Lecture

On the Origin of Galaxy Bi-modality: Cold Flows, Clustering and Feedback

- Observed bi-modality
- Shock heating vs cold flows
- Cold filaments in hot halos -- clustering scale
- Feedback Processes
- Origin of the bi-modality

1. Observed Bimodality

Observed Scale

- bi-modality/transition at

$M_* \sim 3\times10^{10} M_\odot$ $\sim L_*$ $M_{halo} \sim 6\times10^{11} M_\odot$

below: disks, blue, star forming, low Z, LSB, M/L decreasing with M along a "fundamental line", in field (small halos), …

above: spheroids, red, old-pop, high Z, HSB, M/L increasing with M, "fundamental plane", clustered (massive halos), AGNs, …

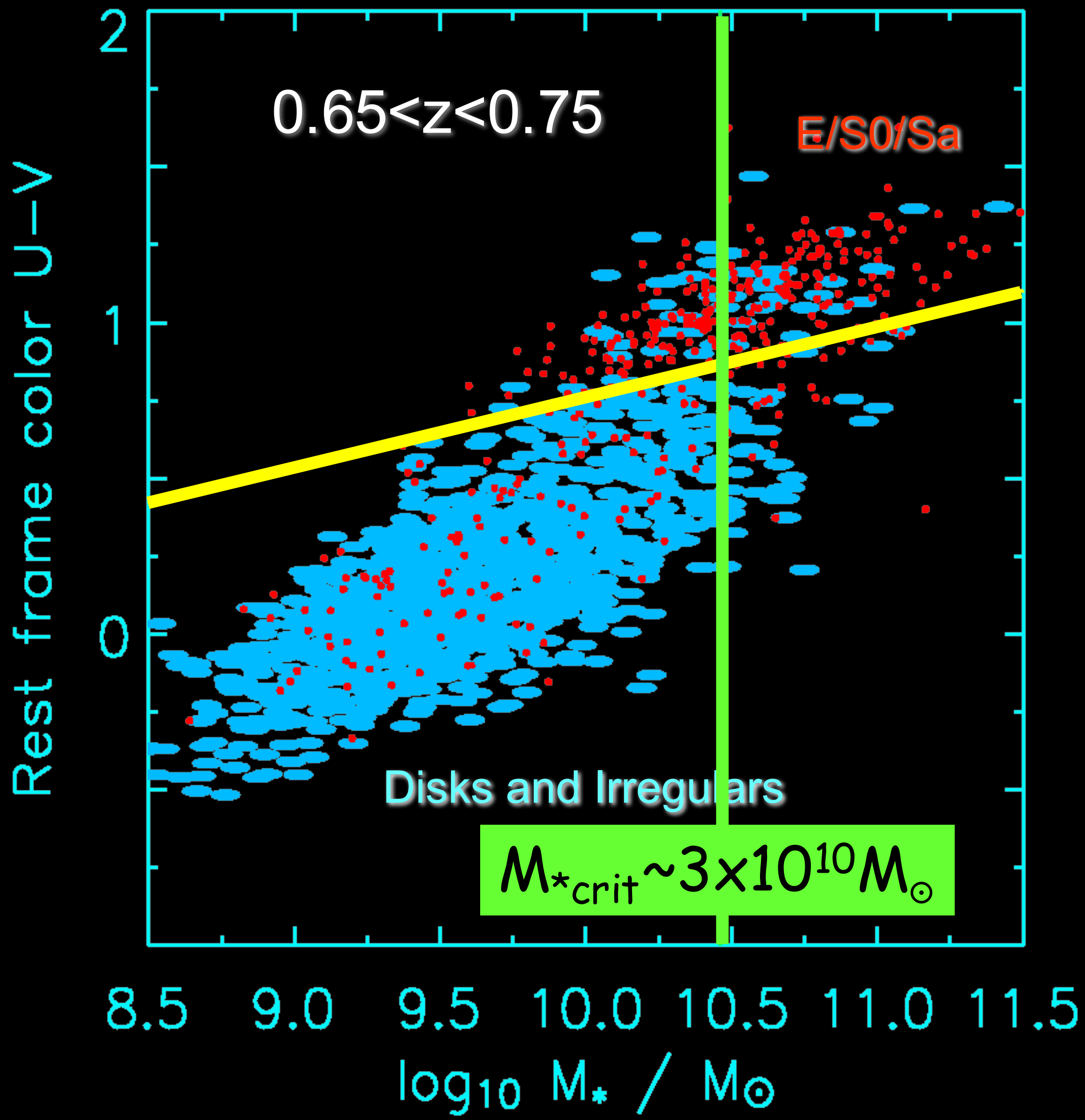
- very blue galaxies → bursty star formation
- big blue galaxies at z~2-3 (e.g. SCUBA)

→ early star formation in big objects

- luminous red galaxies at z~0-1 (e.g. EROs)

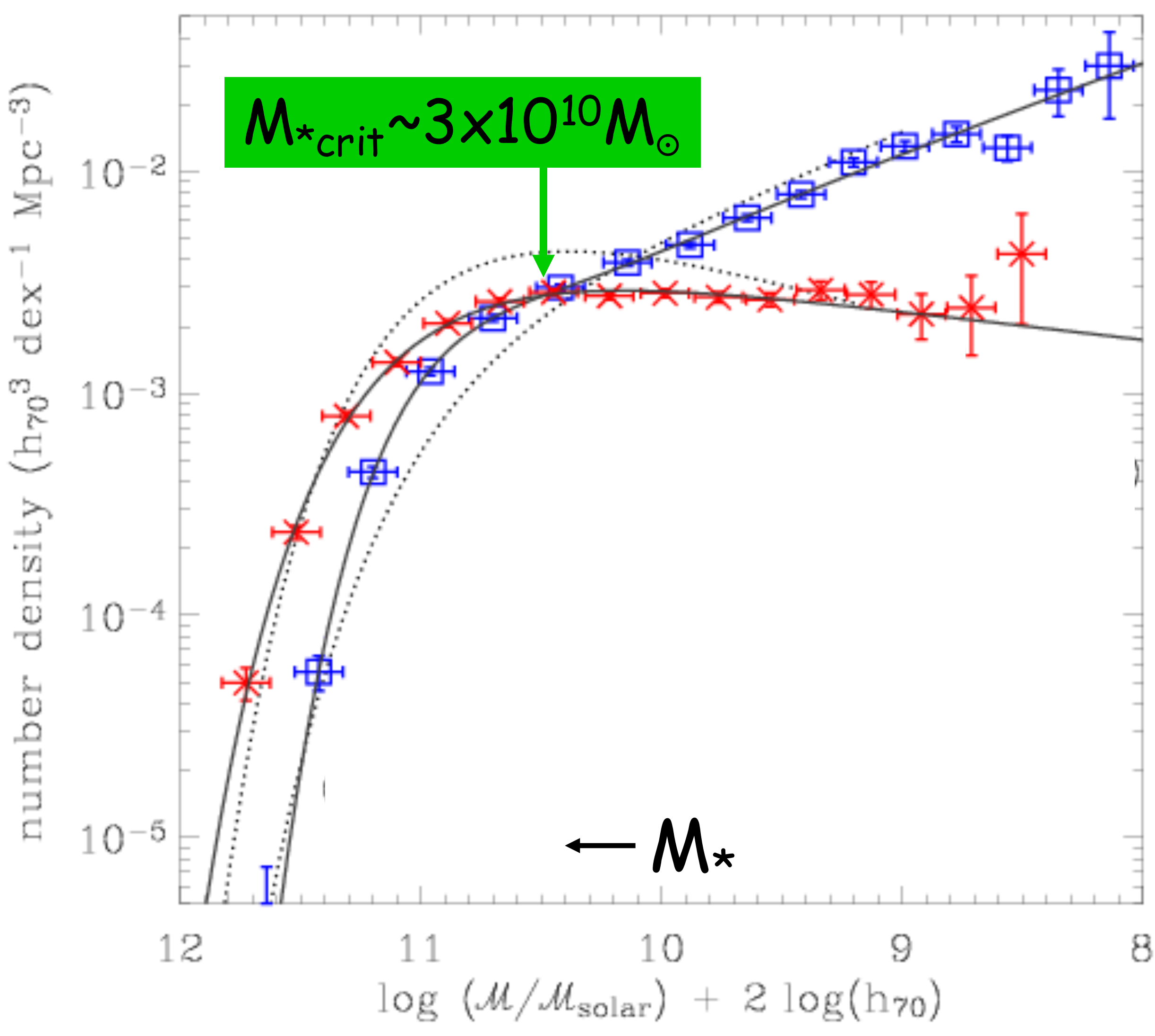
→ early star formation, then shut off

Bi-modality in color, SFR, bulge/disk



Bell

Luminosity function: Red vs Blue

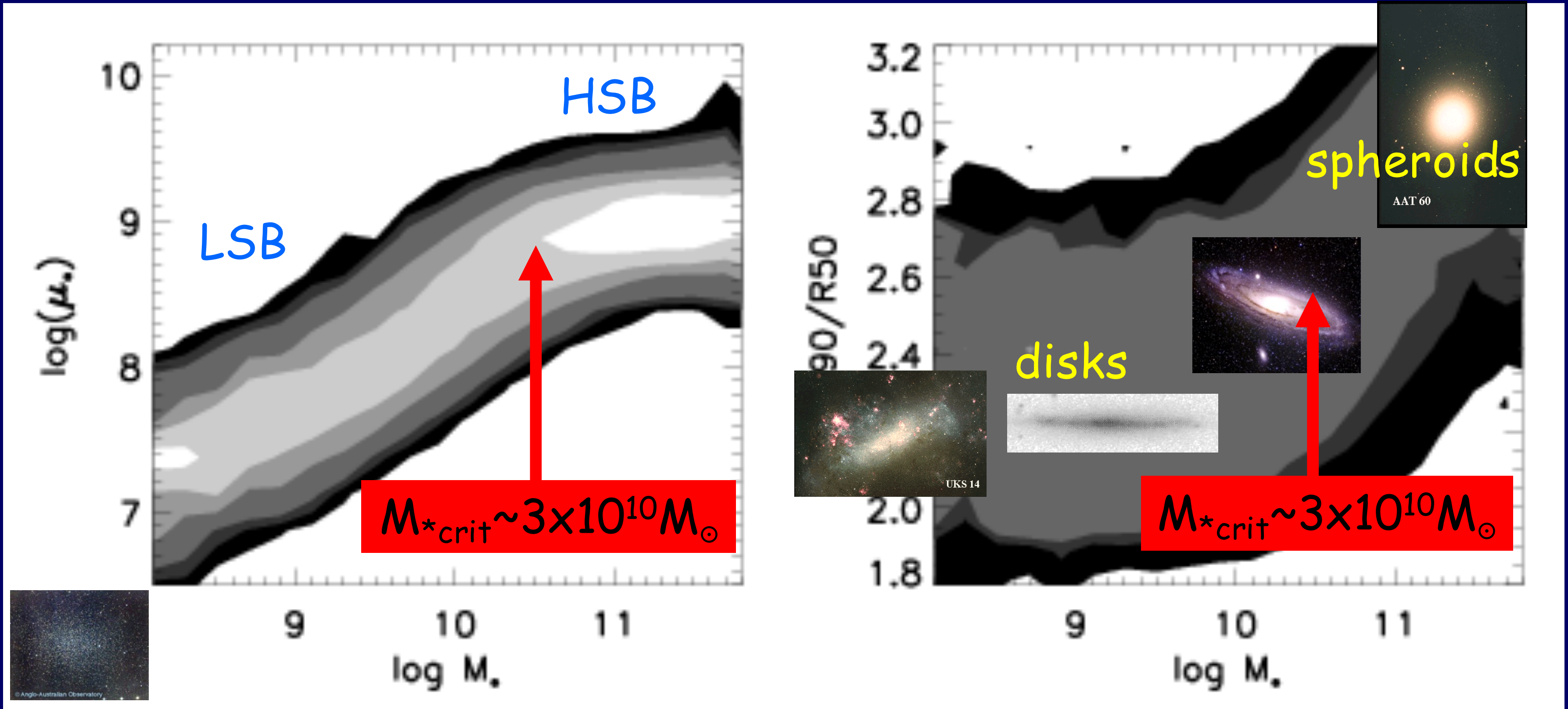


SDSS
Baldry et al. 04

Transition Scale

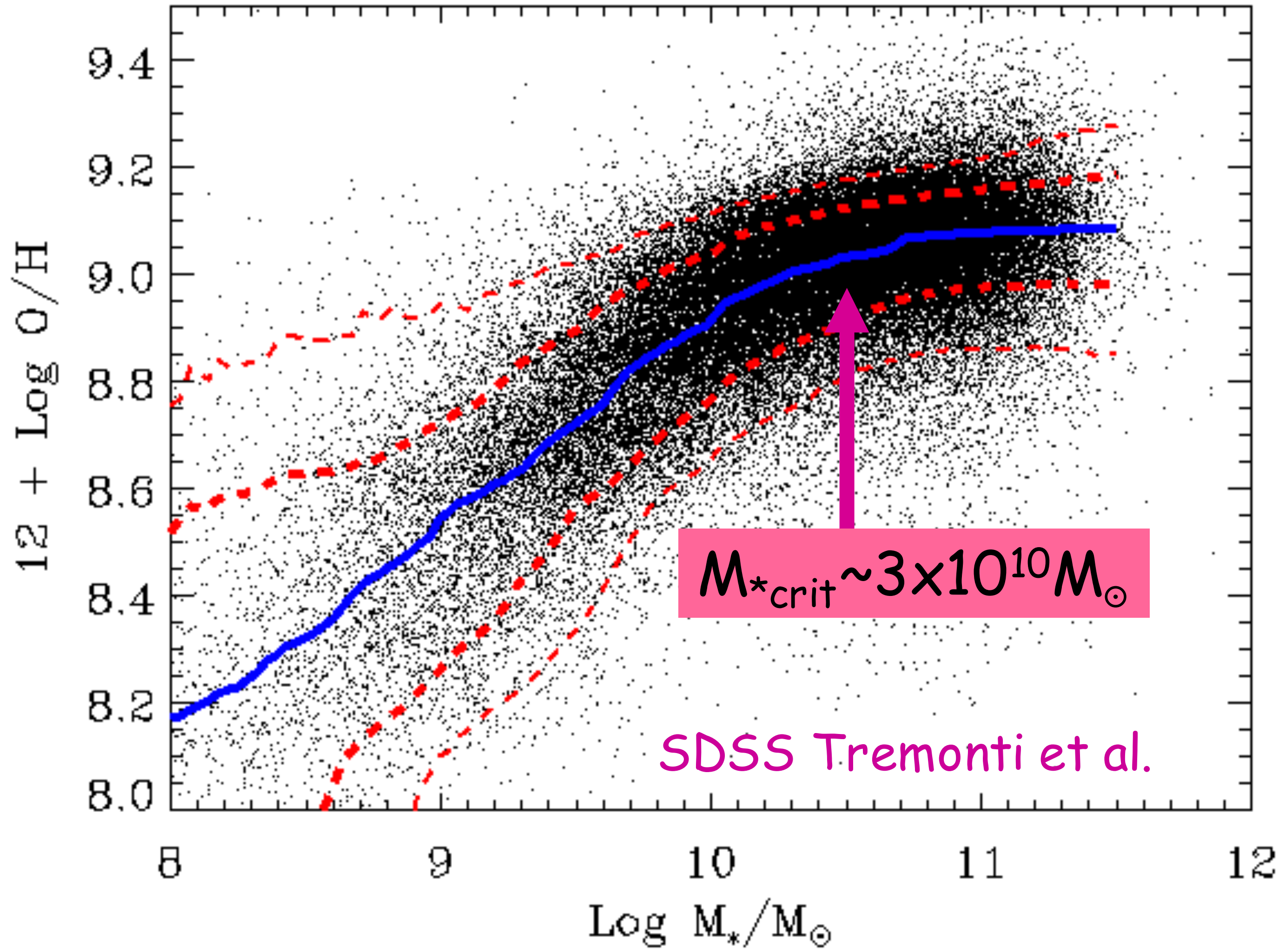
Surface Brightness

Bulge/Disk



SDSS Kauffmann et al. 03

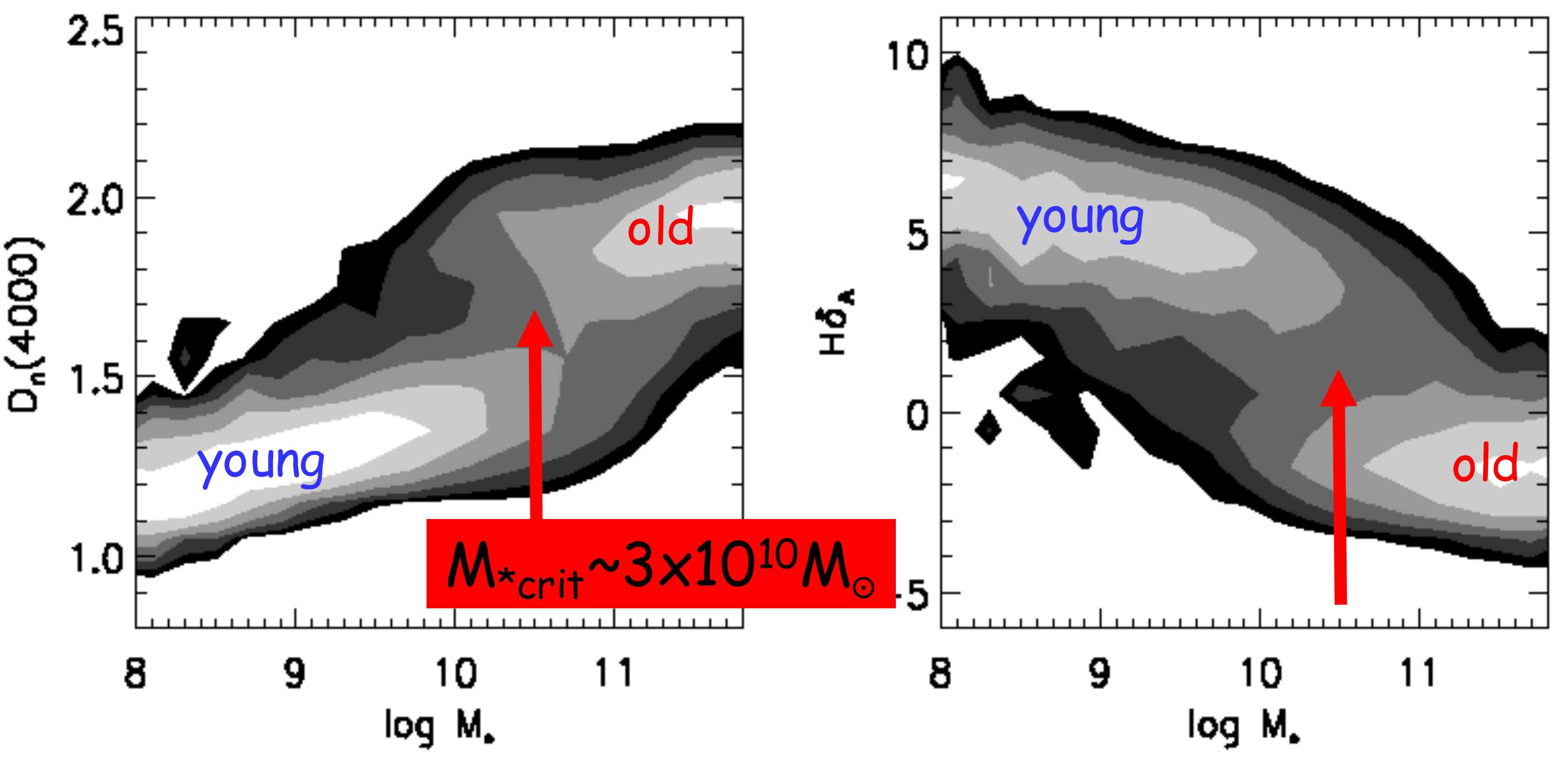
Transition in Metallicity



$M_{*crit} \sim 3\times10^{10} M_\odot$

SDSS Tremonti et al.

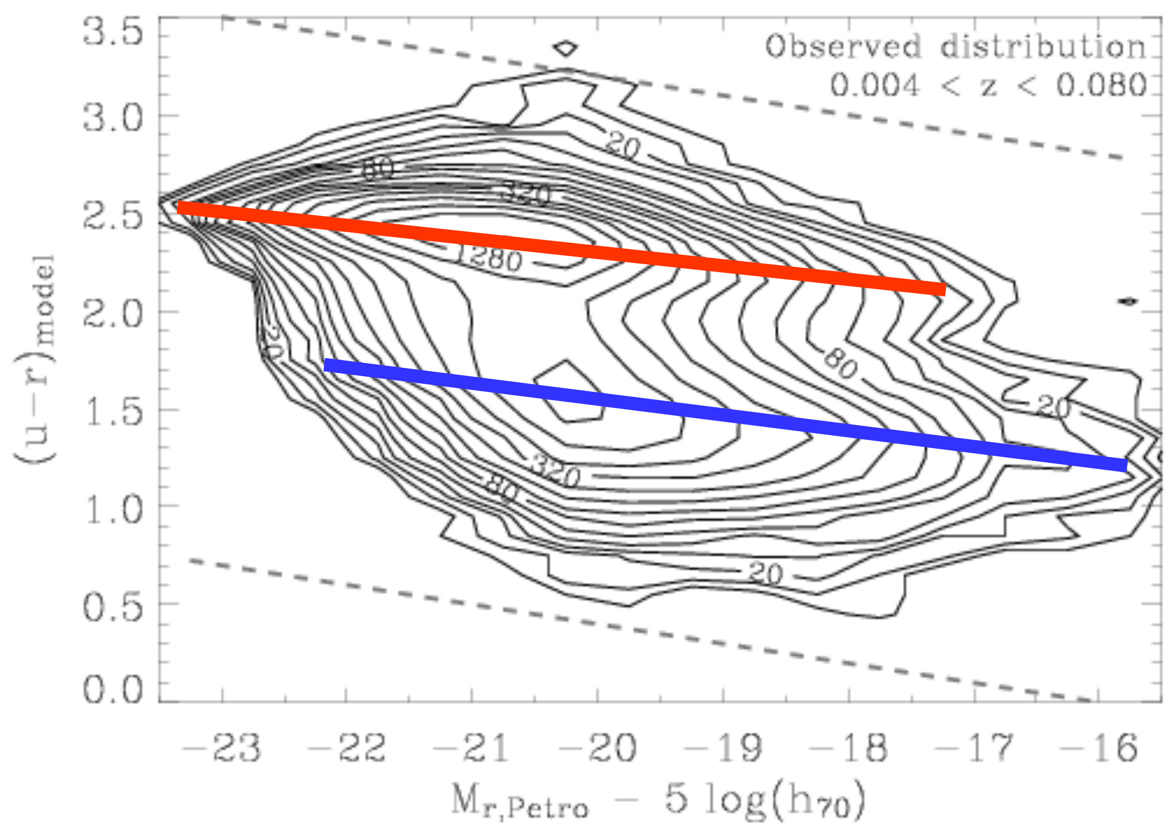
Bi-modality: Age vs Stellar Mass



$M_{*crit} \sim 3 \times 10^{10} M_\odot$

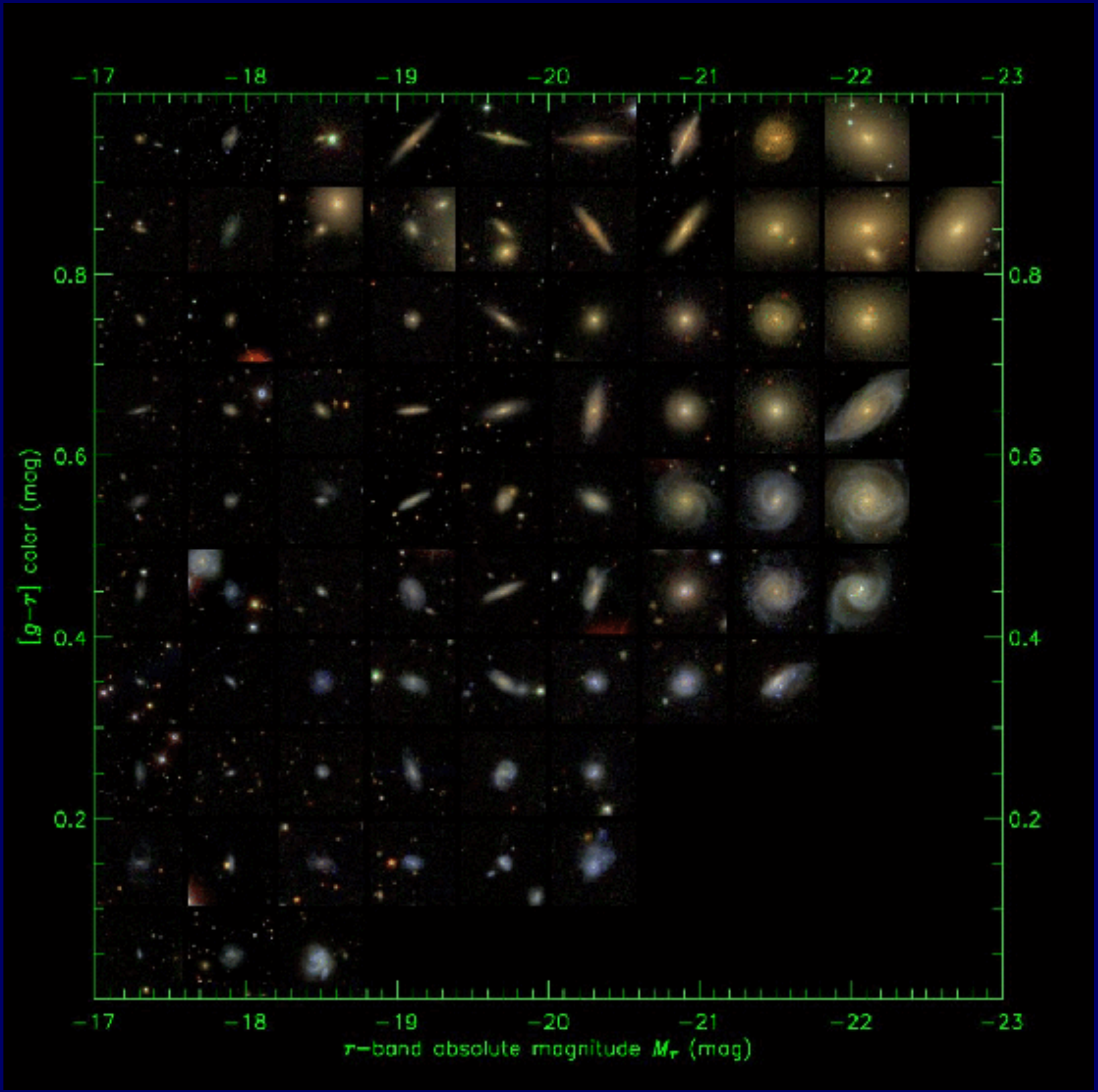
SDSS Kauffmann et al. 03

Bi-modality in Color-Magnitude



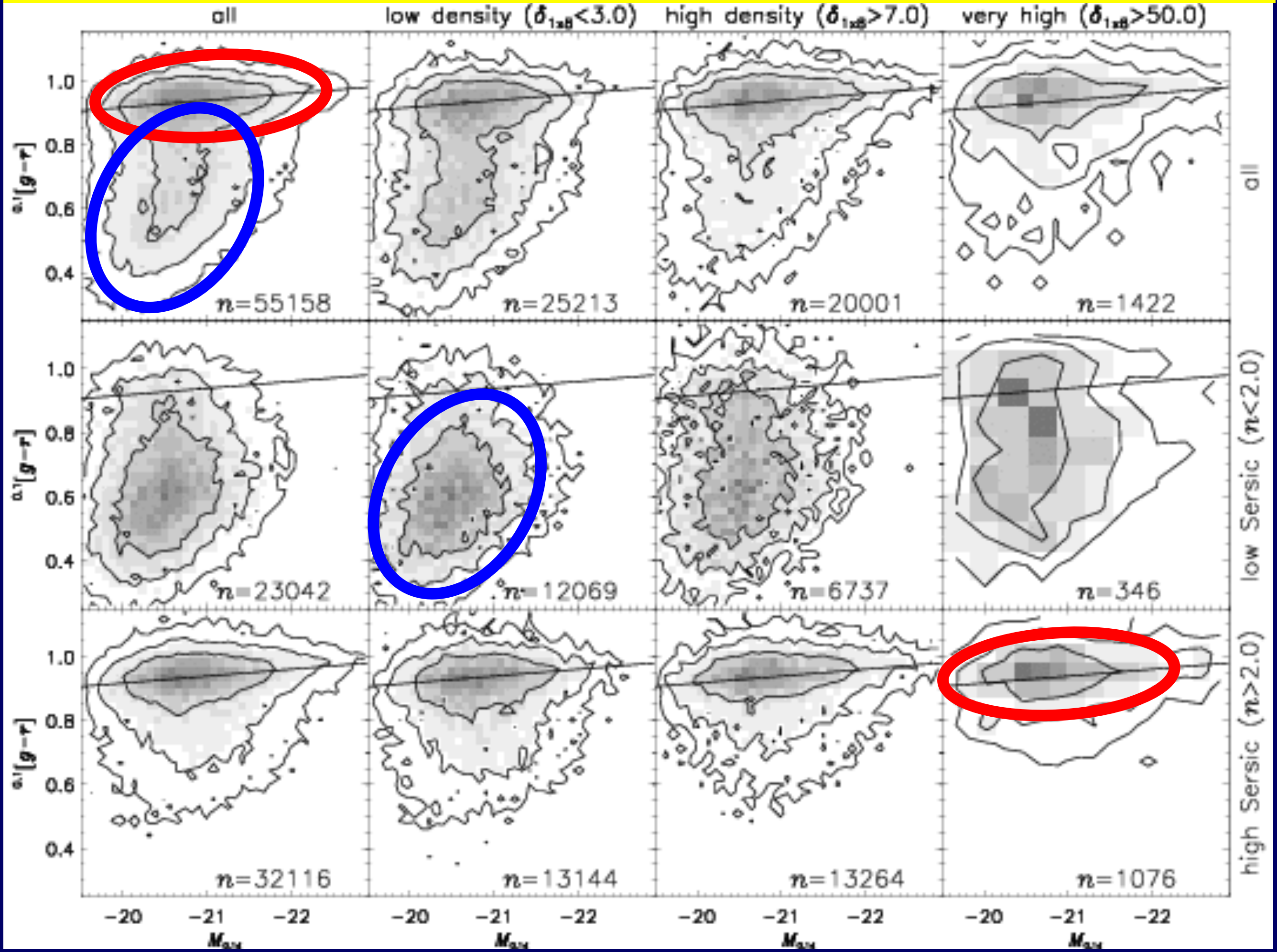
SDSS Baldry et al. 04

Color-Magnitude-Morphology in SDSS



Color-Magnitude bimodality & B/D depend on environment ~ halo mass

environment density: low high very high



disks

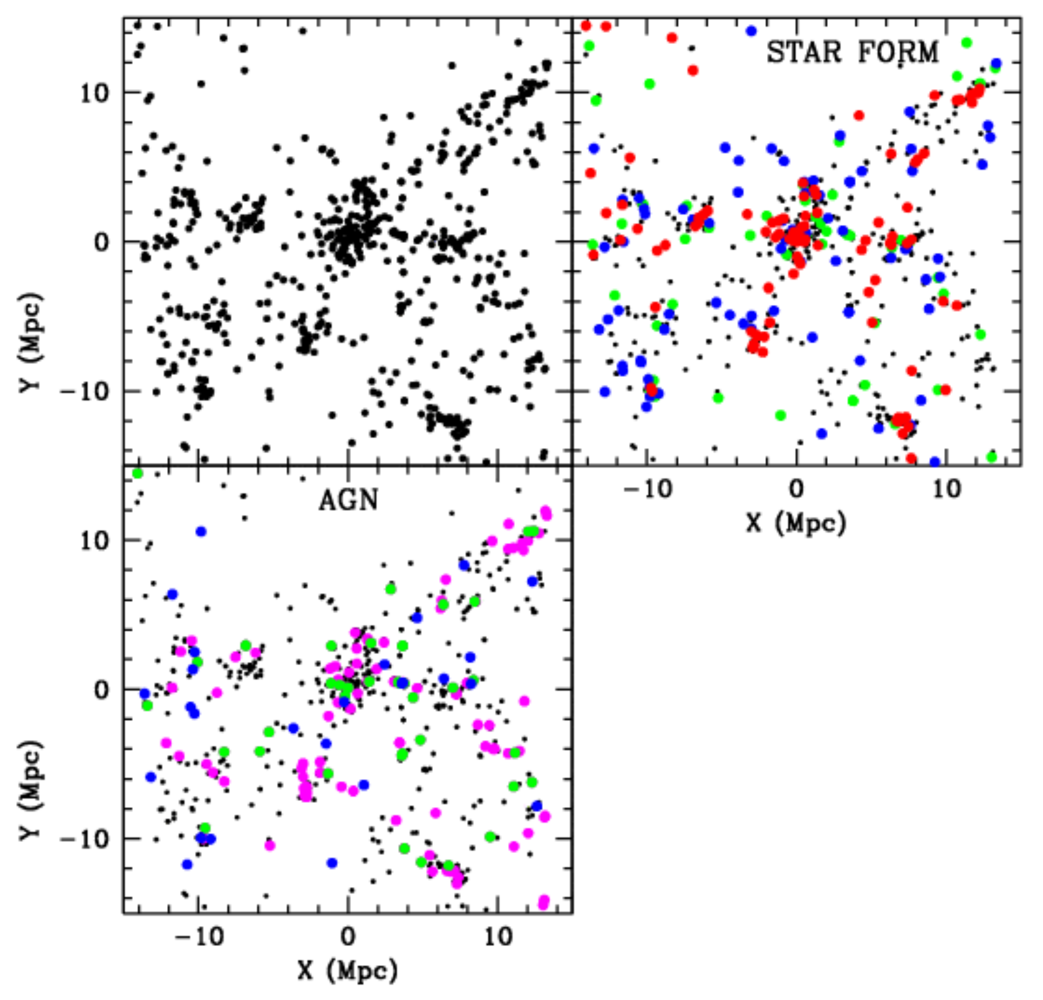
spheroids

$M_{halo}<6\times10^{11}$
"field"

$M_{halo}>6\times10^{11}$
"cluster"

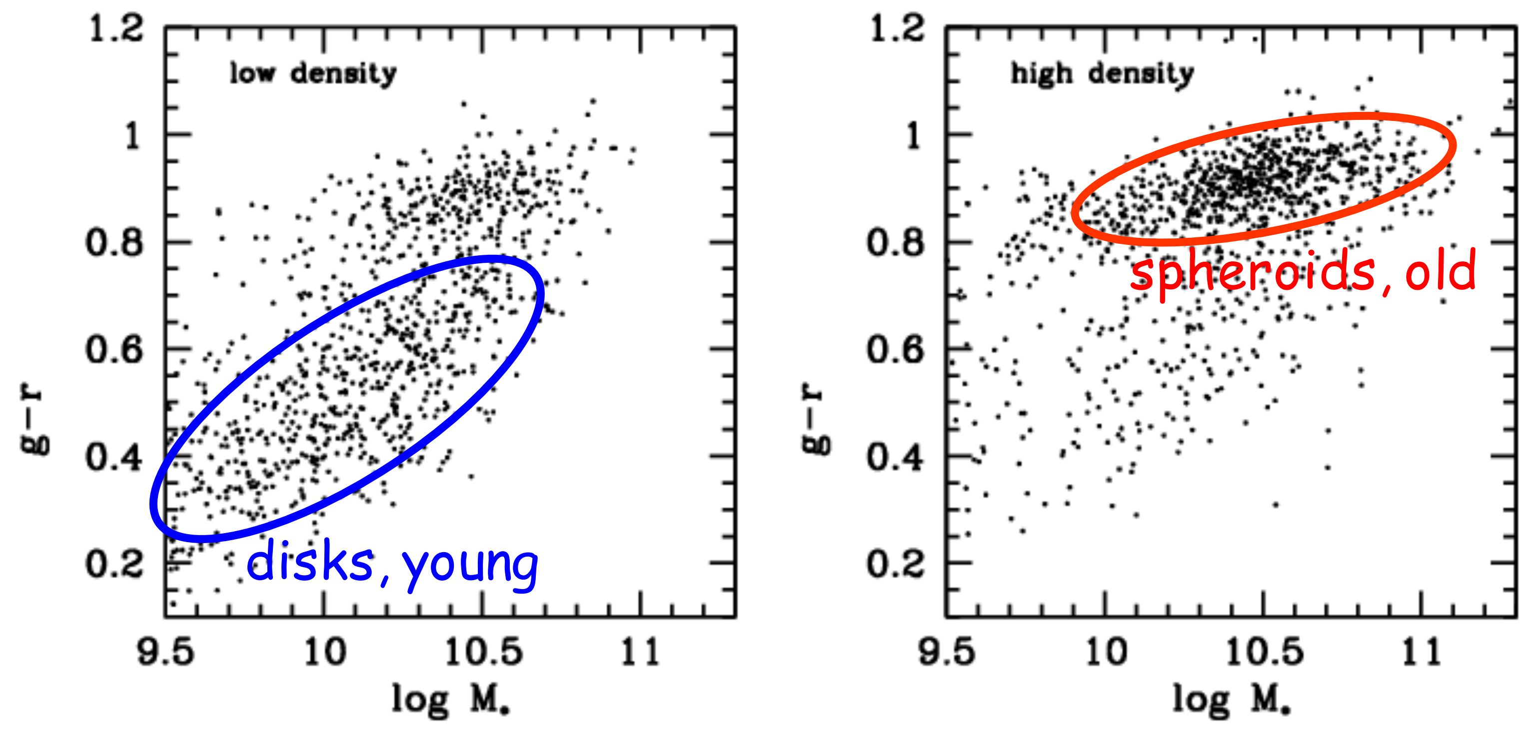
SDSS: Hogg et al. 03

Color - Environment



Age & Color bi-modalily correlated with environment density, or halo mass

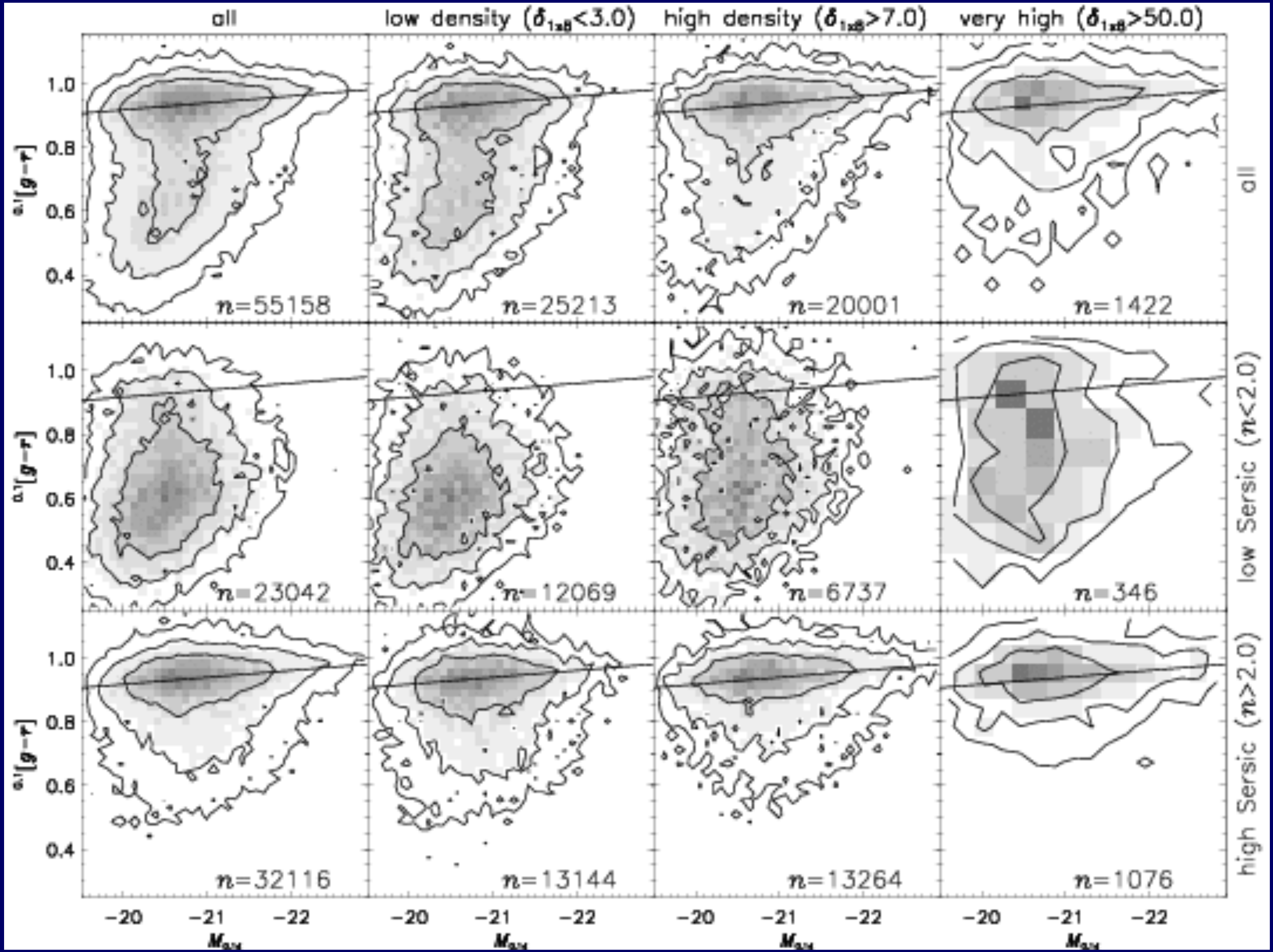
$M_{halo}<6\times10^{11}$ "field" $M_{halo}>6\times10^{11}$ "cluster"



