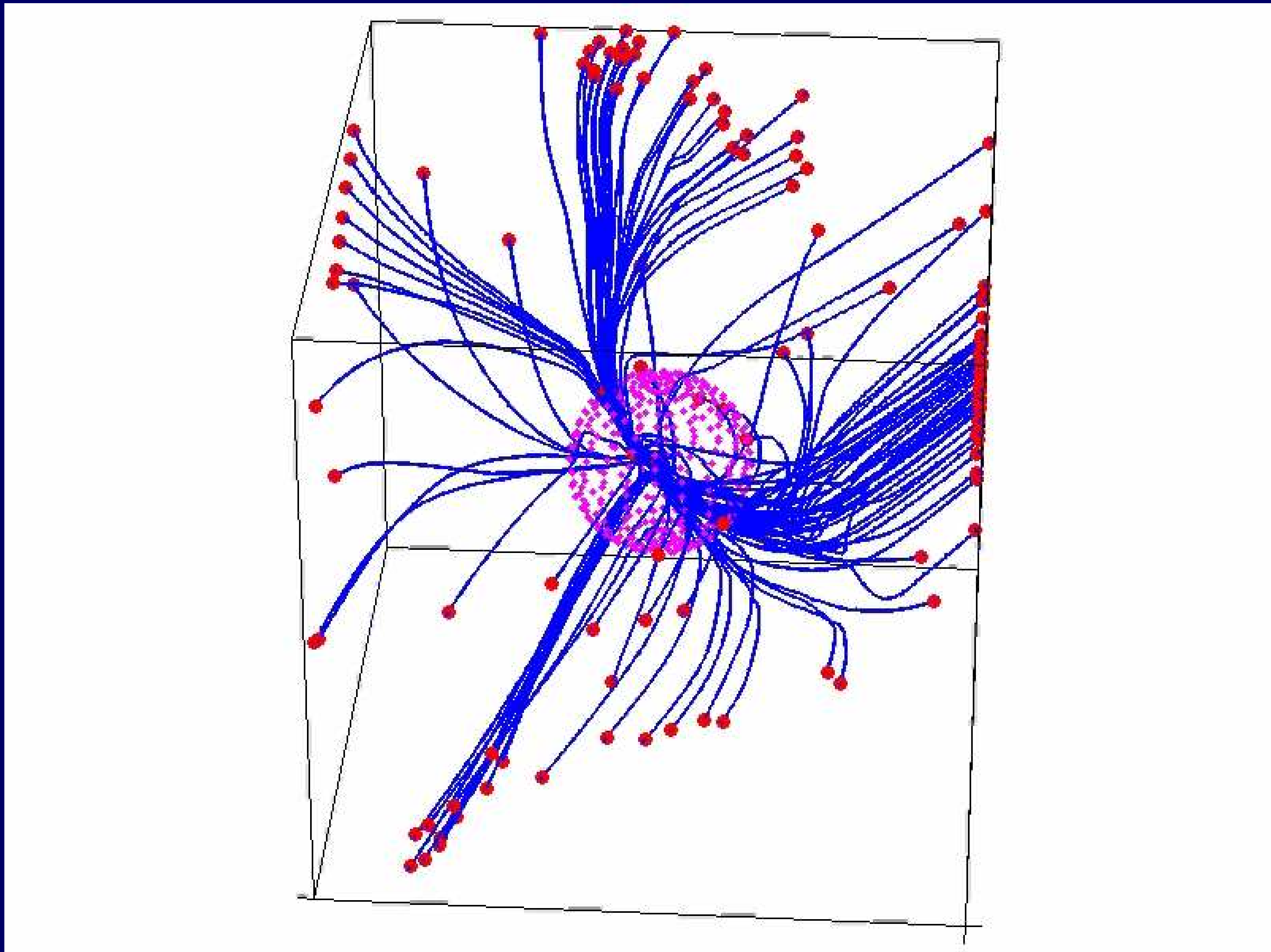
Stream-lines

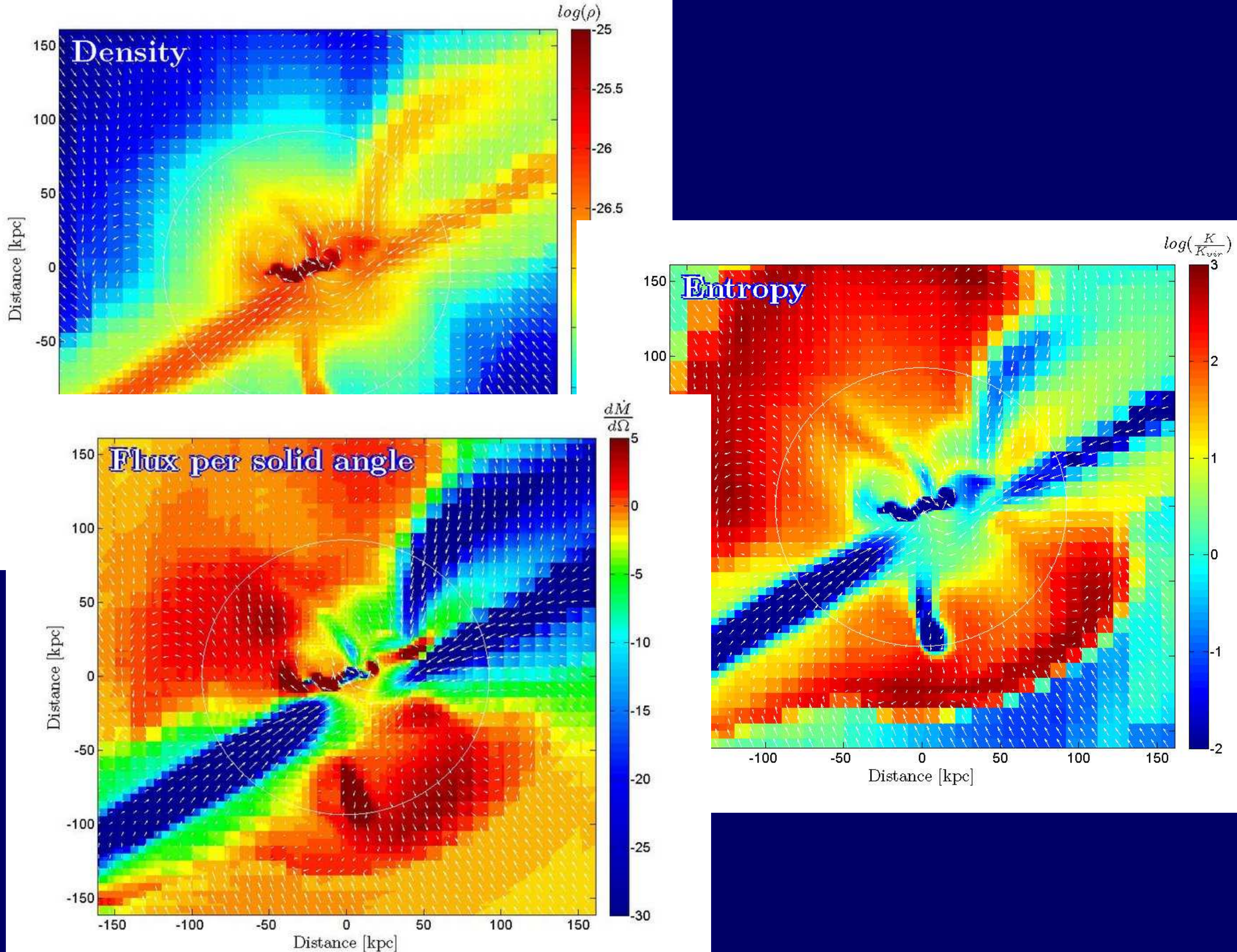
Engel, Mumcuoglu, Goerdt



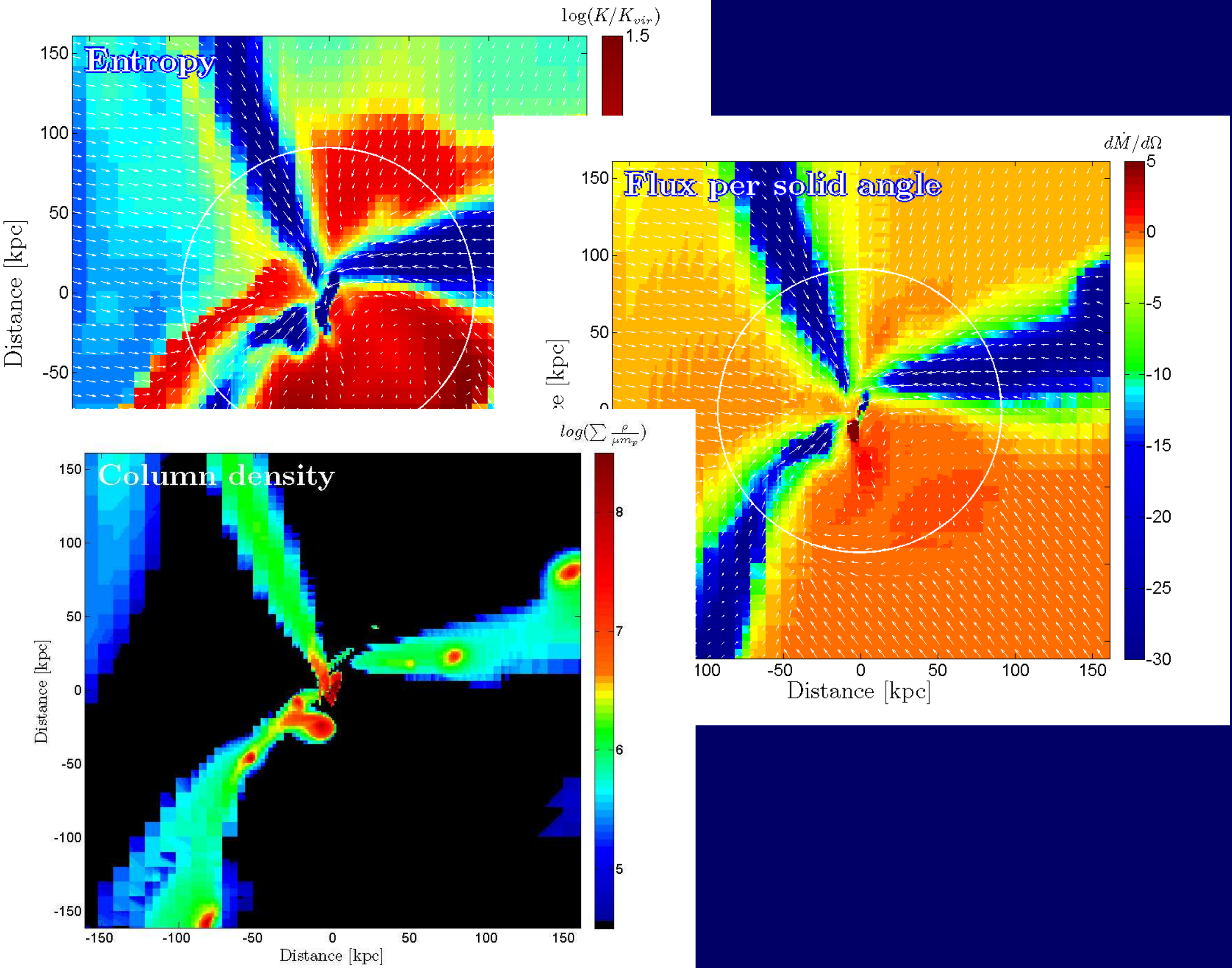
Penetrating Stream-lines

Engel, Mumcuoglu, Goerdt





Density
$log(\rho)$
Distance [kpc]
Entropy
$log(\frac{K}{K_{vir}})$
Distance [kpc]
Flux per solid angle
$\frac{d\dot{M}}{d\Omega}$
Distance [kpc]
Distance [kpc]



Entropy
$\log(K/K_{vir})$
1.5
150
100
50
0
-50
Distance [kpc]
Flux per solid angle
$d\dot{M}/d\Omega$
5
0
-5
-10
-15
-20
-25
-30
150
100
50
0
100
-50
0
50
100
150
Distance [kpc]
Column density
$log(\sum \frac{\rho}{\mu m_p})$