Kauffmann et al. 2004

Color-Magnitude Bimodality depends on B/D and Environment

density: low high very high

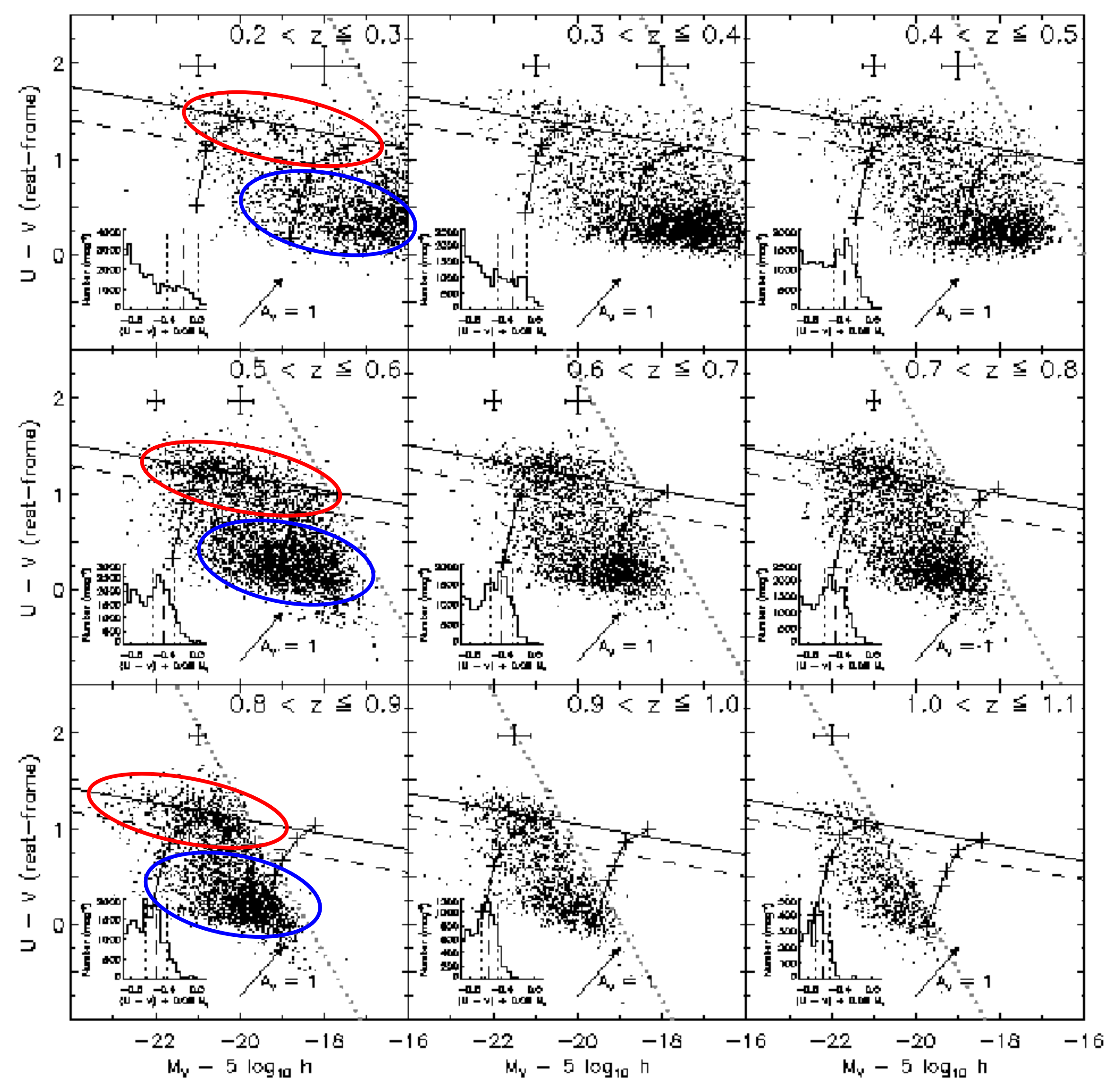


disks

spheroids

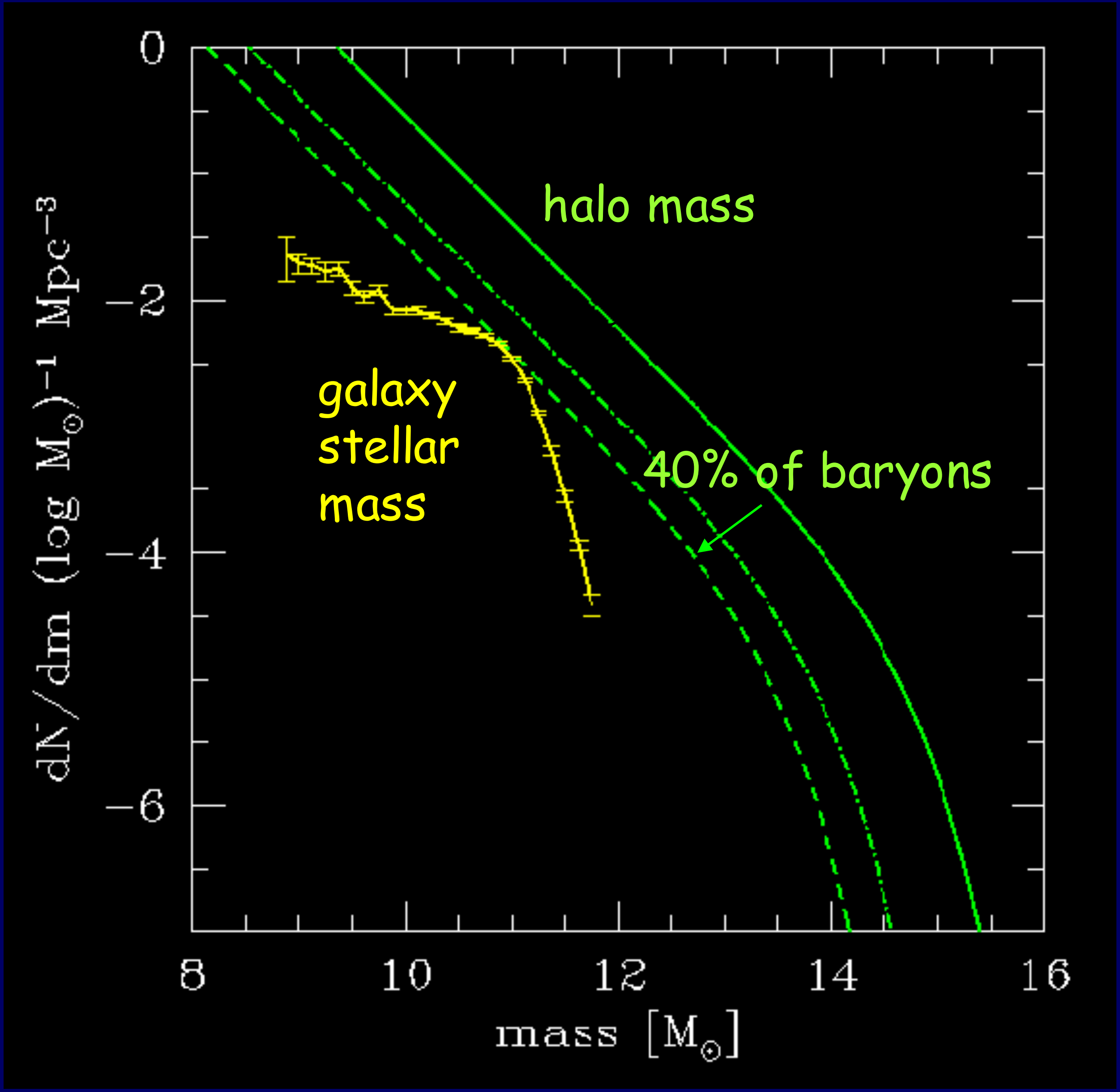
SDSS: Hogg et al. 03

Bi-modality at high z

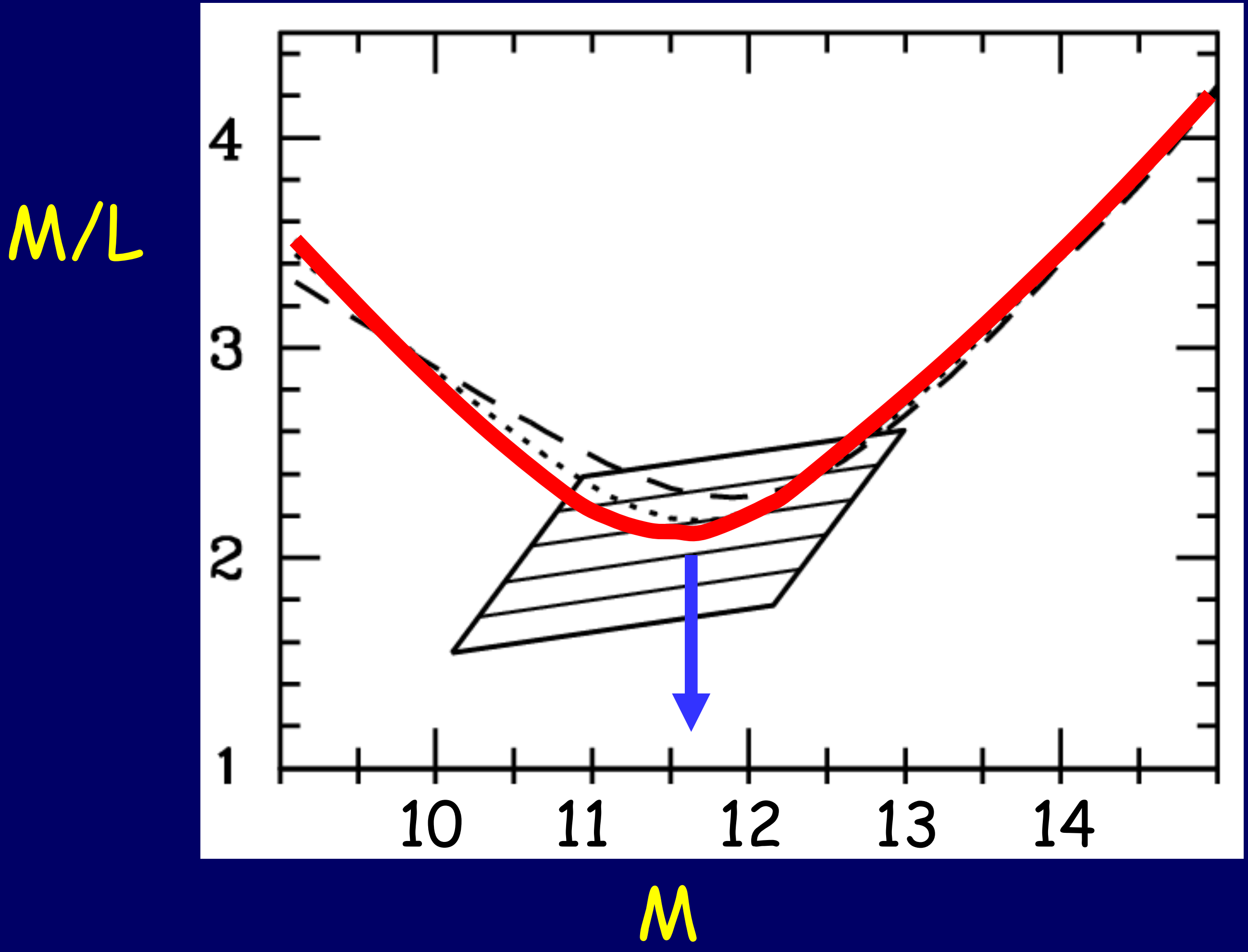


Combo-17

Mass versus Light Distribution

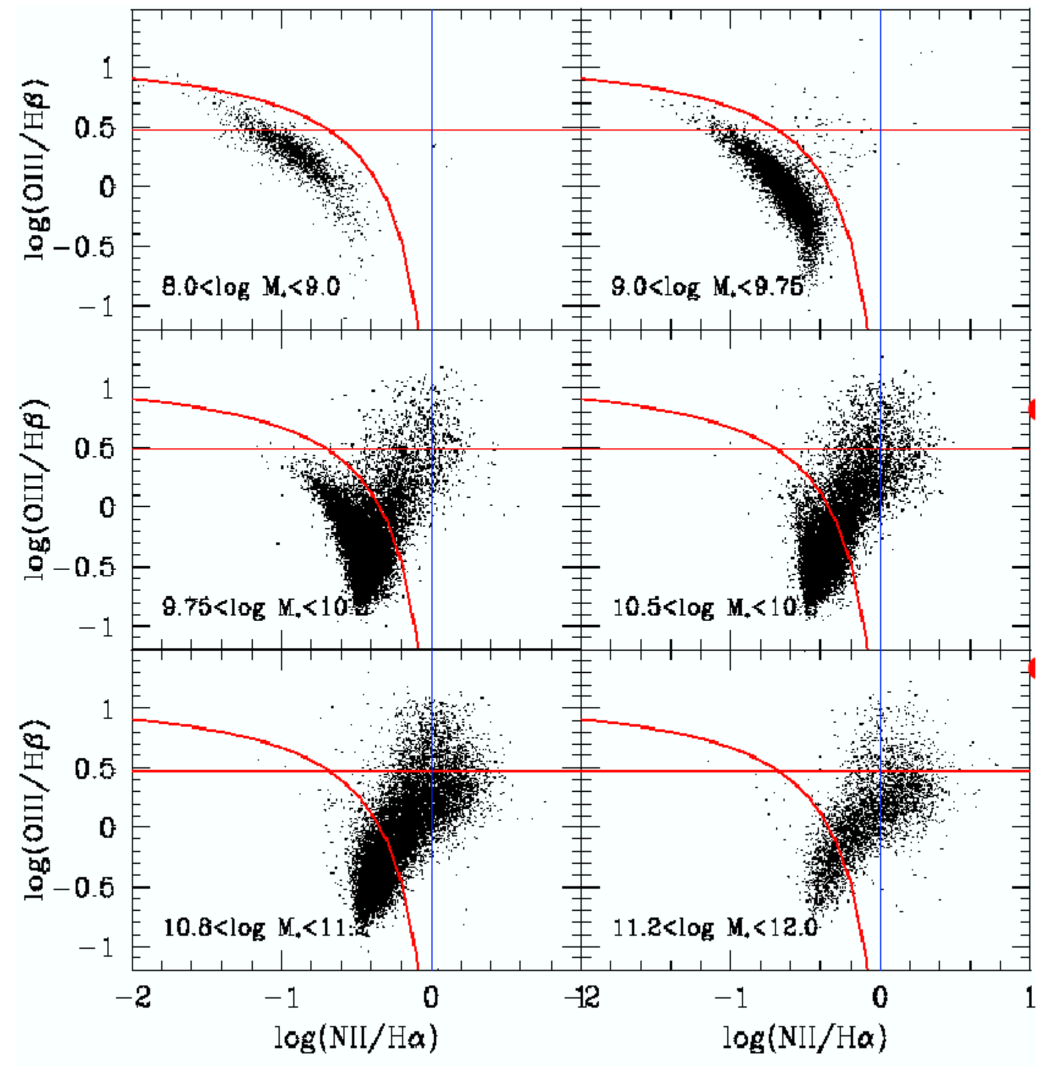


<M/L> vs M for halos in 2dF assuming ΛCDM



Using conditional luminosity function: Van den Bosch, Mo, Yang 03

Emission Properties vs. Stellar Mass



low-mass emission galaxies are almost all star formers

high-mass emission galaxies are almost all AGN

Kauffmann et al. 2004

Observed Characteristic Scale

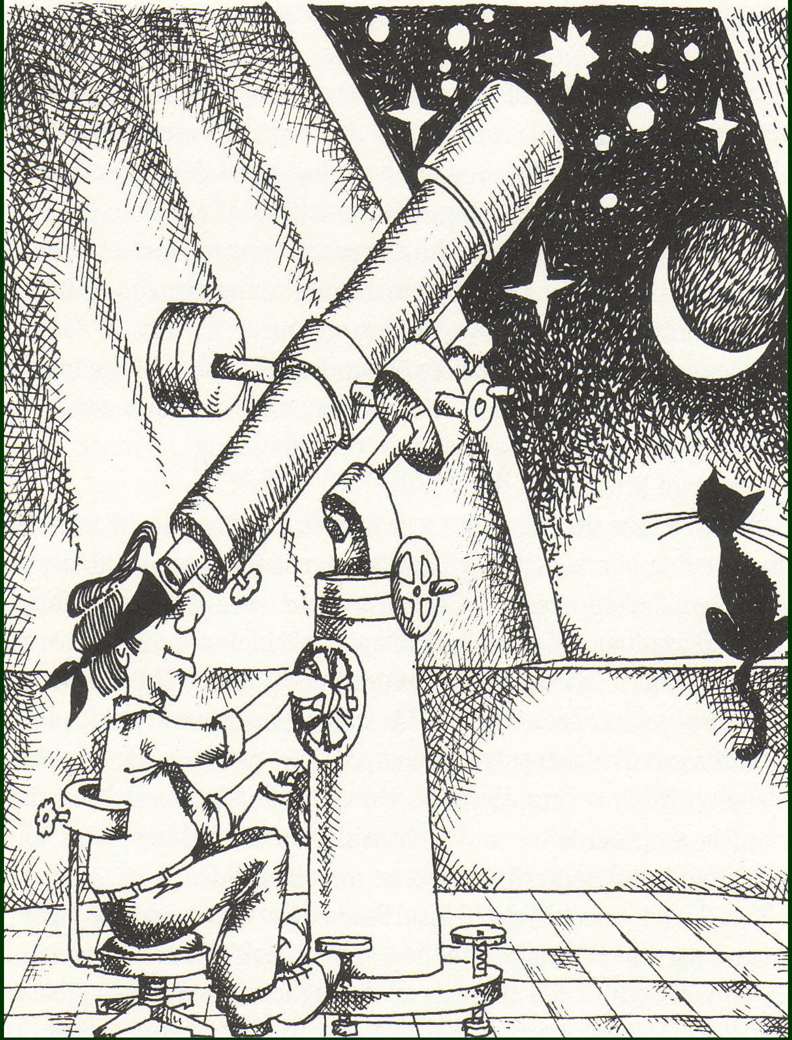
bi-modality / transition

$M_* \sim 3\times10^{10} M_\odot$ $M_{vir} \sim 6\times10^{11} M_\odot$ $V_{vir} \sim 120$ km/s

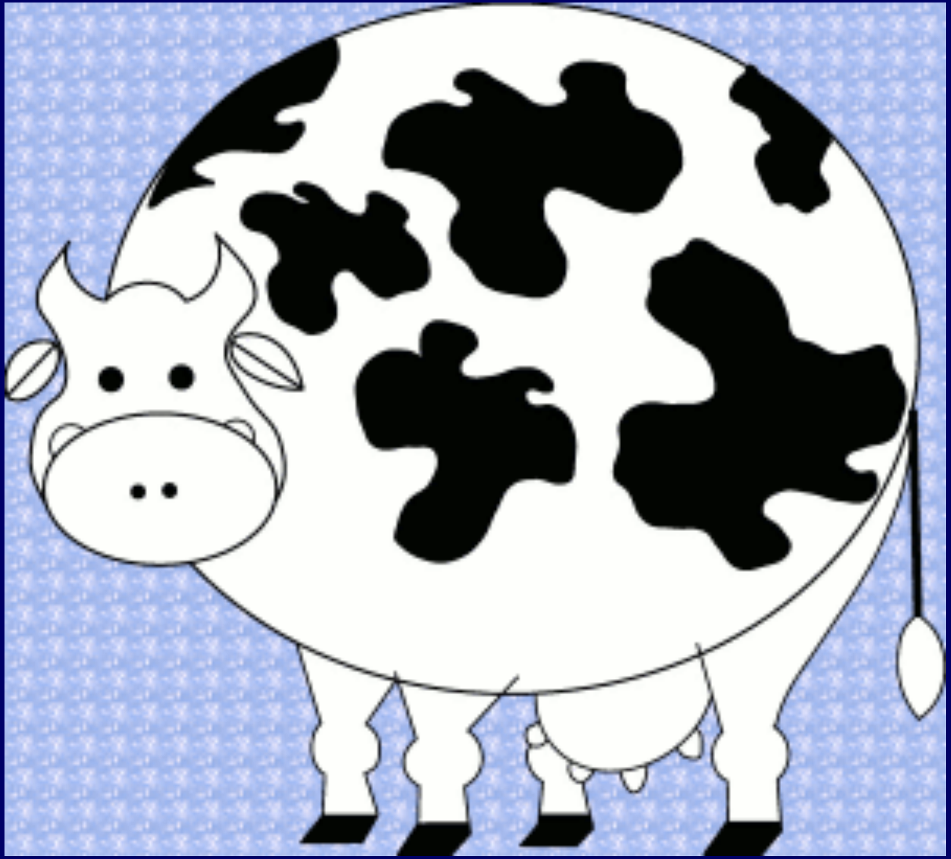
discs, blue star-forming, low Z, LSB $M/L \propto M^{-1}$, fundamental line, small halos (field)

spheroids, red old-pop, high Z, HSB $M/L \propto M$, fundamental plane, massive halos (clustered), AGNs

Theory



Consider a spherical cow…



Standard Picture of Infall to a Disc

Rees & Ostriker 77, Silk 77, White & Rees 78, …

Perturbed expansion

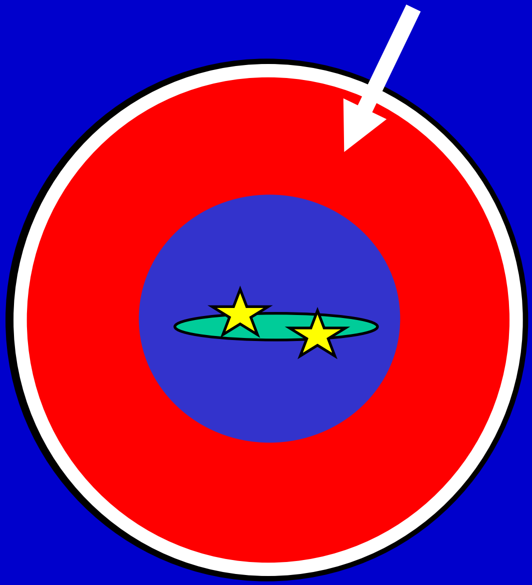
Halo virialization

Gas infall, shock heating at the virial radius

Radiative cooling

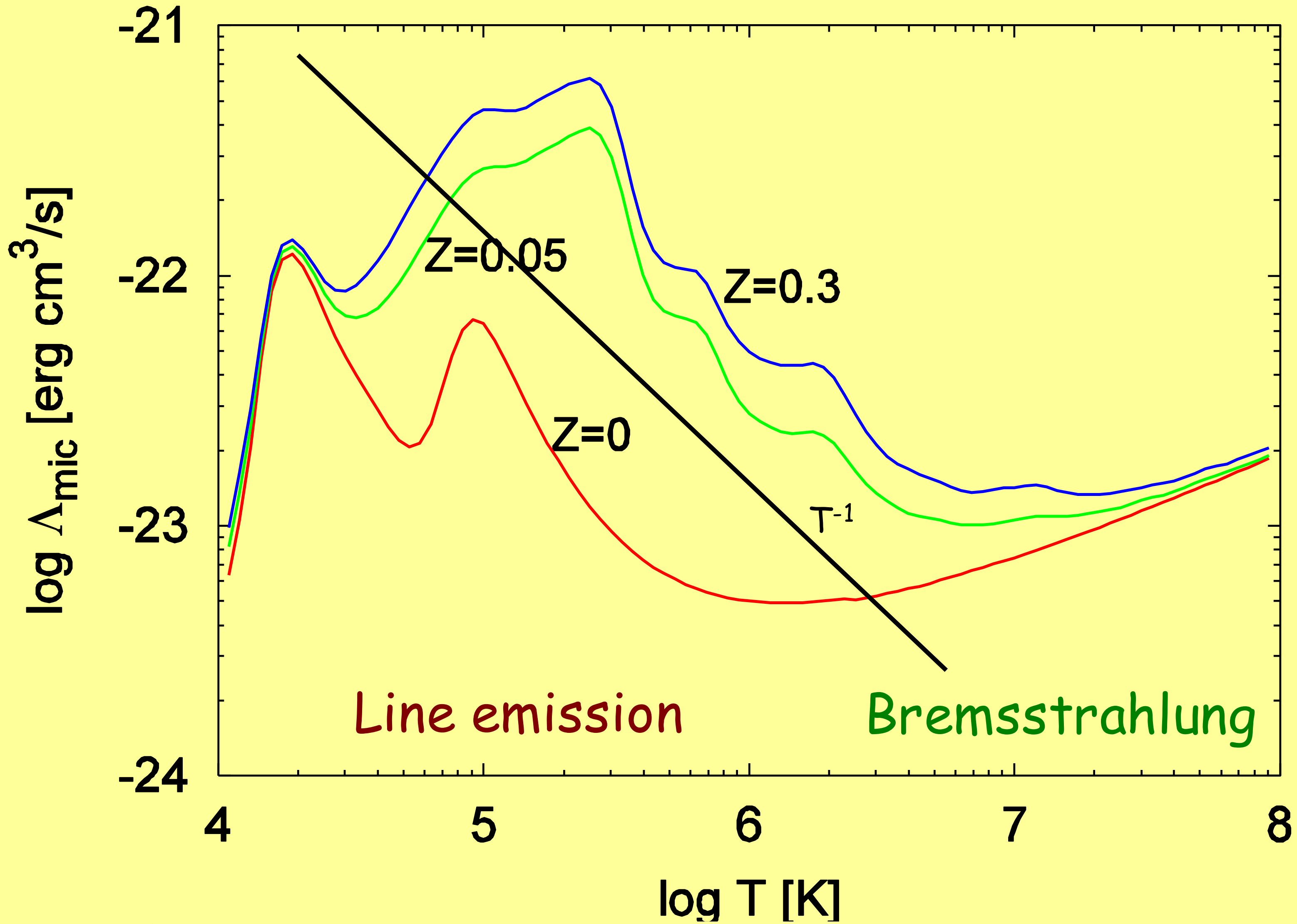
Accretion to disc if $t_{cool} < t_{ff}$

Stars & feedback



$M < M_{cool} \sim 10^{12-13} M_{\odot}$

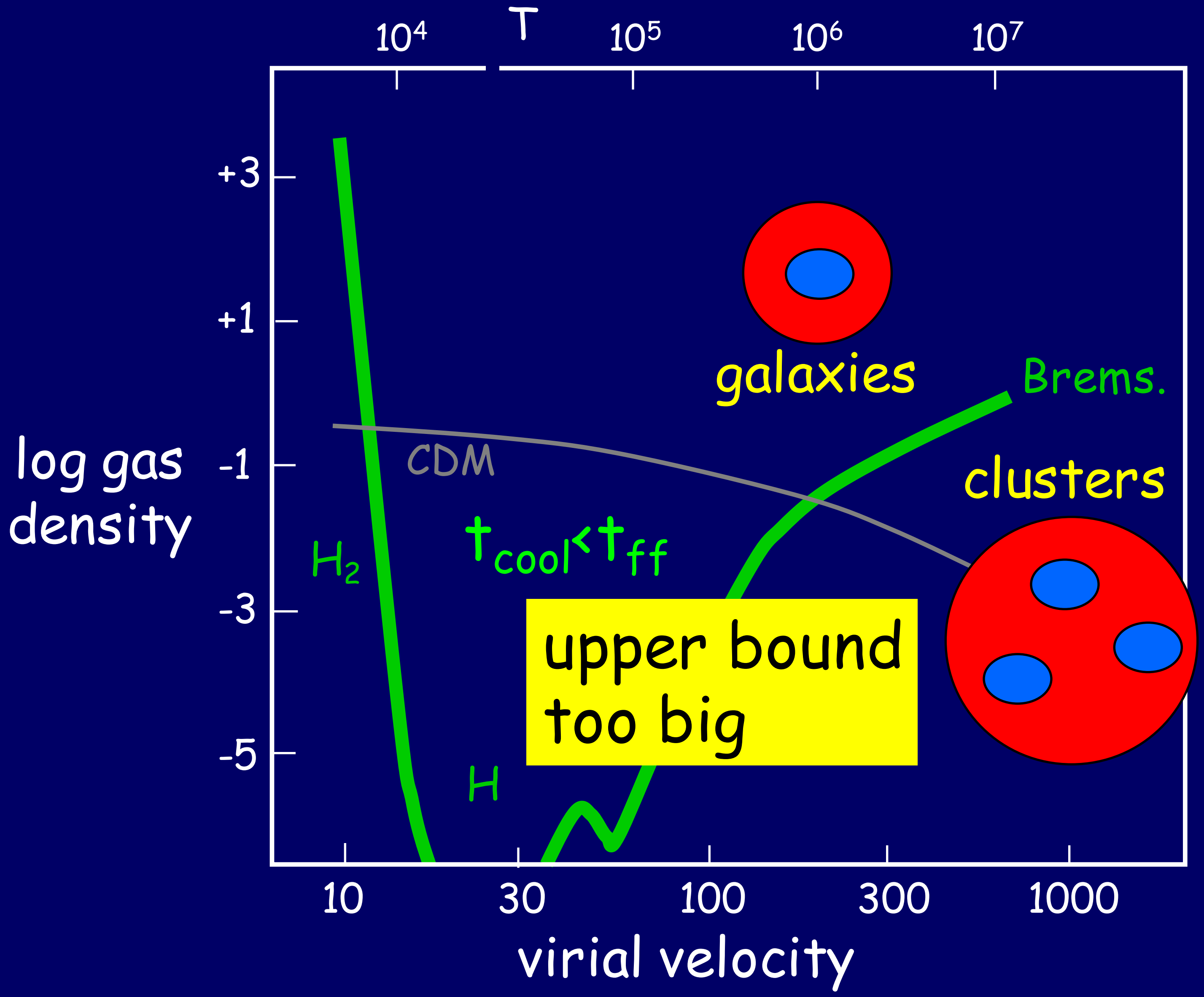
Cooling rate



$$q = \frac{N_A^{\,2}\chi^2}{\mu^2}\Lambda(T)\rho \quad [\mathrm{erg\,g^{-1}\,s^{-1}}] \qquad N_A/\mu \text{ molecules per g} \qquad \chi\ \mathrm{e^-} \text{ per particle}$$

Cooling vs Free Fall

Rees & Ostriker 77, Silk 77, White & Rees 78 Blumenthal, Faber, Primack & Rees 86



2. Shock-Heating vs Cold Flows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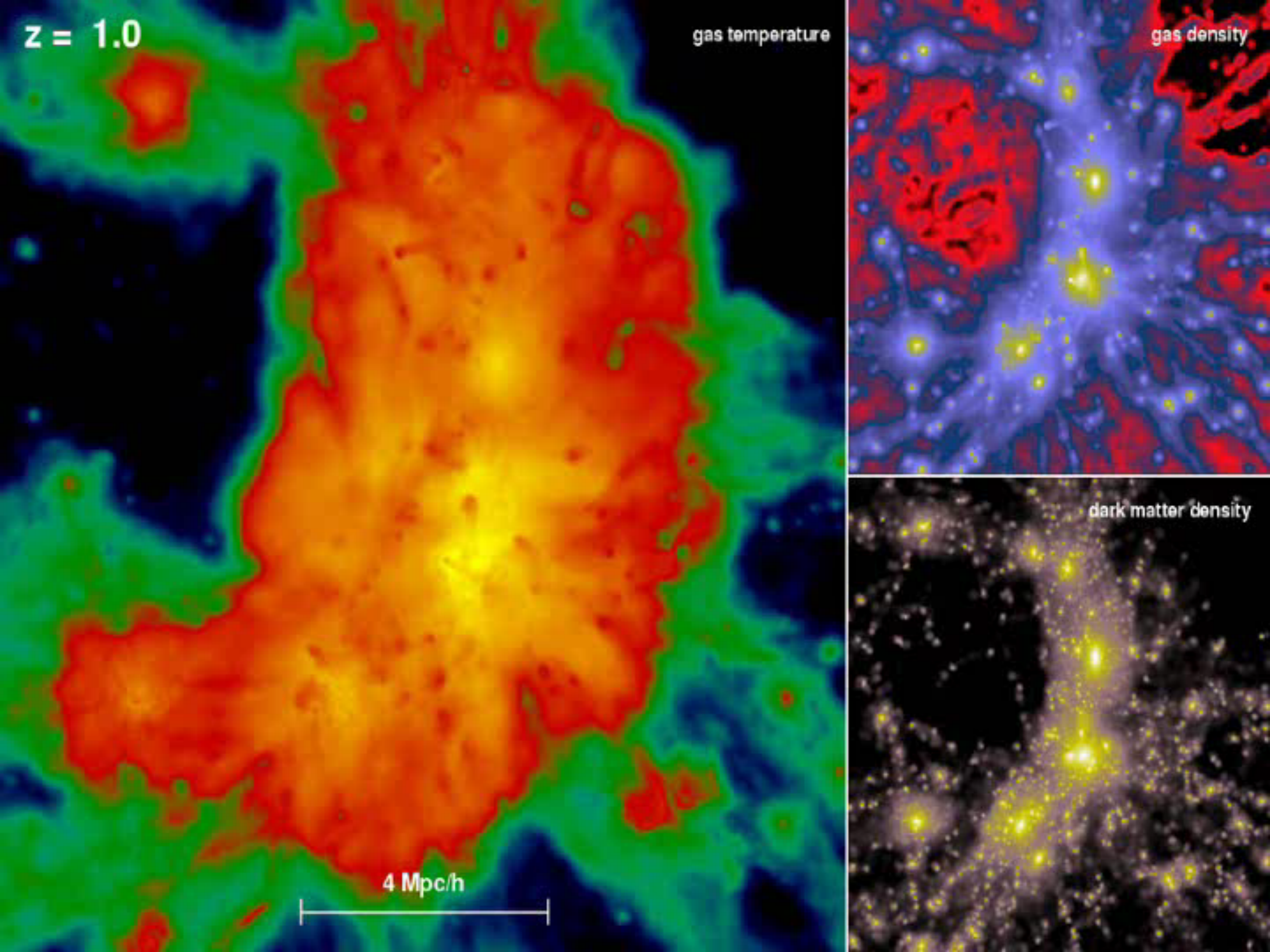
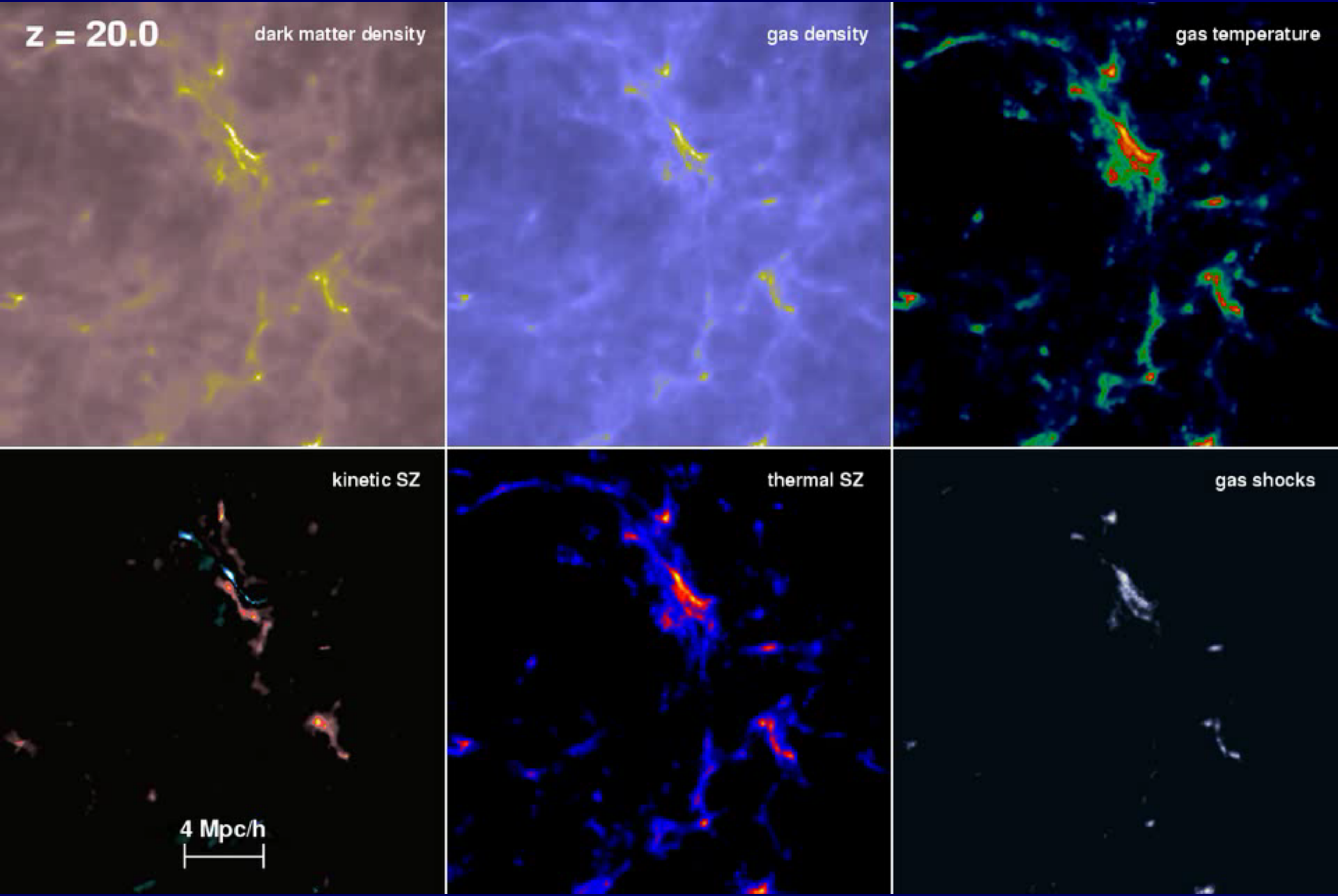
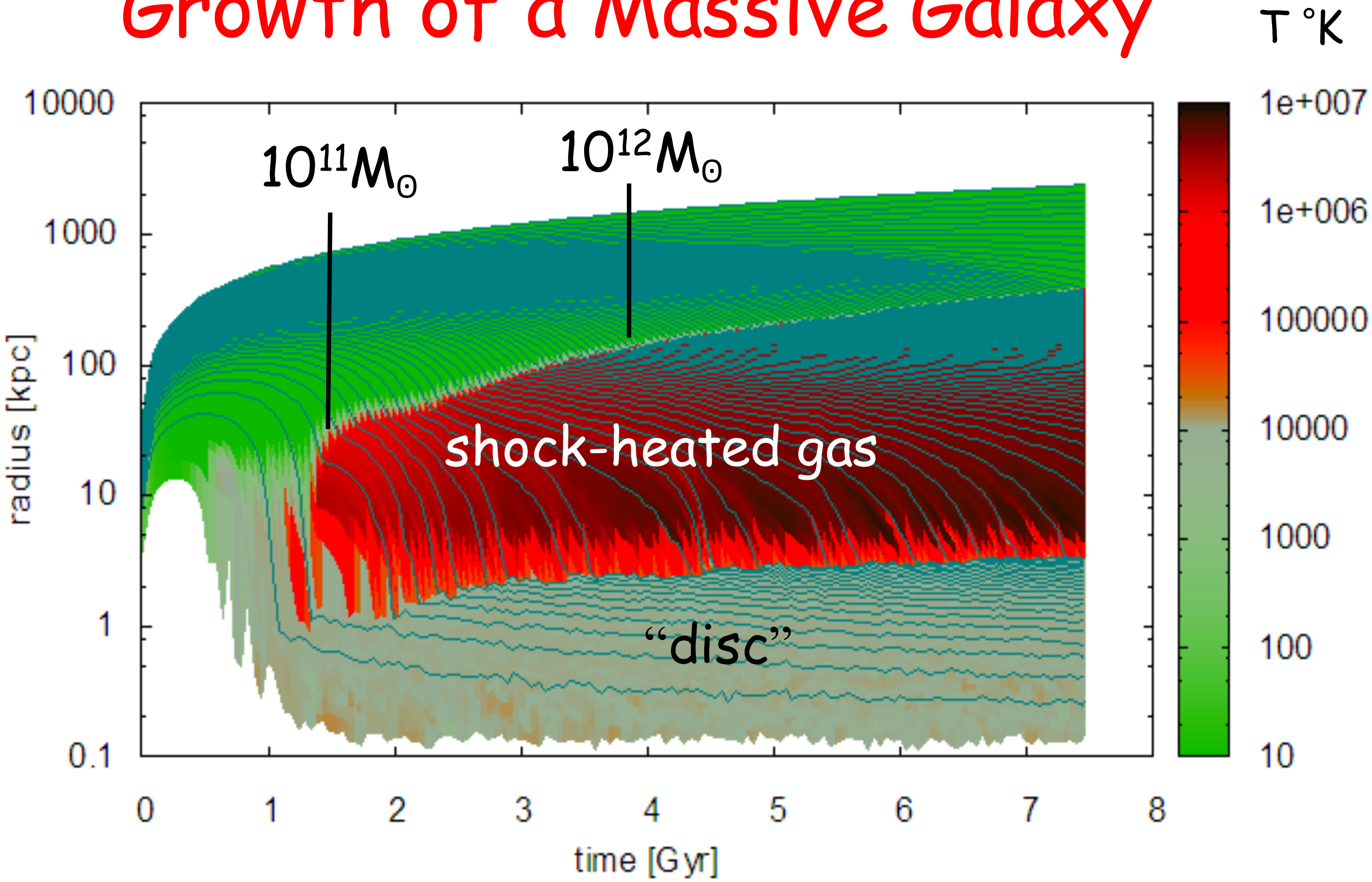

z = 1.0
gas temperature
4 Mpc/h
gas density
dark matter density


z = 20.0
dark matter density
gas density
gas temperature
kinetic SZ
thermal SZ
gas shocks
4 Mpc/h

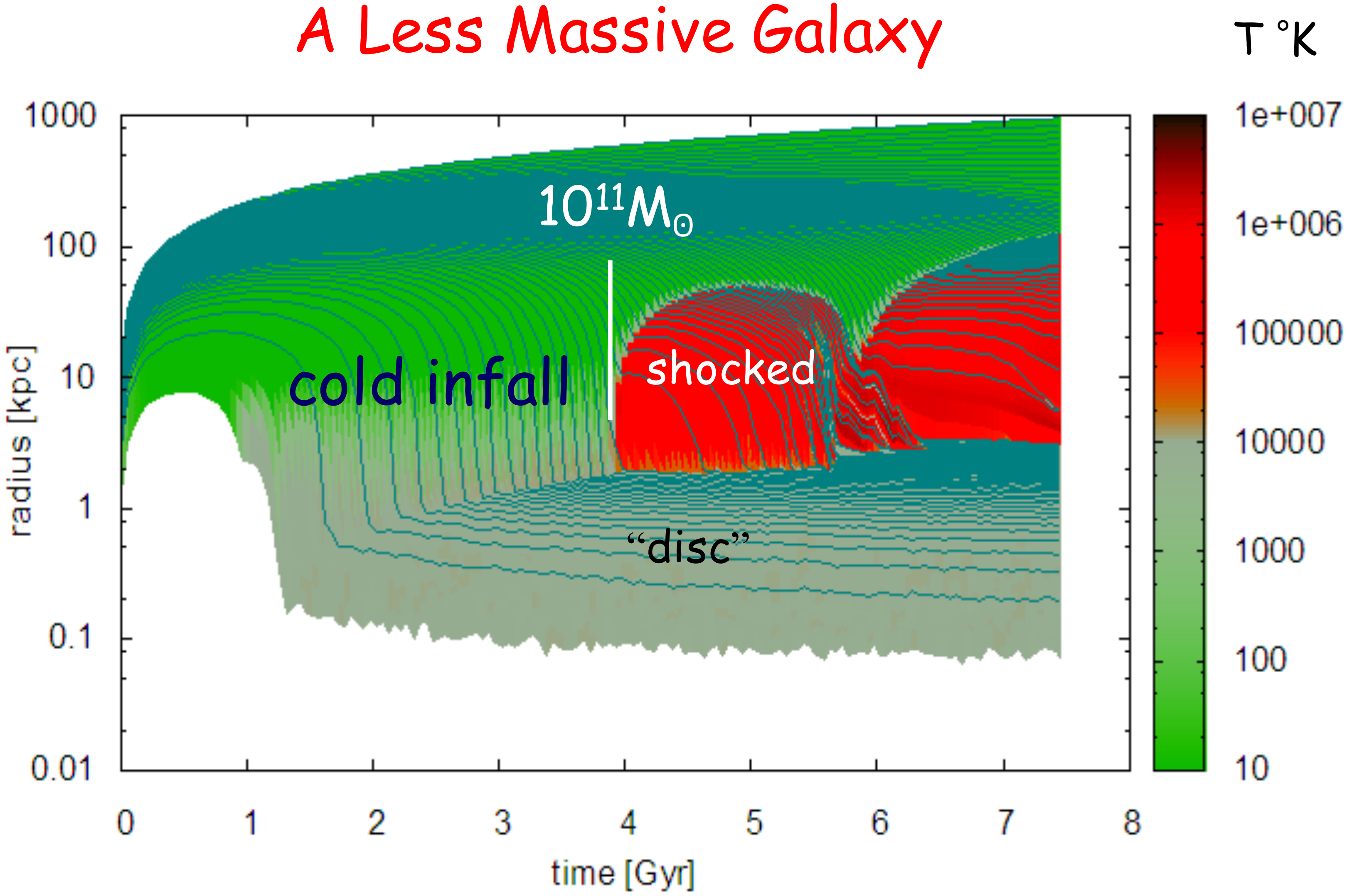
Growth of a Massive Galaxy



Spherical hydro simulation

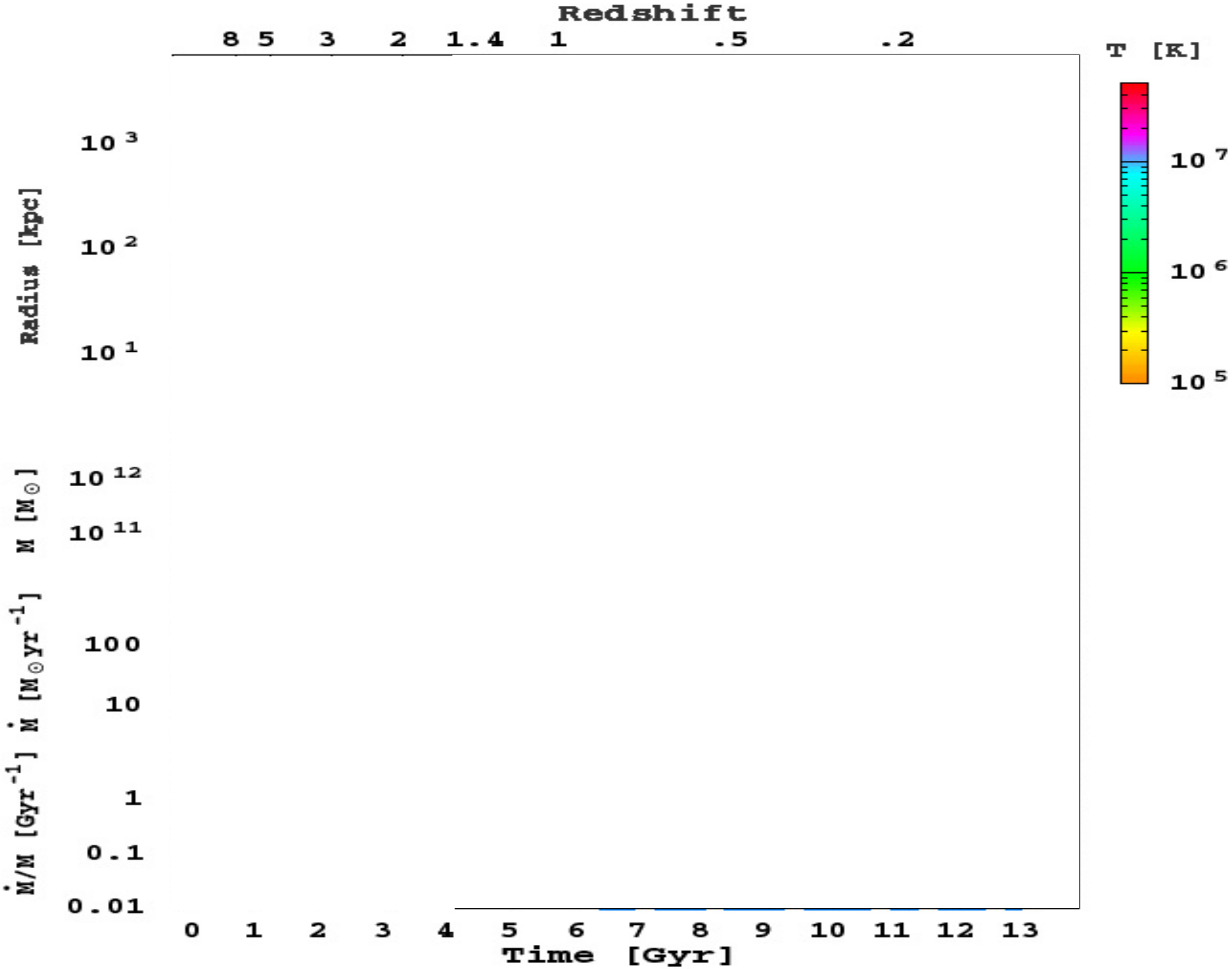
Birnboim & Dekel 03

A Less Massive Galaxy



Spherical hydro simulation

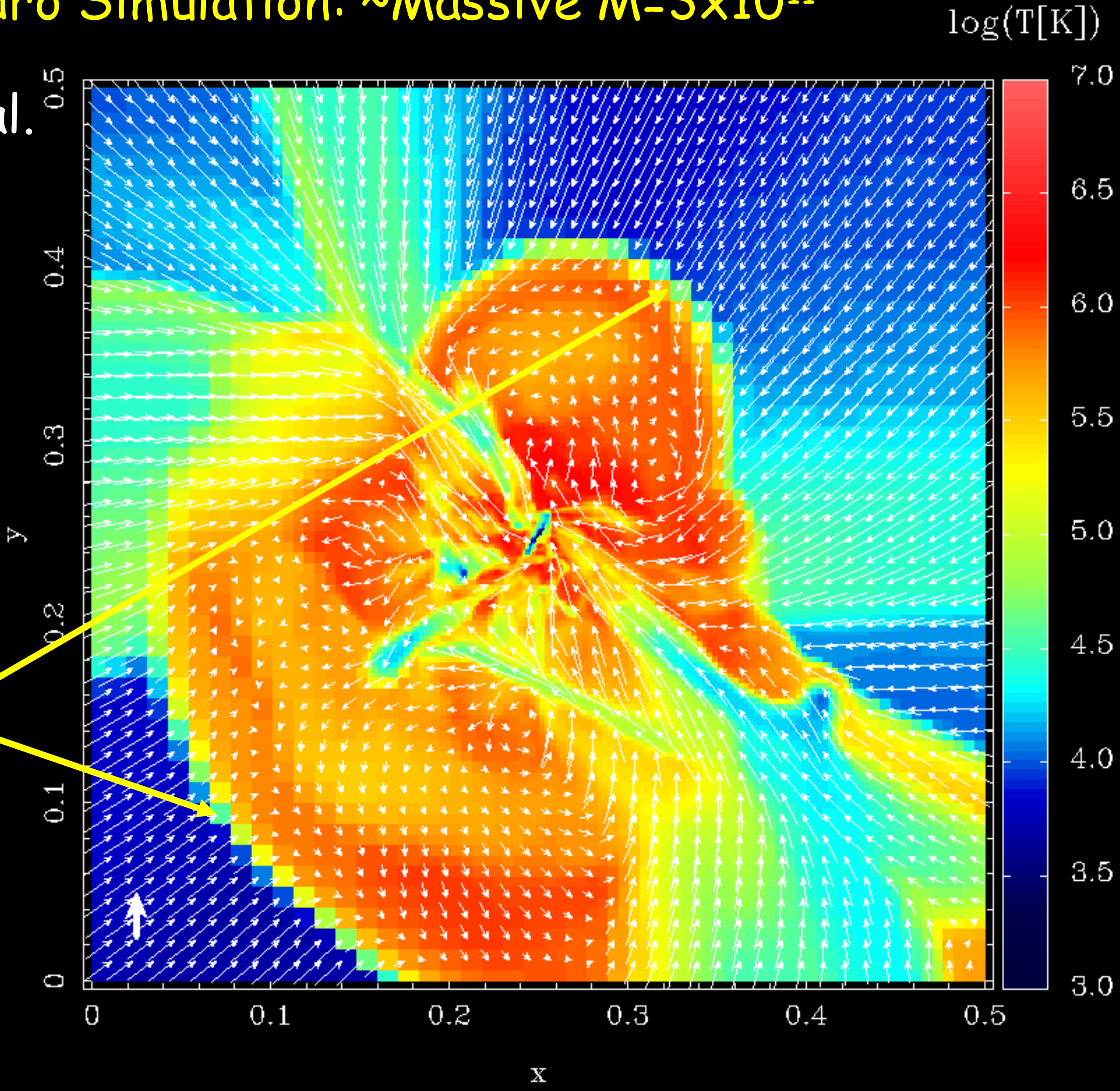
Birnboim & Dekel 03


Redshift
8 5 3 2 1.4 1 .5 .2
T [K]
10^7
10^6
10^5
Radius [kpc]
10^3
10^2
10^1
M [$M_\odot$]
10^{12}
10^{11}
$\dot{M}/M$ [Gyr^{-1}] $\dot{M}$ [$M_\odot$ yr^{-1}]
100
10
1
0.1
0.01
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Time [Gyr]

Hydro Simulation: ~Massive $M=3\times10^{11}$

Kravtsov et al.

$z=4$
$M=3\times10^{11}$
$T_{vir}=1.2\times10^{6}$
$R_{vir}=34$ kpc

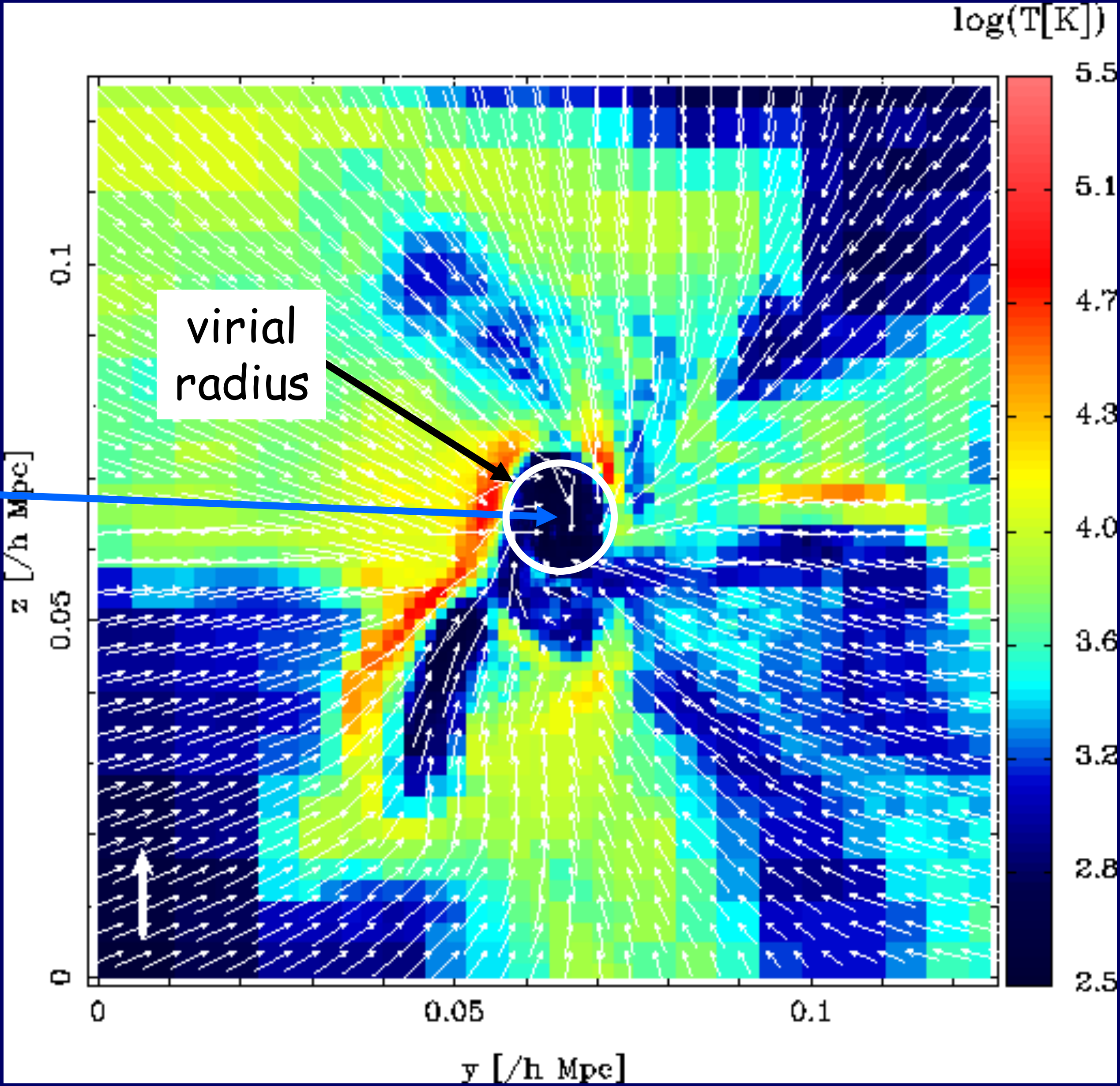


virial shock

Less Massive $M=1.8\mathrm{x}10^{10}$

Kravtsov et al.

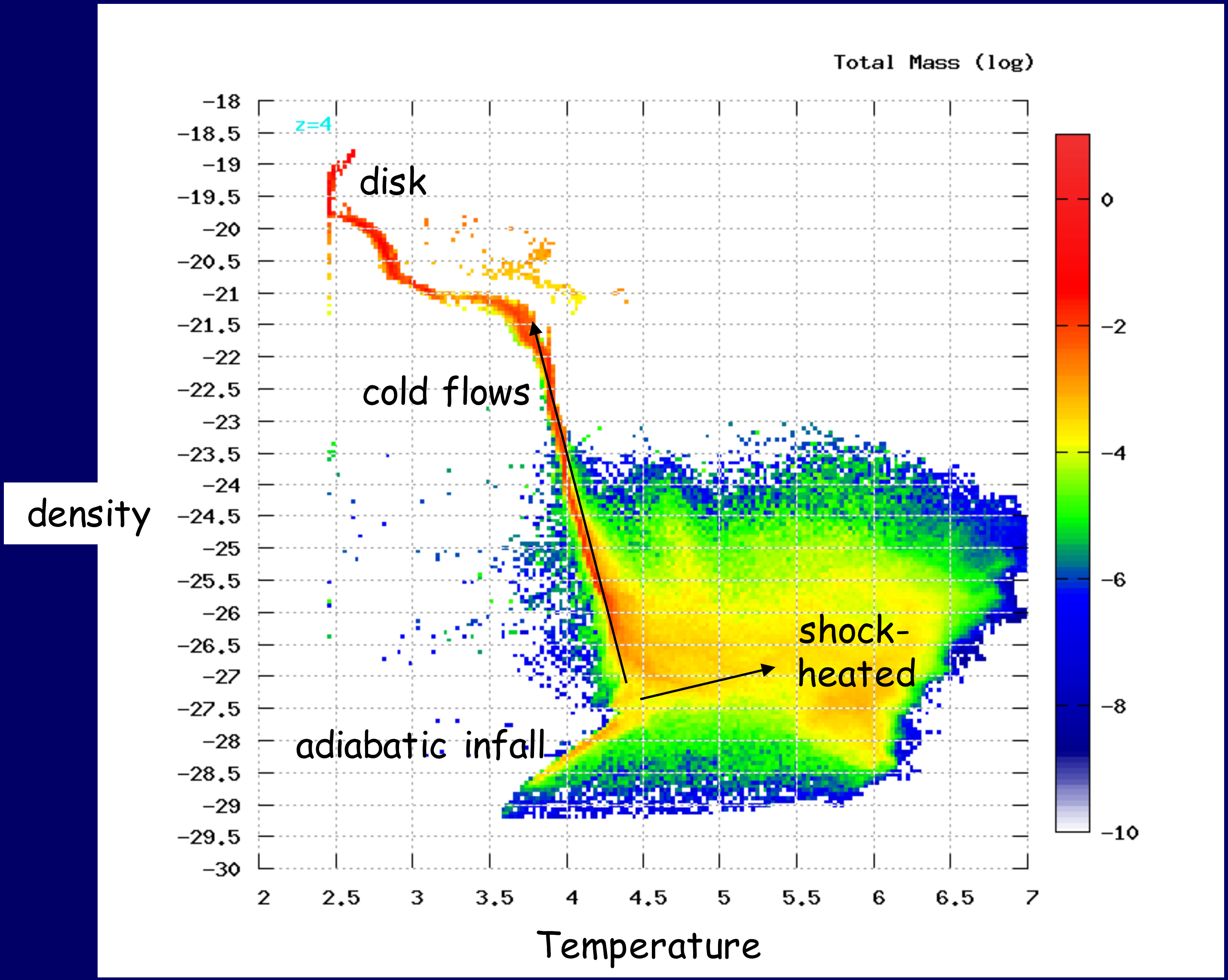
cold infall



virial radius

$z=9$
$M=1.8\mathrm{x}10^{10}$
$T_{vir}=3.5\mathrm{x}10^5$
$R_{vir}=7$ kpc

Mass Distribution of Halo Gas

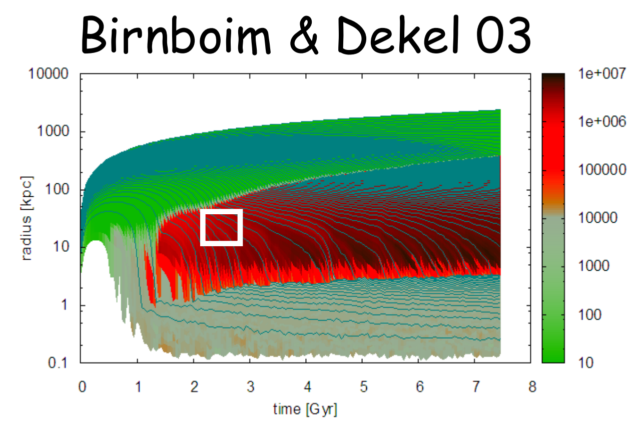


Analysis of Eulerian hydro simulations by Birnboim, Zinger, Dekel, Kravtsov

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

adiabatic: $$\gamma = \left(\frac{\partial \ln P}{\partial \ln \rho}\right)_s$$

stable: $$\gamma > 4/3$$



with cooling rate q (internal energy e):

$$\gamma_{eff} \equiv \frac{d(\ln P)}{d(\ln \rho)} = \gamma - \frac{\rho}{\dot{\rho}}\frac{q}{e} = \frac{5}{3} - \frac{5}{21}\frac{t_{comp}}{t_{cool}}$$

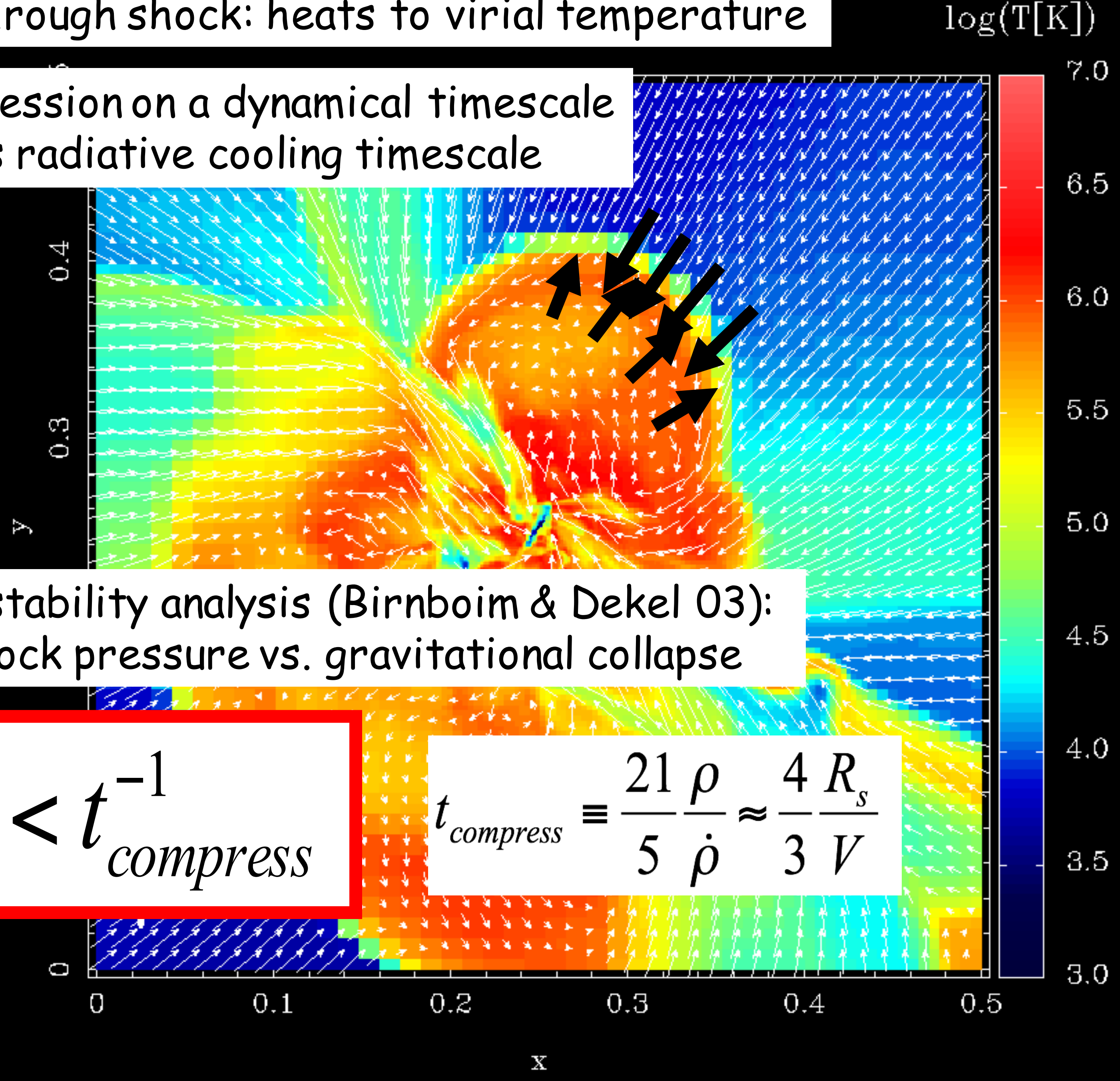
$$\dot{e} = -P\dot{V} - q$$

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

$$t_{cool} \equiv \frac{e}{q} \propto \frac{T}{\rho\Lambda(T,Z)} \qquad T \approx \frac{3}{16}V^2 \qquad \rho_{post} \approx 4\rho_{pre}$$

Stability criterion: $$\gamma_{eff} > \frac{10}{7} \longrightarrow \boxed{t_{cool}^{-1} < t_{compress}^{-1}}$$

Gas through shock: heats to virial temperature



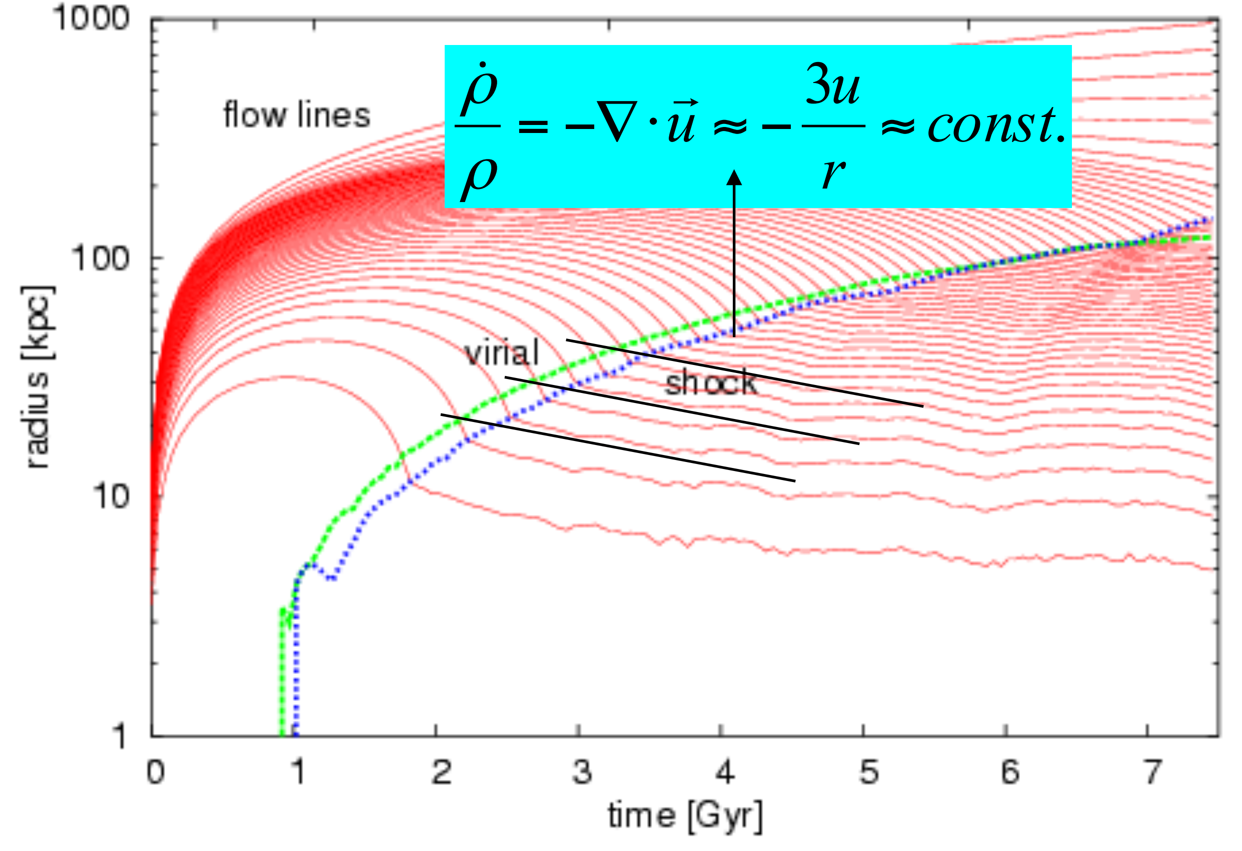
compression on a dynamical timescale
versus radiative cooling timescale

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

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

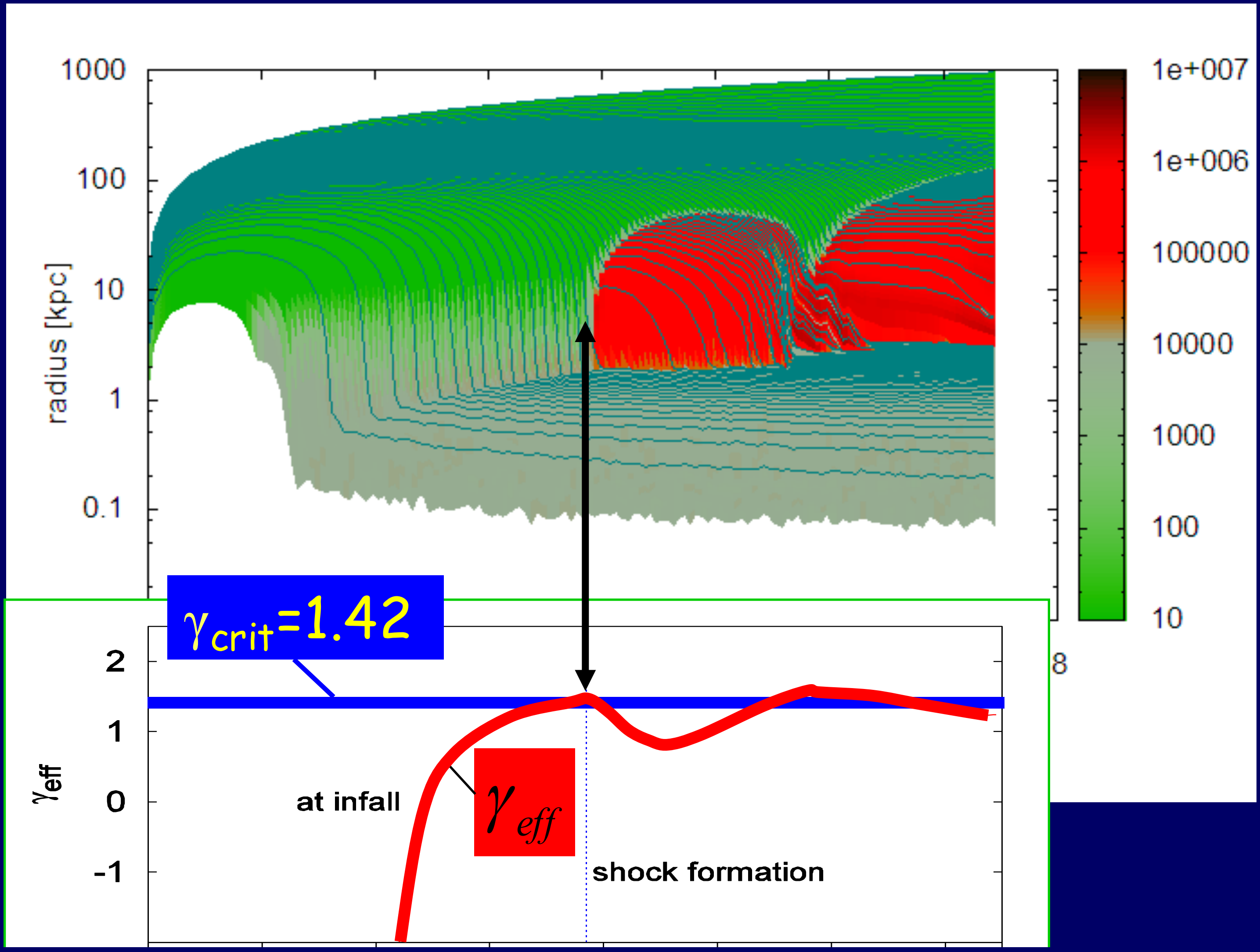
$$t_{compress} \equiv \frac{21}{5}\frac{\rho}{\dot{\rho}} \approx \frac{4}{3}\frac{R_s}{V}$$

Compression



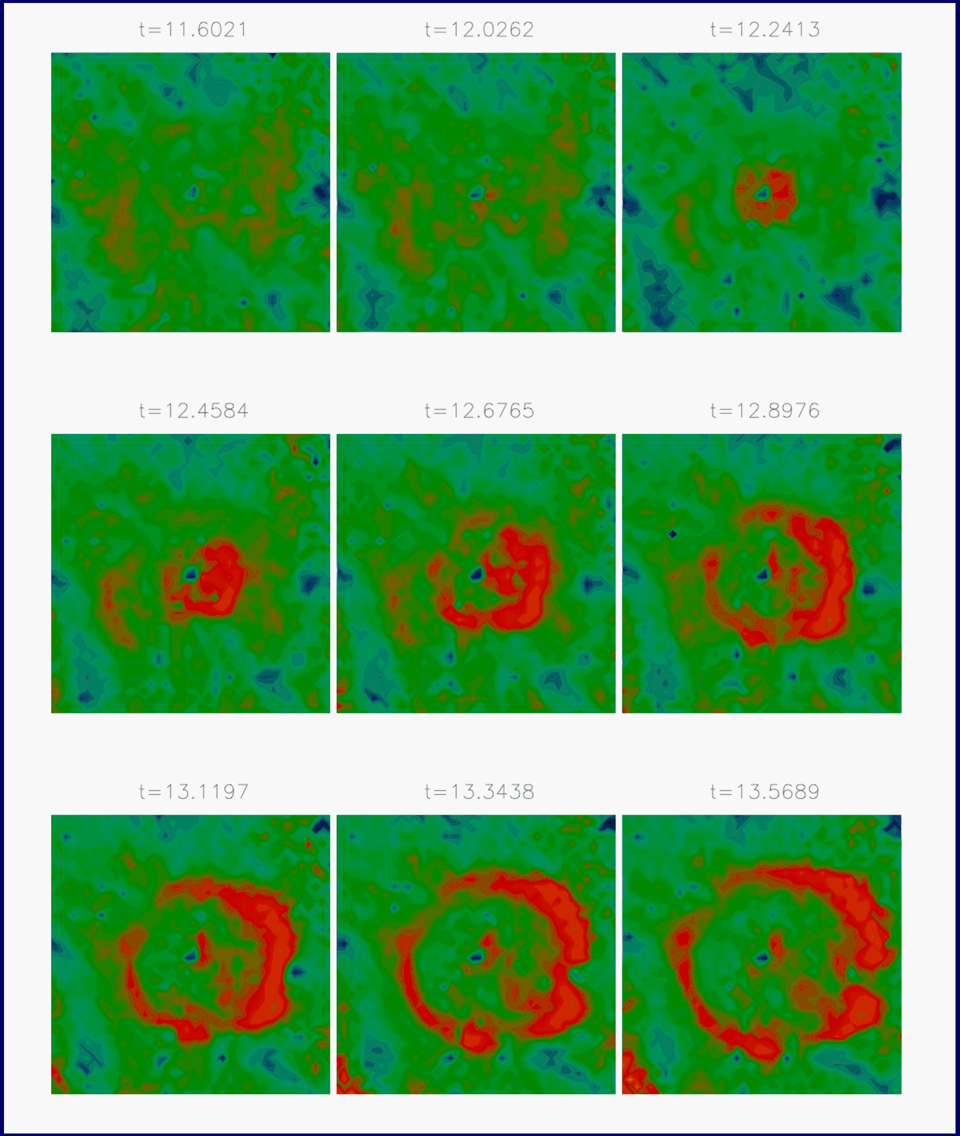
$$\frac{\dot{\rho}}{\rho} = -\nabla \cdot \vec{u} \approx -\frac{3u}{r} \approx const.$$

Spherical Simulation vs Model



time →

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



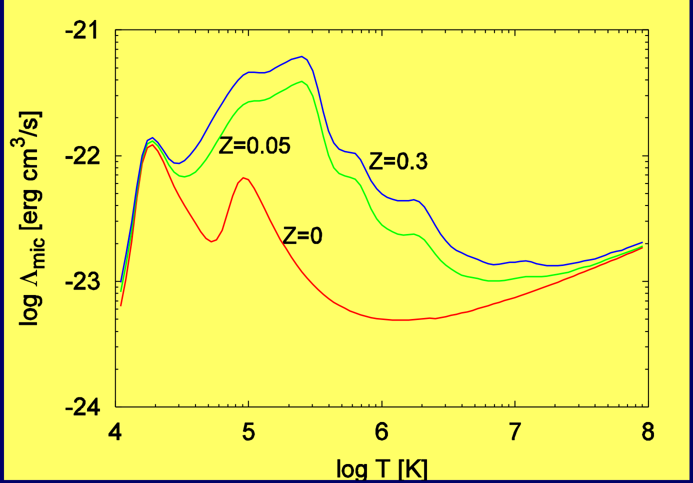
d(Entropy)/dt

Libeskind,
Birnboim,
Dekel 08

Critical mass for shock heating:

Apply $t_{cool} \sim t_{compress}$ with ρ, V, R at the virial radius for ΛCDM halos

Approximate cooling: $\Lambda \propto Z^{0.7} \, T^{-1}$



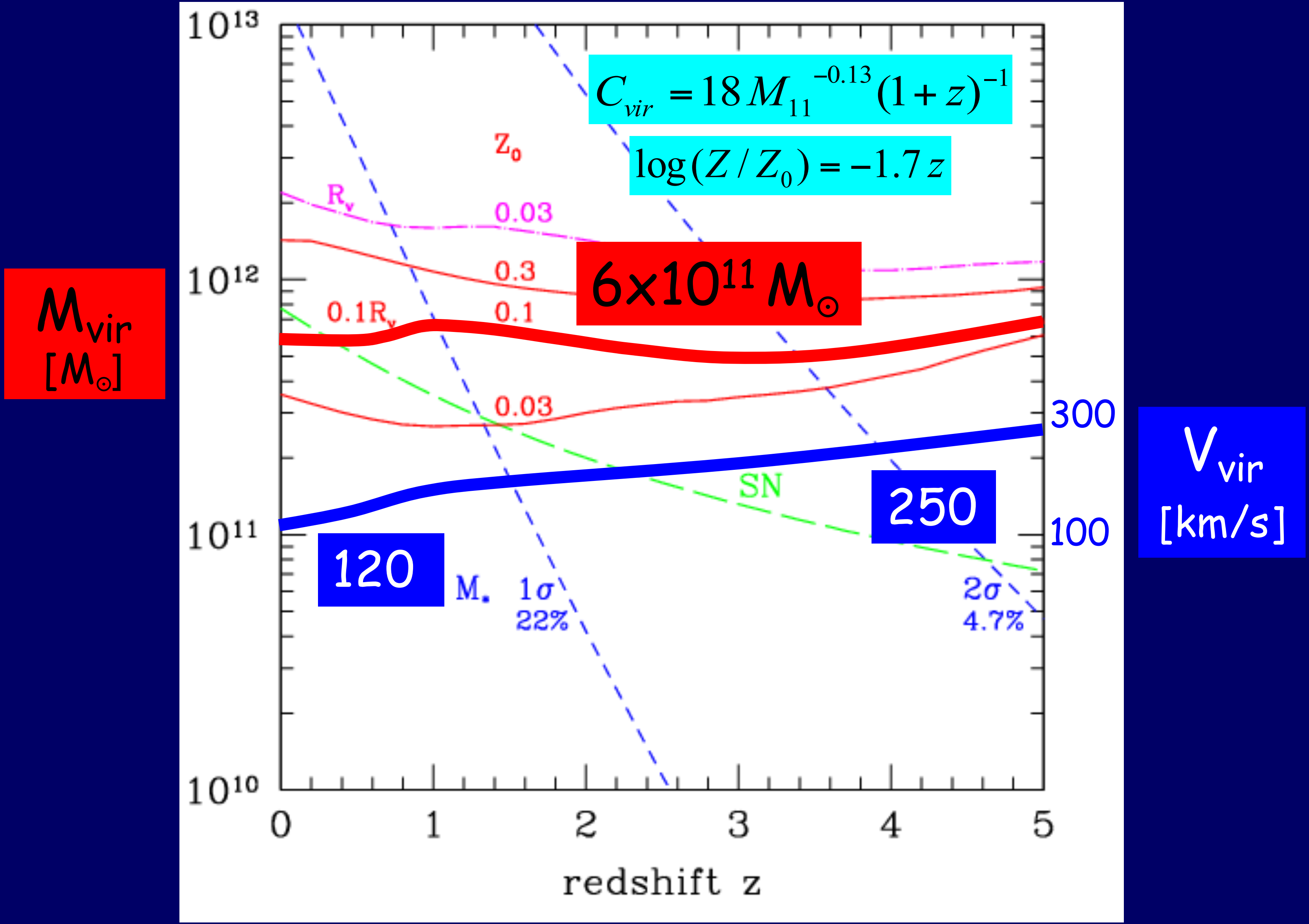
$T \sim 1.6\times10^{6}$ K $[\,(Z/0.1)^{0.7}\ (f_b/0.05)\ (\rho r/v)_{0.1Rv}\ (1+z)^{3/2}]^{1/2}$

$V_{vir} \sim 140$ km/s $[\,(Z/0.1)^{0.7}\ (f_b/0.05)\ (\rho r/v)_{0.1Rv}\ (1+z)^{3/2}\,]^{1/4}$

$M_{halo} \sim 7\times10^{11}\,M_\odot$ $[\,(Z/0.1)^{0.7}\ (f_b/0.05)\ (\rho r/v)_{0.1Rv}\ (1+z)^{-1/2}\,]^{3/4}$