8
7
6
5
150
100
50
0
-50
-100
-150
-150
-100
-50
0
50
100
150
Distance [kpc]

Average Assembly Rate into R_{vir} by EPS

Neistein, van den Bosch, Dekel 06; Birnboim, Dekel, Neistein 07, Neistein & Dekel 07, 08

Growth rate of main progenitor:

$$\frac{d\ln M}{d\omega} \approx -(2/\pi)^{1/2}\left(\sigma^2(M/q)-\sigma^2(M)\right)^{-1/2}$$

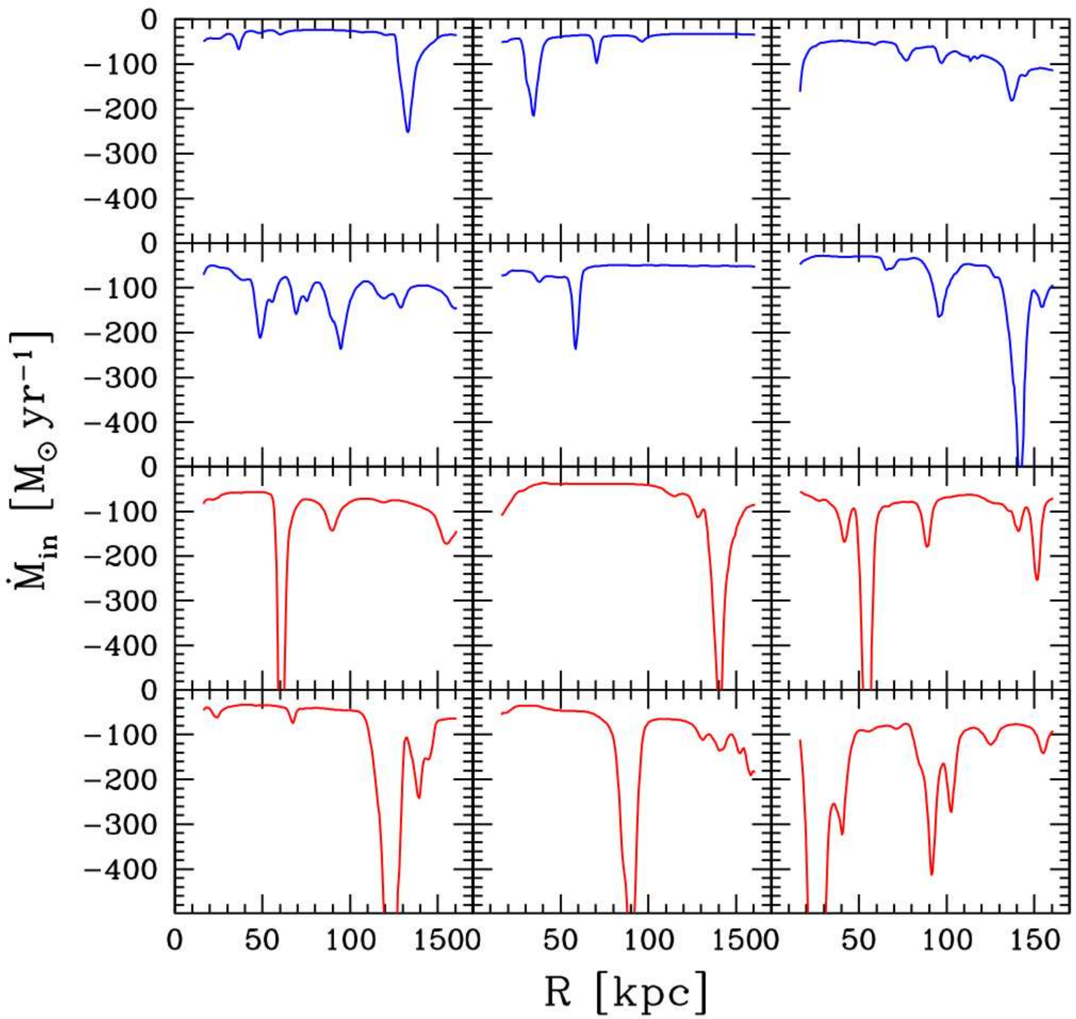
$$\omega \equiv \frac{\delta_c}{D(t)} \qquad q \approx 2.2$$

Approximate for LCDM

$$\left\langle \dot{M}_b \right\rangle_{vir} \approx 6.6\, M_{\Theta} yr^{-1}\, M_{12}^{1.15} (1+z)^{2.25}\, f_{0.165}$$