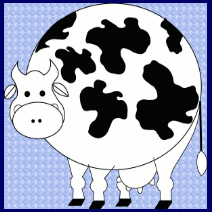
~coincides with the bi-modality scale

Shock-Heating Scale



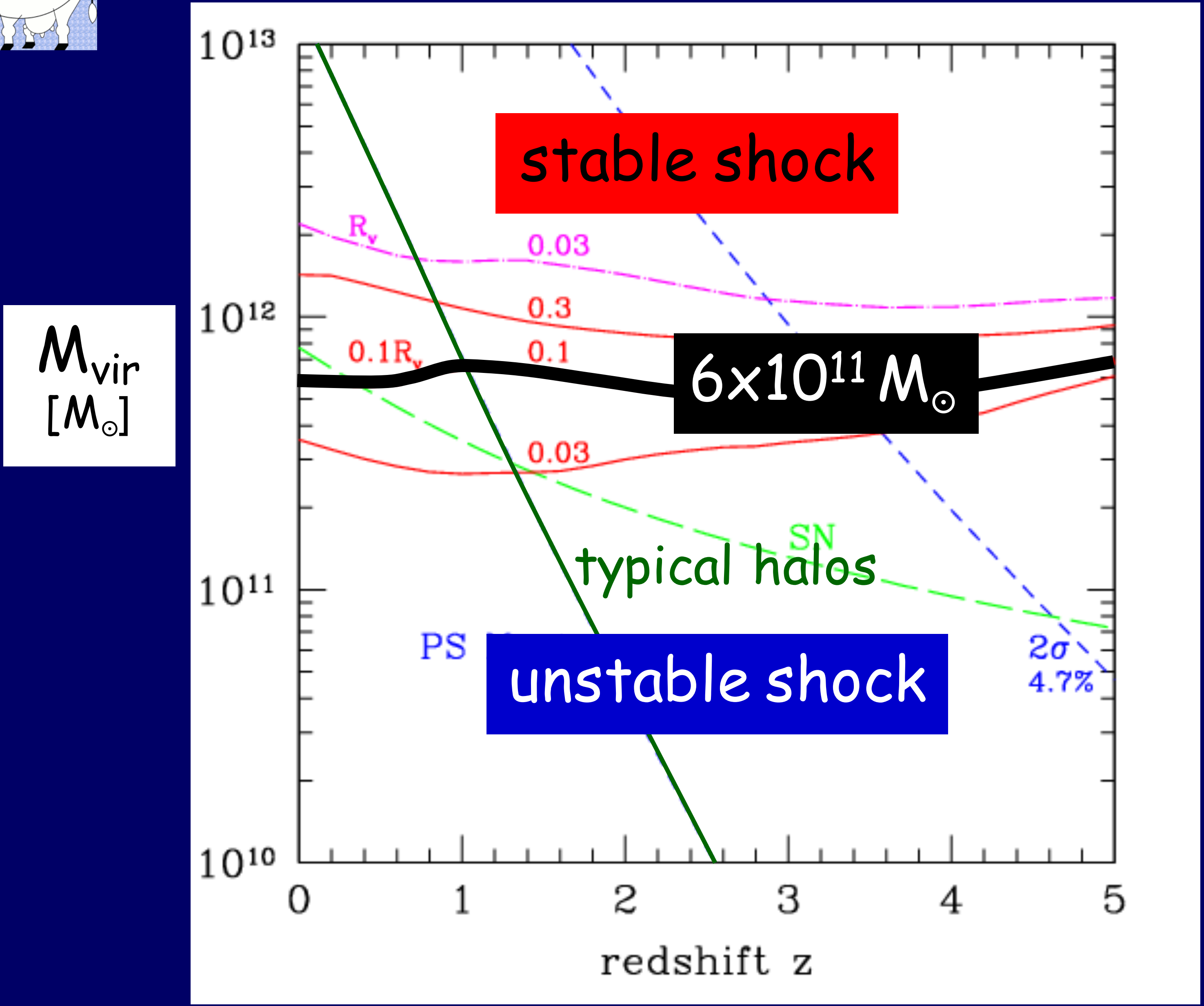
$$C_{vir} = 18\, M_{11}^{-0.13} (1+z)^{-1}$$

$$\log(Z/Z_0) = -1.7\, z$$

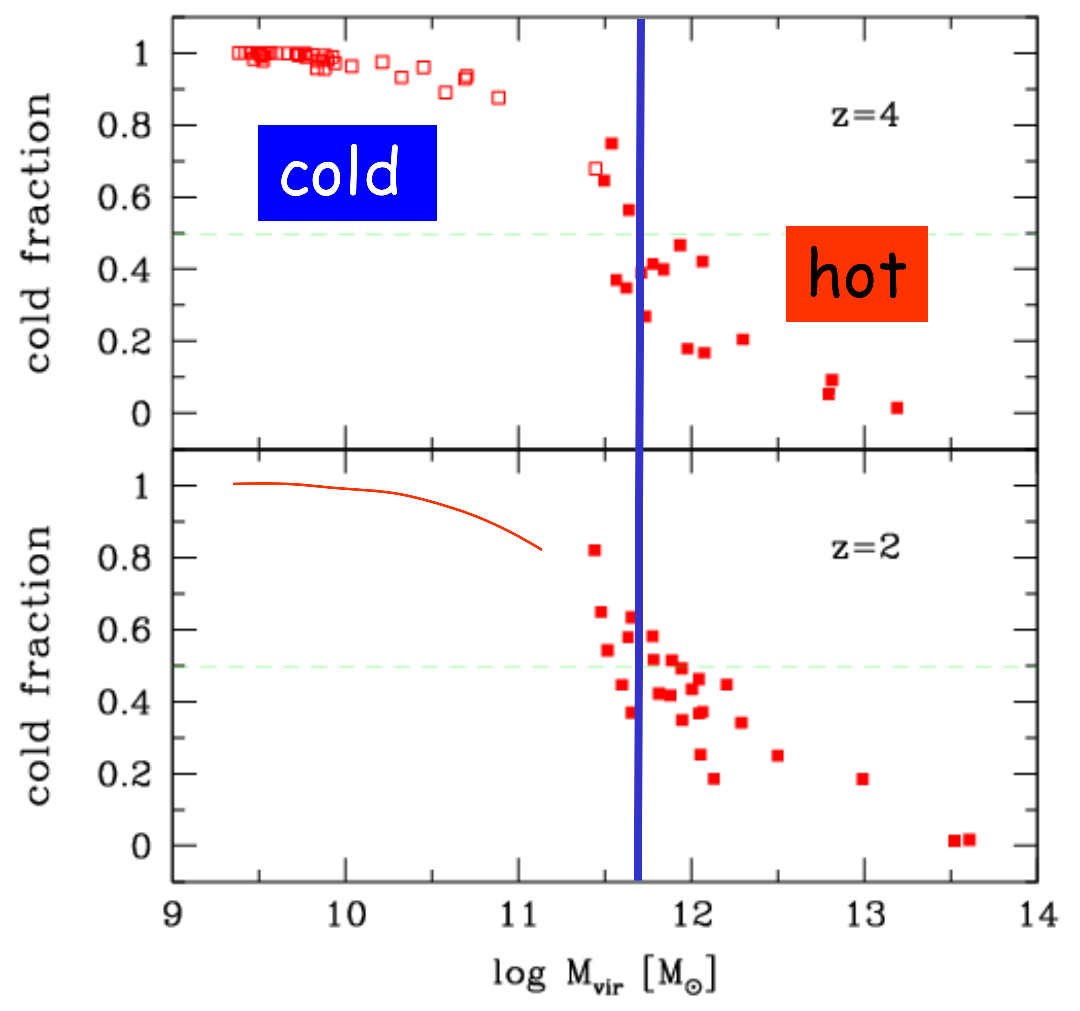


Shock-Heating Scale

Dekel & Birnboim 06



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



Birnboim, Dekel, Neistein 2007

Zinger, Birnboim, Dekel, Kravtsov

Fraction of cold/hot accretion

SPH simulation

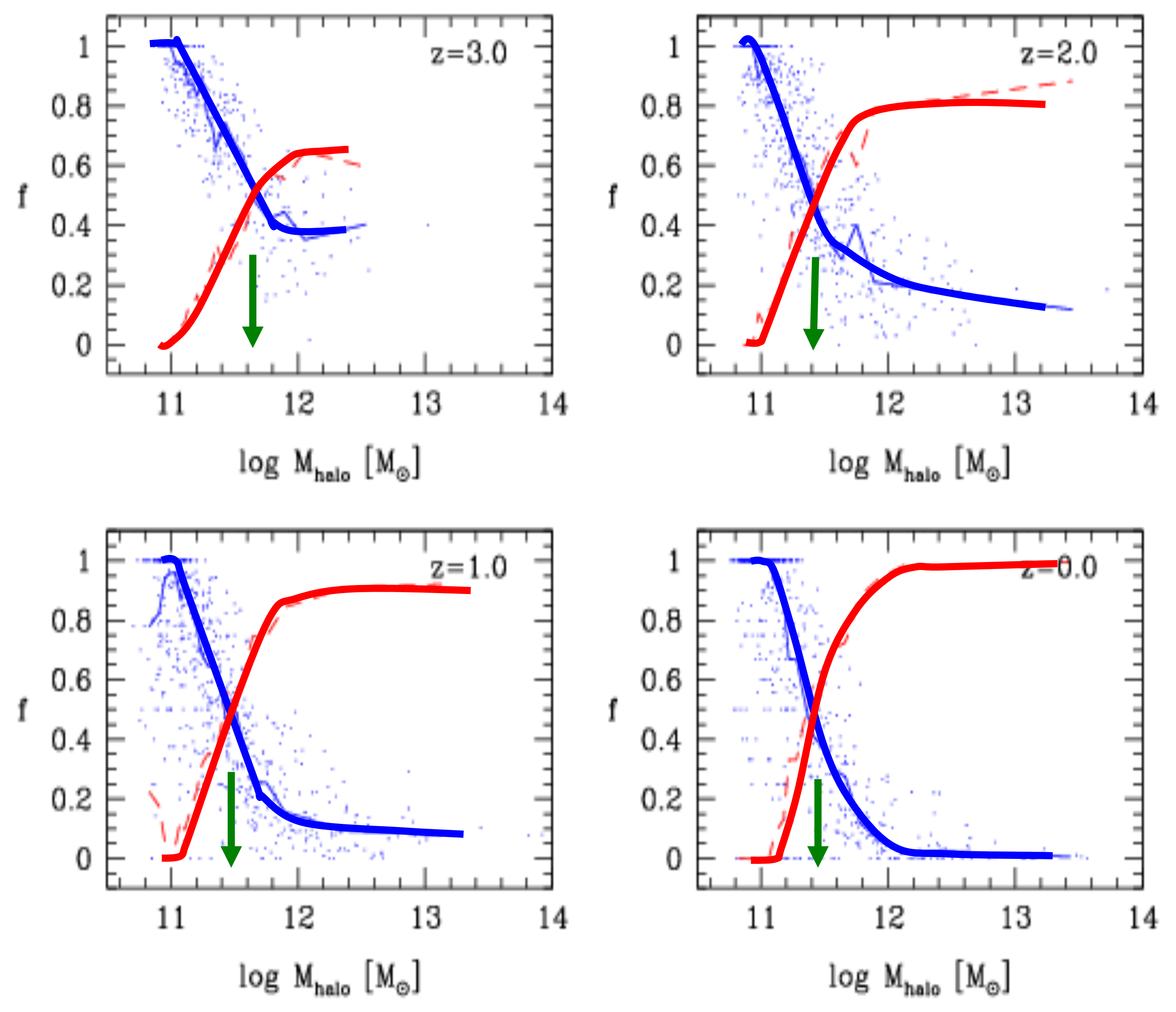
Keres, Katz, Weinberg, Dav'e 2004

Z=0, under-estimating M_{shock}

sharp transition

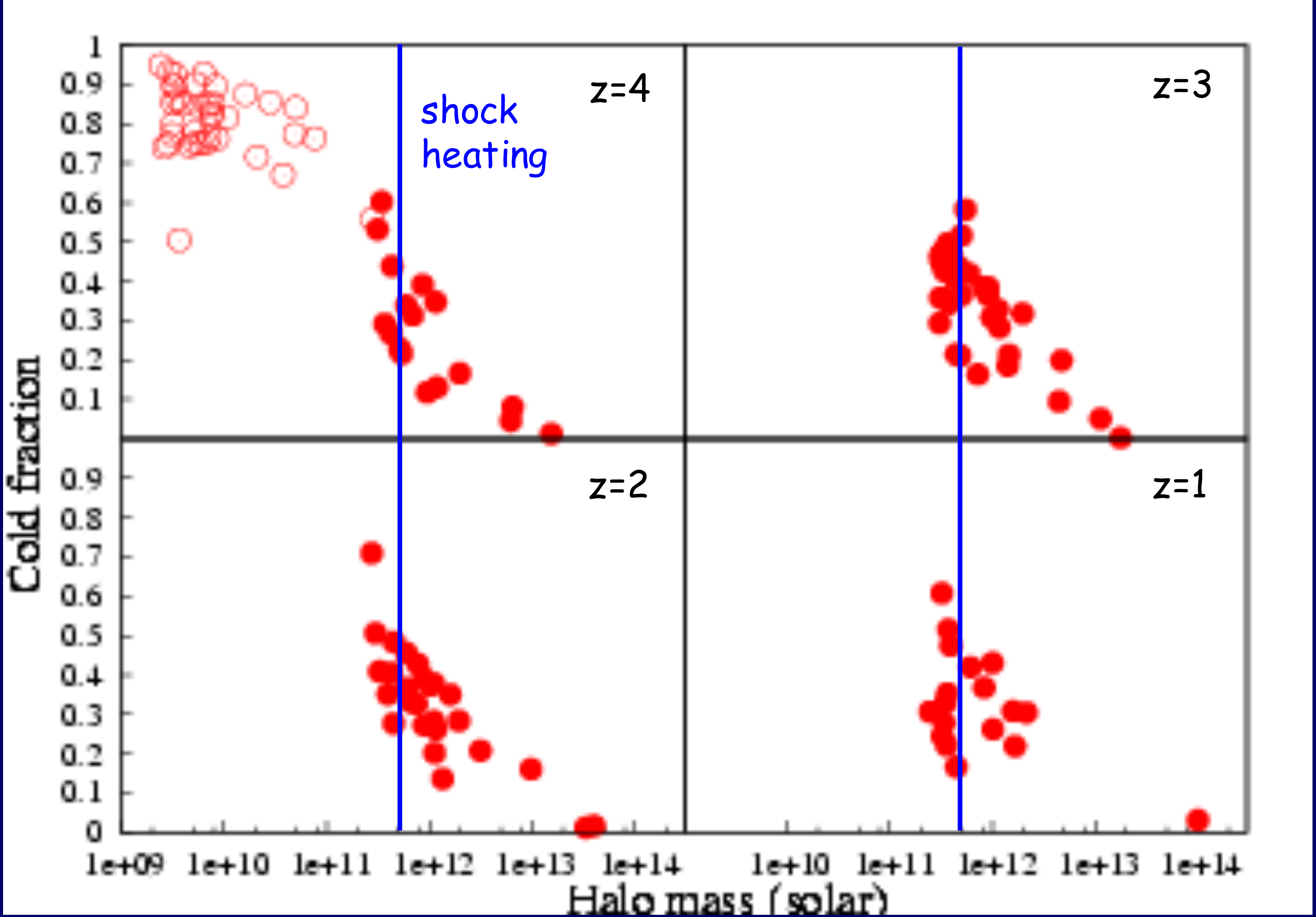
$$\frac{M_{cold}}{M_{tot}} \propto M^{-2/3}$$

$$\rightarrow \frac{M}{L} \propto M^{2/3}$$

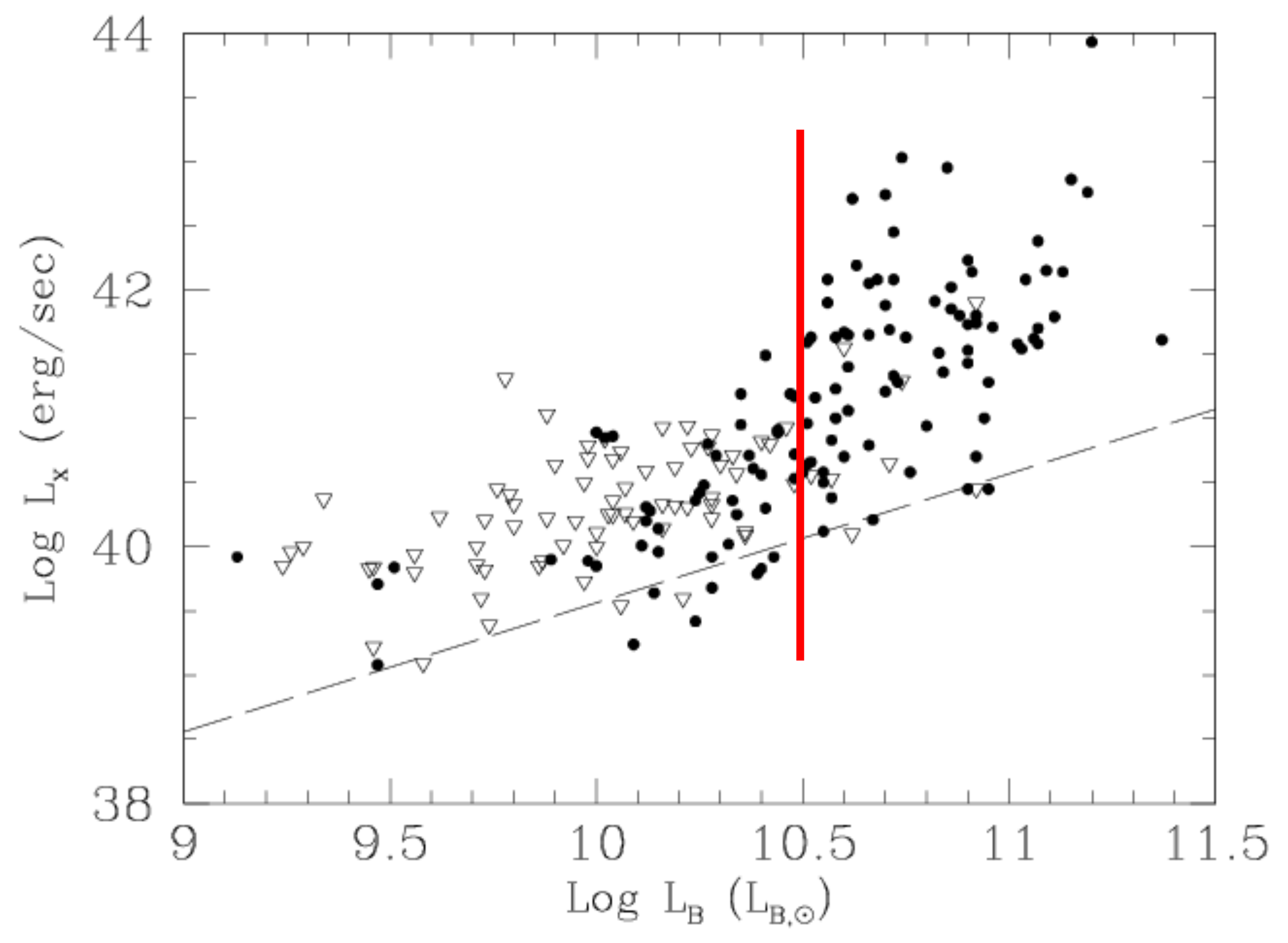


Fraction of cold gas in halos: Eulerian simulations

Birnboim, Dekel, Kravtsov, Zinger 2007

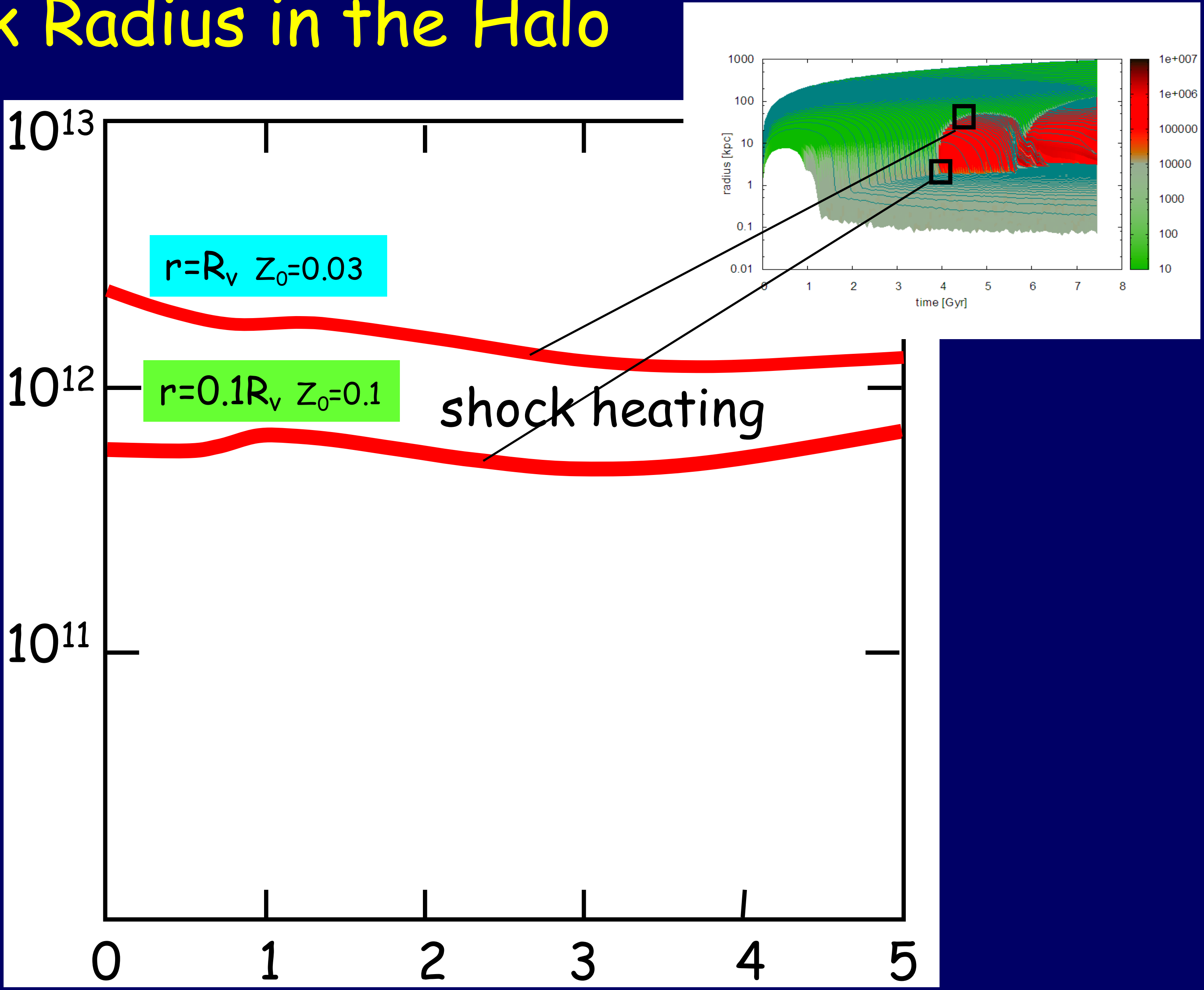


Hot Gas in Elliptical Galaxies

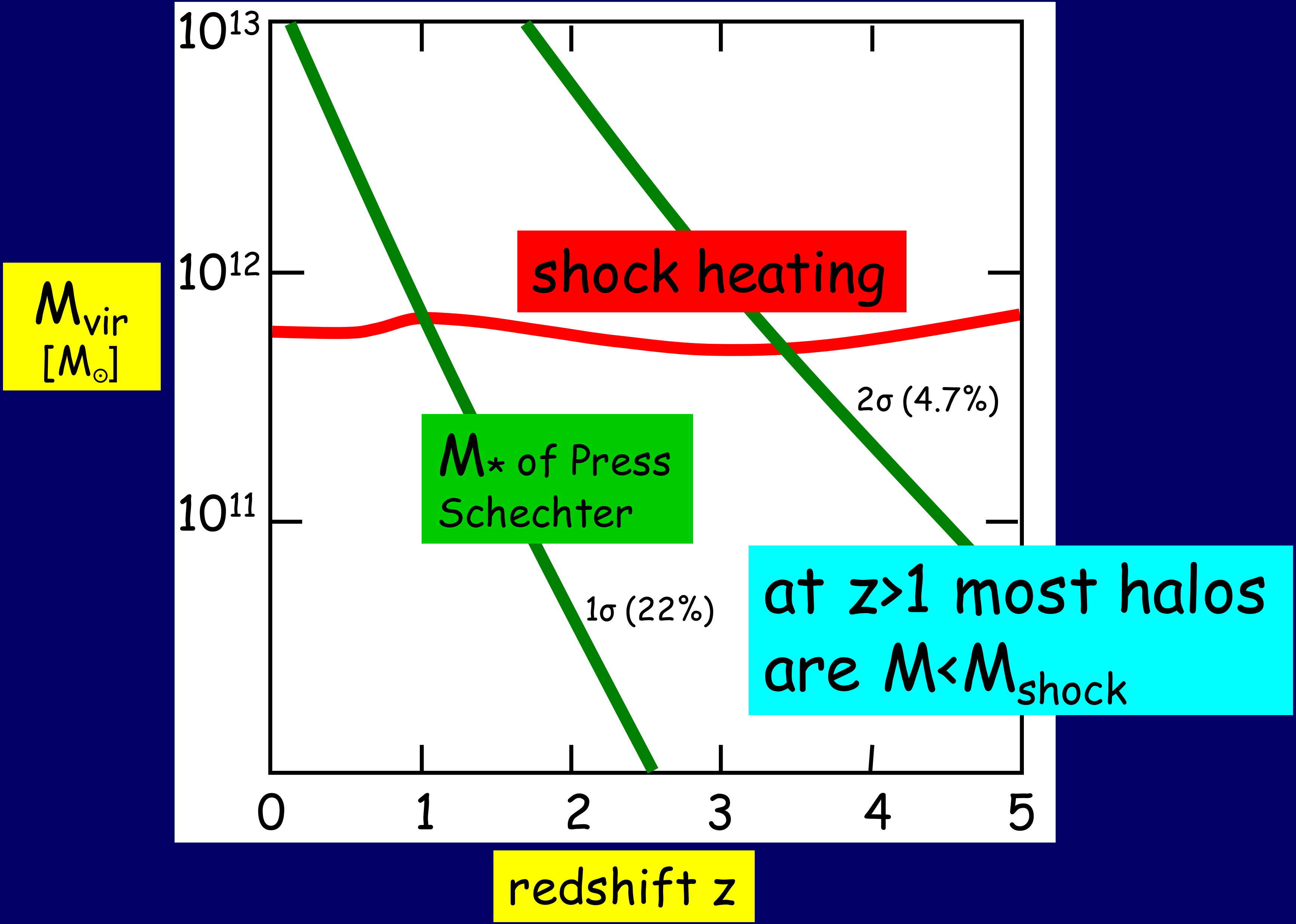


Mathews & Brighenti 04; O'Sullivan et al. 01

Shock Radius in the Halo



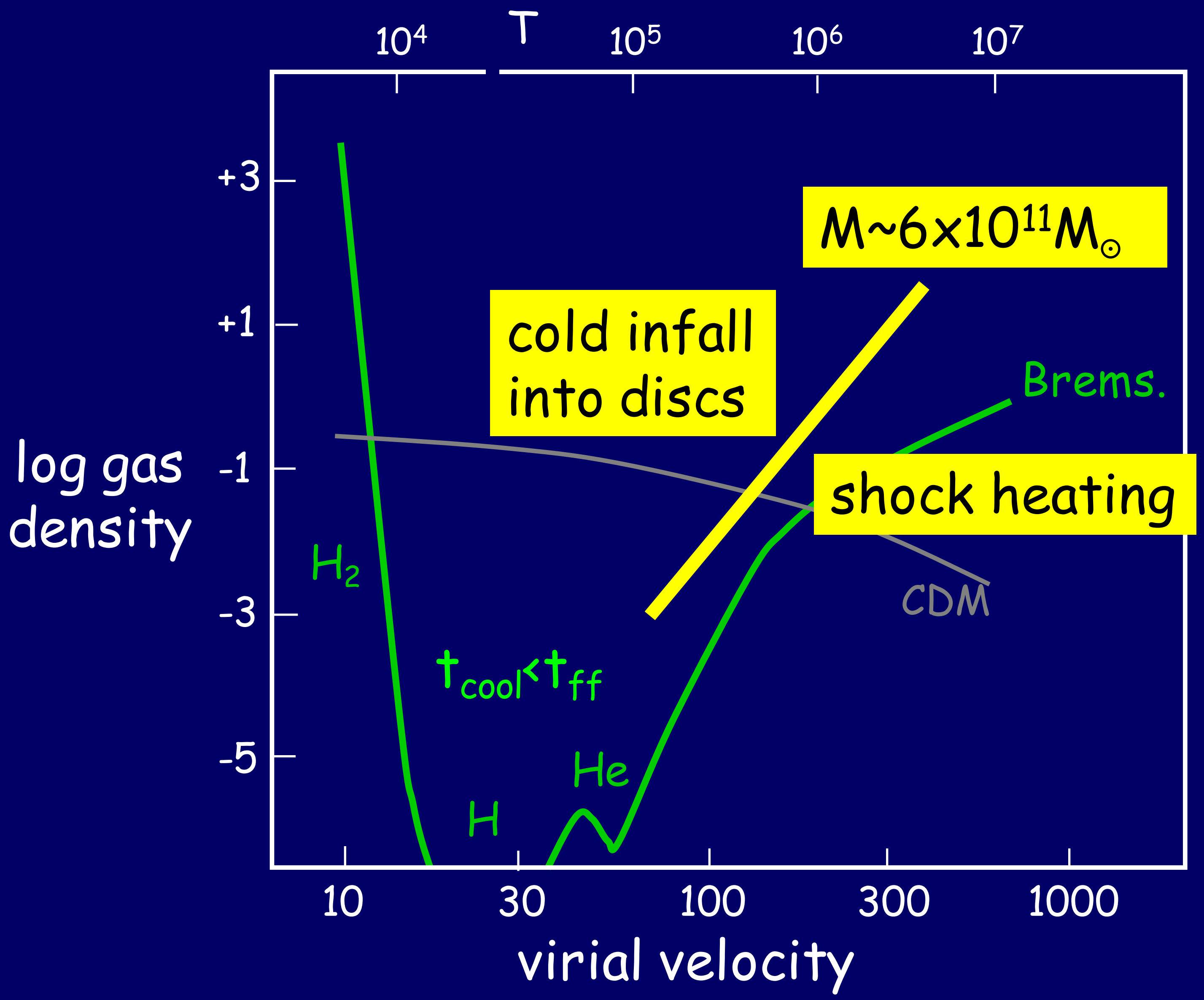
Cold Flows in Typical Halos



at z>1 most halos are $M<M_{shock}$

Shock-heating Scale

Birnboim & Dekel 03



3. Filaments in Hot Medium

At high redshift, in relatively isolated galaxies

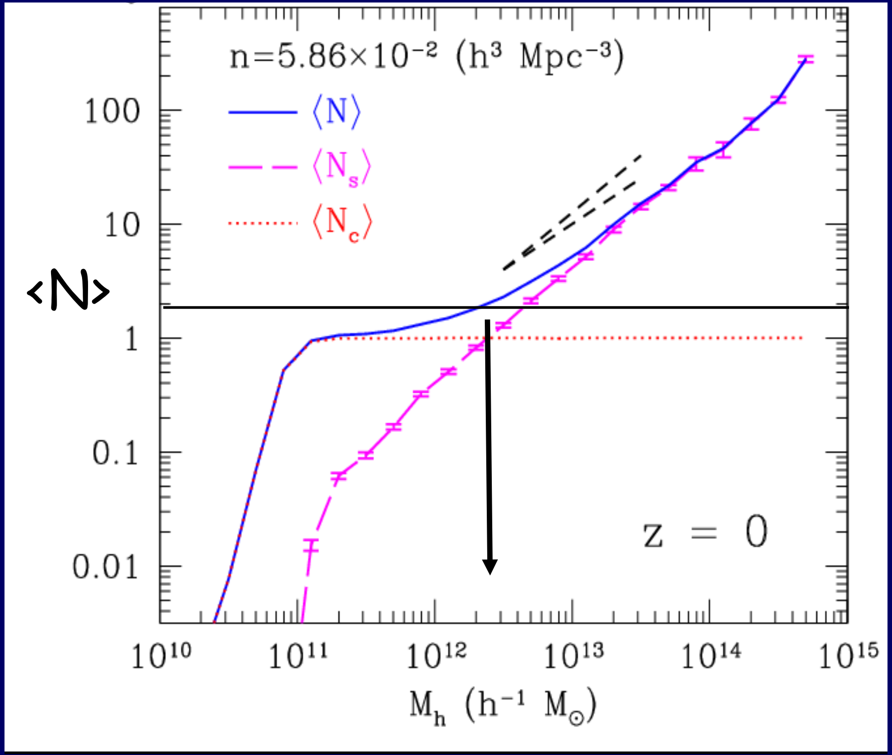
Relation to the universal clustering scale

Clustering Scale

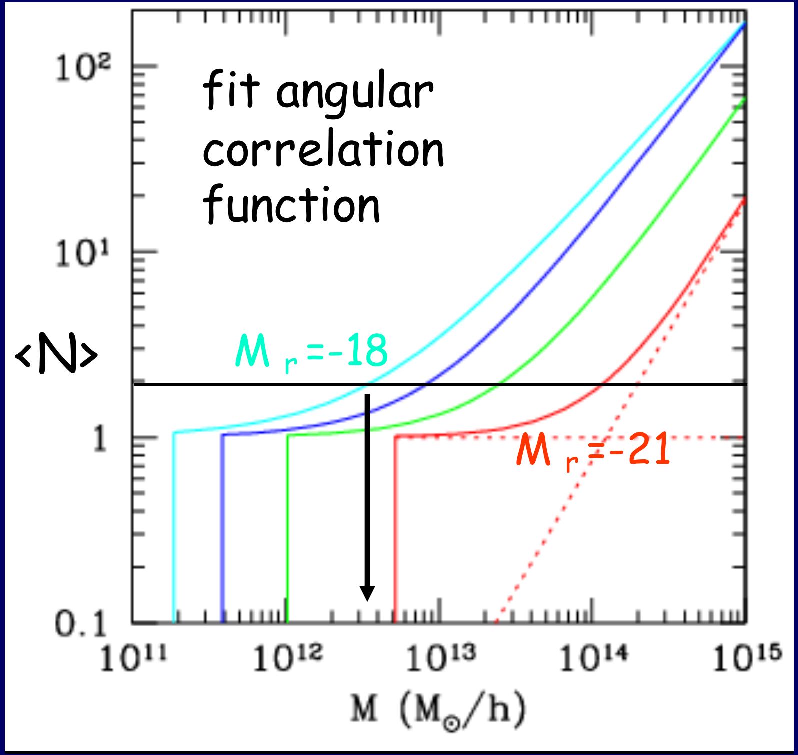
Cooling vs dynamical time scales?

or/and gravity + fluctuation amplitude?

Dark-Matter Halo Occupation Distribution



Kravtsov et al. 04, N-body simulations



Zehavi et al. 04, SDSS

$M \sim M_*(t) \rightarrow$ group

at $z=0$ $\sim 10^{13} M_\odot$ at $z=1$ $\sim 10^{12} M_\odot$

$M \ll M_*(t) \rightarrow$ early formation,
satellites decay by dynamical friction

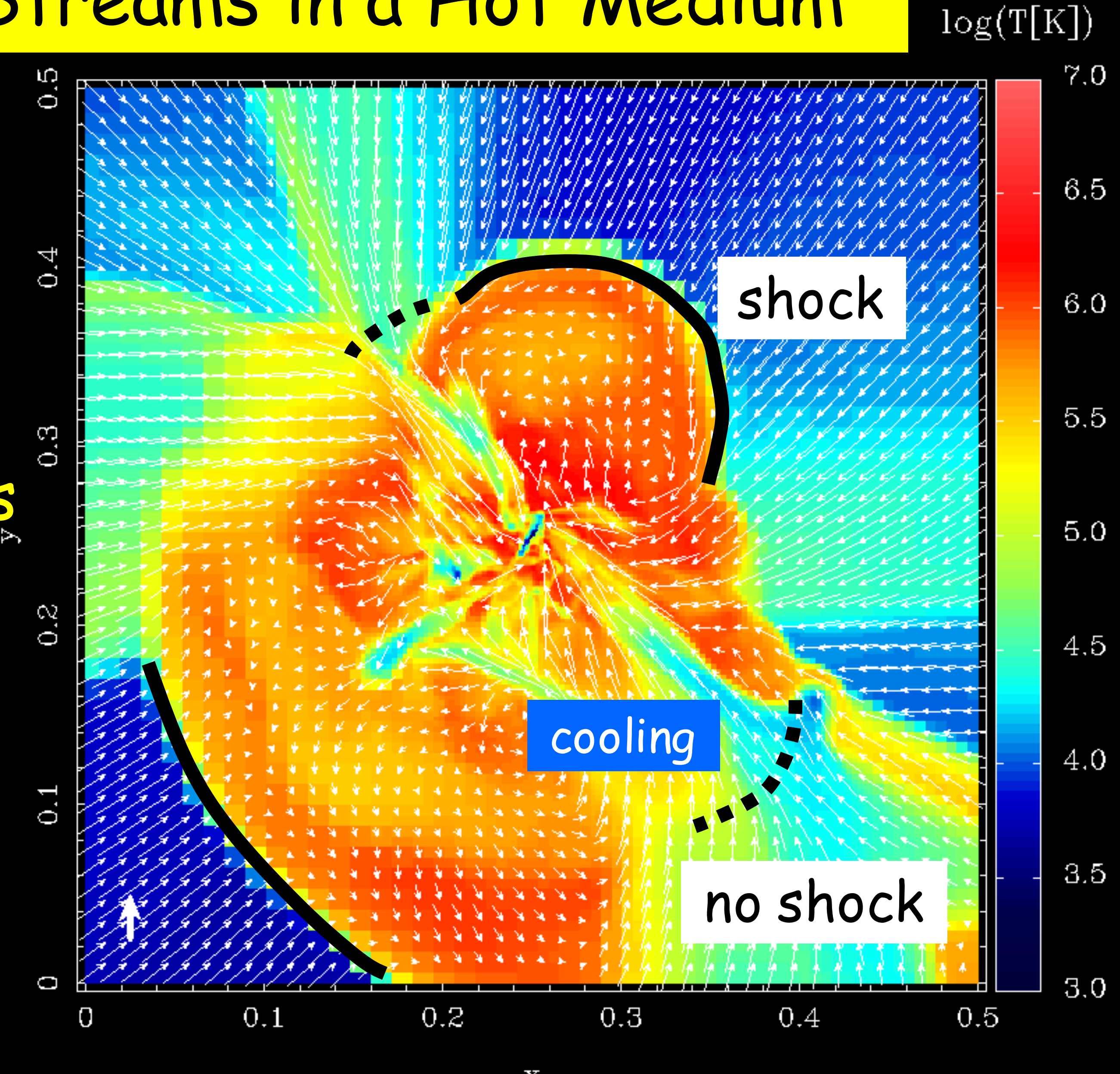
$$\frac{m_{sat}}{M_{halo}} < (0.01-0.1)\left(\frac{M_{halo}}{M_{*0}}\right)^{0.3}$$

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

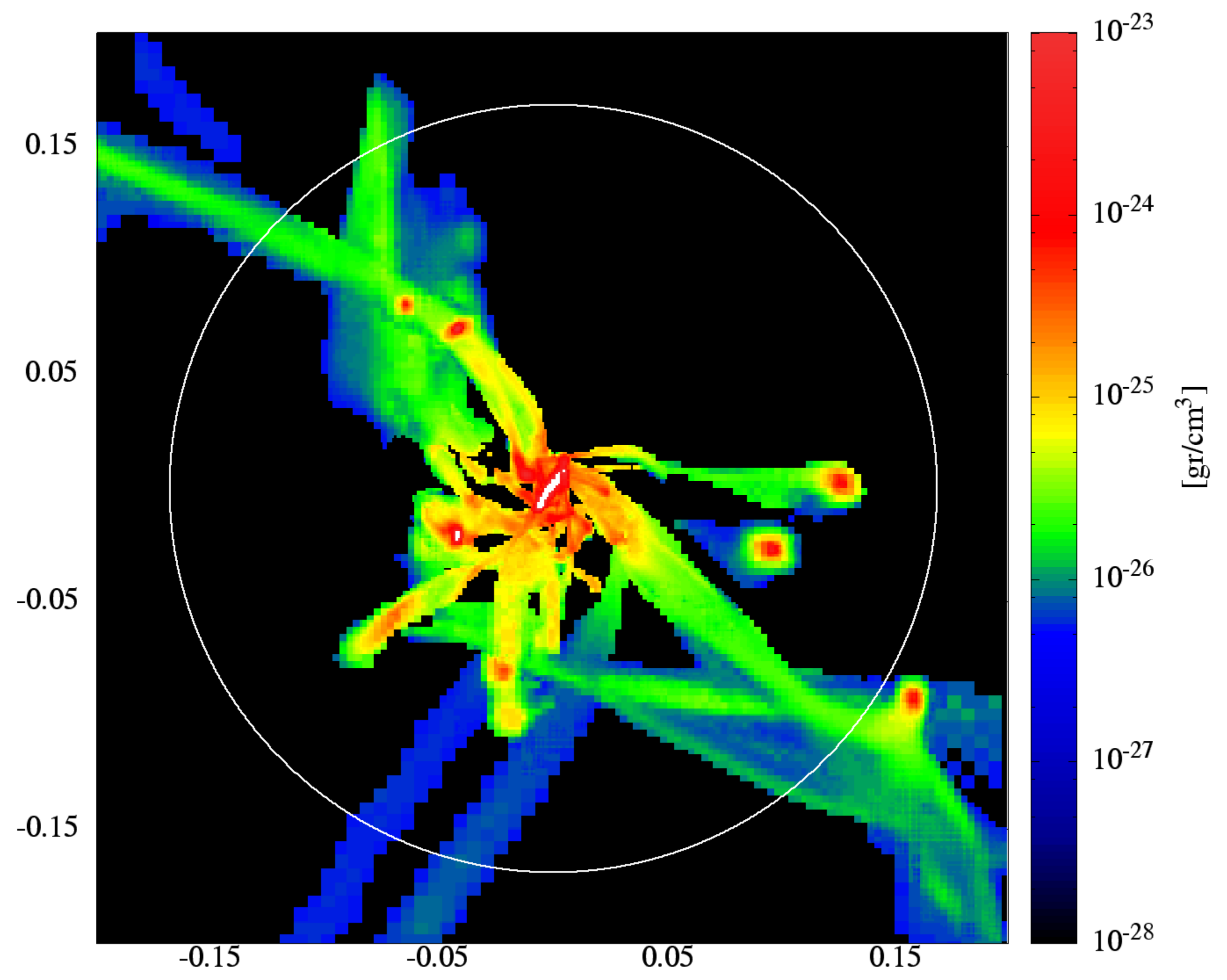
in $M > M_{shock}$

Totally hot
at z<1

Cold streams
at z>2

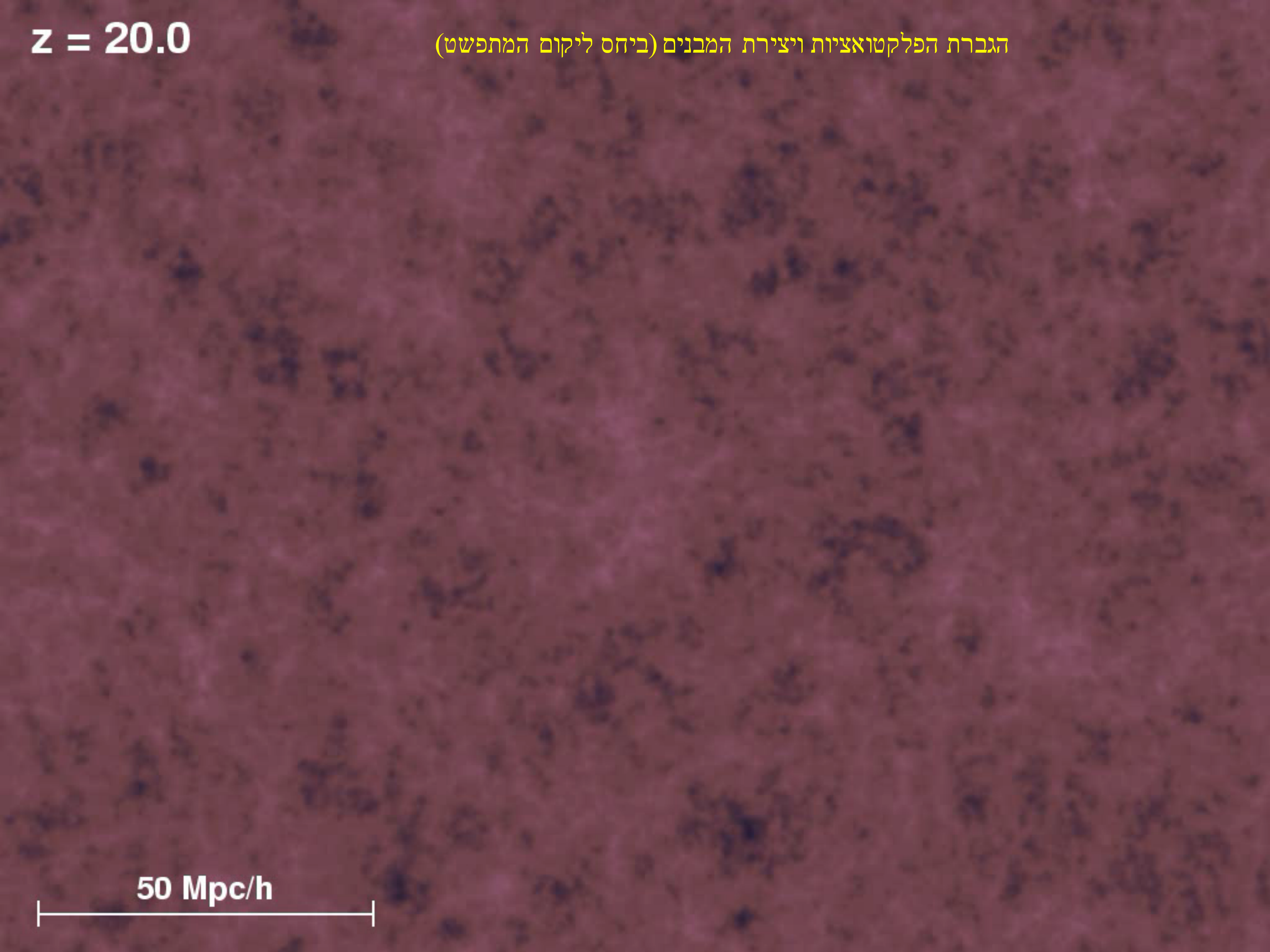


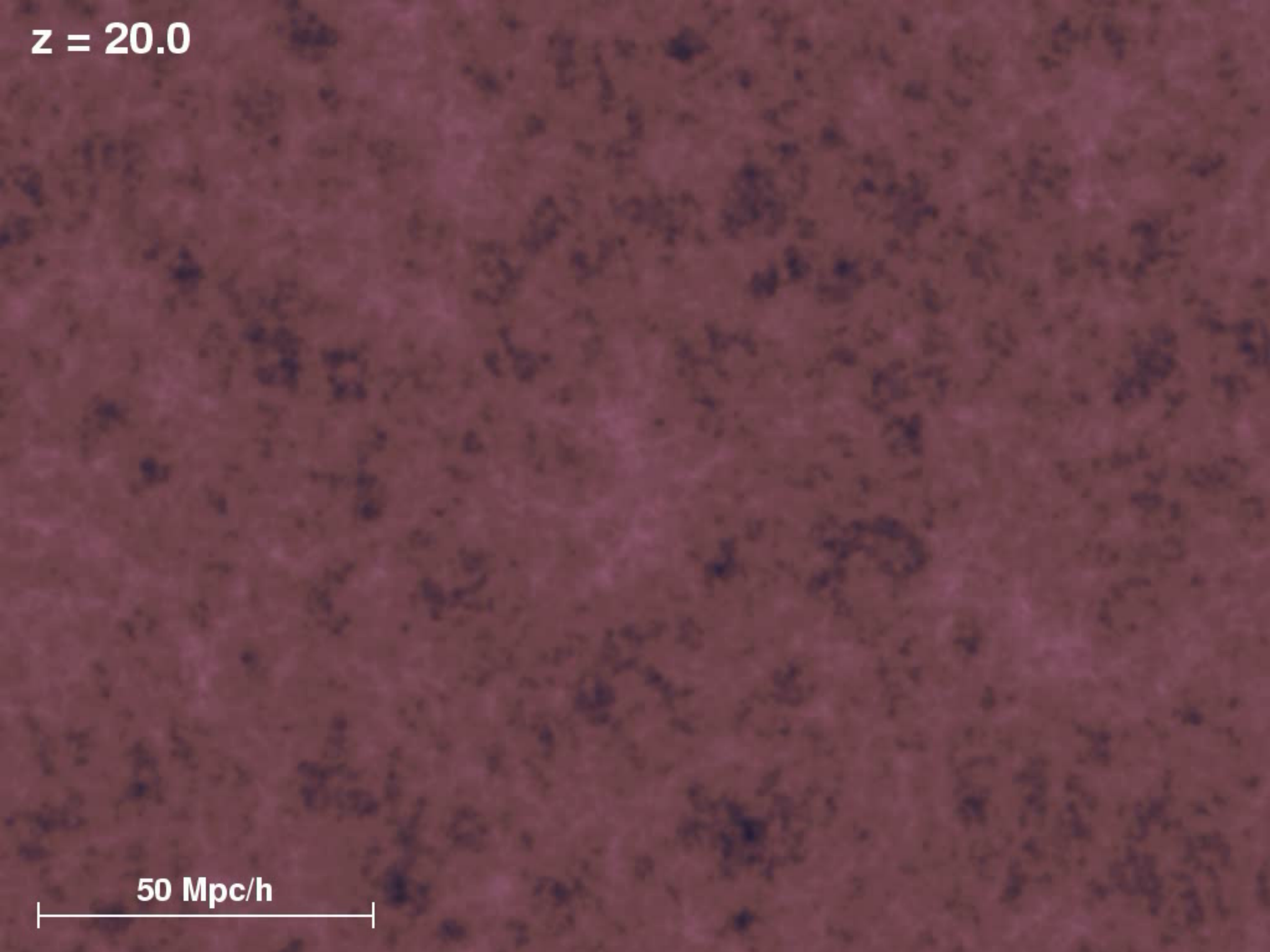
Cold, dense filaments and clumps (50%) riding on dark-matter filaments and sub-halos



Birnboim,
Zinger,
Dekel,
Kravtsov

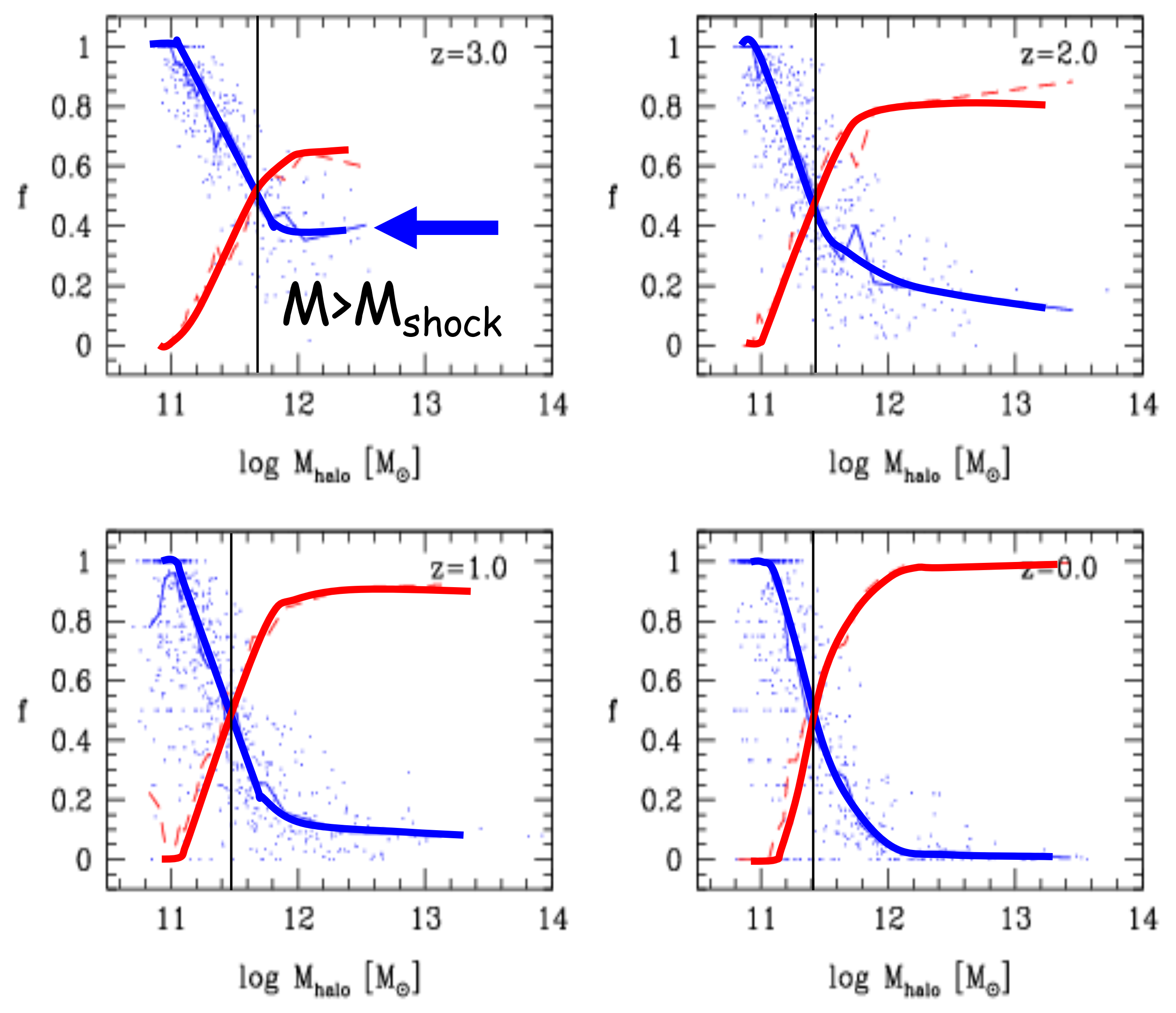
הגברת הפלקטואציות ויצירת המבנים (ביחס ליקום המתפשט)




z = 20.0
50 Mpc/h

Fraction of cold/hot accretion

cold streams in a hot medium

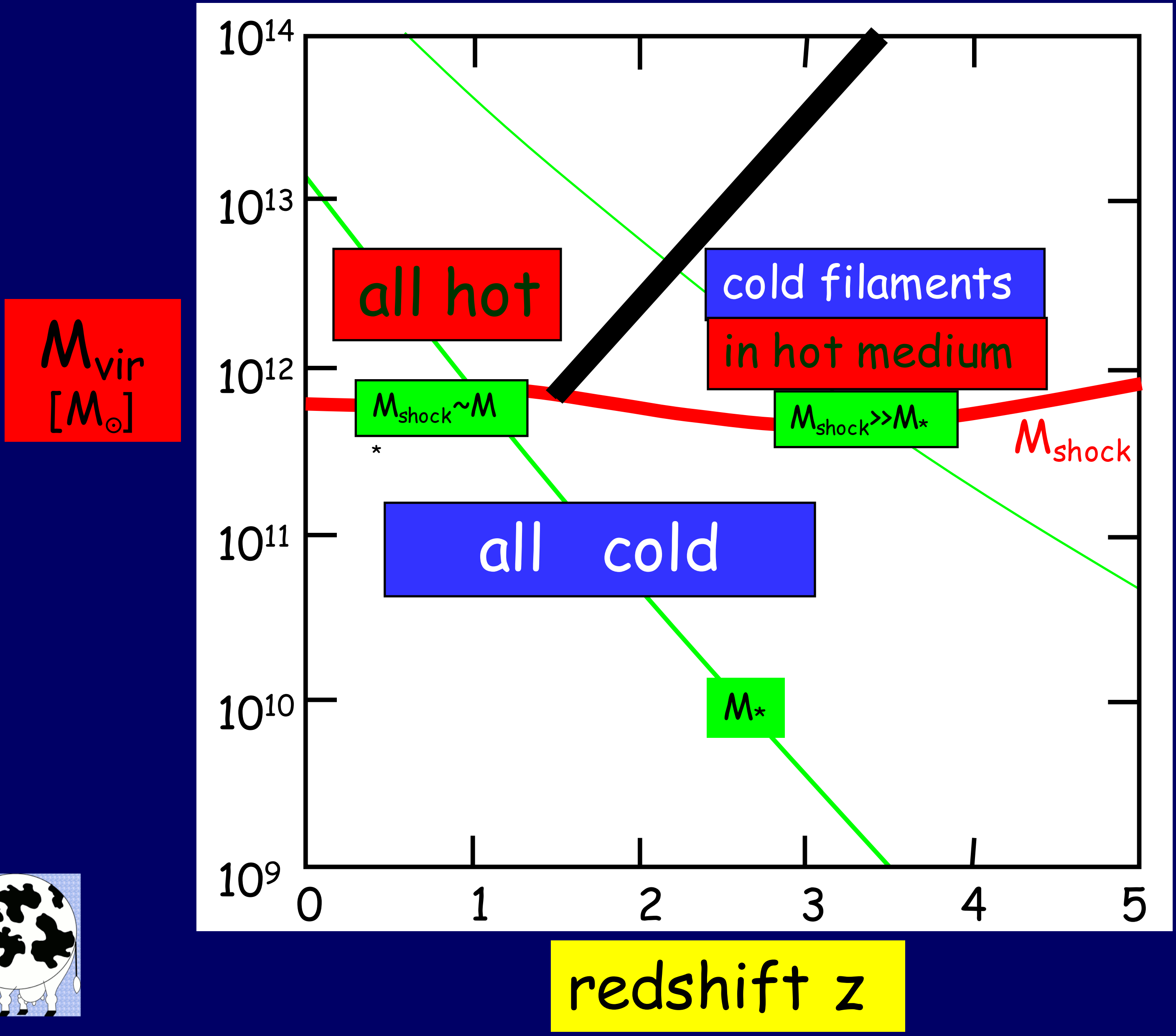


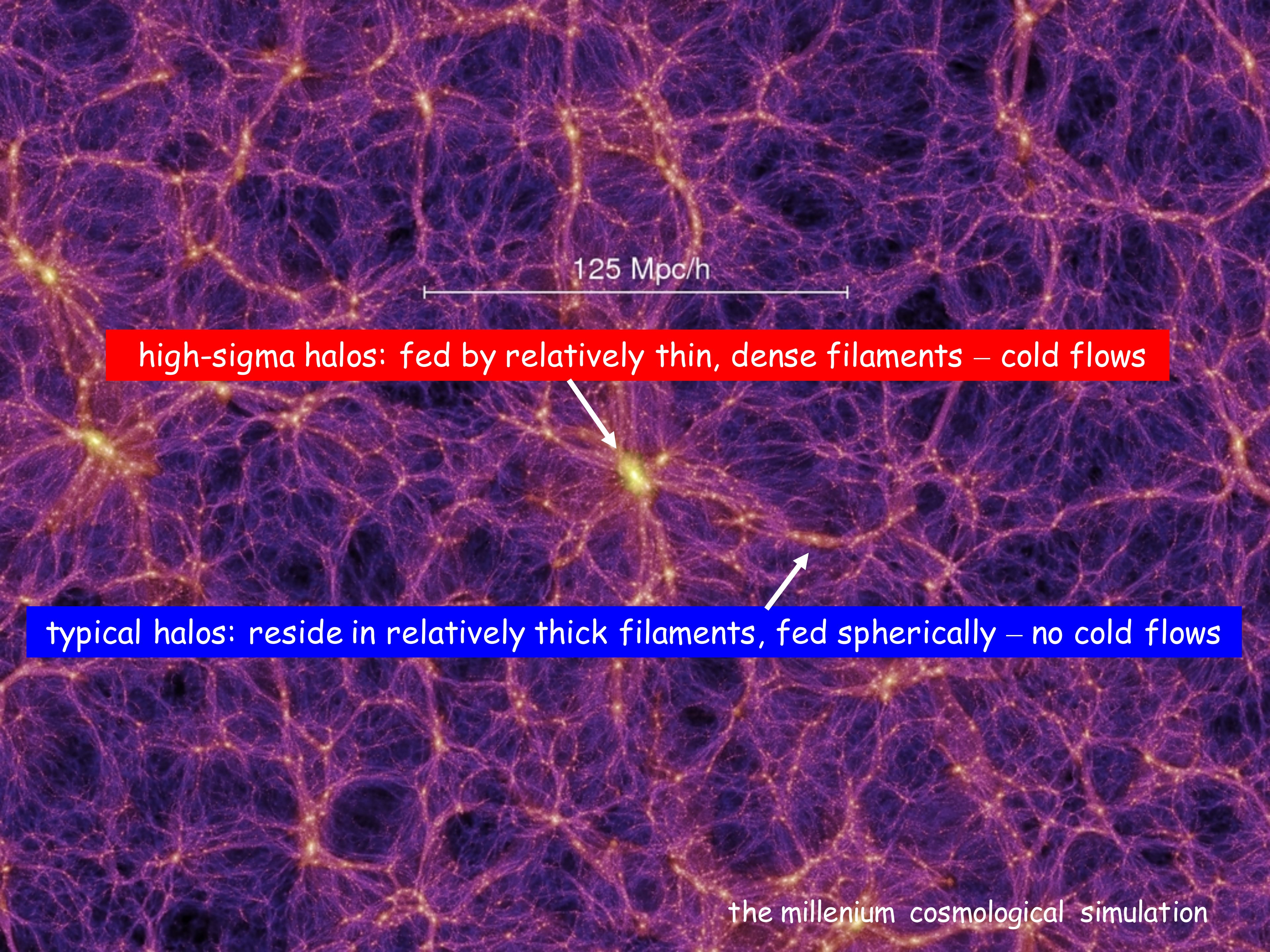
$M>M_{shock}$

SPH simulation

Keres, Katz, Weinberg, Dav'e 2004

Cold Streams in Big Galaxies at High z





high-sigma halos: fed by relatively thin, dense filaments – cold flows

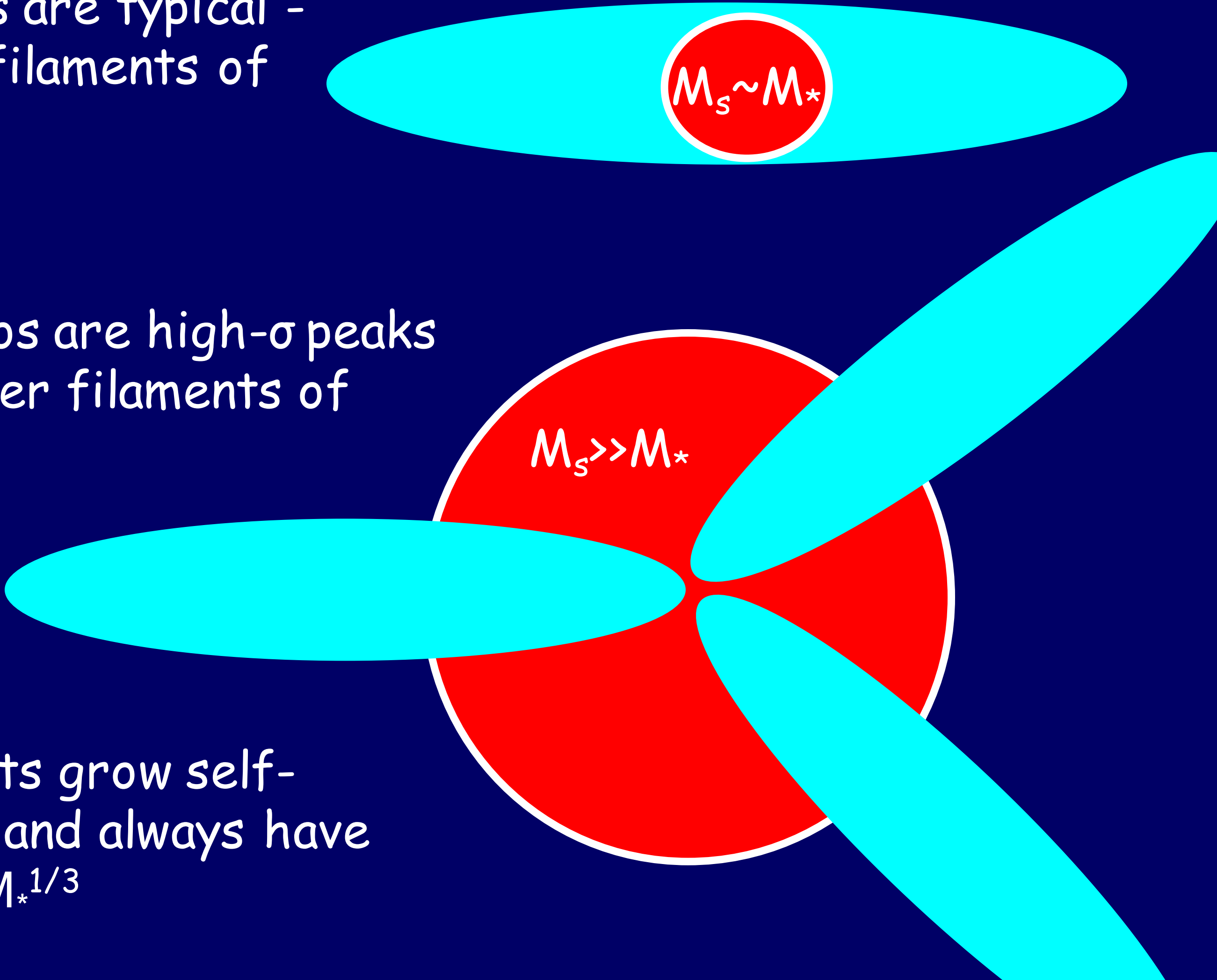
typical halos: reside in relatively thick filaments, fed spherically – no cold flows

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 - residiing in thicker filaments of comparable density

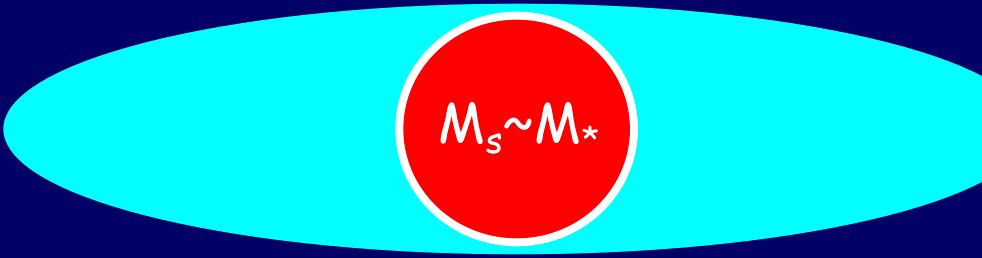
At high z, M_{shock} halos are high-σ peaks - fed by a few thinner filaments of higher density



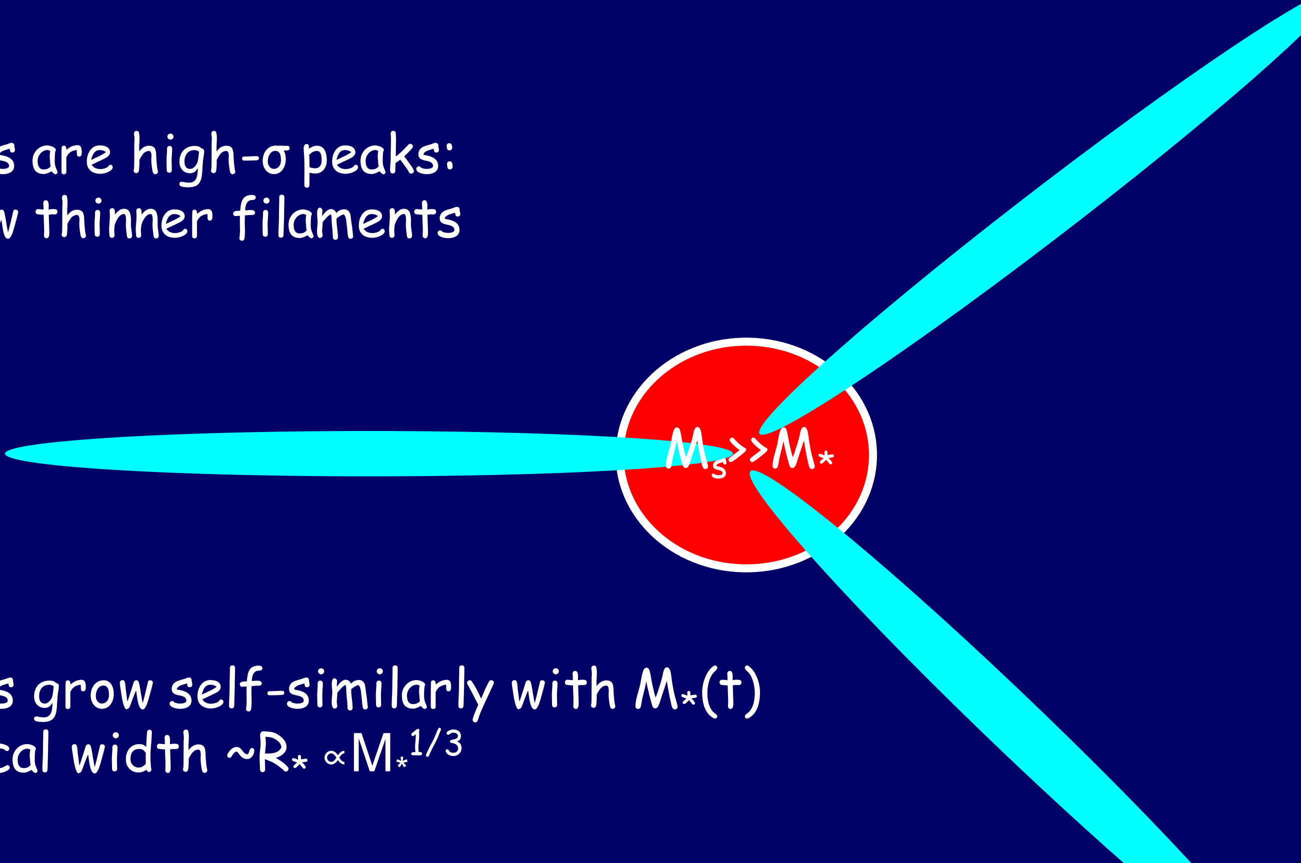
Large-scale filaments grow self-similarly with $M_*(t)$ and always have typical width $\sim R_* \propto M_*^{1/3}$

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



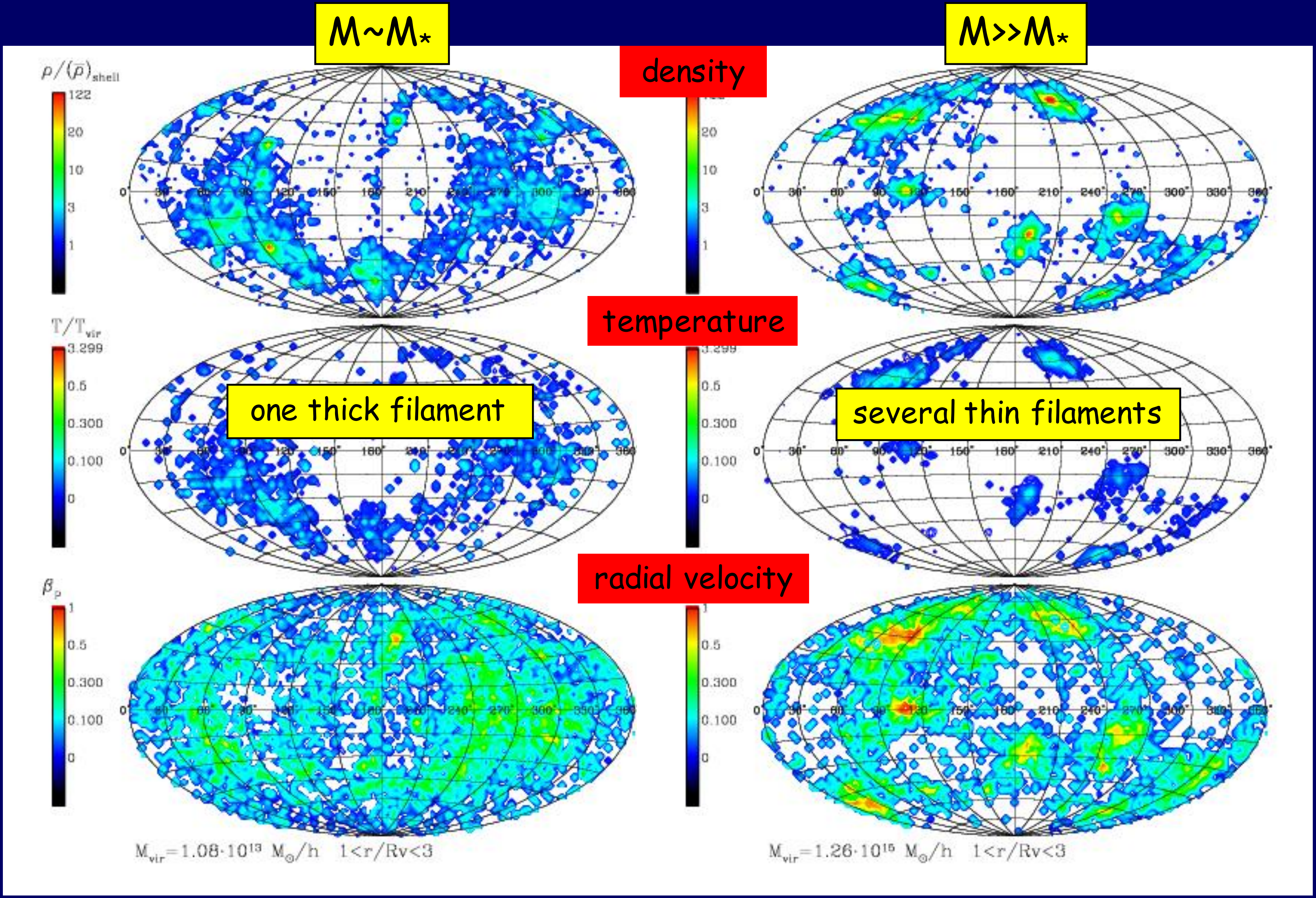
At high z, M_{shock} halos are high-σ peaks:
they are fed by a few thinner filaments
of higher density



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

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

Seleson & Dekel



M~M*

M>>M*

density

temperature

radial velocity

one thick filament

several thin filaments

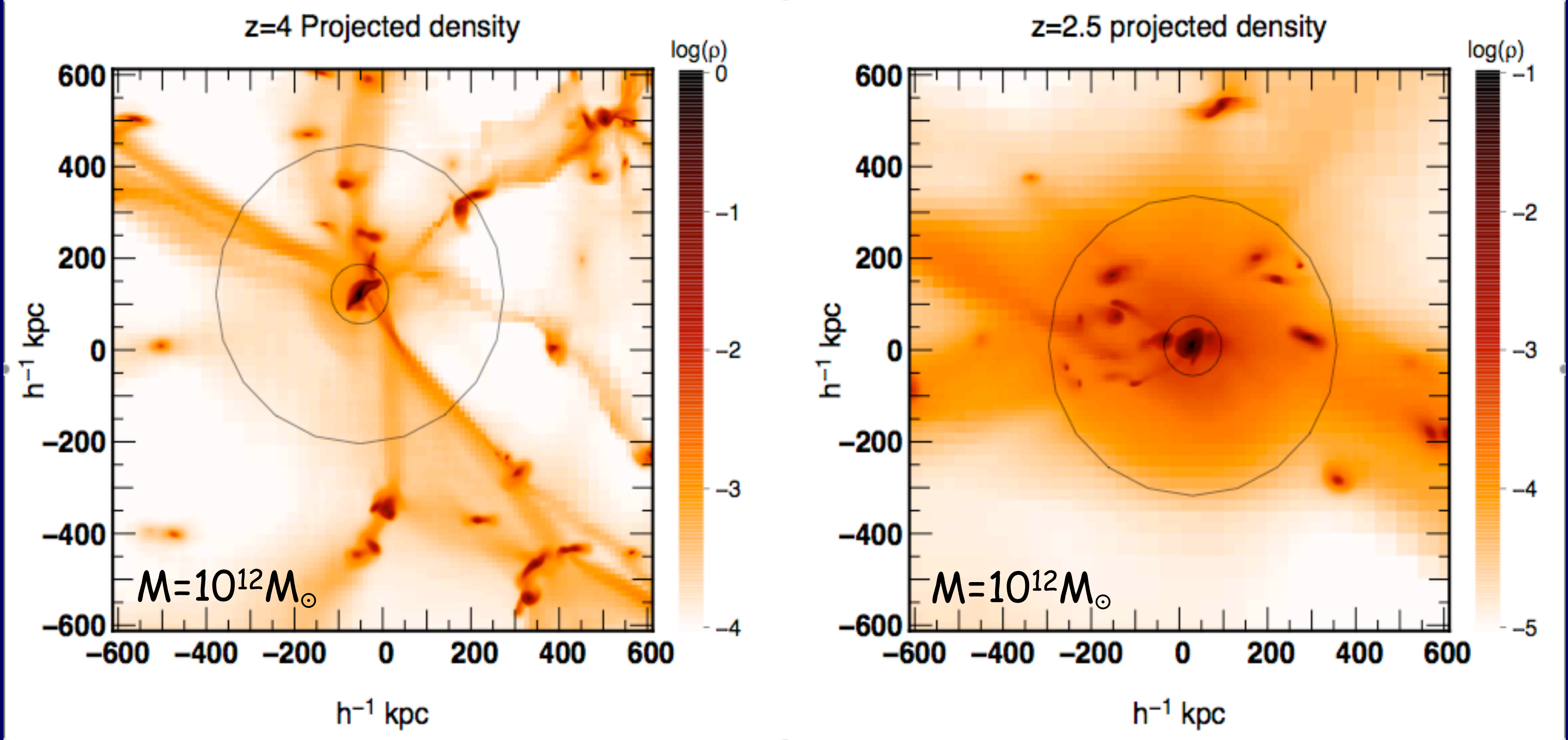
$M_{vir}=1.08\cdot10^{13}\ M_\odot/h \quad 1<r/Rv<3$