$M=2\times10^{12} M_{\odot}$ $z=2.2$ → $dM/dt \sim 200\ M_{\odot} yr^{-1}$

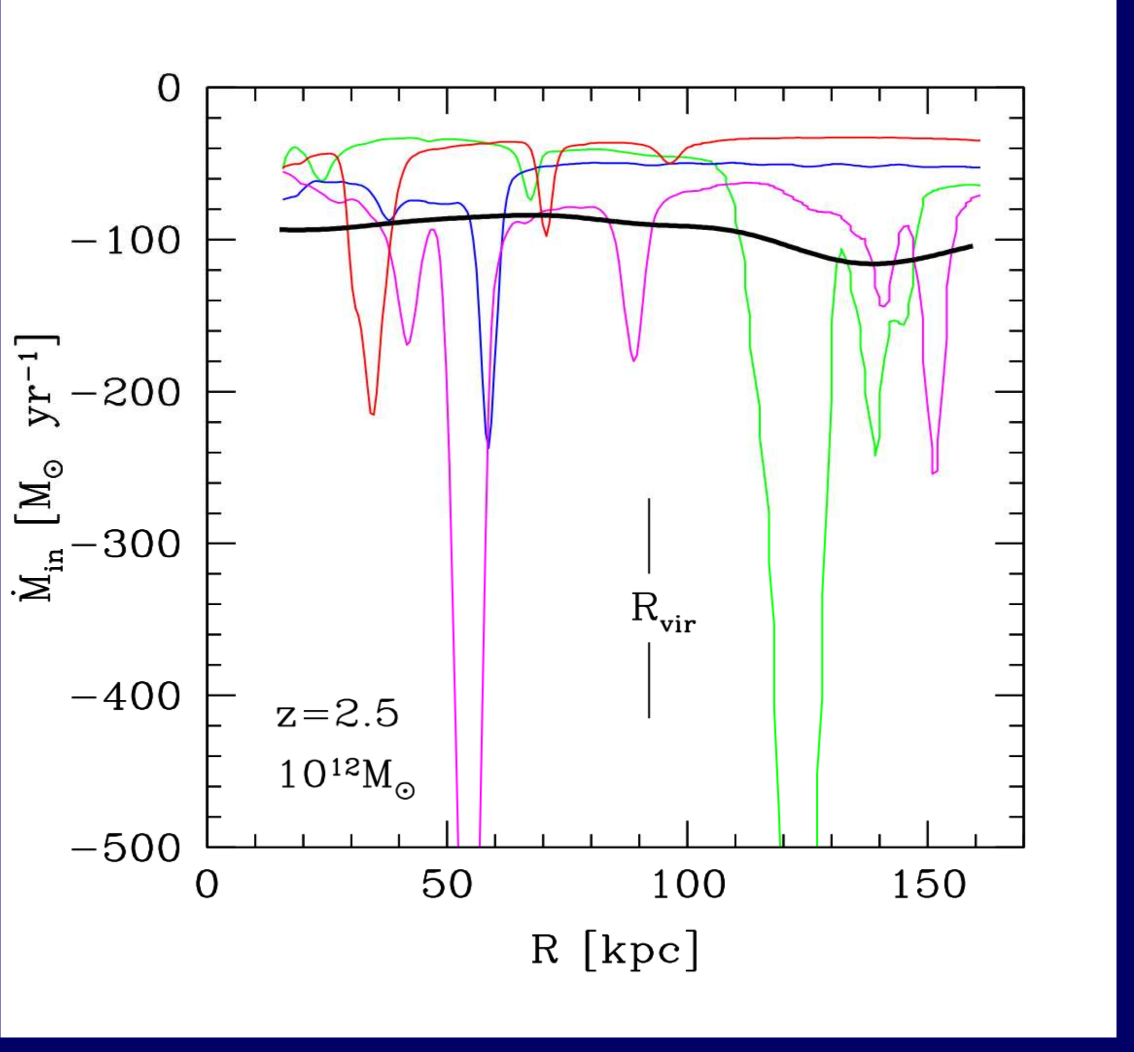
May explain high-SFR galaxies
if a similar flux penetrates to the disk,
if it is gas rich, and if SFR follows rapidly



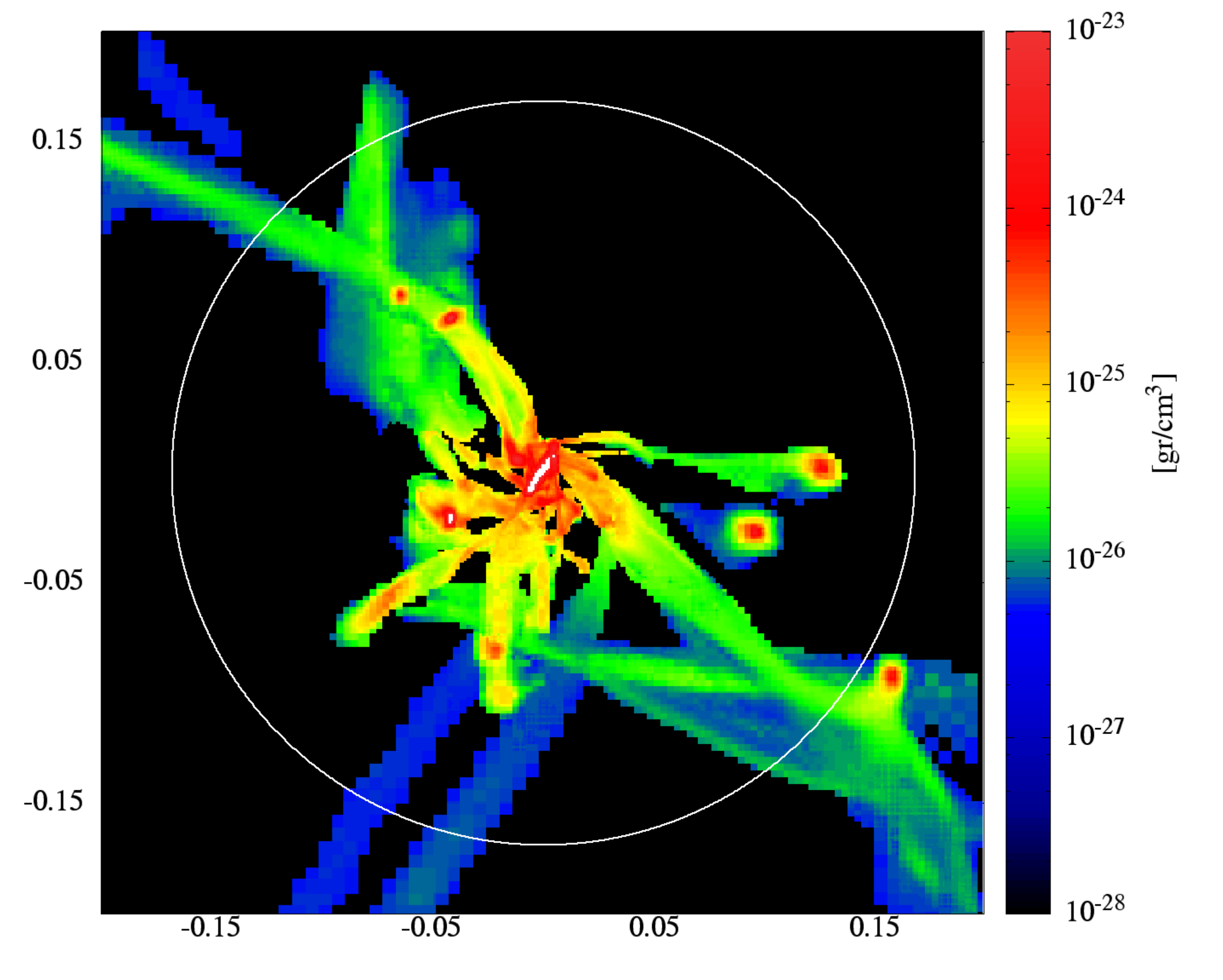
$\dot{M}_{in}$ [$M_\odot$ yr^{-1}]
R [kpc]
0
−100
−200
−300
−400
0
50
100
150

Inflow Rate into the Disk

At z=2-3, $M=10^{12}M_{\odot}$, the input rate into the disk is comparable to the infall rate into the virial radius, most of it along narrow streams

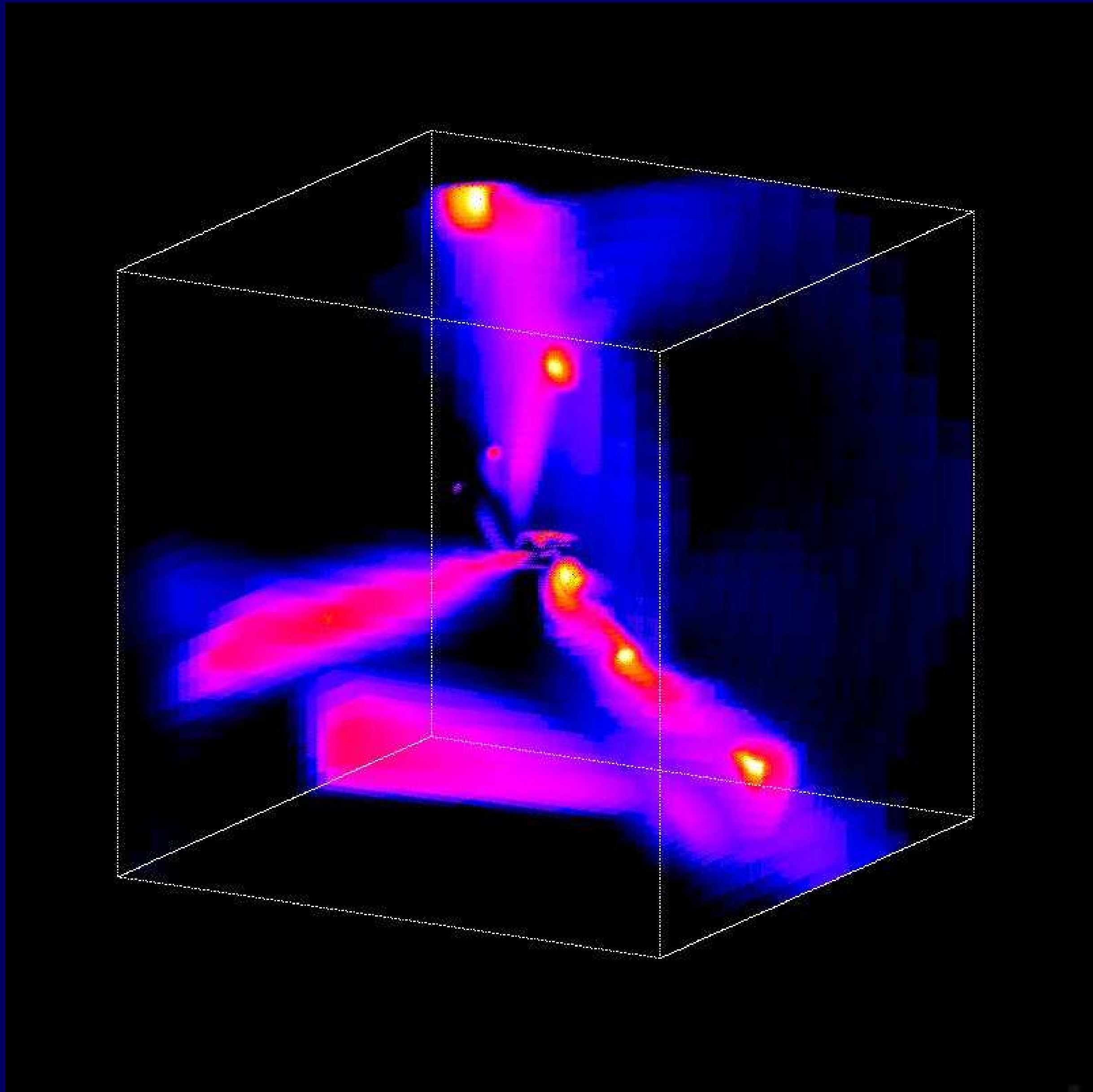


Cold, dense filaments and clumps (50%) riding on dark-matter filaments and sub-halos