$M_{vir}=1.26\cdot10^{15}\ M_\odot/h \quad 1<r/Rv<3$

Gas Density in Massive Halos $2\times10^{12}M_\odot$

high z

low z

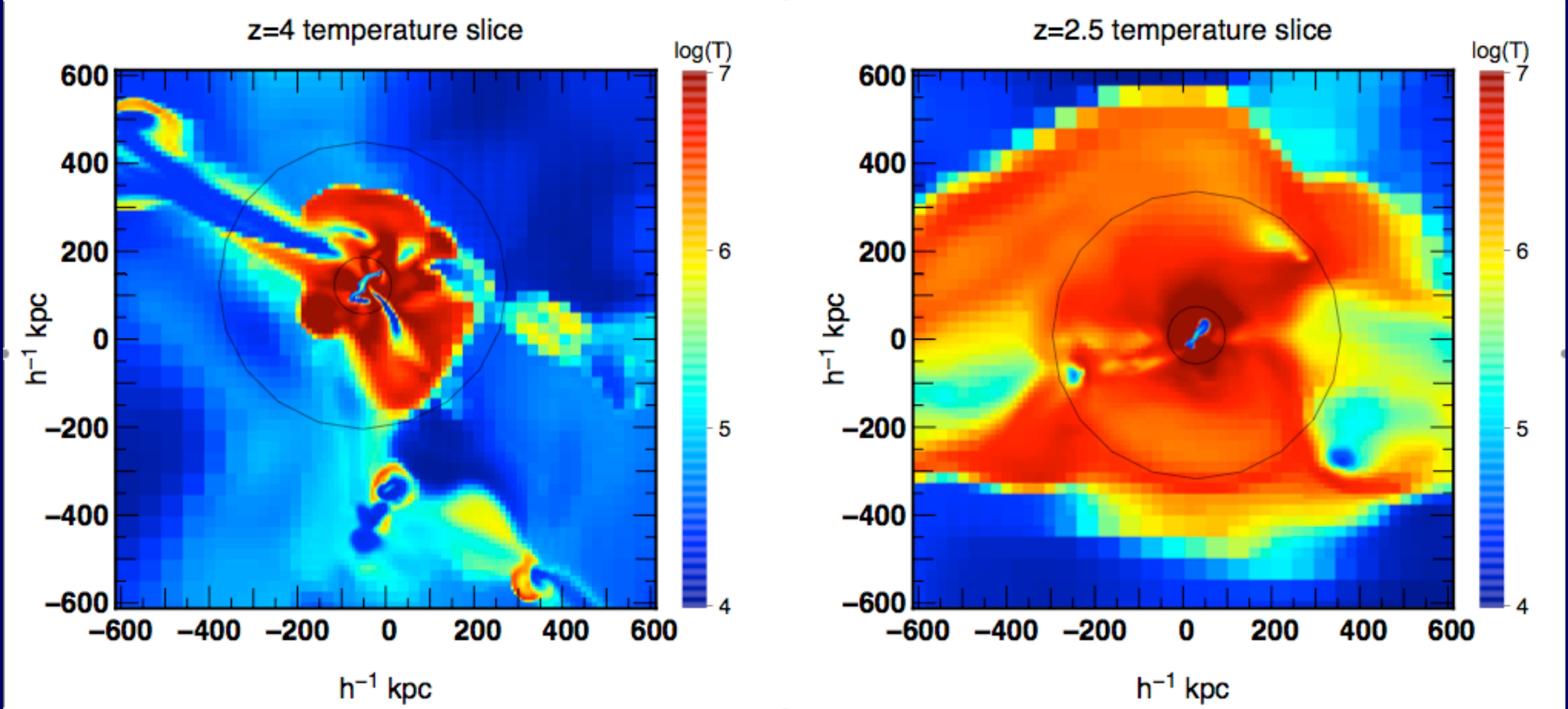


Ocvirk, Pichon, Teyssier 08

Temperature in Massive Halos $2\times10^{12}M_\odot$

high z

low z

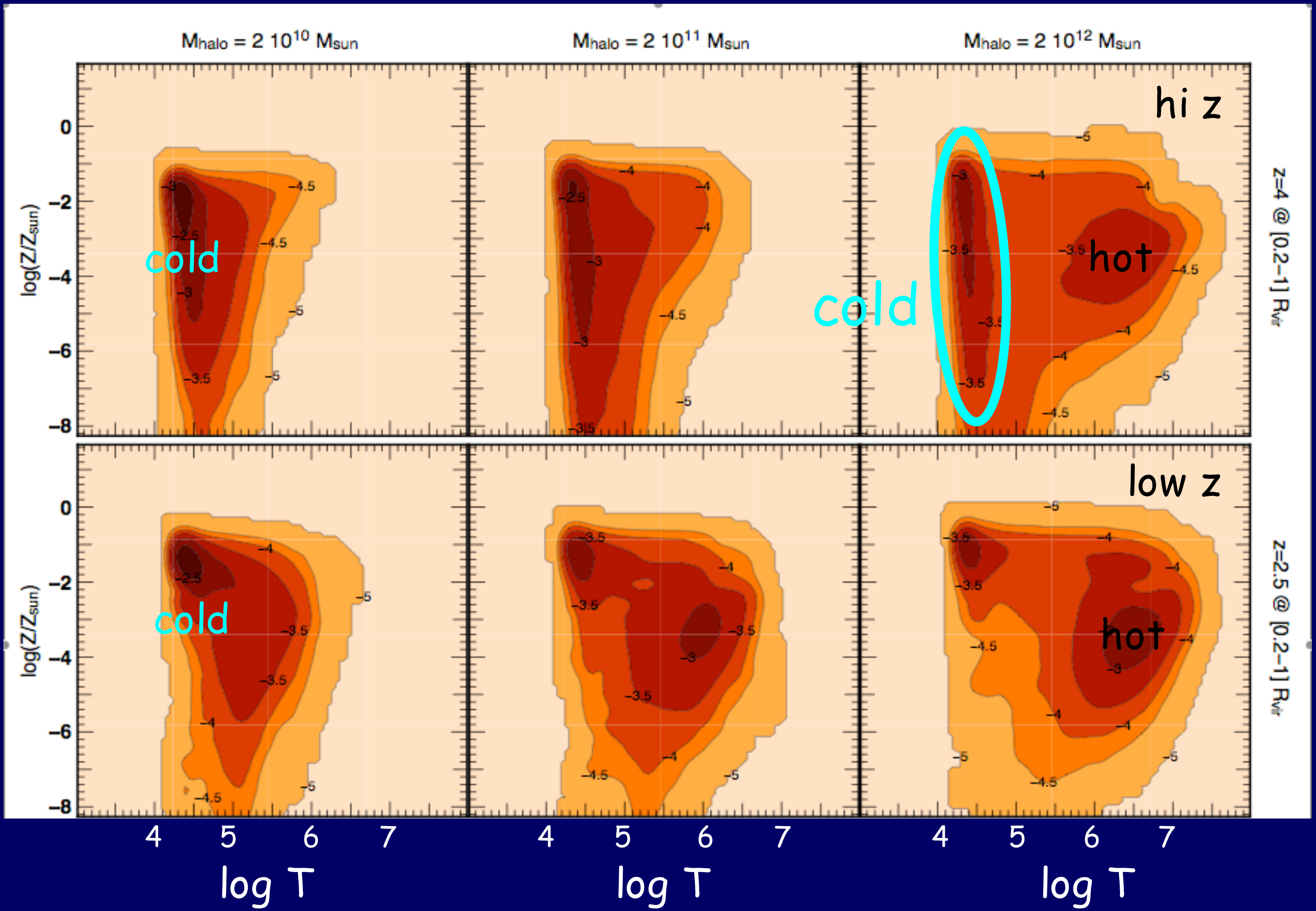


Ocvirk, Pichon, Teyssier 08

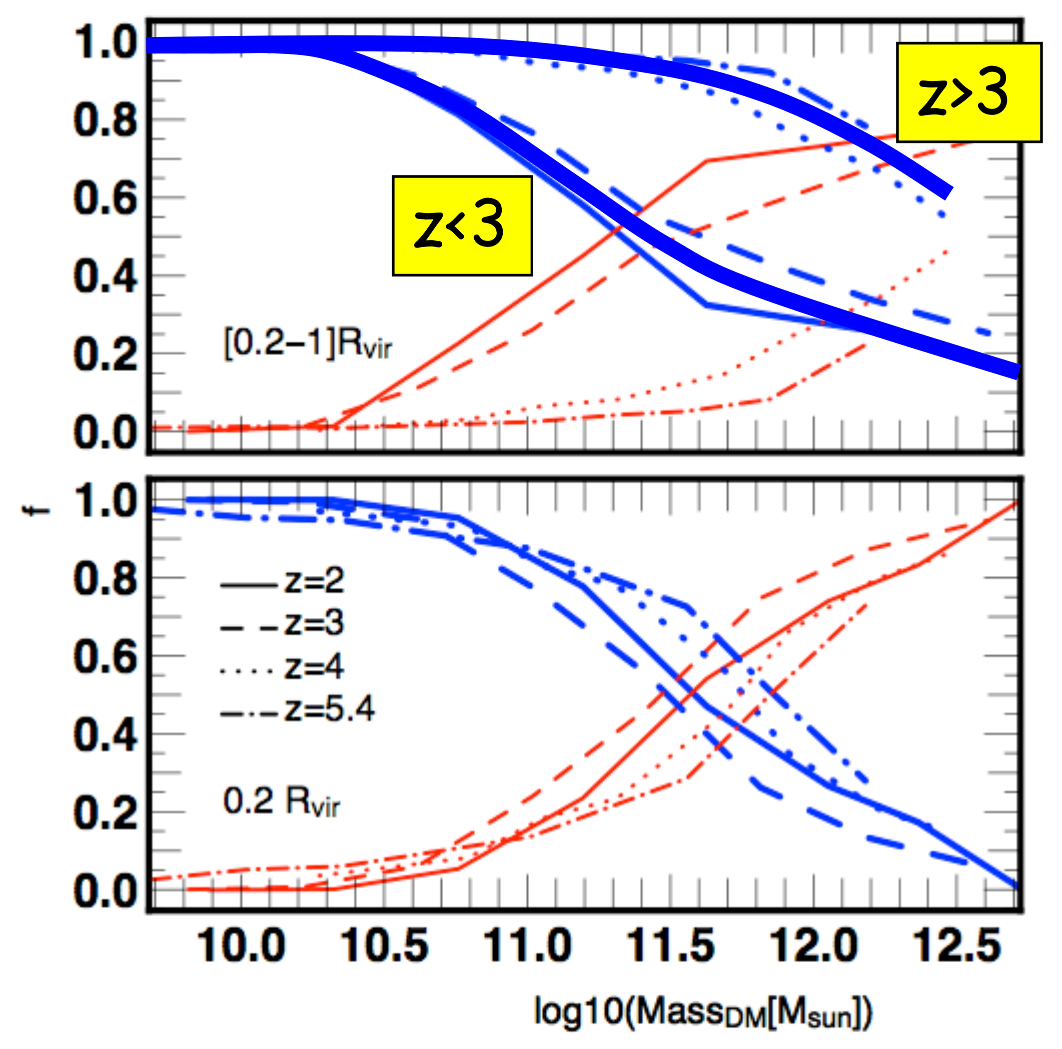
Flux Weighted Temperature Distribution

Halo Mass →

Ocvirk, Pichon, Teyssier 08



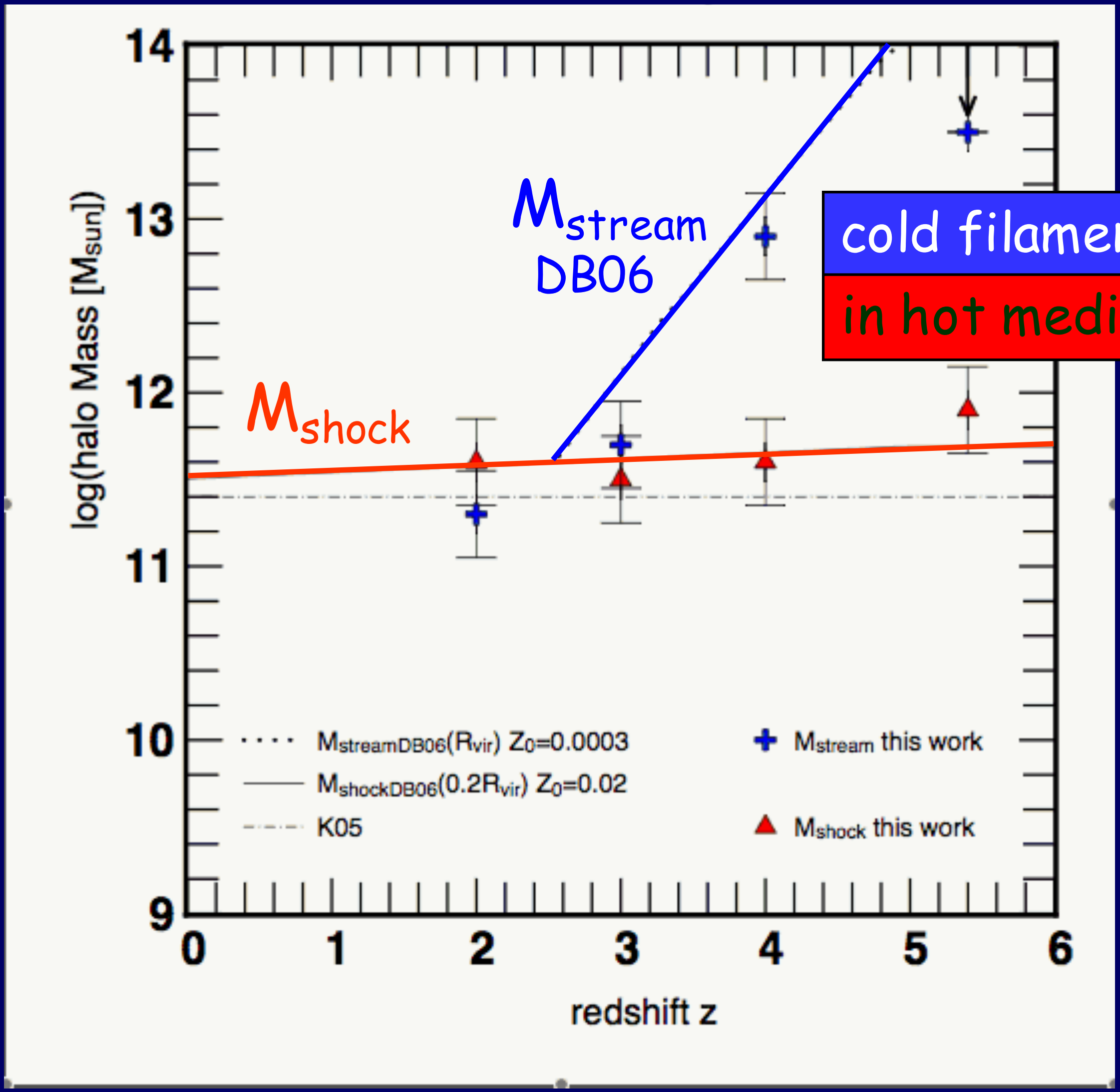
Cold Fraction of Inward Flux



Ocvirk, Pichon, Teyssier 08

Critical Mass in Cosmological Simulations

Ocvirk, Pichon, Teyssier 08



M_{stream} DB06

M_{shock}

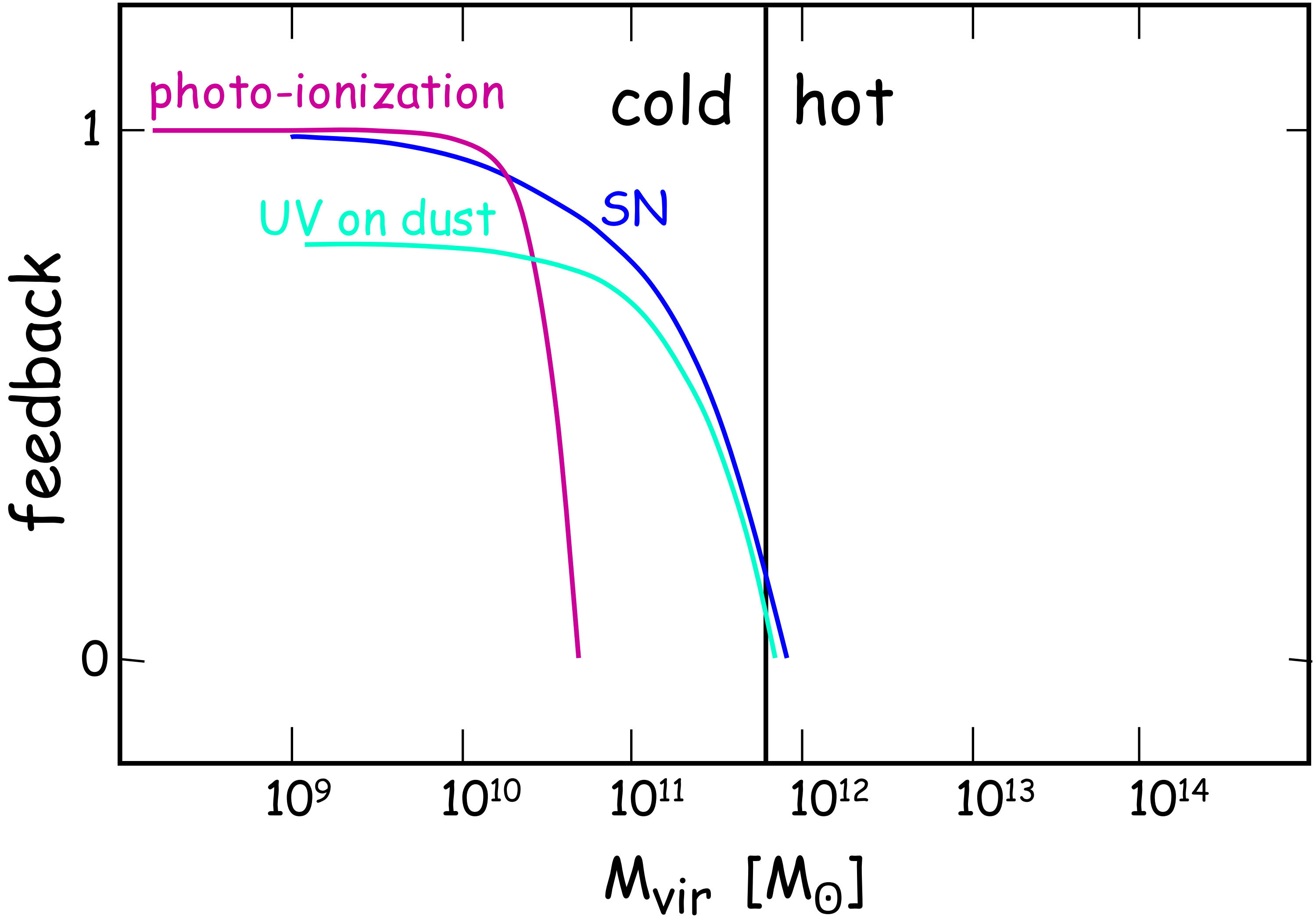
cold filaments

in hot medium

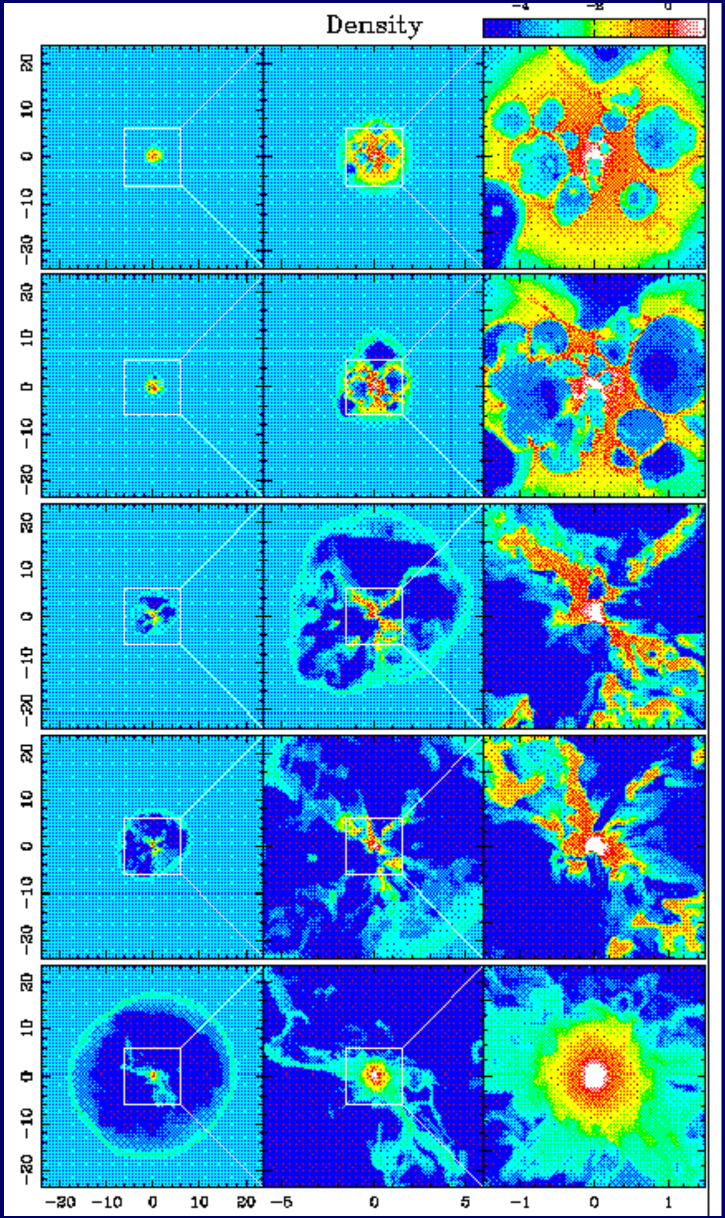
4. Feedback Processes

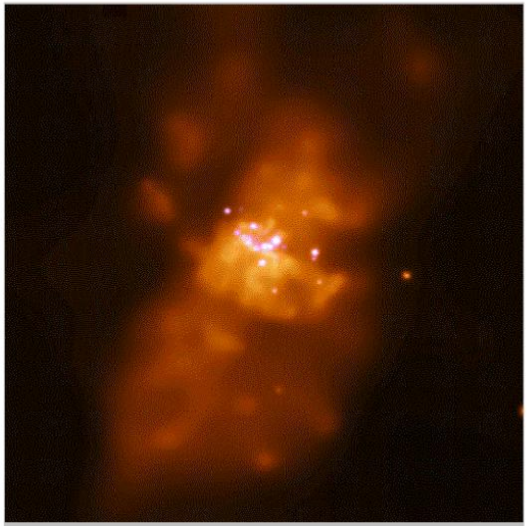
and the shock-heating scale

Below the Shock-Heating Mass



Supernova Feedback

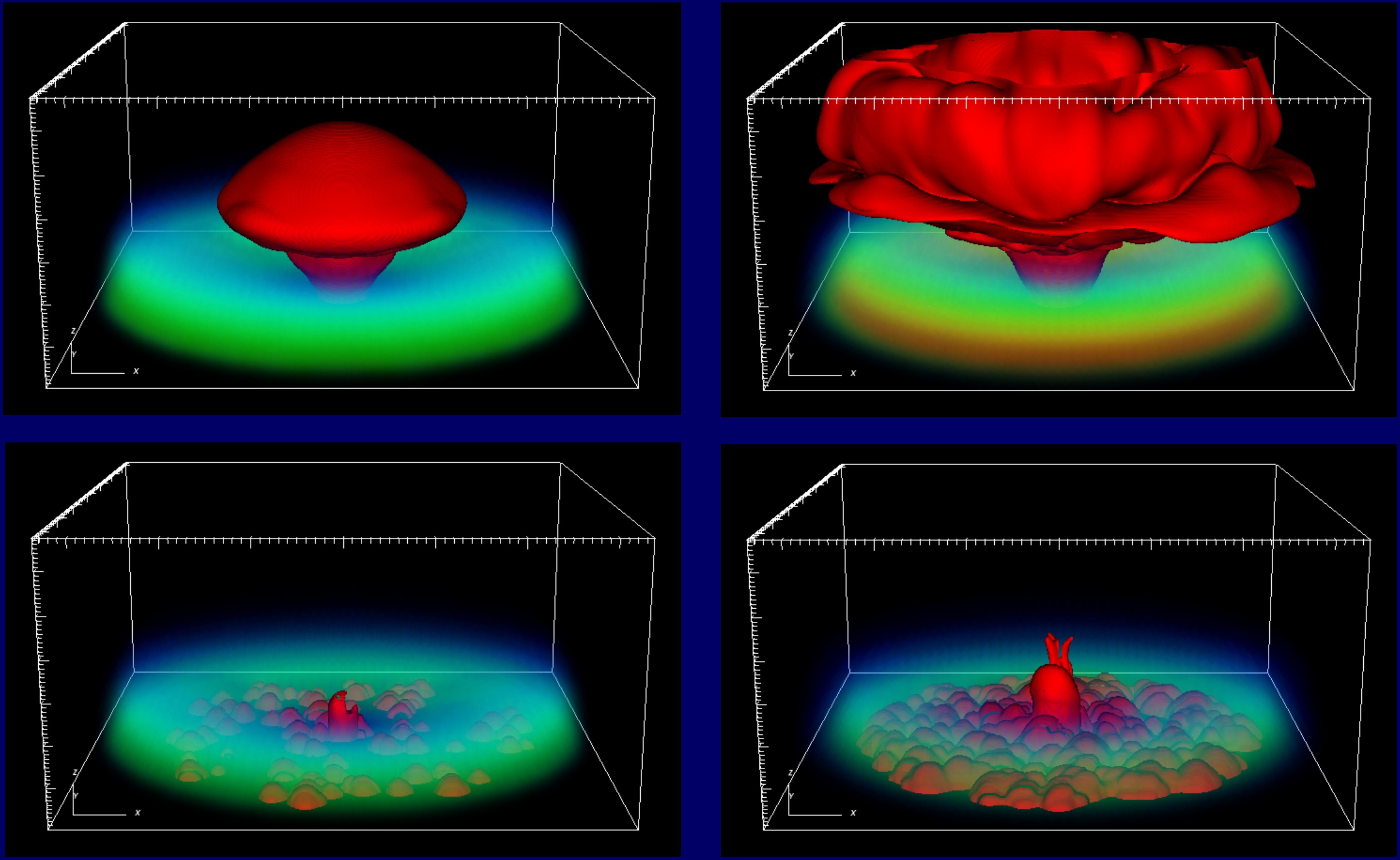




Chandra X-Ray Observatory image of M82

Mori et al.

Supernova Feedback



Fragile, Murray, Lin 04

Supernova Feedback Scale

(Dekel & Silk 86, Dekel & Woo 03)

Energy fed to the ISM during the “adiabatic” phase:

$$E_{\rm SN} \approx \nu\varepsilon \dot{M}_* t_{\rm rad} \quad \propto M_* (t_{\rm rad}/t_{\rm ff})$$

$$\dot{M}_* \approx M_*/t_{\rm ff}$$

≈ 0.01

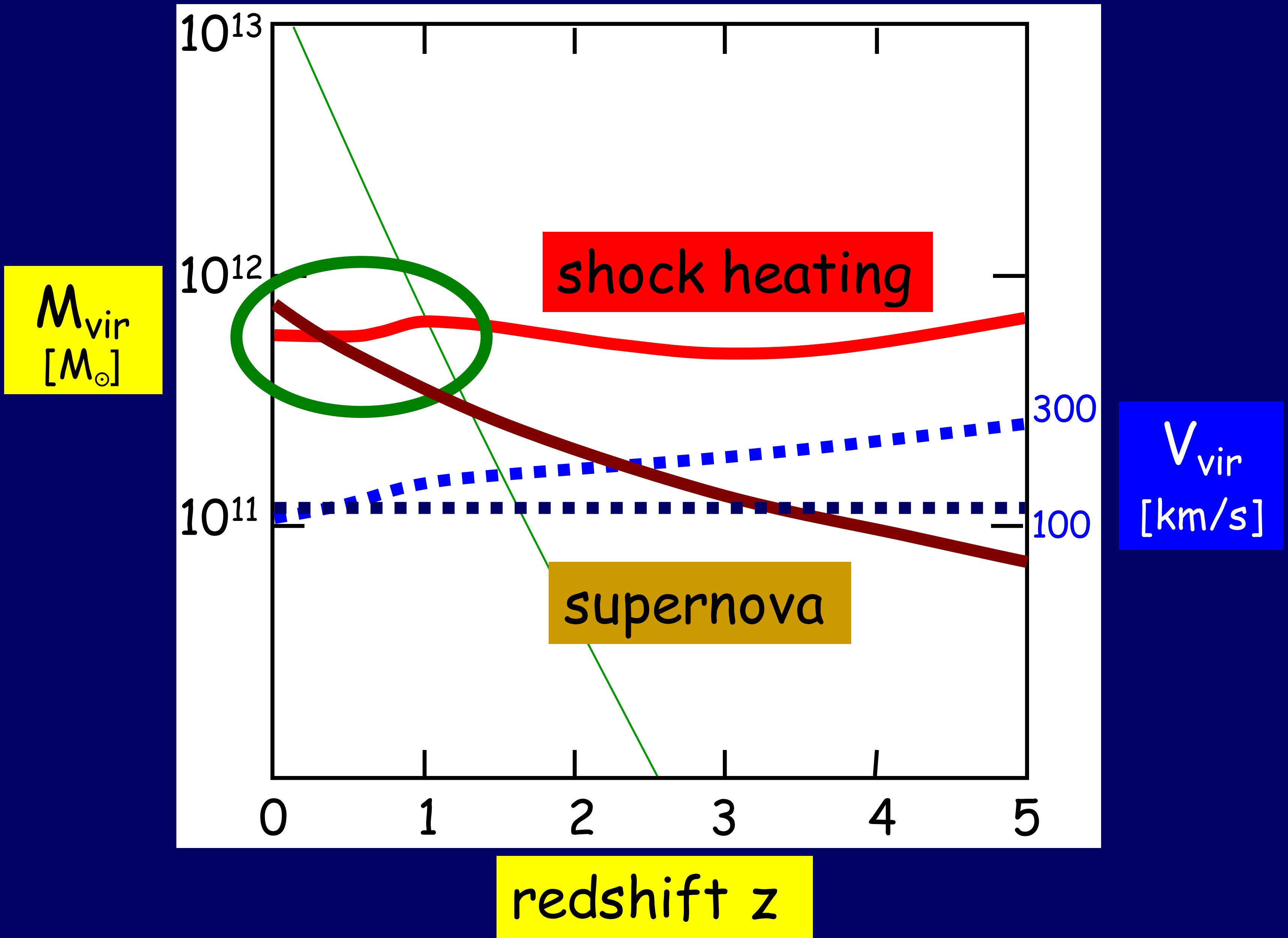
for $\Lambda \propto T^{-1}$ at $T \sim 10^5 K$

Energy required for blowout:

$$E_{\rm SN} \approx M_{\rm gas} V^2$$

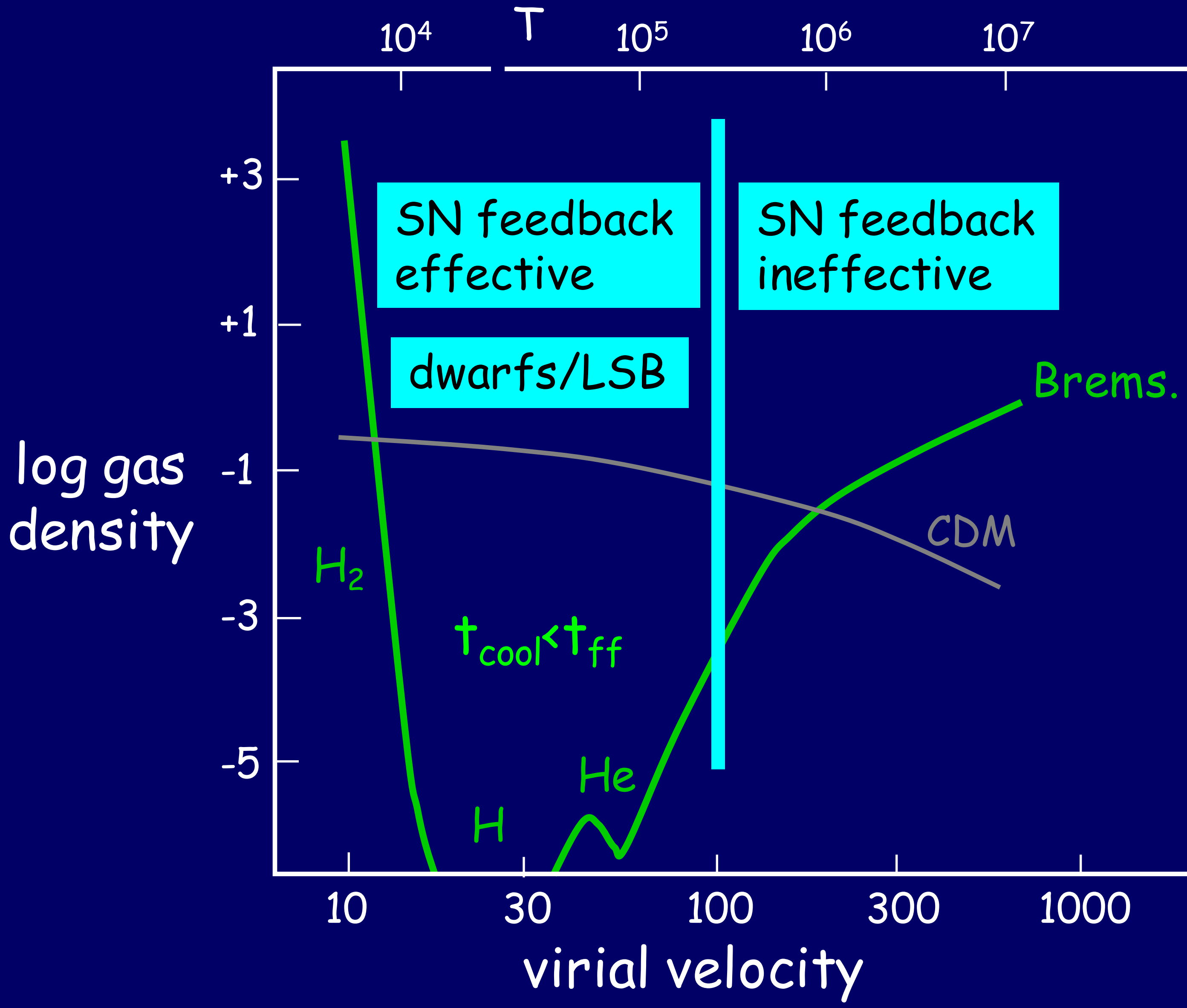
$$\rightarrow \quad V_{\rm crit} \approx 120 \ \ {\rm km/s} \quad \rightarrow \quad M_{\rm crit} \approx 7\times10^{11} M_\odot$$

Shock-Heating vs Supernova Scale



Supernova Feedback Scale

Dekel & Silk 86



Model: fundamental line of LSB/Dwarfs

(Dekel & Woo 03)

- Energy: $E_{\rm SN} \propto M_* \propto M_{gas} V^2$ $\longrightarrow$ $\boxed{M_* / M_{gas} \propto V^2}$

$<<1$

- Virial halo: $V^3 \propto M \propto R^3$

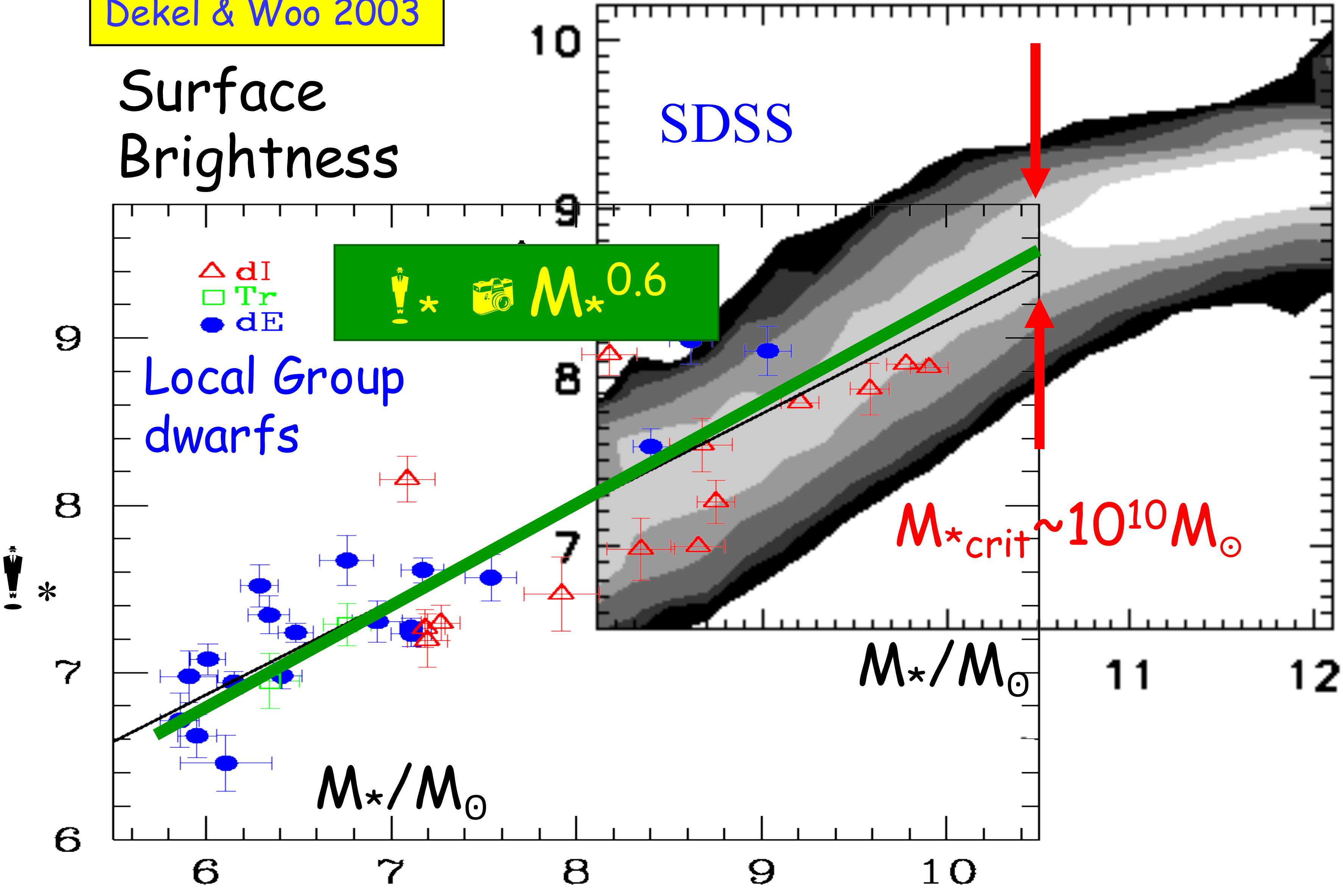
$\longrightarrow$ $\boxed{V \propto M_*^{1/5}}$ "Tully Fisher"

$Z \propto M_* / M_{gas}$ $\longrightarrow$ $\boxed{Z \propto M_*^{2/5}}$ metallicity

$R_* \approx \lambda R$ $\longrightarrow$ $\boxed{\mu \propto \lambda^{-2} M_*^{3/5}}$ surface brightness

“Fundamental Line” of LSB/Dwarfs

Dekel & Woo 2003



Surface Brightness

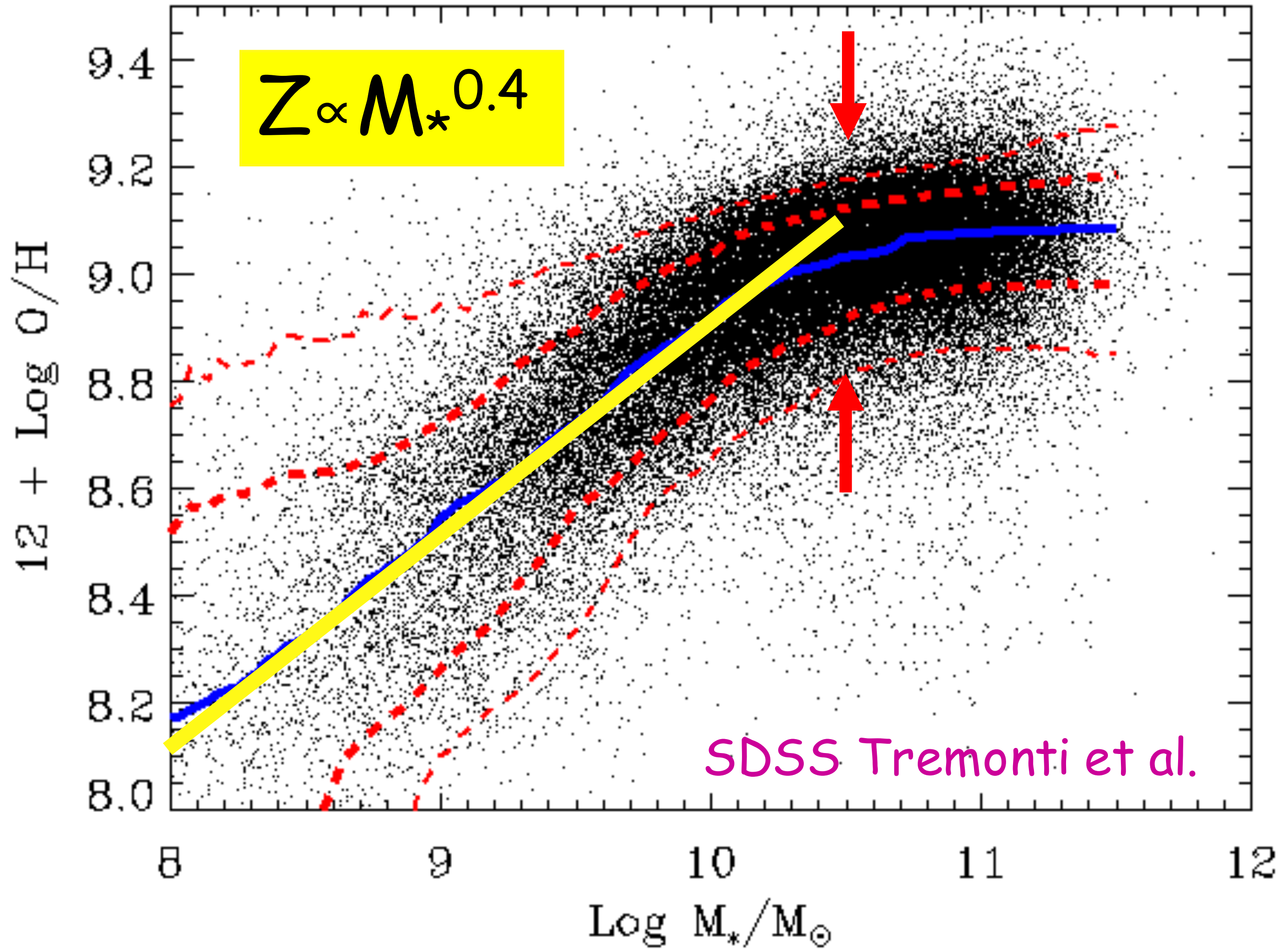
SDSS

Local Group dwarfs

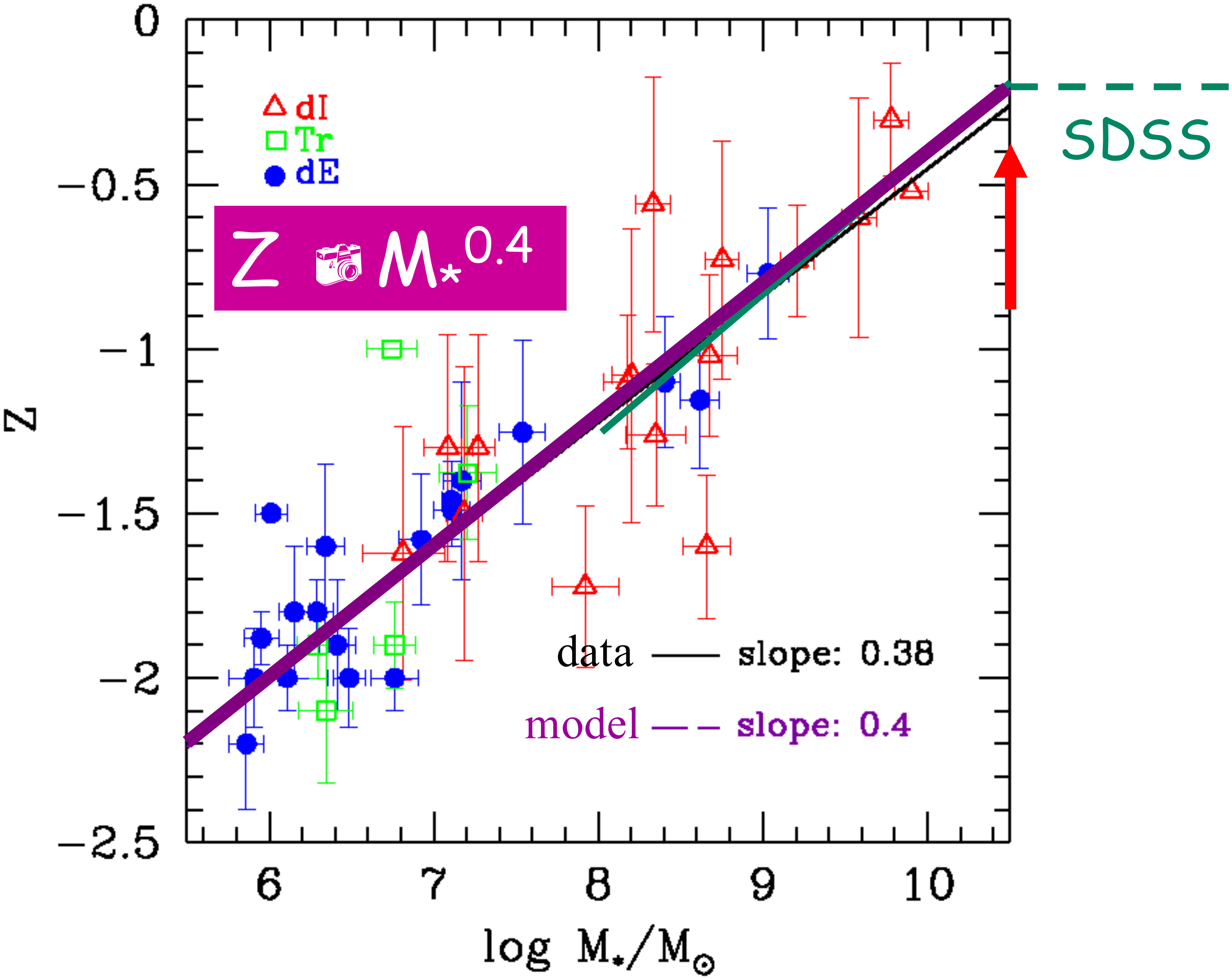
$\mu_* \propto M_*^{0.6}$

$M_{*crit} \sim 10^{10} M_\odot$

Metallicity

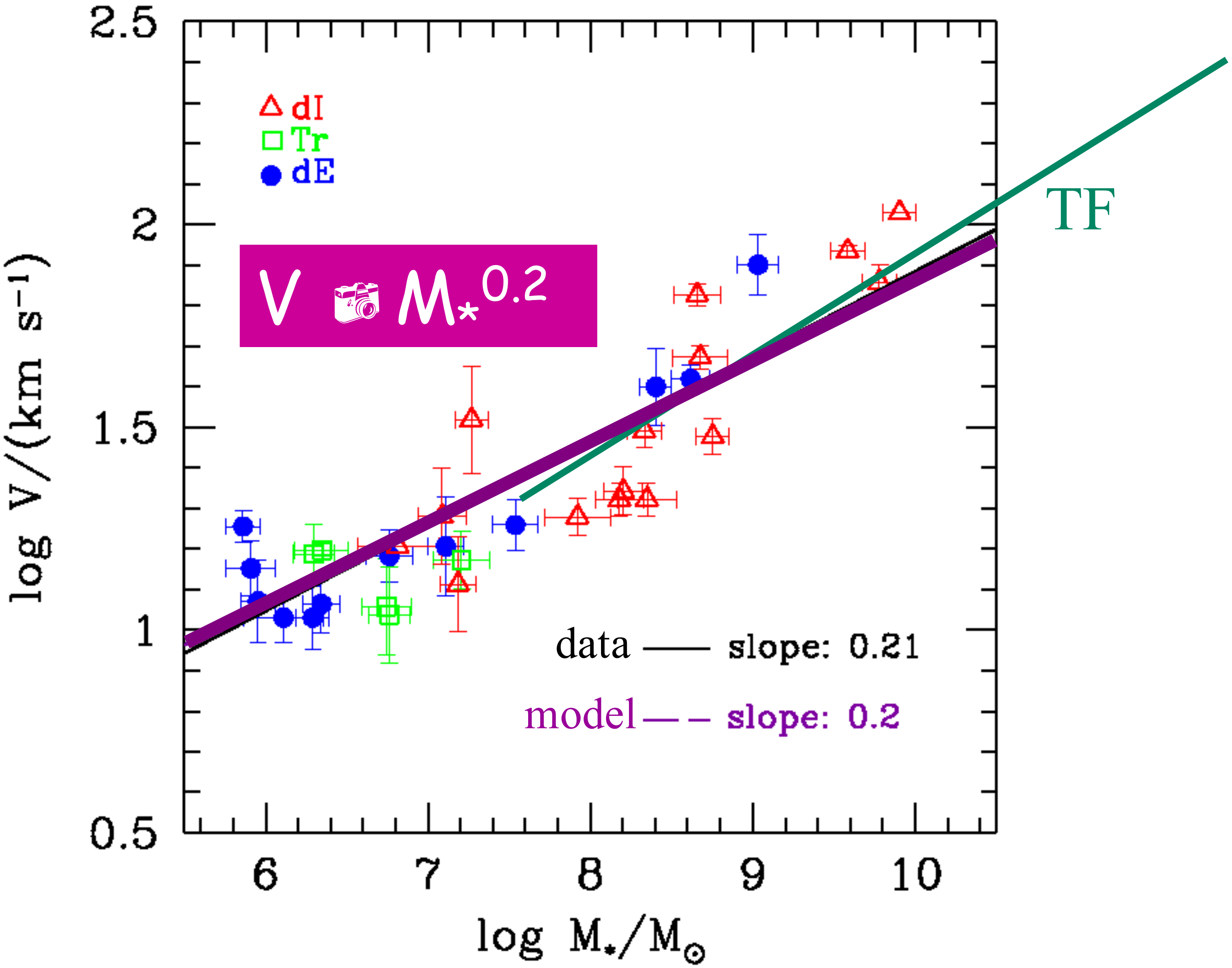


Local Group Dwarfs: Metallicity



Z 📷 $M_*^{0.4}$

LG Dwarfs: Velocity



V 📷 $M_*^{0.2}$

Summary: SN feedback

Could be partly responsible for the transition scale at $M_*=3\times10^{10}$, and the "fundamental line" of LSB/dwarf galaxies, $M^*/M \propto V^2$.