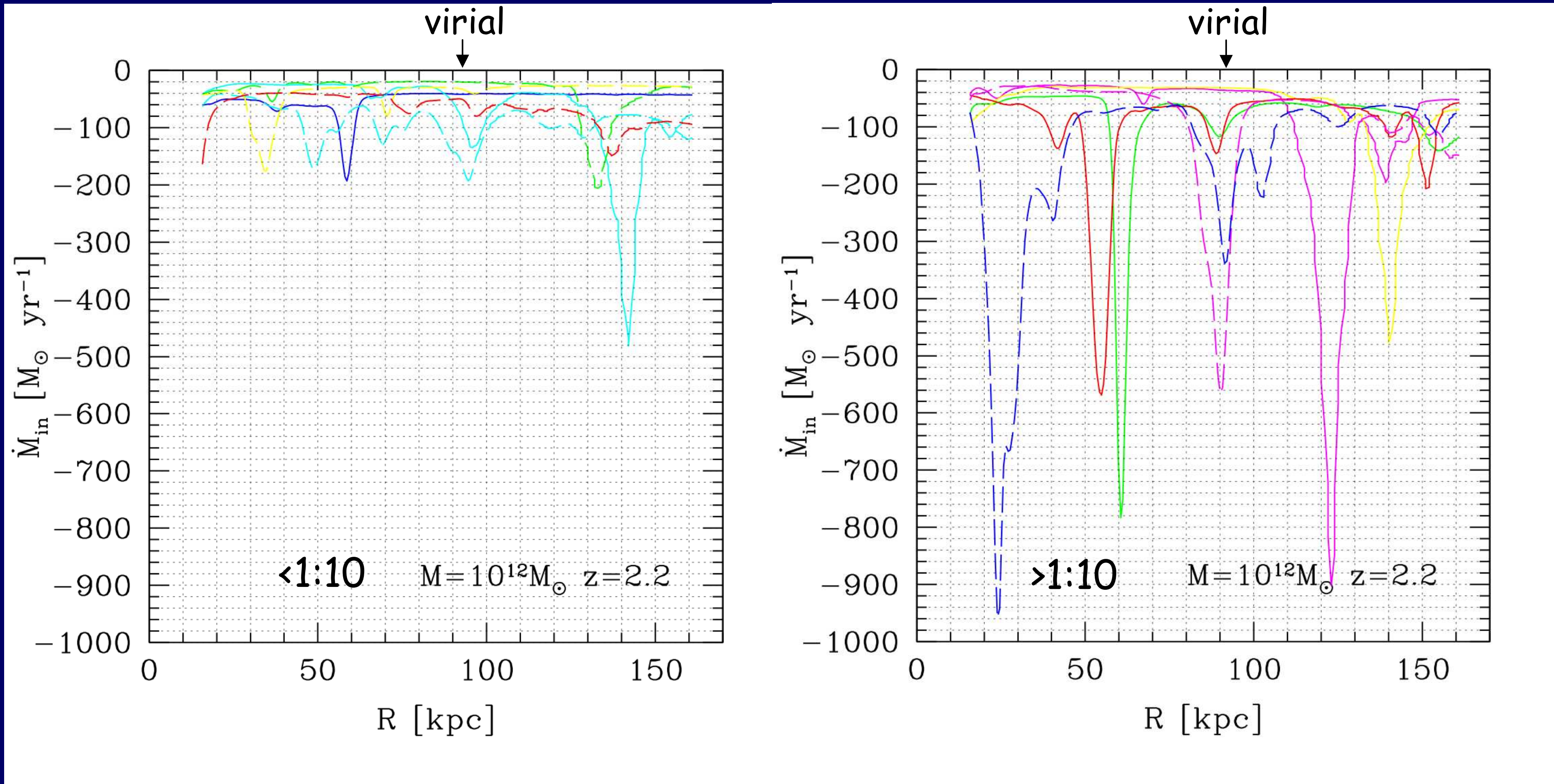


Birnboim, Zinger, Dekel, Kravtsov

Streams in 3D: partly clumpy

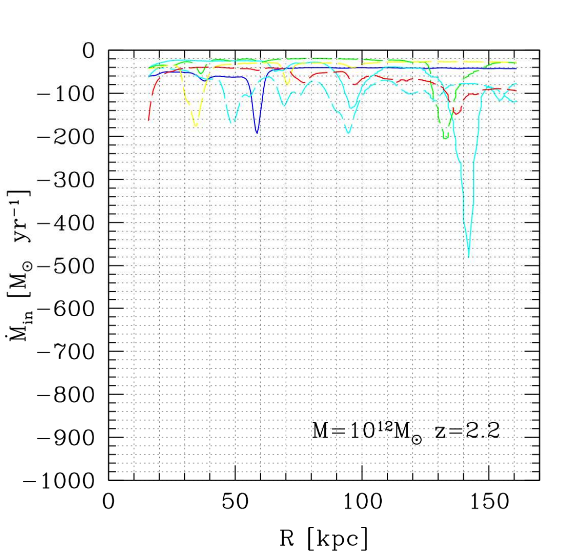


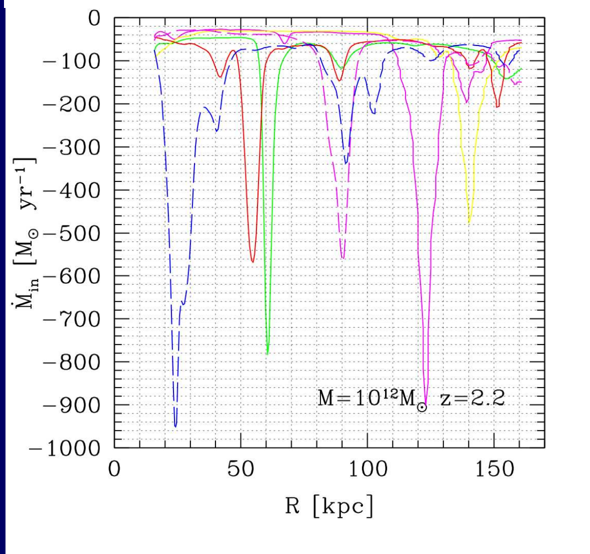
Gas Inflow Rate: clumpiness

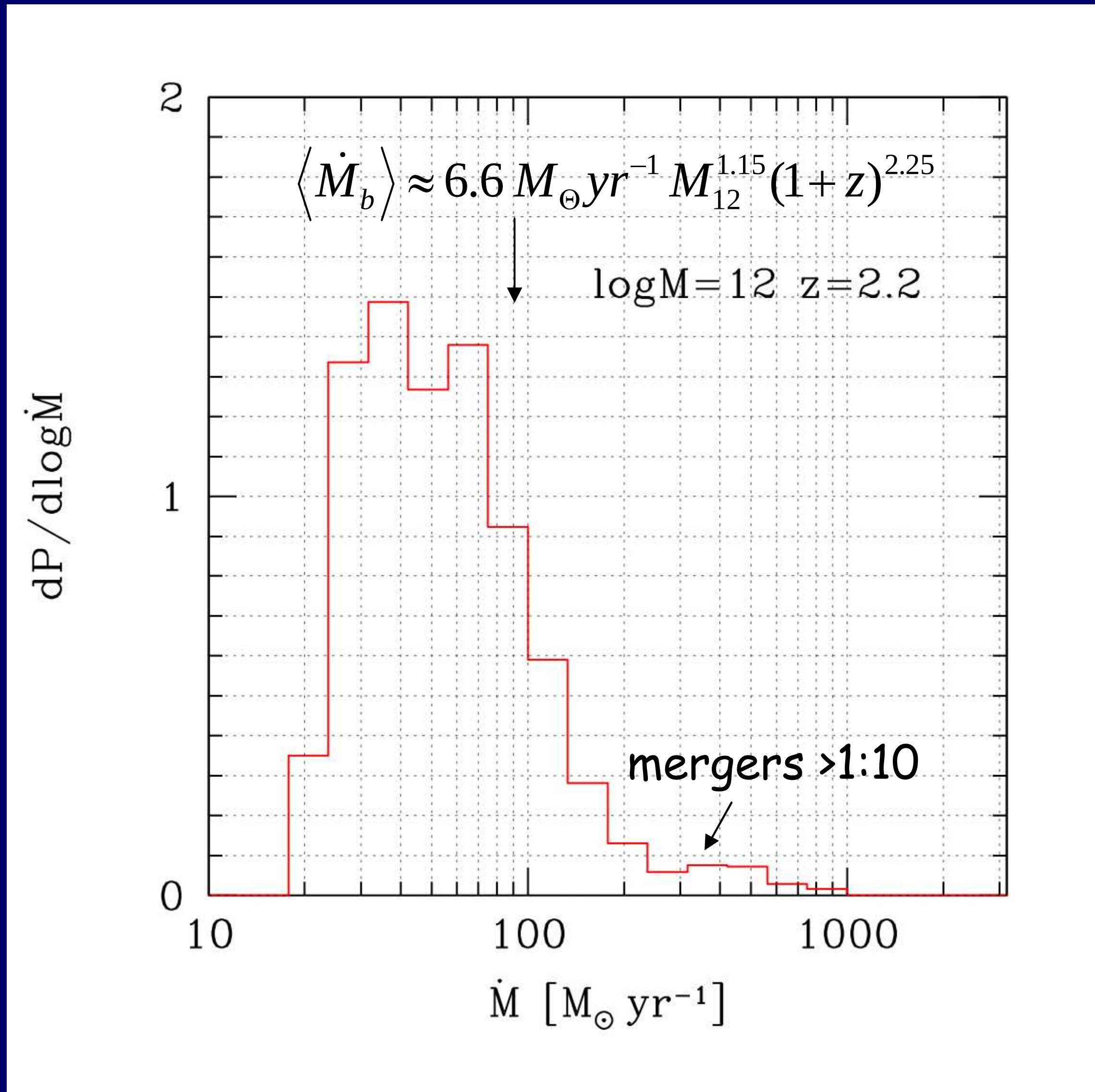


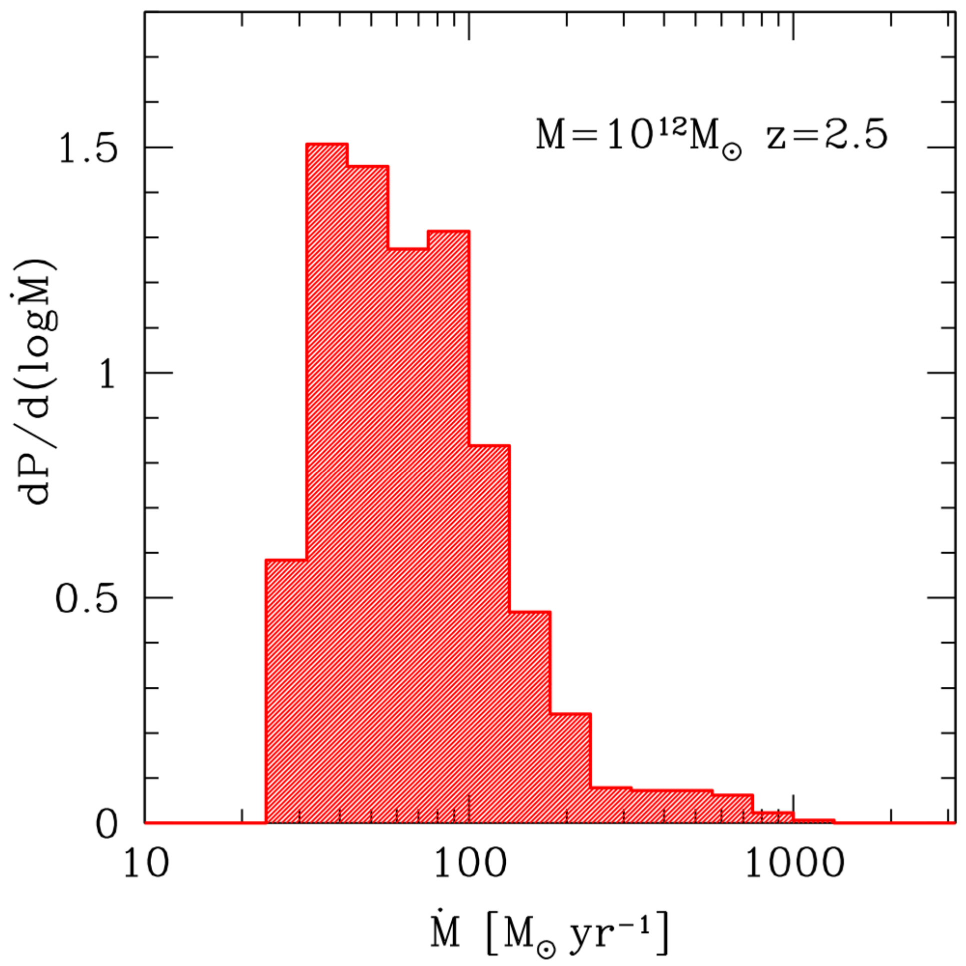
50% of Mdot is in mergers >1:10, but the duty cycle is <10%

Distribution of Gas Inflow Rate

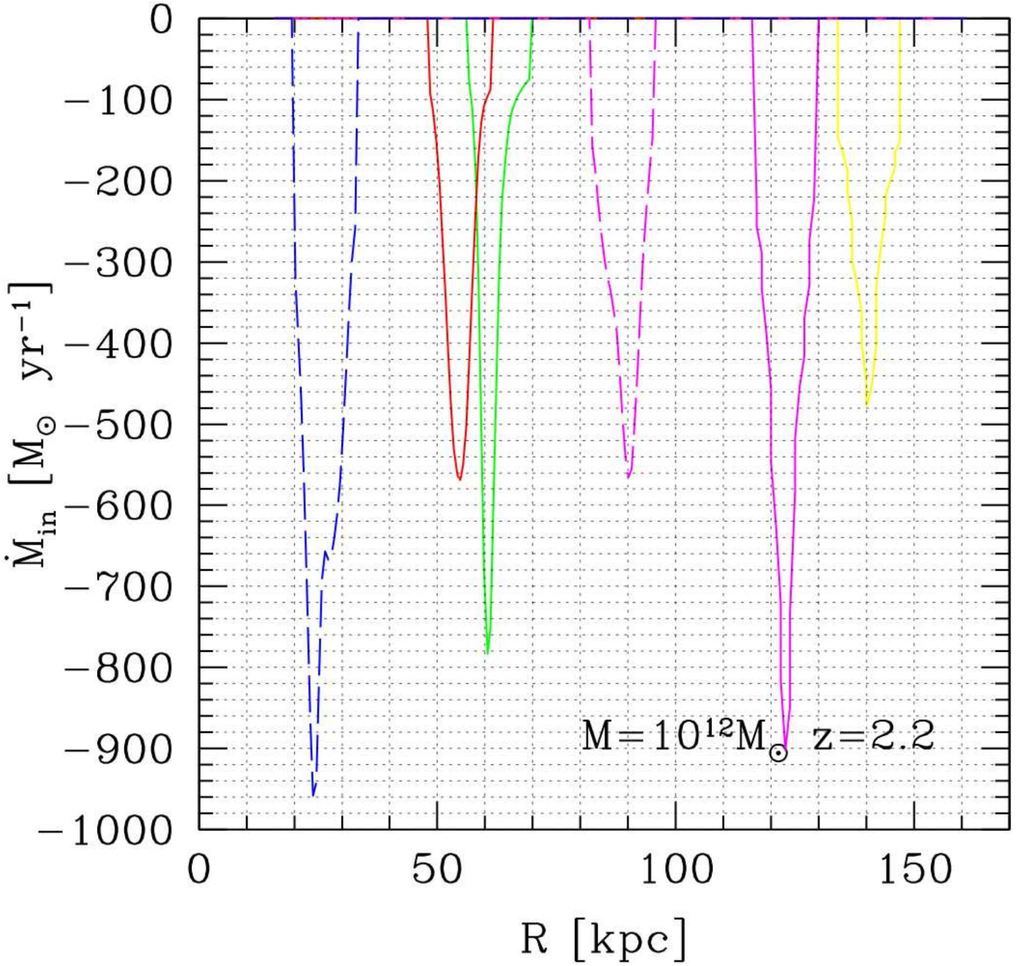








M=10^12M⊙ z=2.5
dP/d(logṀ)
0
0.5
1
1.5
10
100
1000
Ṁ [M⊙ yr^-1]



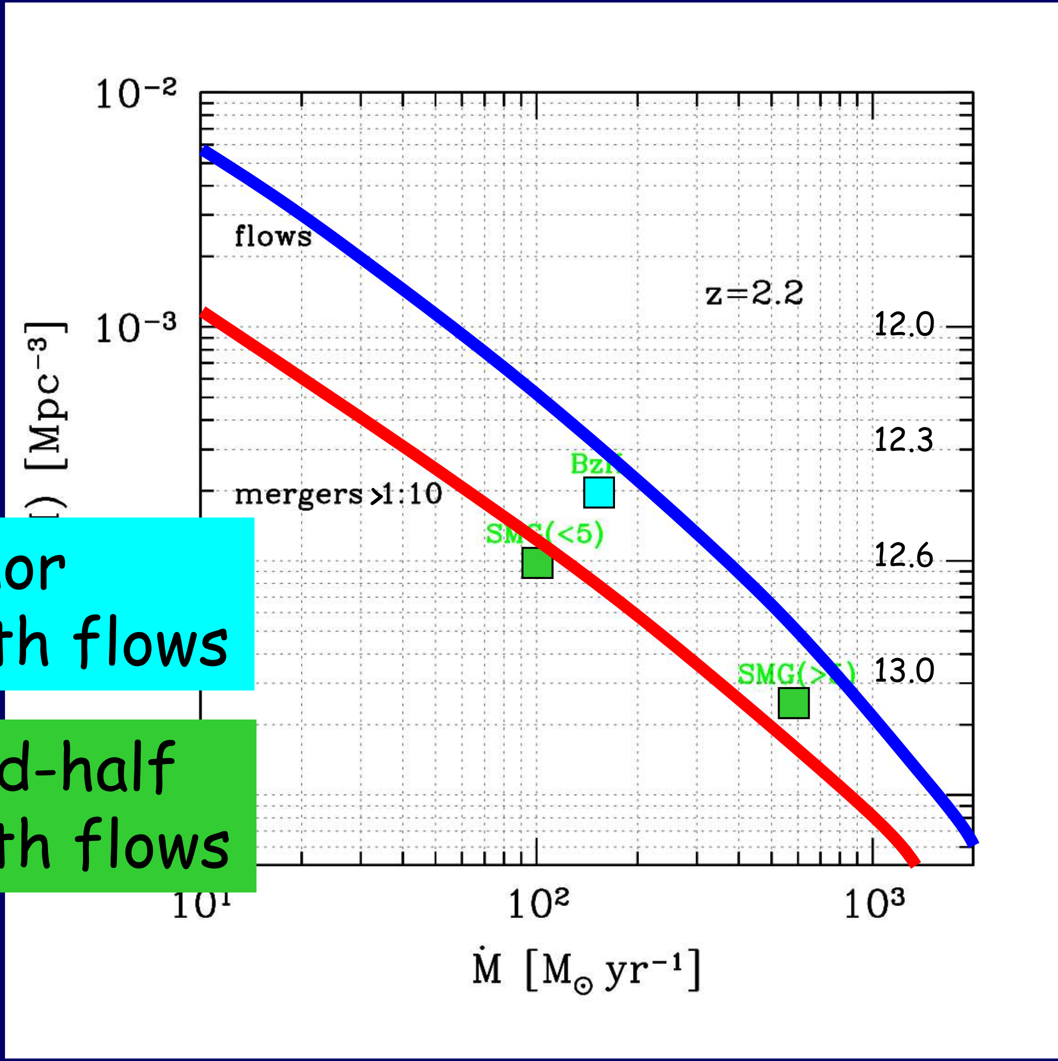
0
−100
−200
−300
−400
−500
−600
−700
−800
−900
−1000
$\dot{M}_{in}$ [$M_\odot$ yr^{-1}]
0
50
100
150
R [kpc]
$M=10^{12}M_\odot$ z=2.2

Comoving Number Density of Galaxies

Assume scaling of P(Mdot)

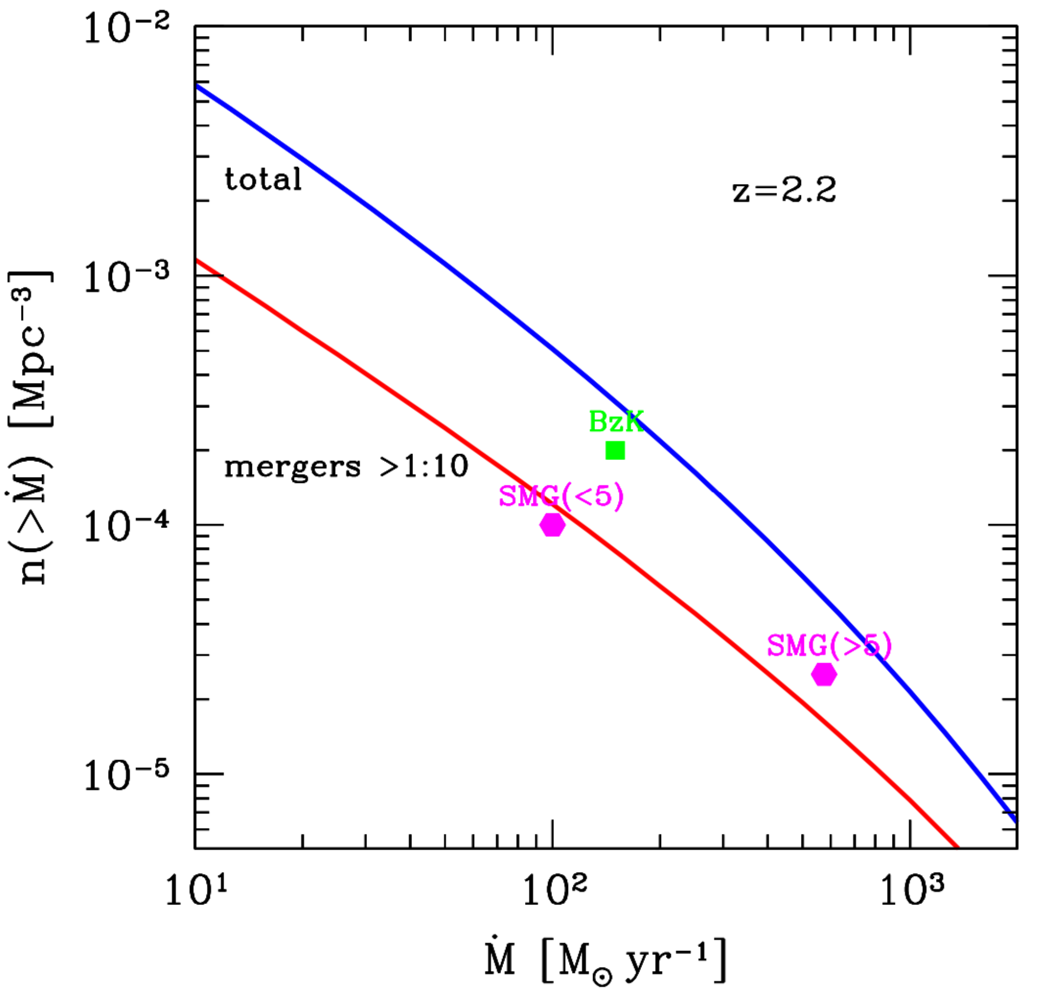
$$\dot{M}_b \approx 6.6\, M_{\Theta} yr^{-1}\, M_{12}^{1.15} (1+z)^{2.25}$$