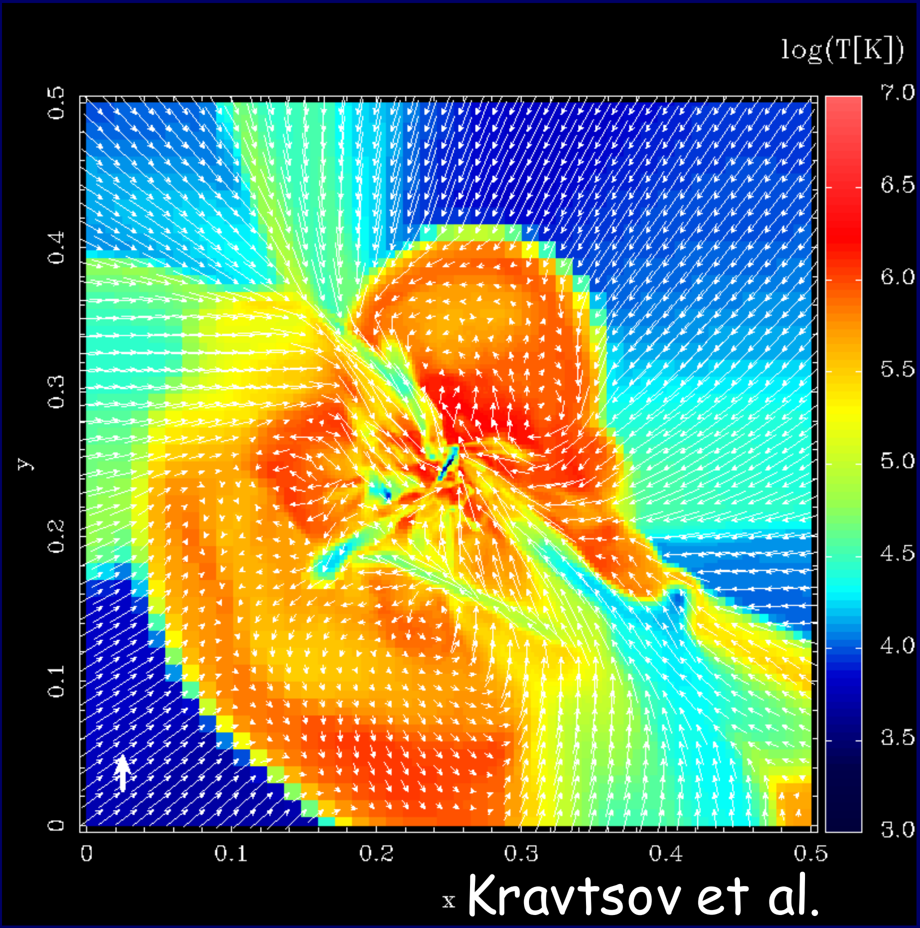
Shock Heating Triggers AGN Feedback

$M > M_{shock}$

More than enough energy is available in AGNs

Hot gas is vulnerable to AGN feedback, while cold streams are shielded

→Shock heating is the trigger for AGN feedback in massive halos

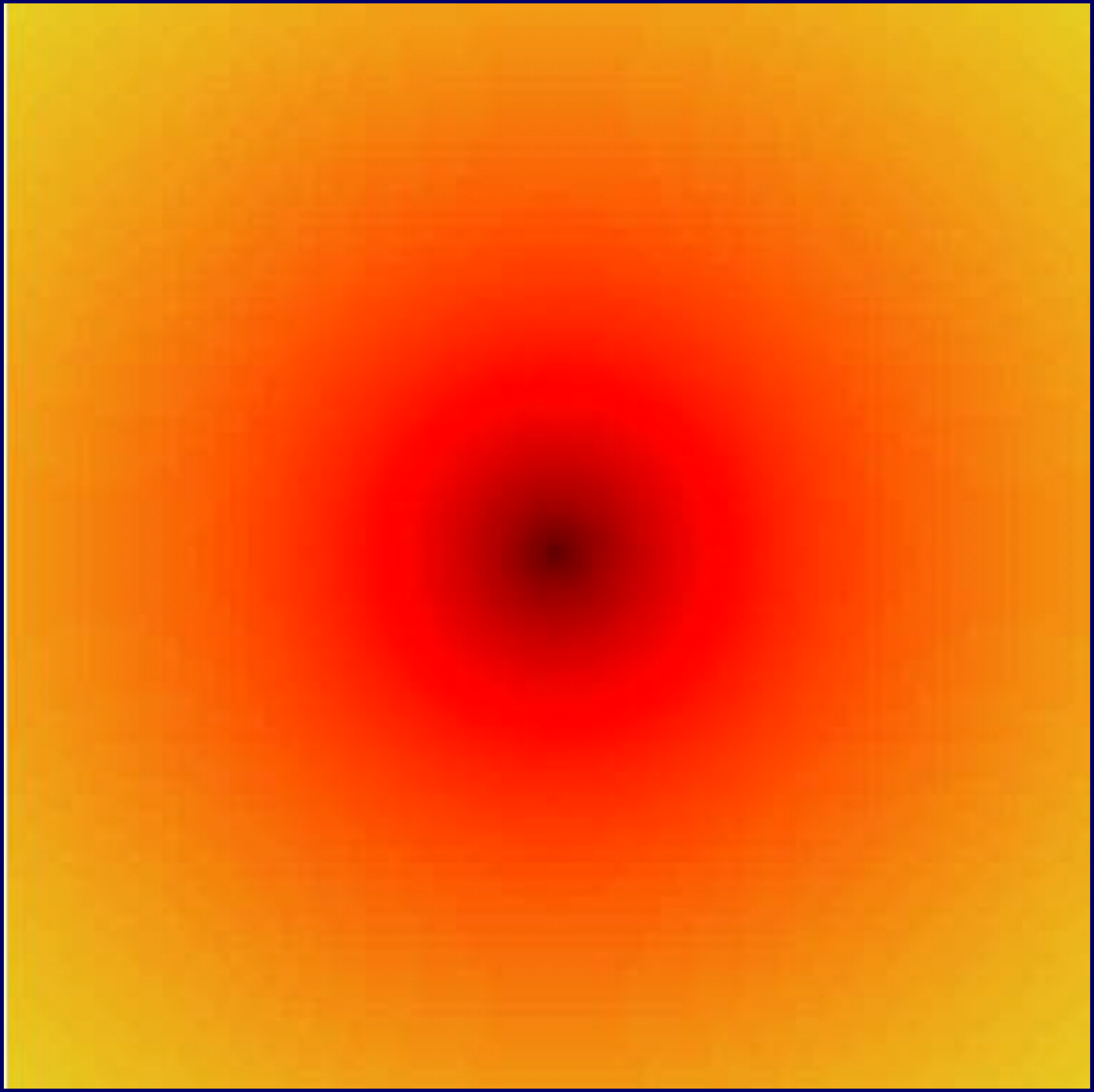


Kravtsov et al.

AGN Feedback in Perseus

Fabian et al.

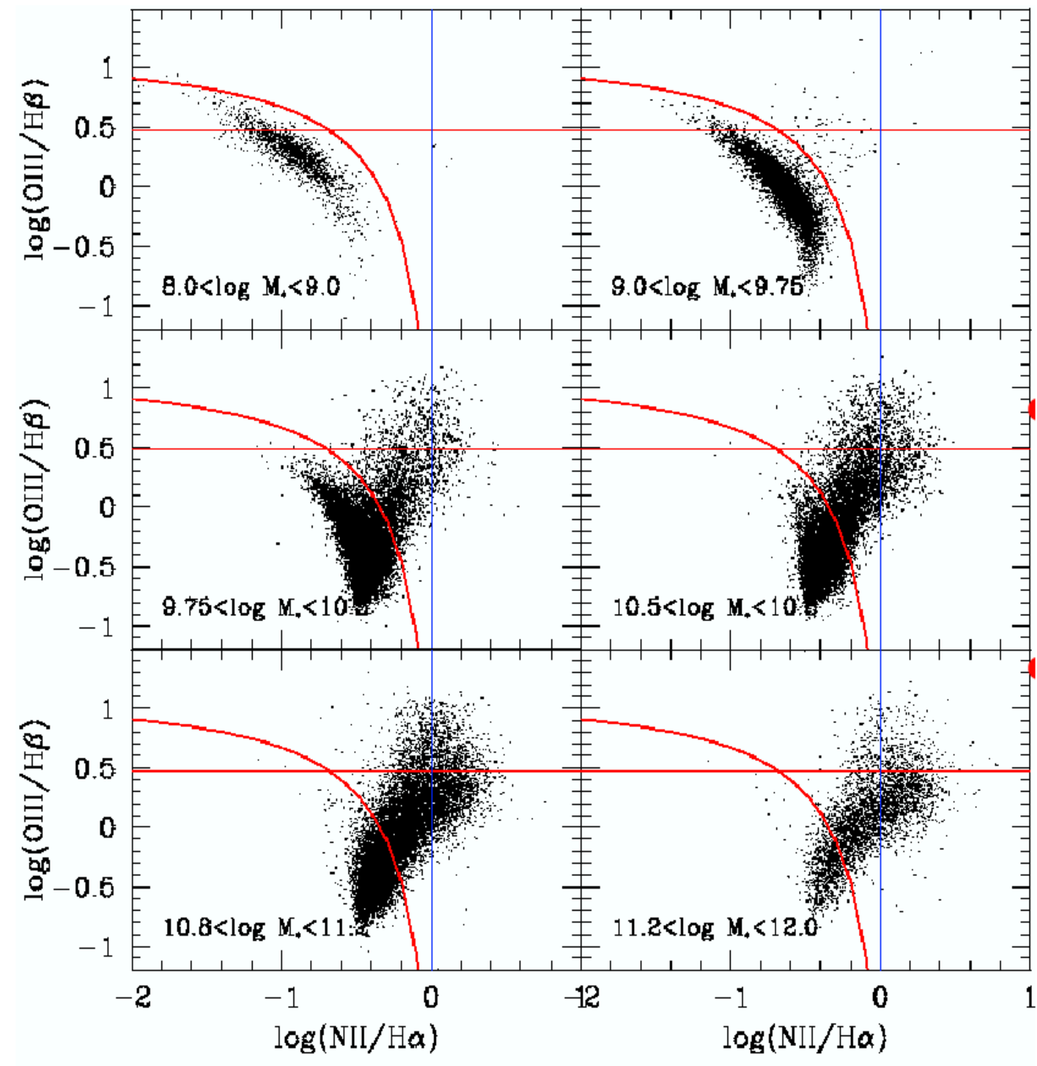
AGN Feedback



Ruszkowski,
Bruggen,
Begelman 03

jets - very hot bubbles - buoyancy - horizontal spread

Emission Properties vs. Stellar Mass

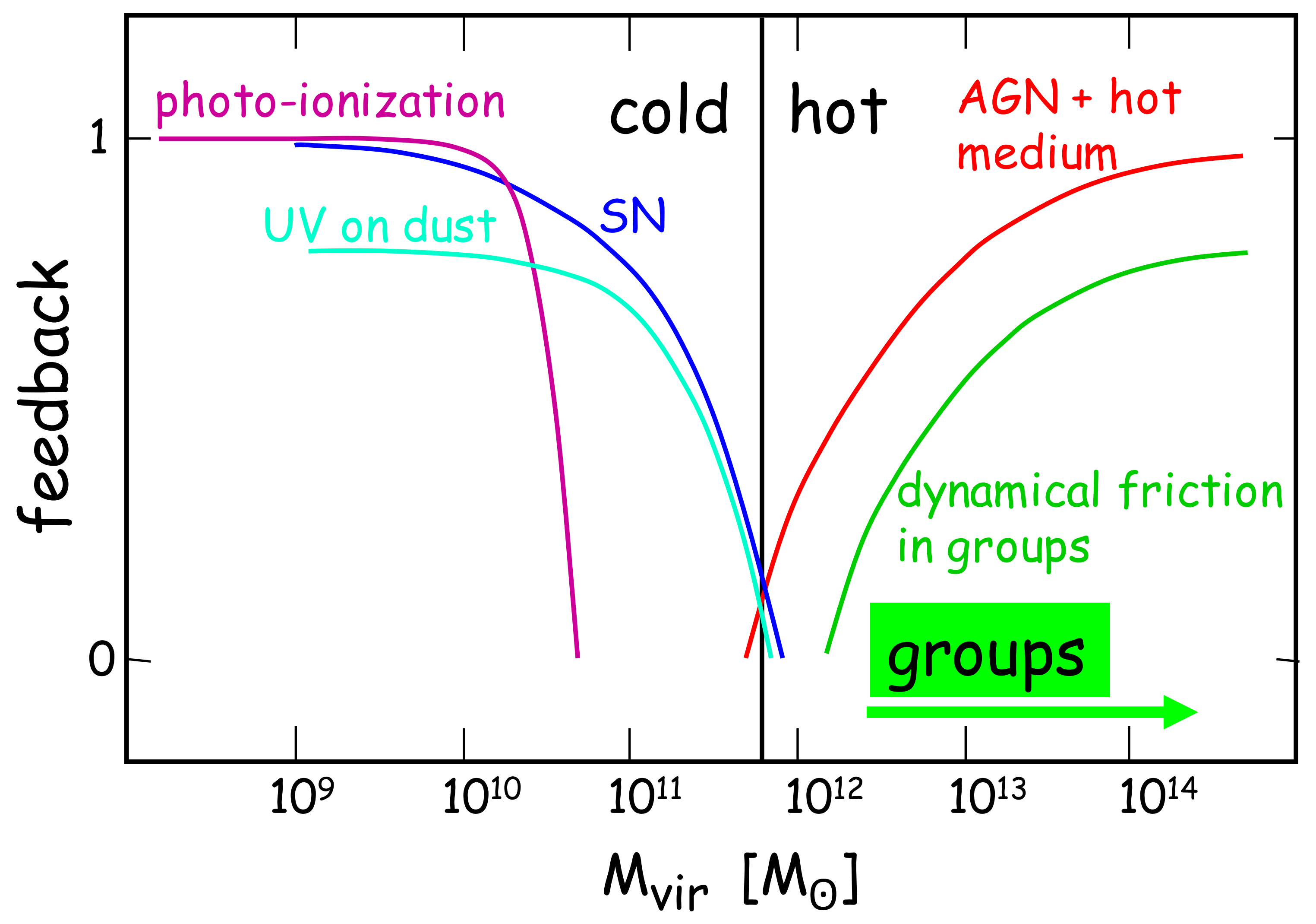


low-mass emission galaxies are almost all star formers

high-mass emission galaxies are almost all AGN

Kauffmann et al. 2004

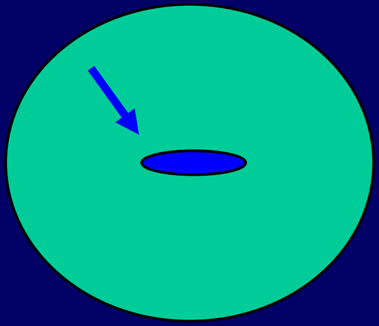
Above the Shock-Heating Mass



Dynamical-Friction Heating

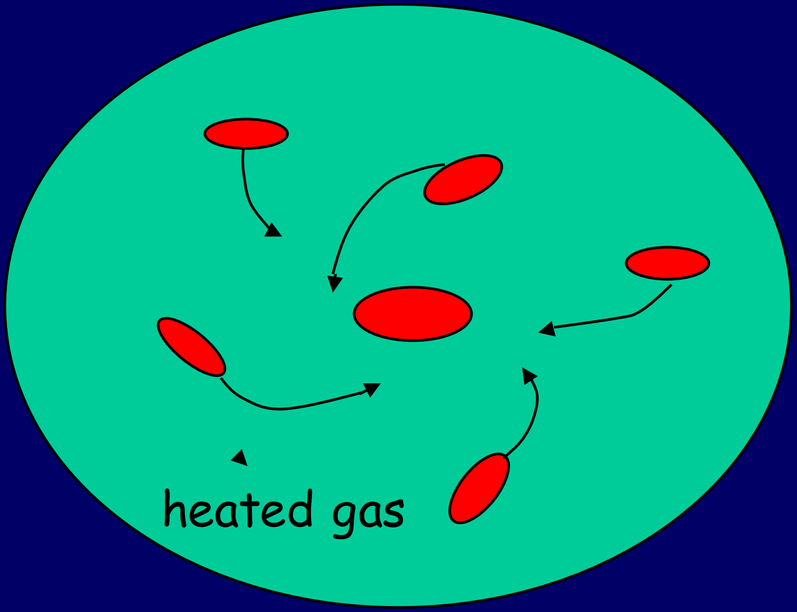
- $M < M_{crit} \rightarrow$ cold flows
- a single-galaxy halo

→ no effect



- $M > M_{crit} \rightarrow$ hot gas
- a multi-galaxy halo

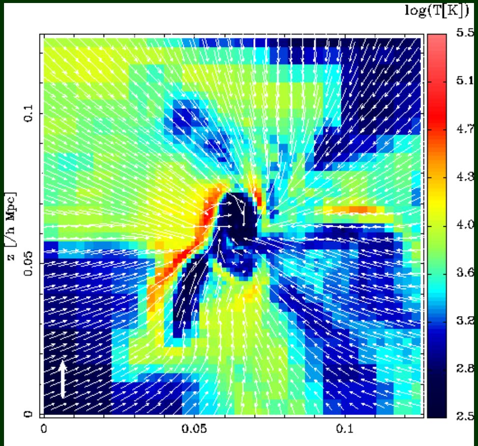
→ dynamical-friction heating of hot gas

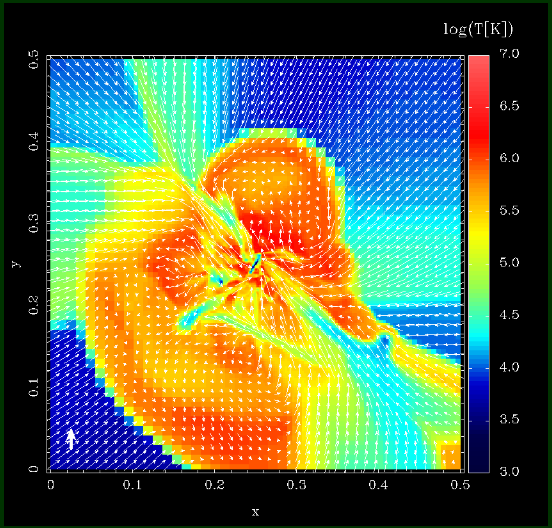


El-Zant, Kim, Kamionkowski 04

5. Origin of the Bi-modality

Dekel & Birnboim 04



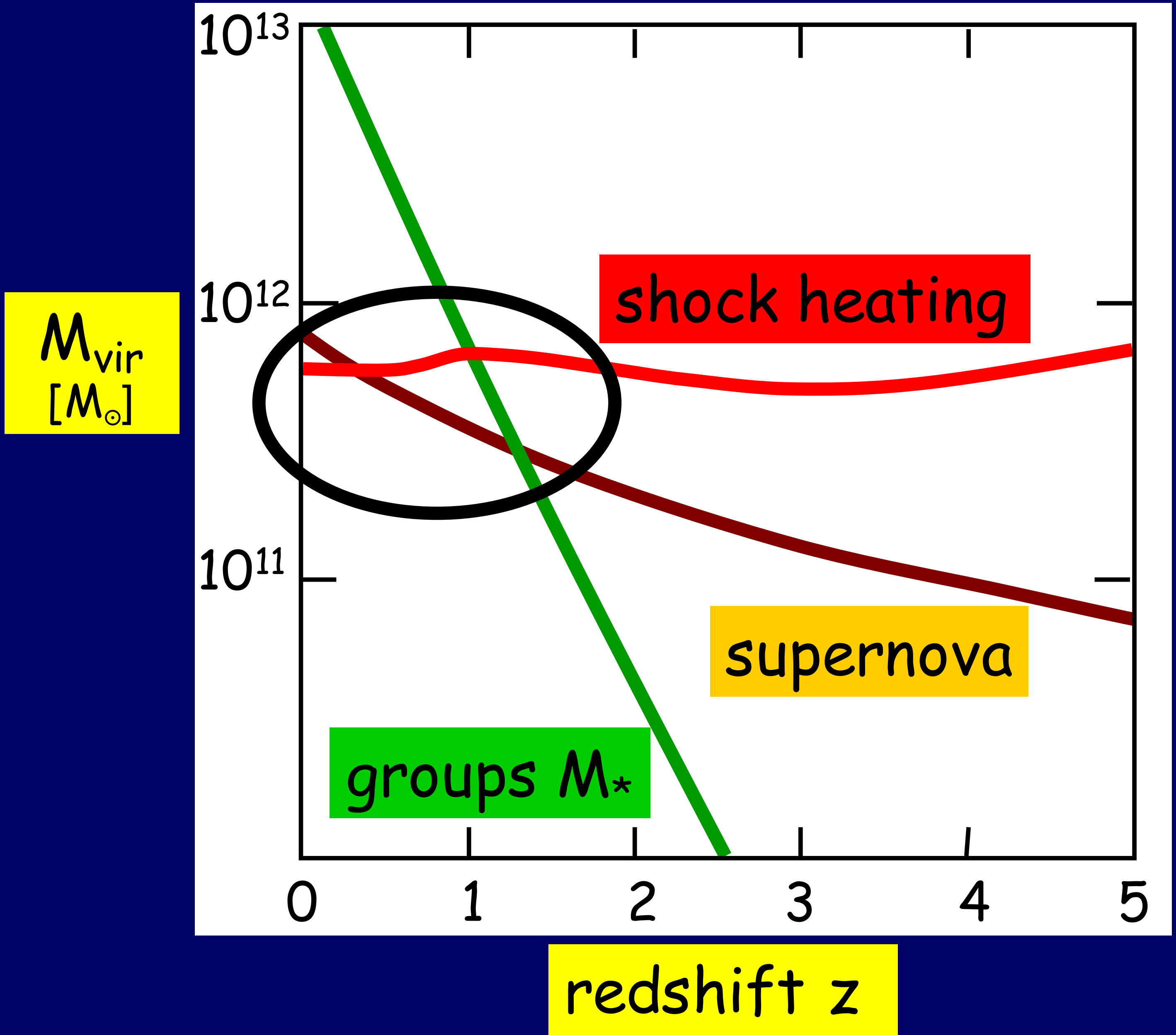


cold vs hot

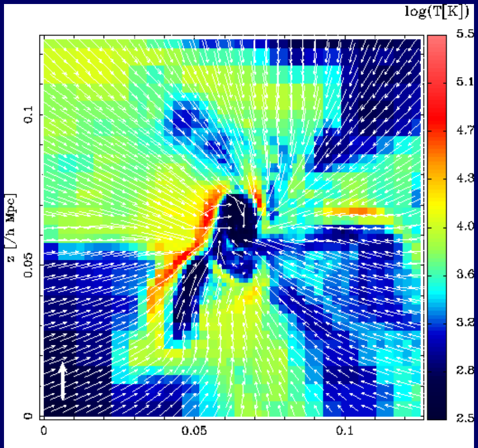
ungrouped vs grouped

SN feedback vs AGN feedback

Scales Roughly Coincide



Key Ideas:



Cold flows → star burst

supersonic stream collides with disk

efficient cooling behind isothermal shock

→ dense, cold slab → star burst

Hot medium → halt star formation

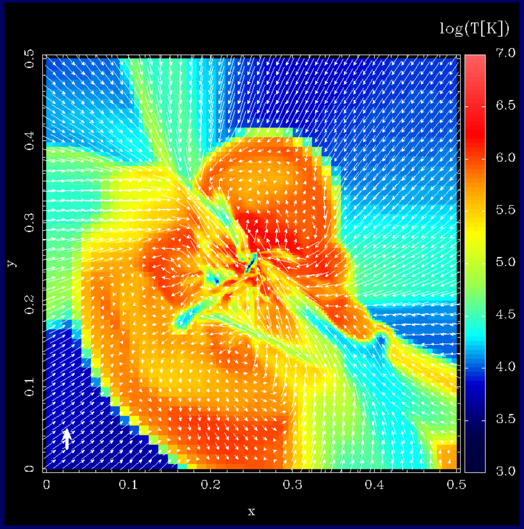
dilute medium vulnerable to AGN fdbk

+ slow cooling because of two-phase medium

+ dynamical-friction in hot groups

→ shock-heated gas never cools

→ shut down disk and star formation



Origin of bi-modality

While halos grow by mergers and accretion

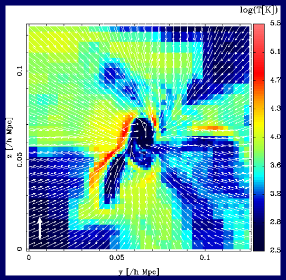
$M<M_{crit}$: The Blue Sequence

cold gas supply → disk growth & star formation

SN-**fdbk** regulates star formation →long duration

bursts → very blue

mergers & bar instability → bulges



$M>M_{crit}$: The Red Sequence

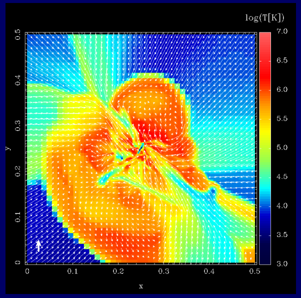
shock-heated gas +AGN fdbk → no new gas supply

+gas exhausted + AGNs especially in bulges

→ no disk growth, star formation shuts off

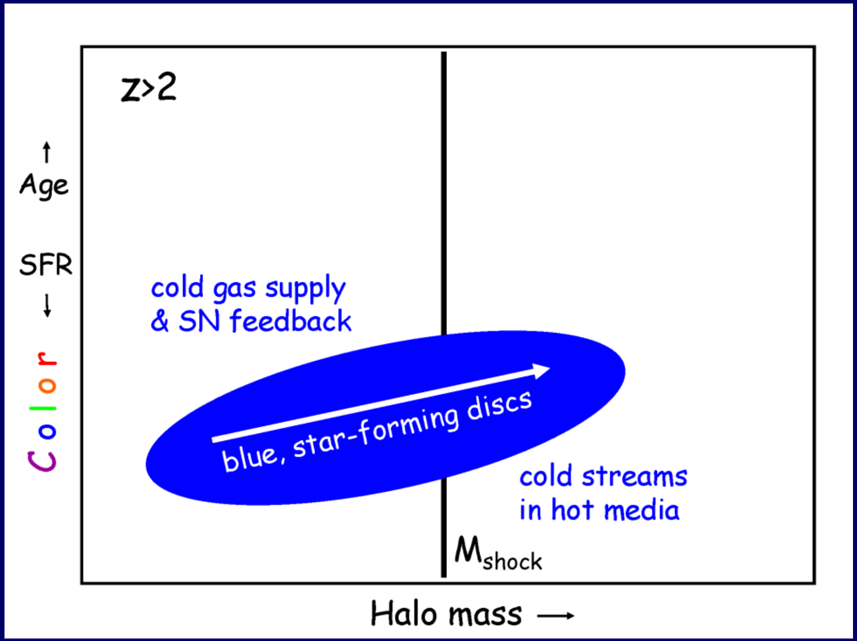
passive stellar evolution → red & dead

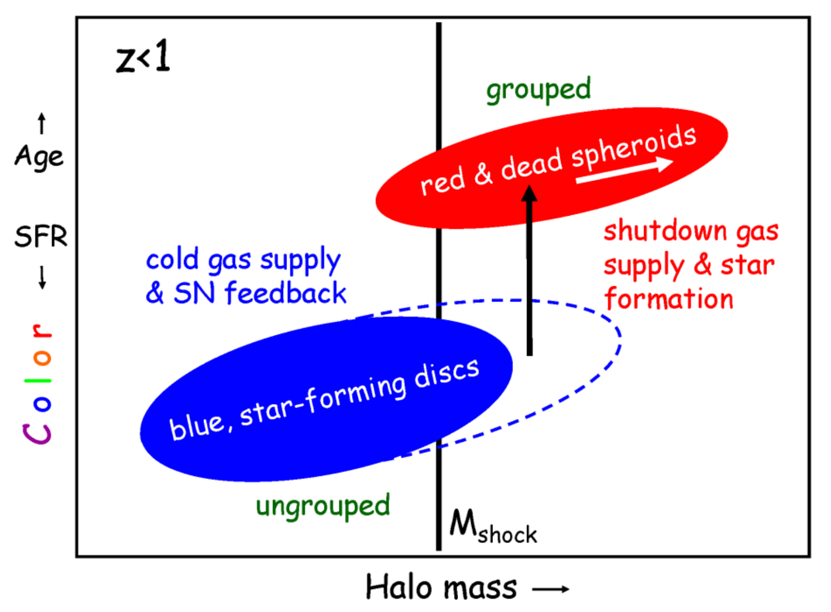
further growth of spheroids by gas-poor mergers

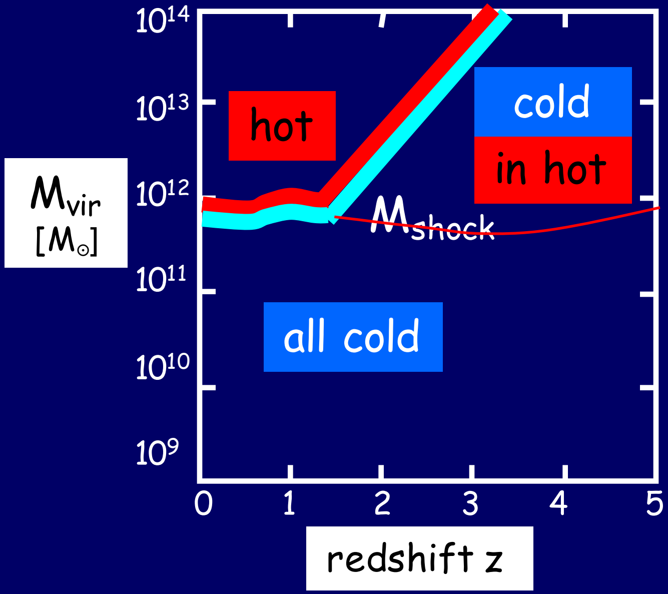


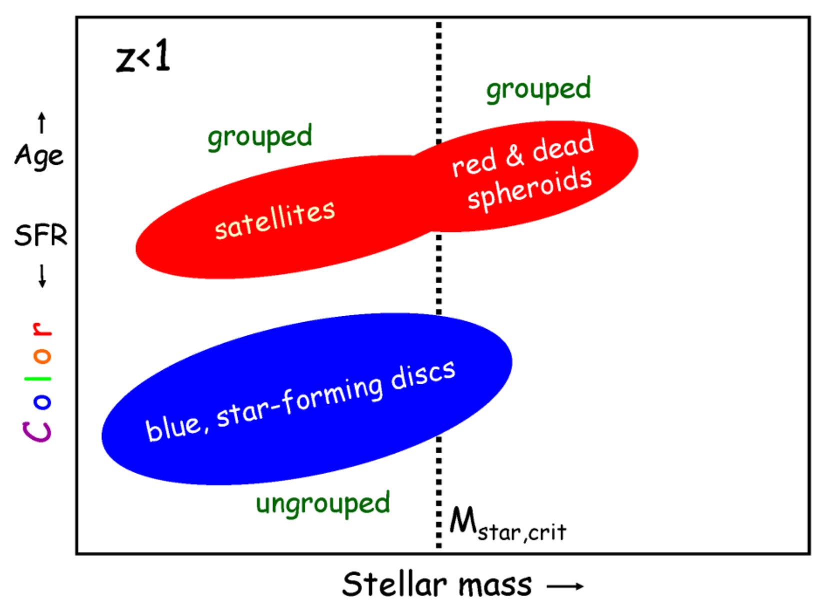
Shutdown above a critical halo mass does wonders

From blue to red sequence by shutdown Dekel & Birnboim 06







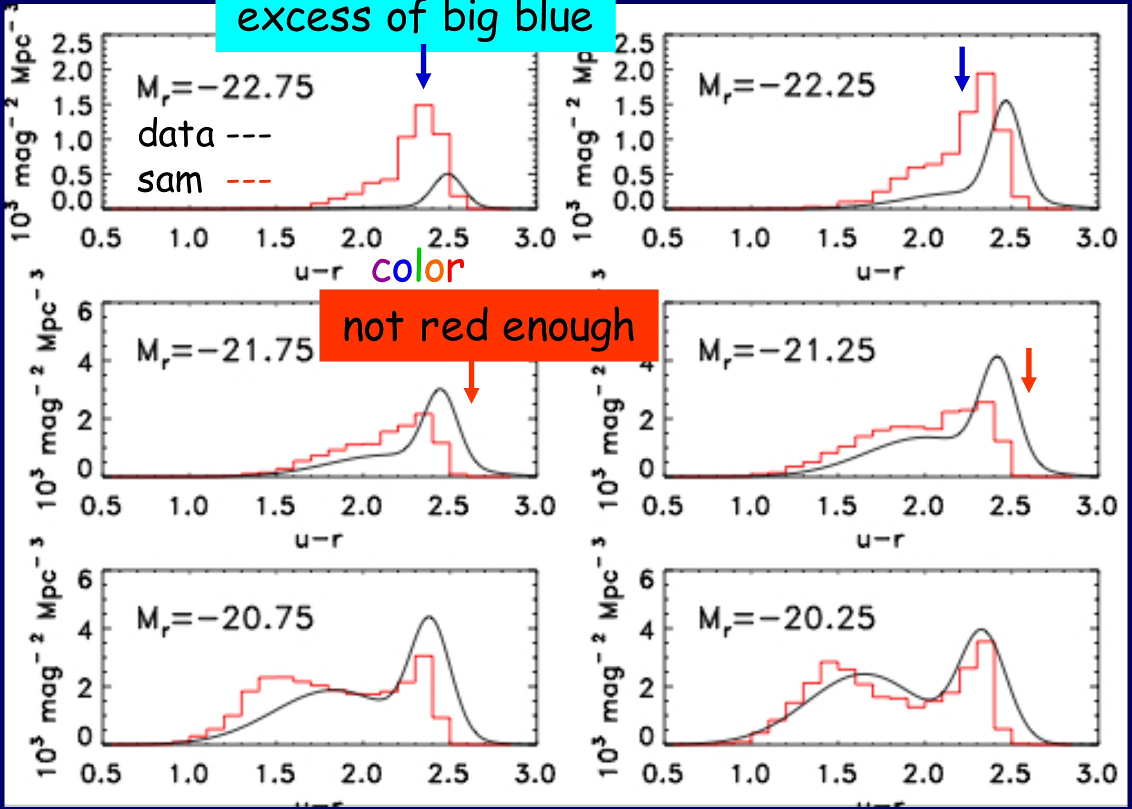


In a standard Semi Analytic Simulation (GalICS)