and P(M) by Sheth-Tormen



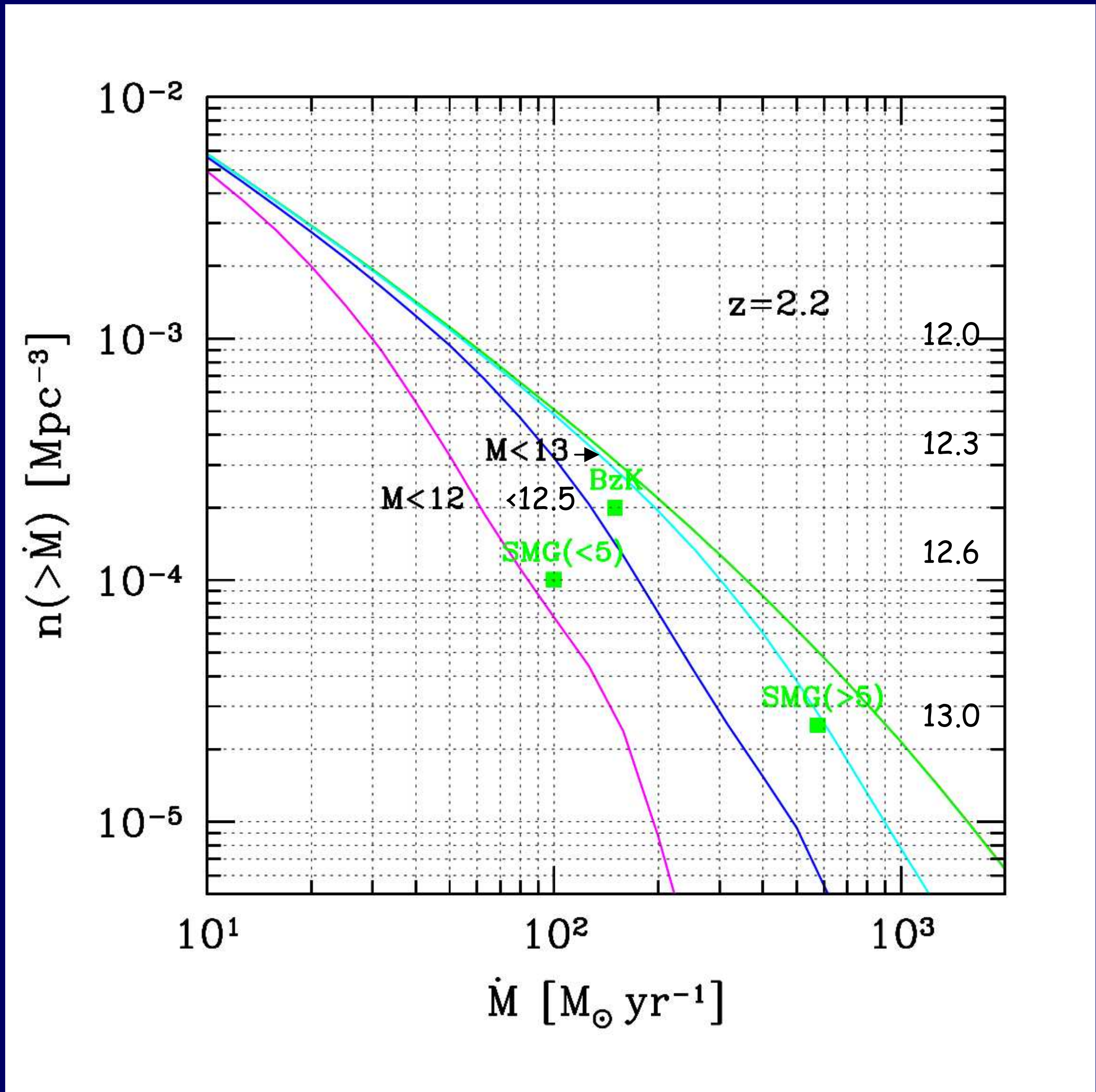
BzK are mostly mini-minor mergers <1:10, i.e. smooth flows

Bright SMG are half-and-half mergers >1:10 and smooth flows

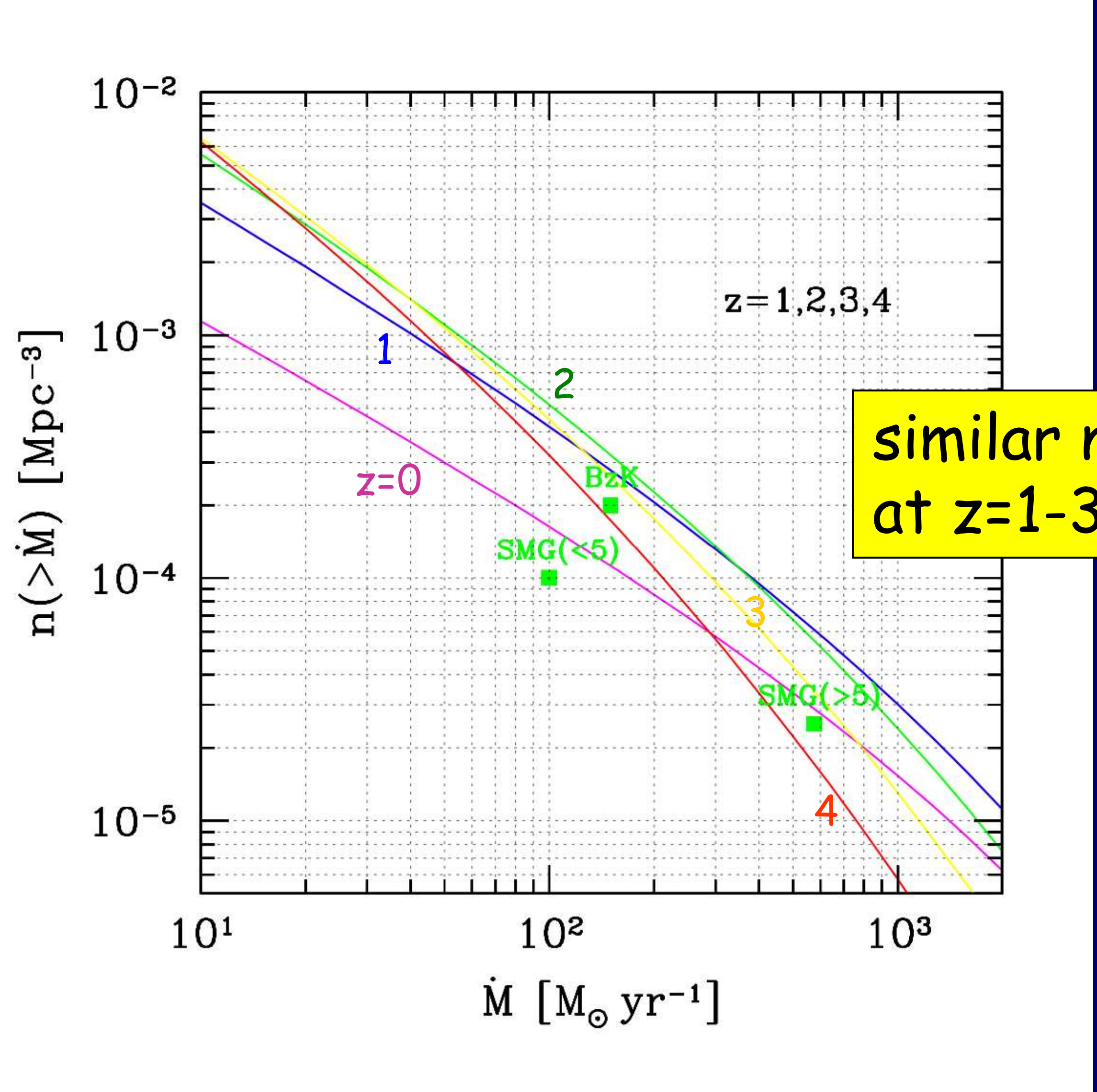


total
z=2.2
BzK
mergers >1:10
SMG(<5)
SMG(>5)
10−2
10−3
10−4
10−5
n(>Ṁ) [Mpc−3]
10¹
10²
10³
Ṁ [M⊙ yr−1]

Contribution of Different Masses



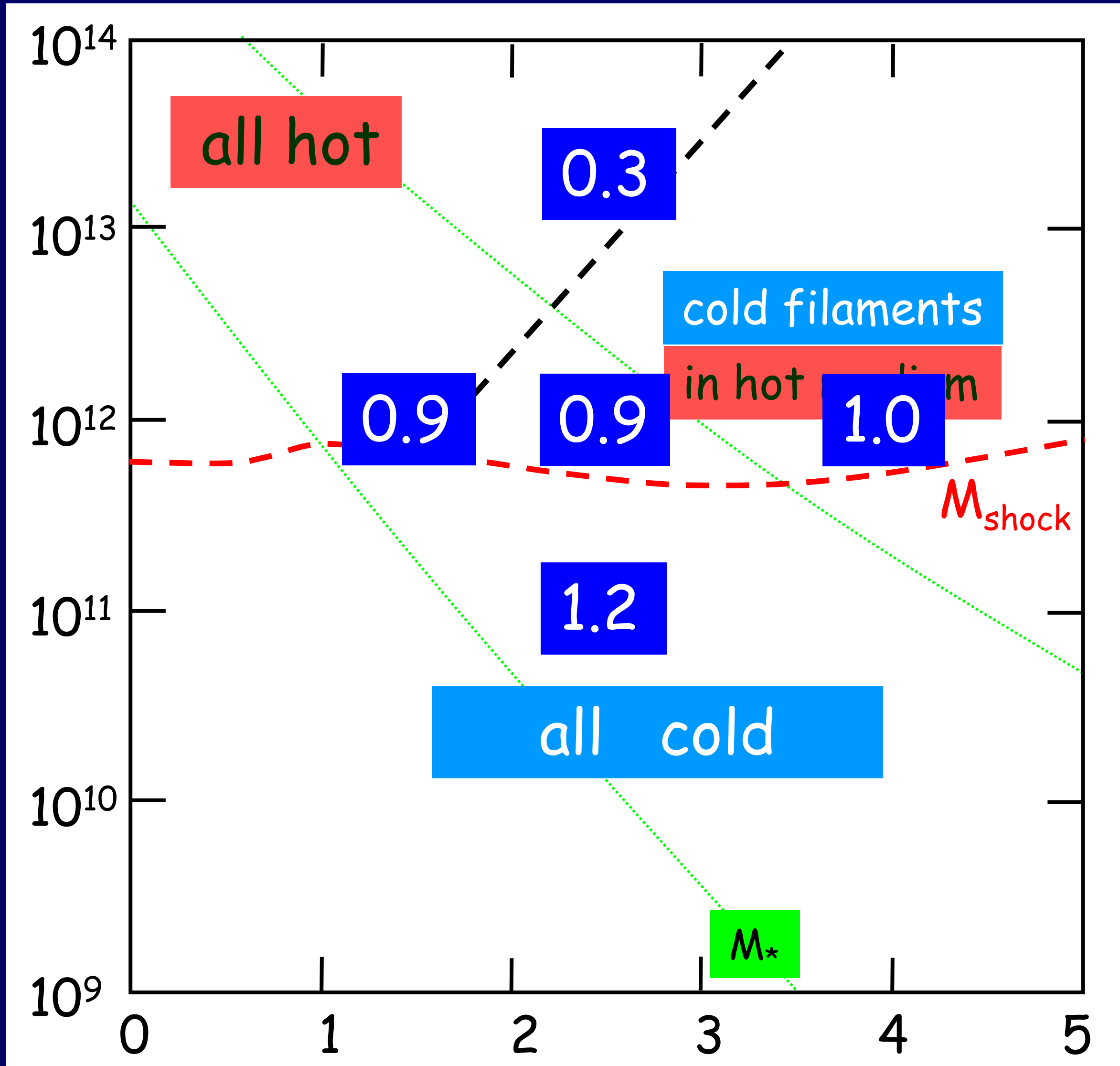
At Different Redshifts



similar n(>SFR) at z=1-3

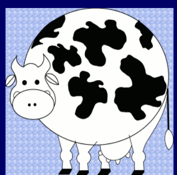
Stream Flux in halos of M at z

M_{vir} $[M_\odot]$



redshift z

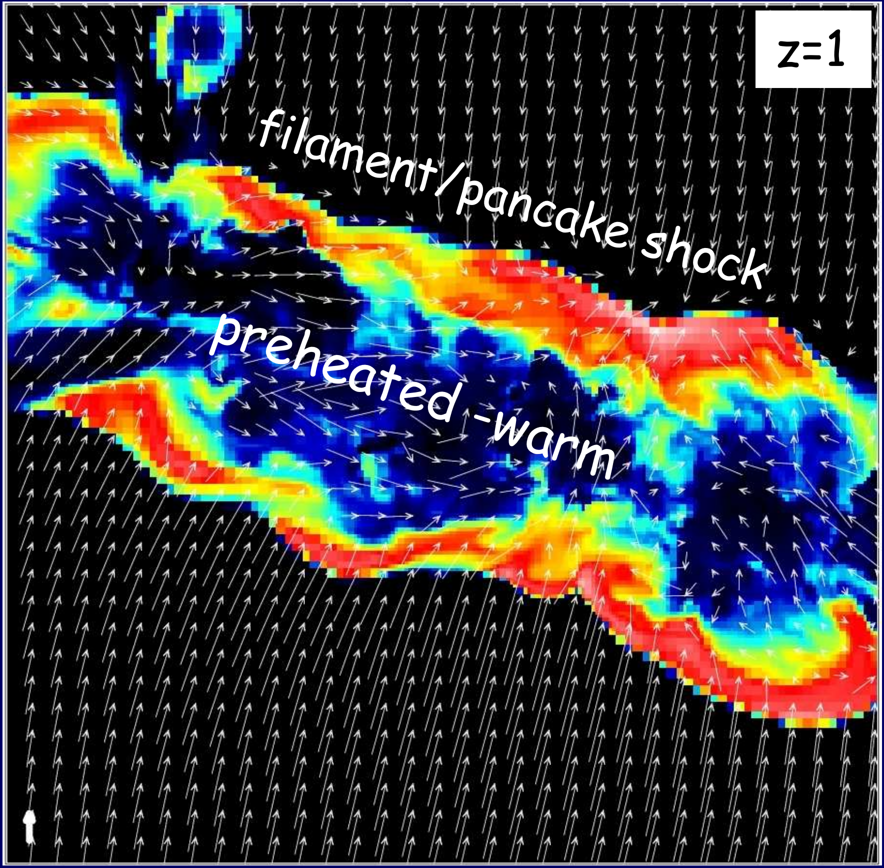
$$\frac{\dot{M}_{disk}}{\dot{M}_{vir}}$$

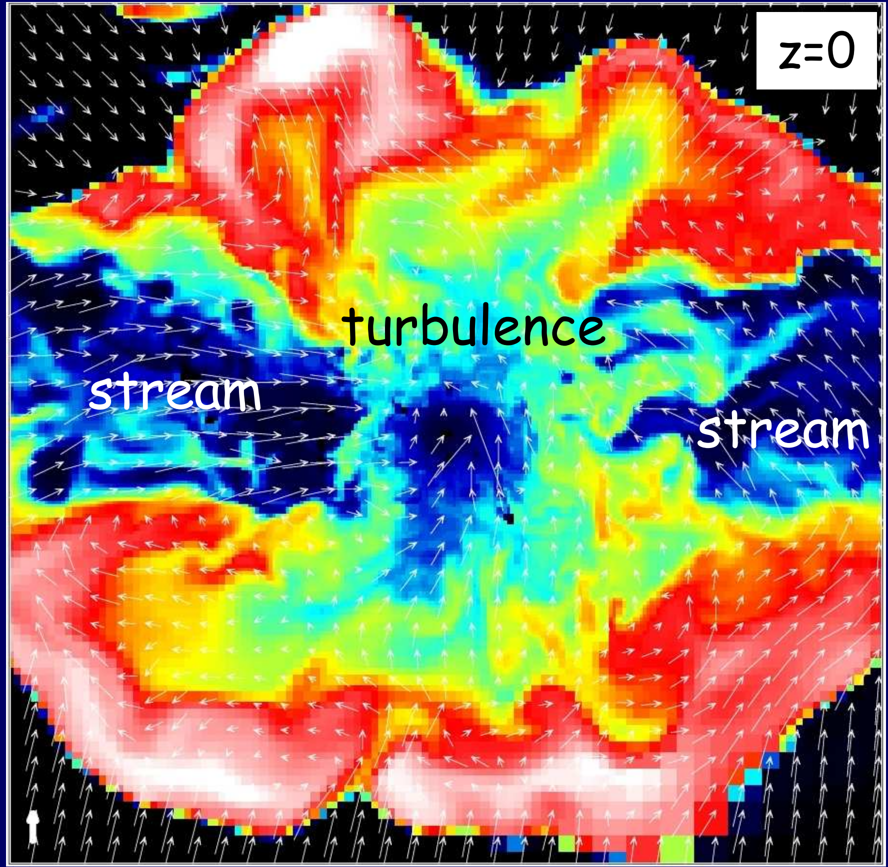


Formation of a Massive Halo at Late z

AMR cosmological simulations of clusters (3 kpc res.): Kravtsov, Nagai

entropy





Conclusions

At z~2-3, disks of M_{star}~$10^{11}M_\odot$ grow rapidly via narrow cold gas-dominated streams penetrating through a shock-heated medium

The input rate to the disk is comparable to the infall rate into the virial radius (EPS)

Half the inflow is mergers >1:10, and half is smother flows

The duty cycle for mergers is ~0.1 → most of the star-forming galaxies are observed while being fed by smooth flows

Smooth flows keep the rotating disk intact, though thick and perturbed. Unstable →SFR follows the high gas input rate

At z~2.2, SFR>150 at n~3×10^{-4} and SFR>500 at n~6×10^{-5}

Most of the BzK are disks fed by smooth flows in halos $2\times10^{12}M_\odot$

Half the SMG are mergers >1:10 in halos $(1.5-4)\times10^{12}M_\odot$
→ compact high-SFR regions

Half the $10^{11}M_\odot$ galaxies at z~2.2 had a major merger during the preceding 1.5 Gyr → compact spheroids of low SFR.

Thank you