Cattaneo, Dekel, Devriendt, Guiderdoni, Blaizot 06

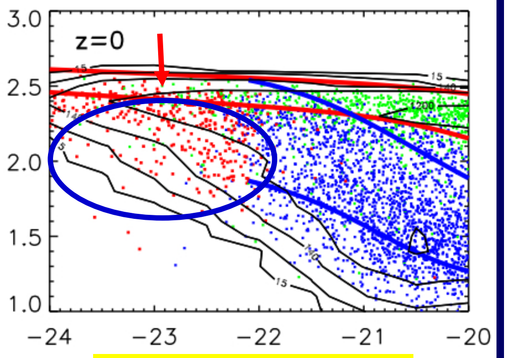
z=0

excess of big blue



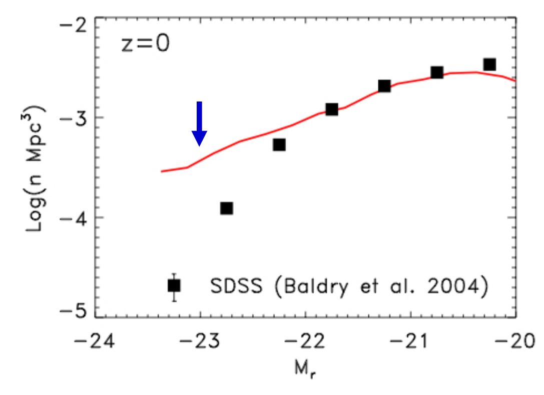
color

not red enough

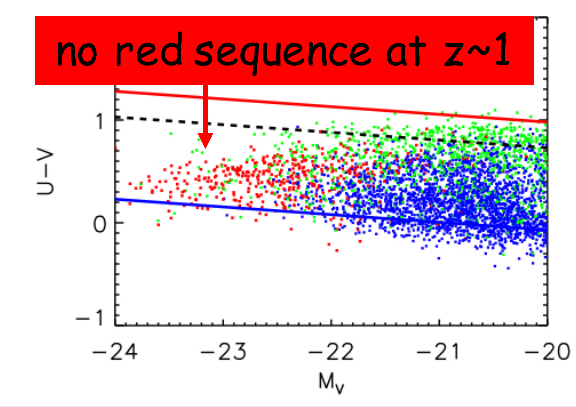


color u-r

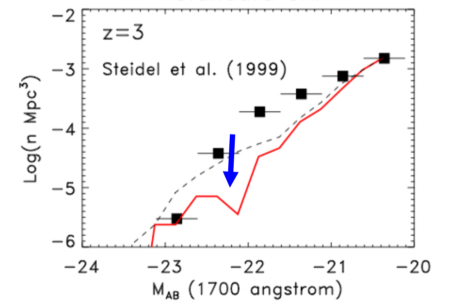
magnitude M_r



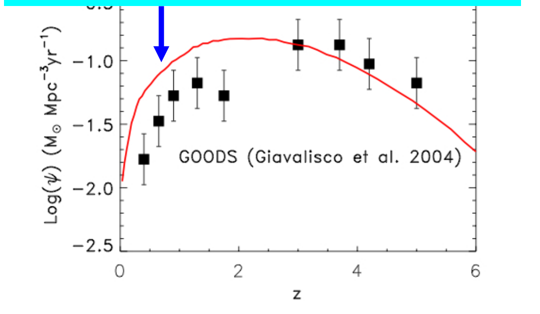
no red sequence at z~1



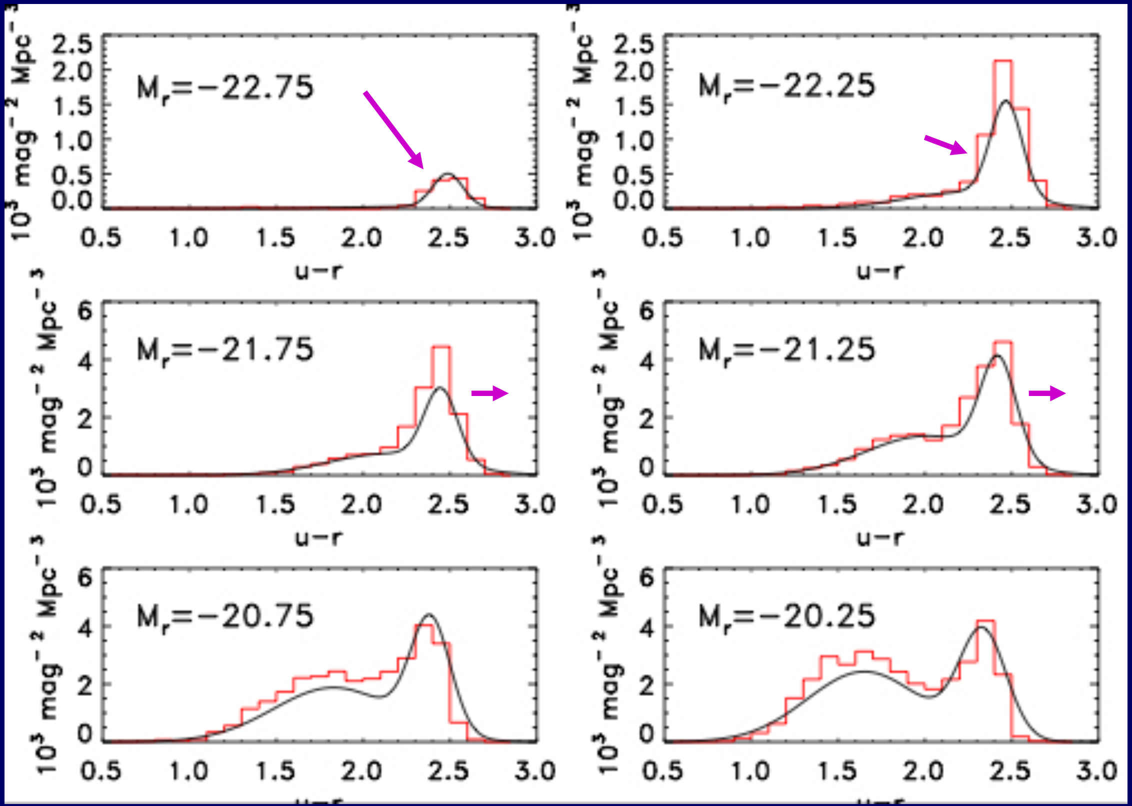
too few galaxies at z~3

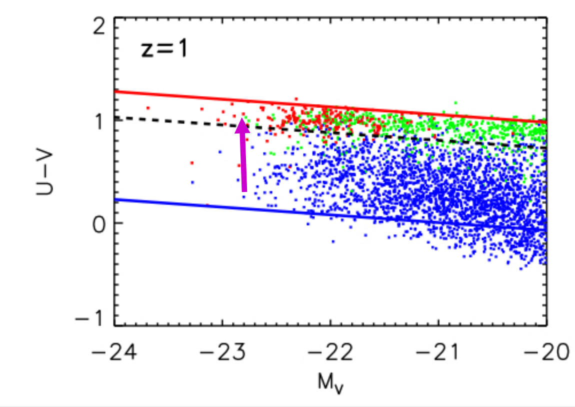


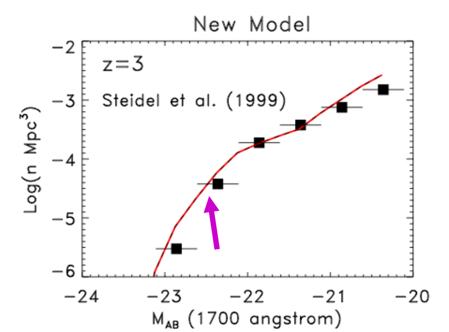
star formation at low z

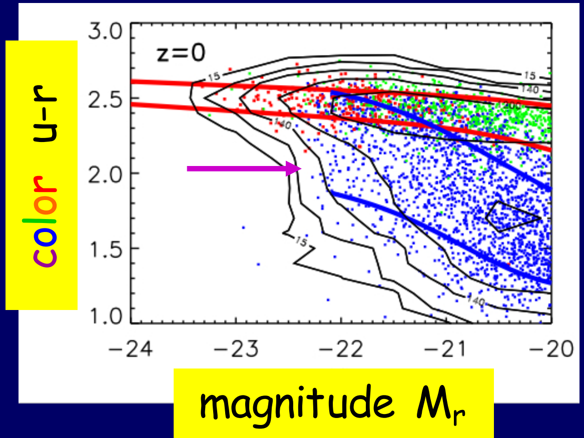


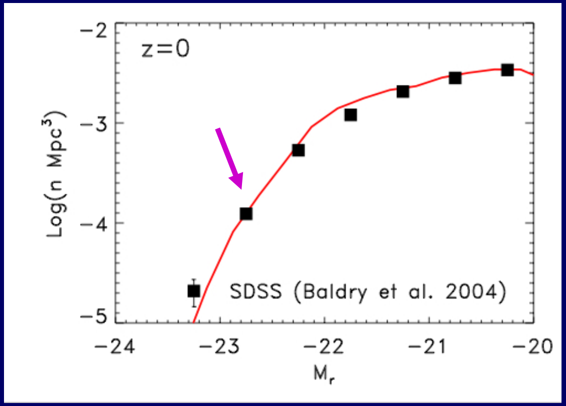
With Shutdown Above 10^{12} $M_\odot$

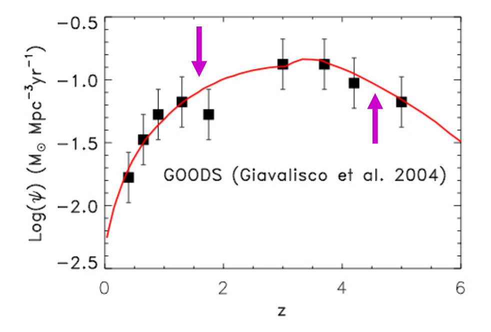




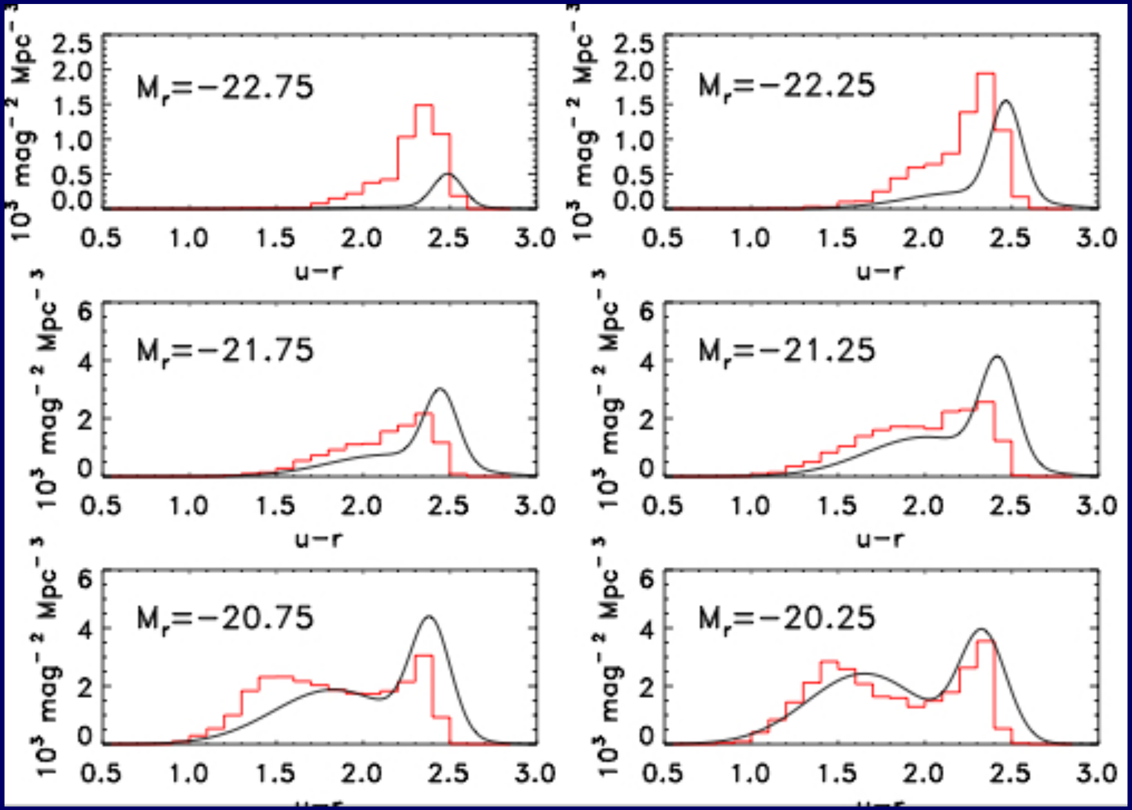


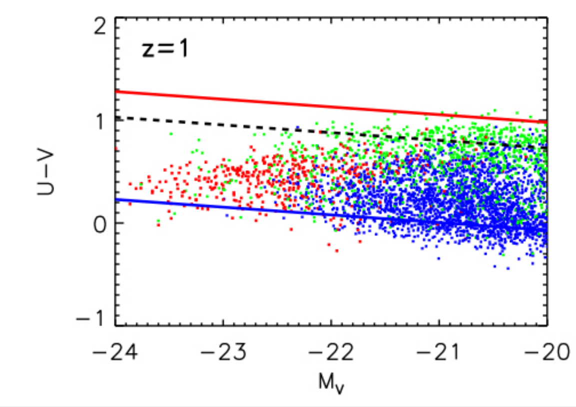


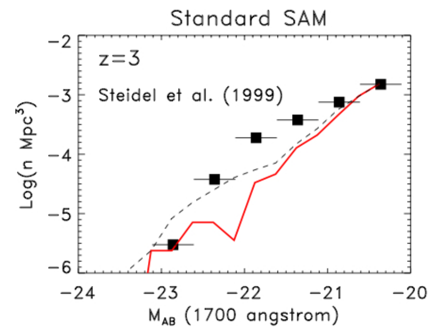


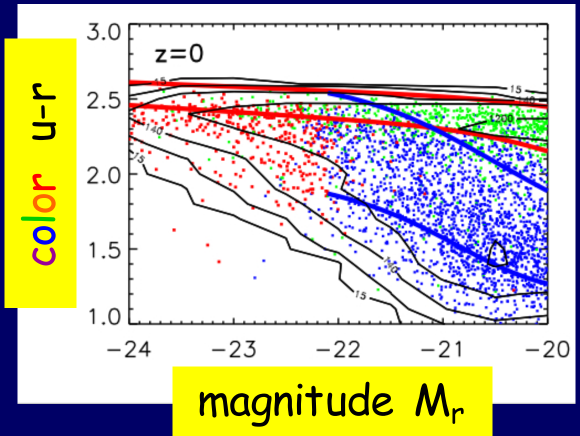


Standard



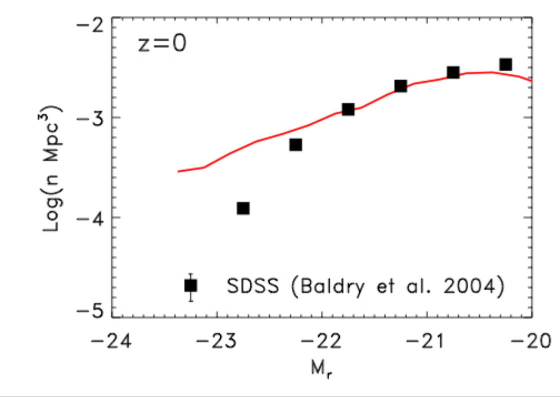


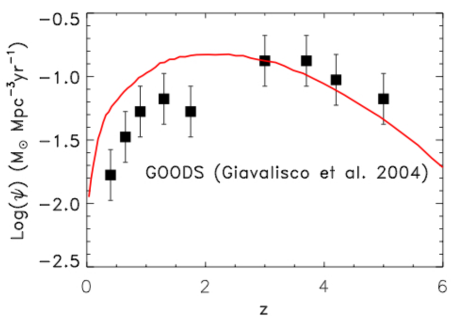




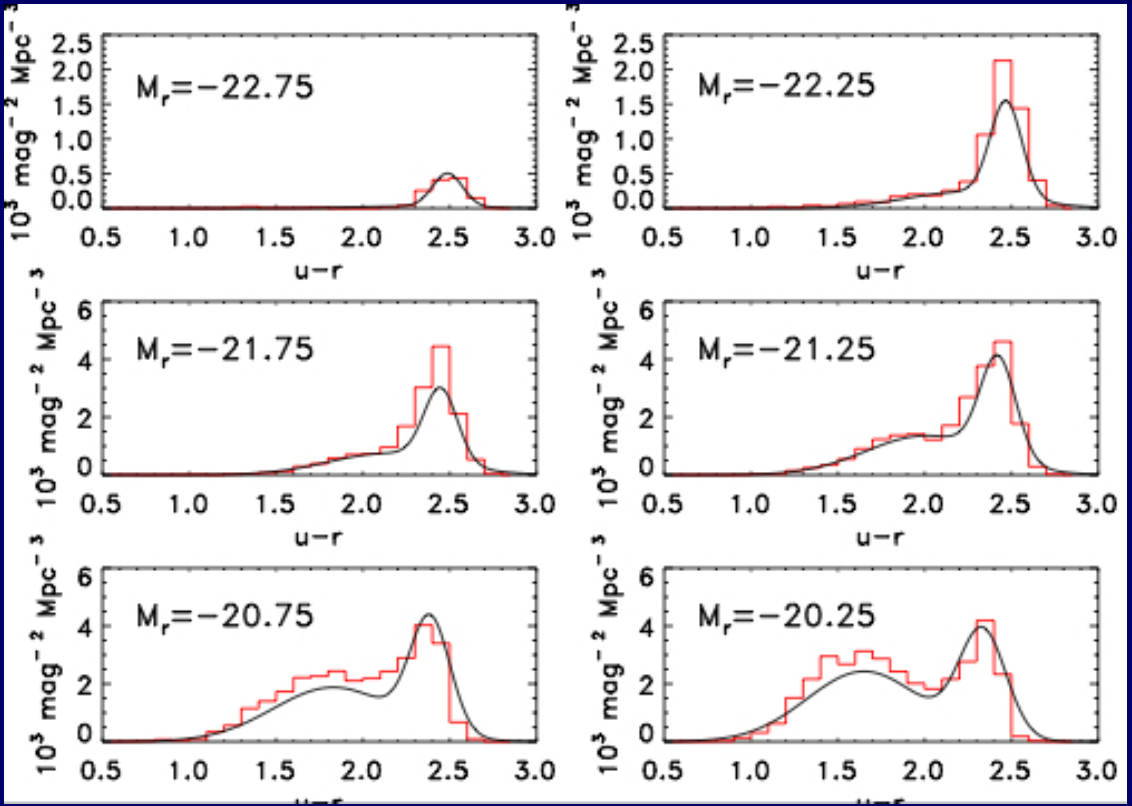
color u-r

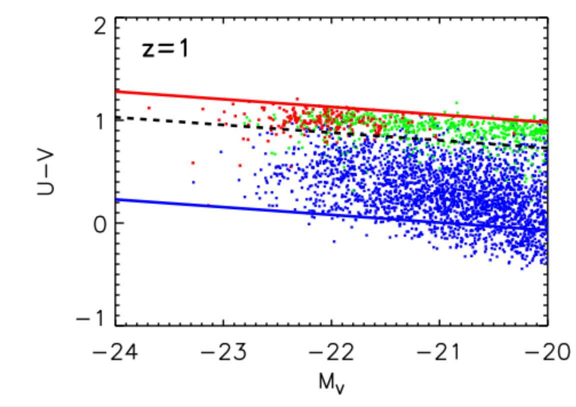
magnitude M_r

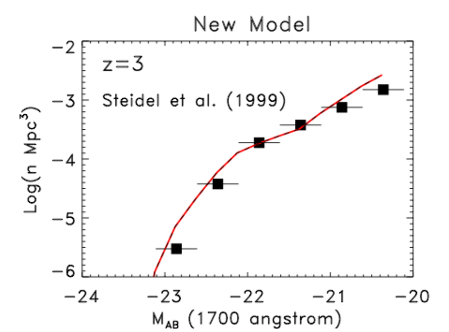


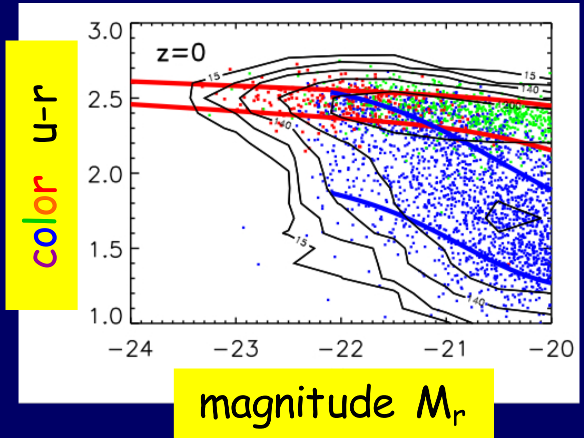


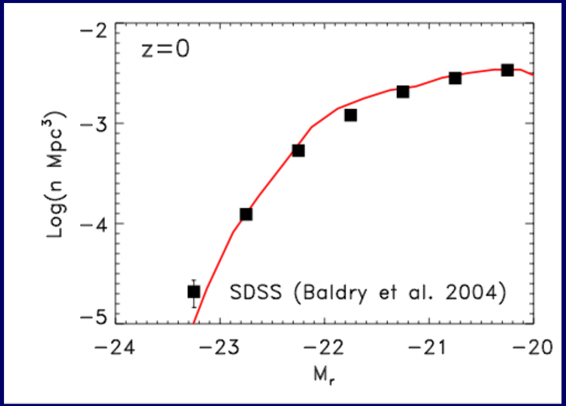
With Shutdown Above 10^{12} $M_\odot$

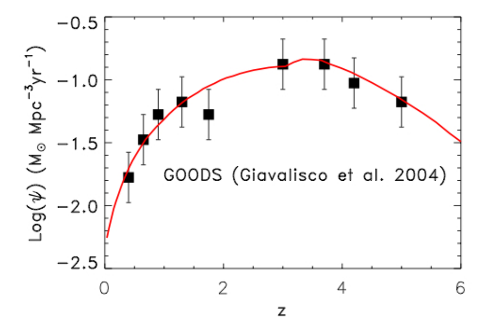




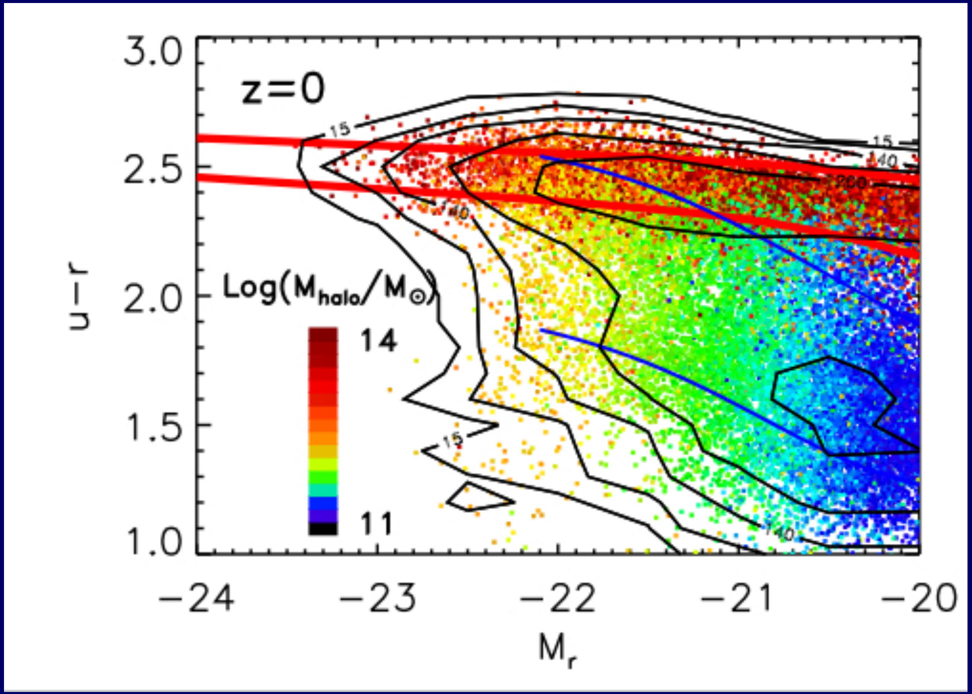




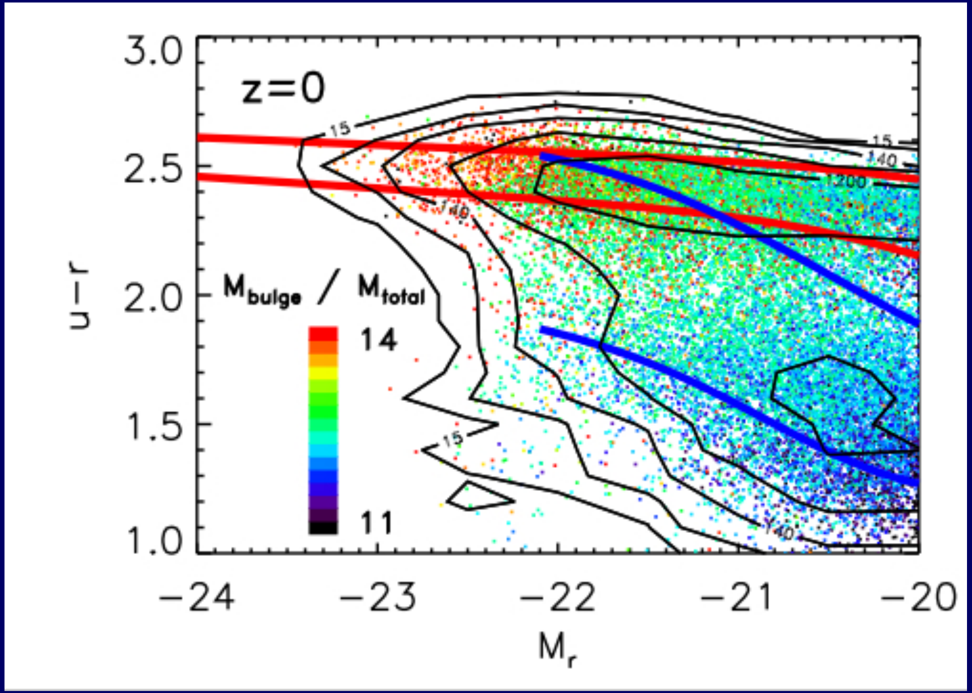




Environment dependence via halo mass



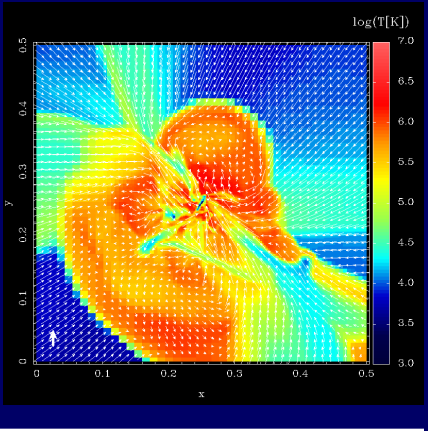
Bulge to disk ratio



Environment Dependence

$M > M_{shock}$ → high HOD groups (at low z)
→ red sequence in dense environment

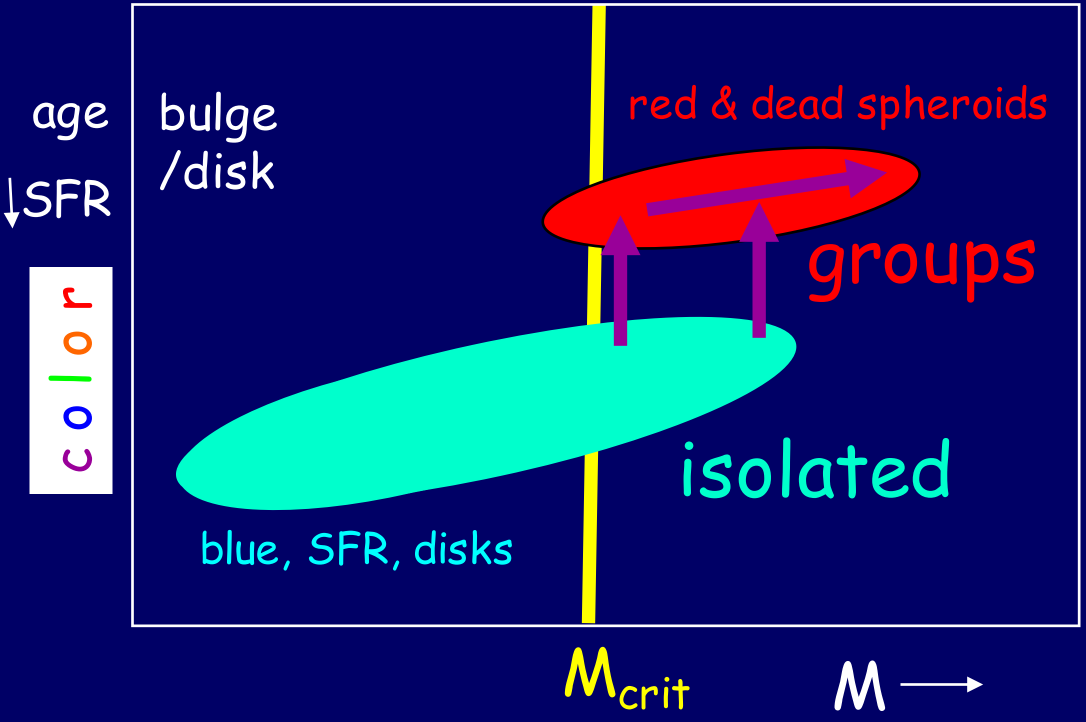
cold streams harassed in groups
but survive in isolated galaxies
even for $M > M_{shock}$



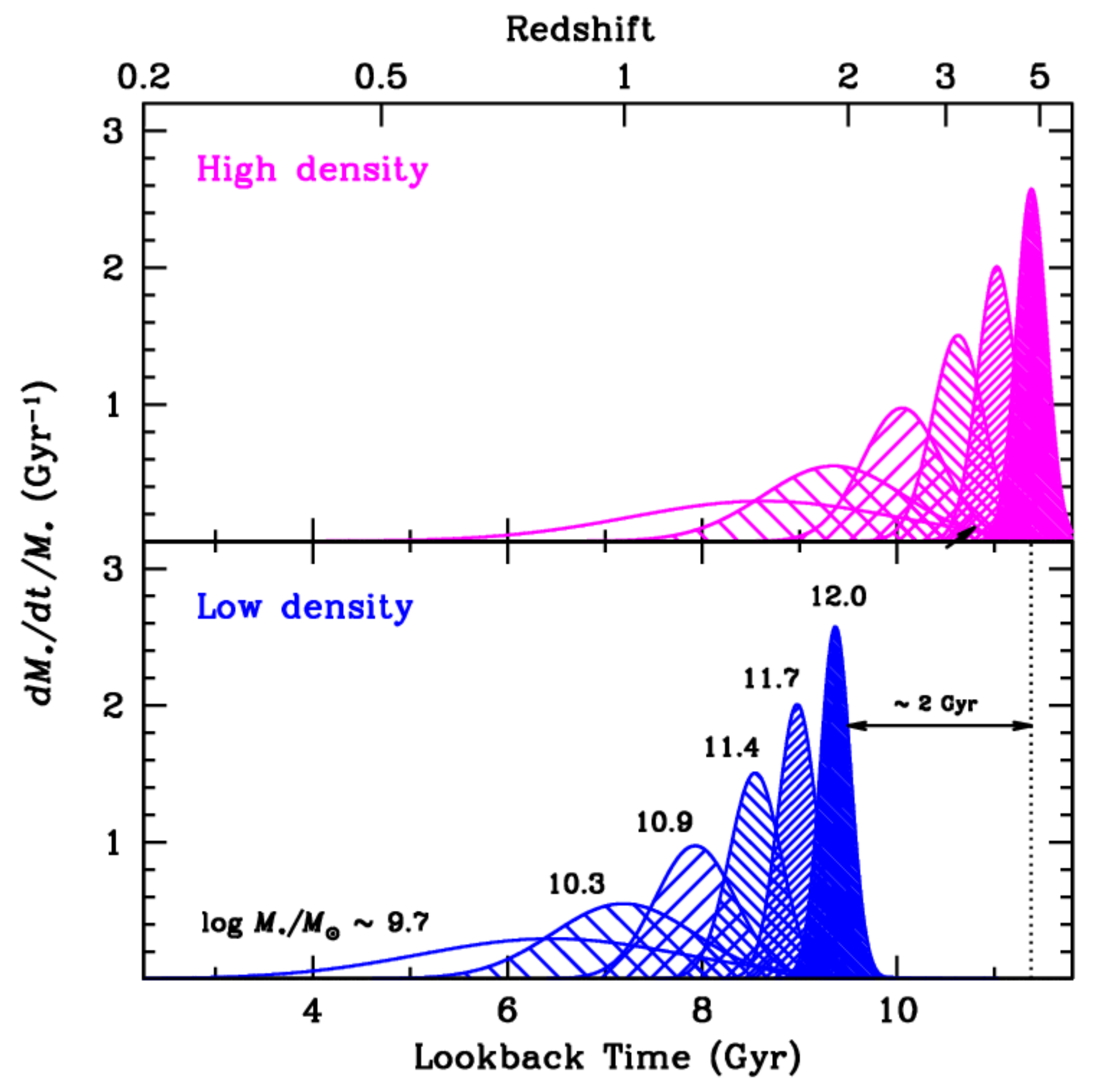
$M_{group} \sim M_*(t)$ ↗

→ big blue disks
form at high z

become big red
spheroids later



Downsizing: epoch of star formation in E's



Thomas et al. 2005

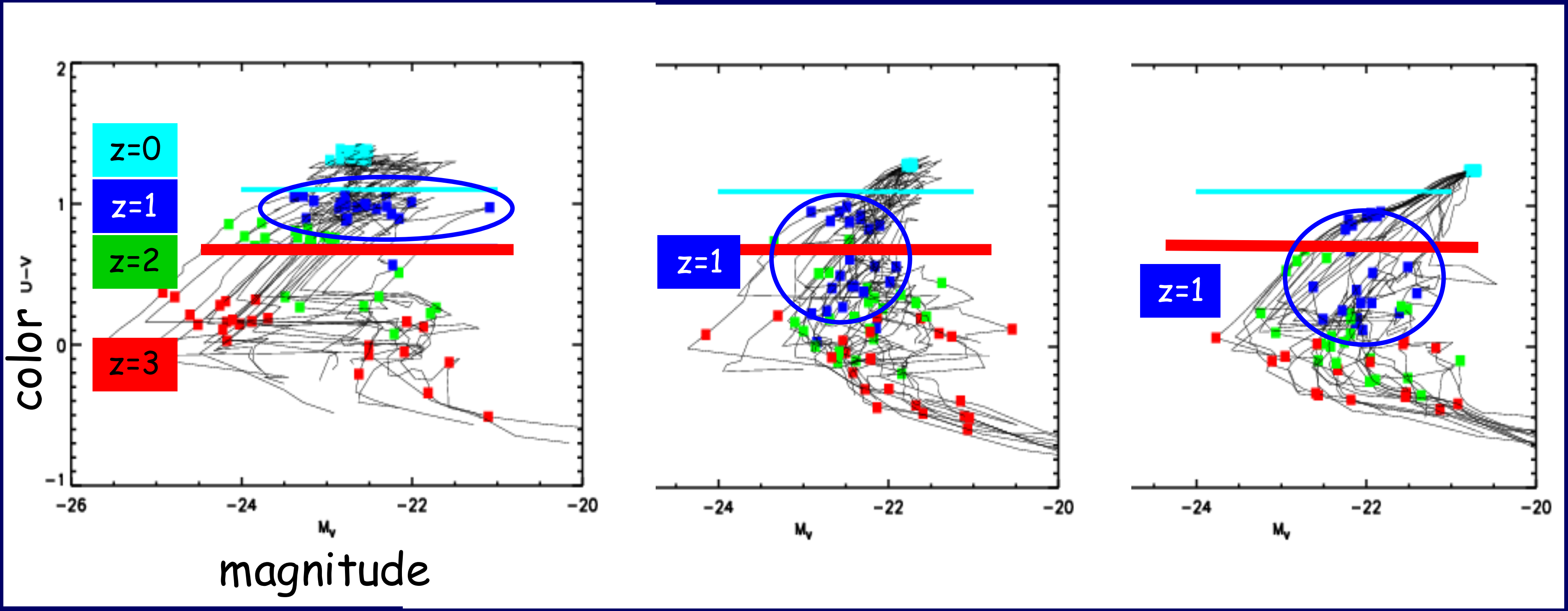
Downsizing due to Shutdown

Cattaneo, Dekel, Faber 2006

bright central

intermediate central/satellites

faint satellites

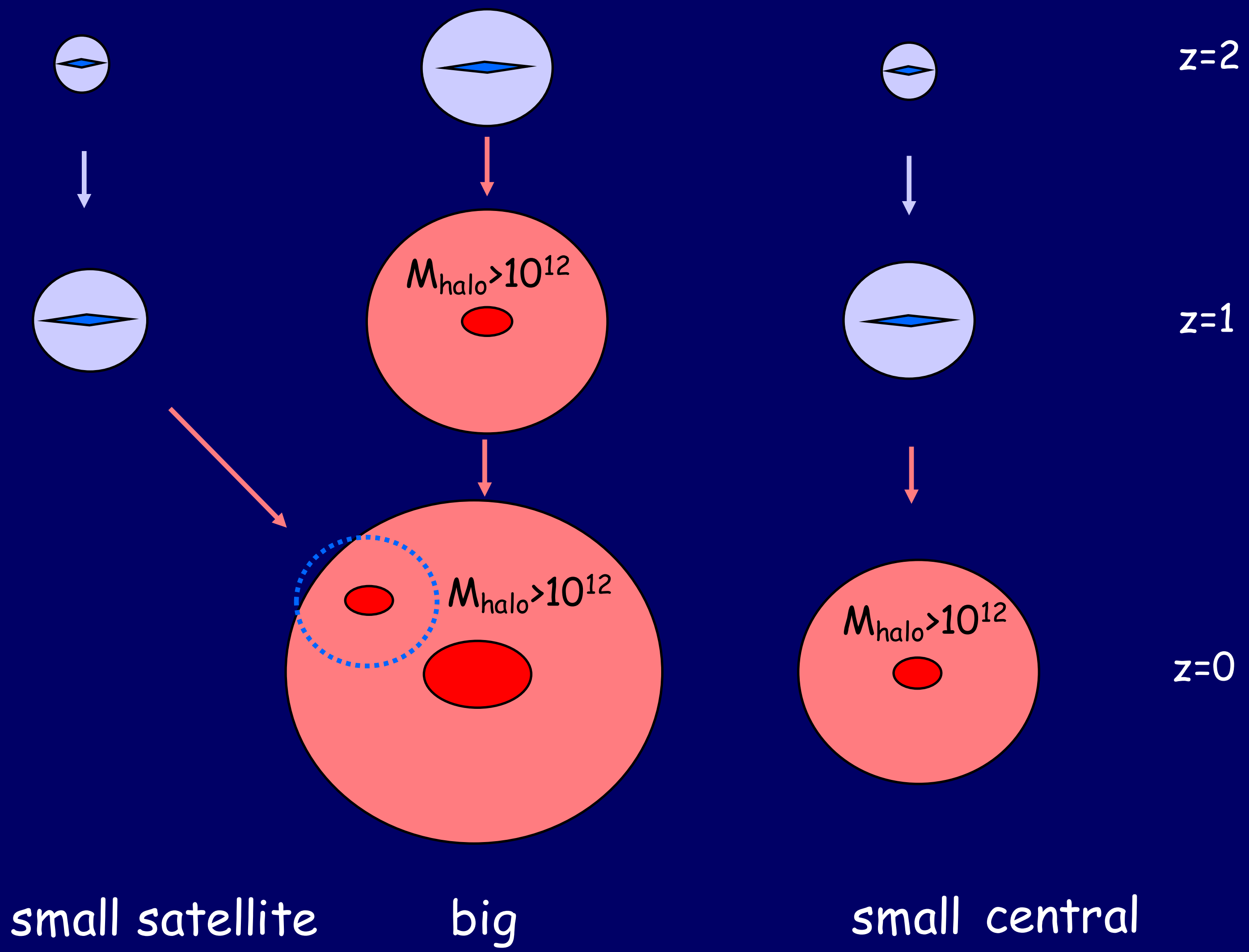


in place by z~1

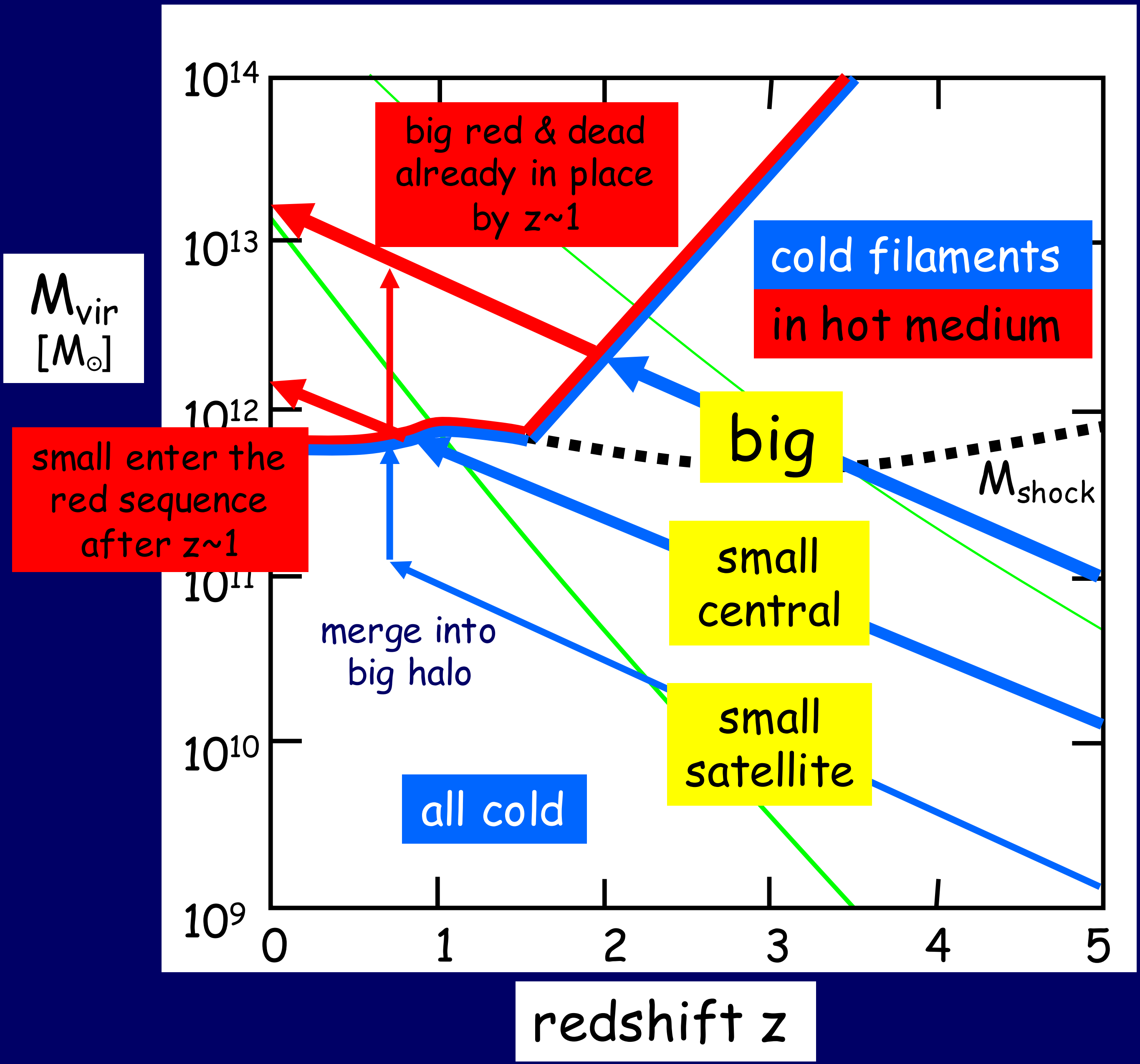
turn red after z~1

Downsizing by Shutdown at $M_{halo}>10^{12}$

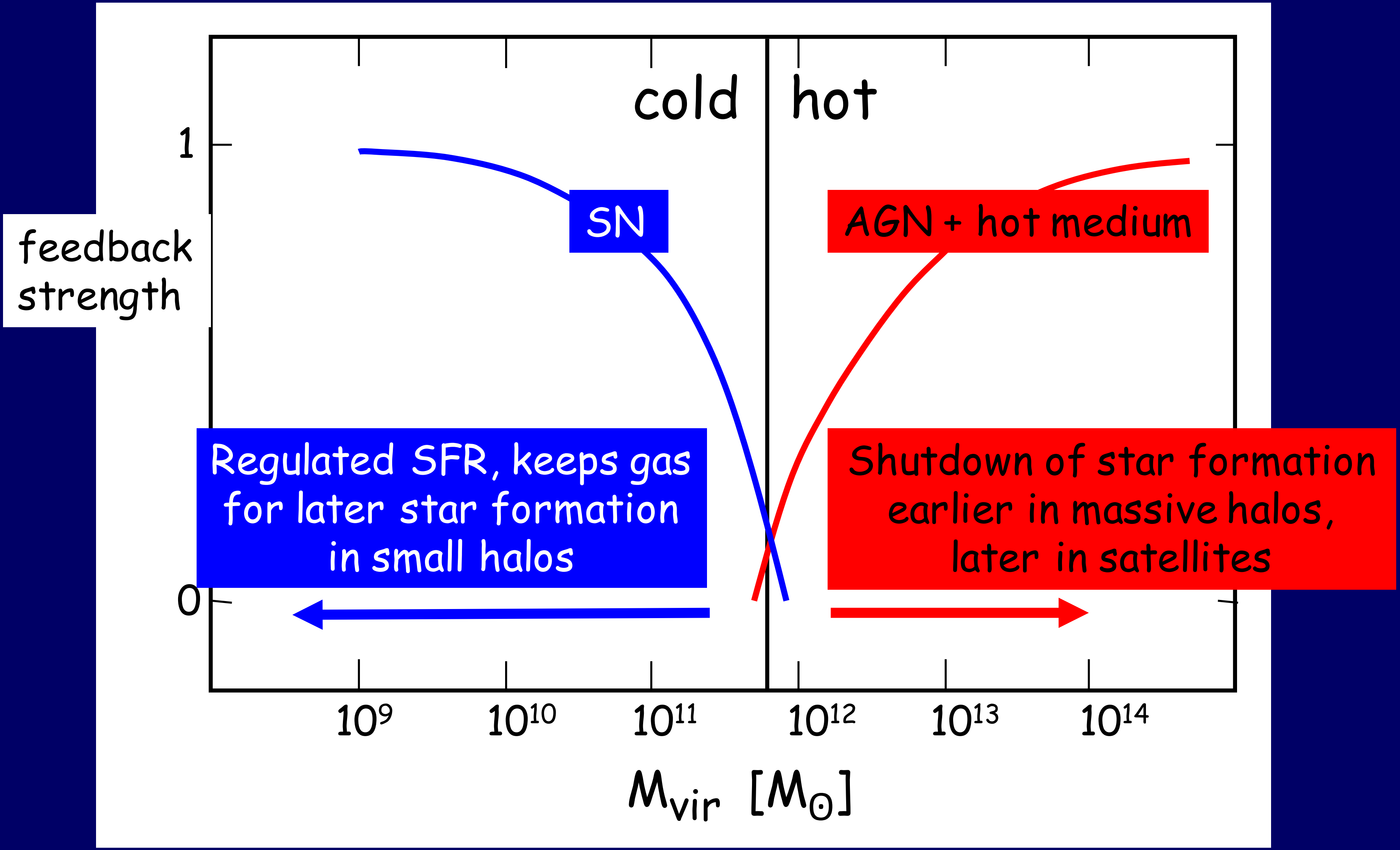
The bright red & dead E's are in place by z~1
while smaller E's appear on the red sequence after z~1



Downsizing by Shutdown at $M_{halo}>10^{12}$



Downsizing by Feedback and Shutdown

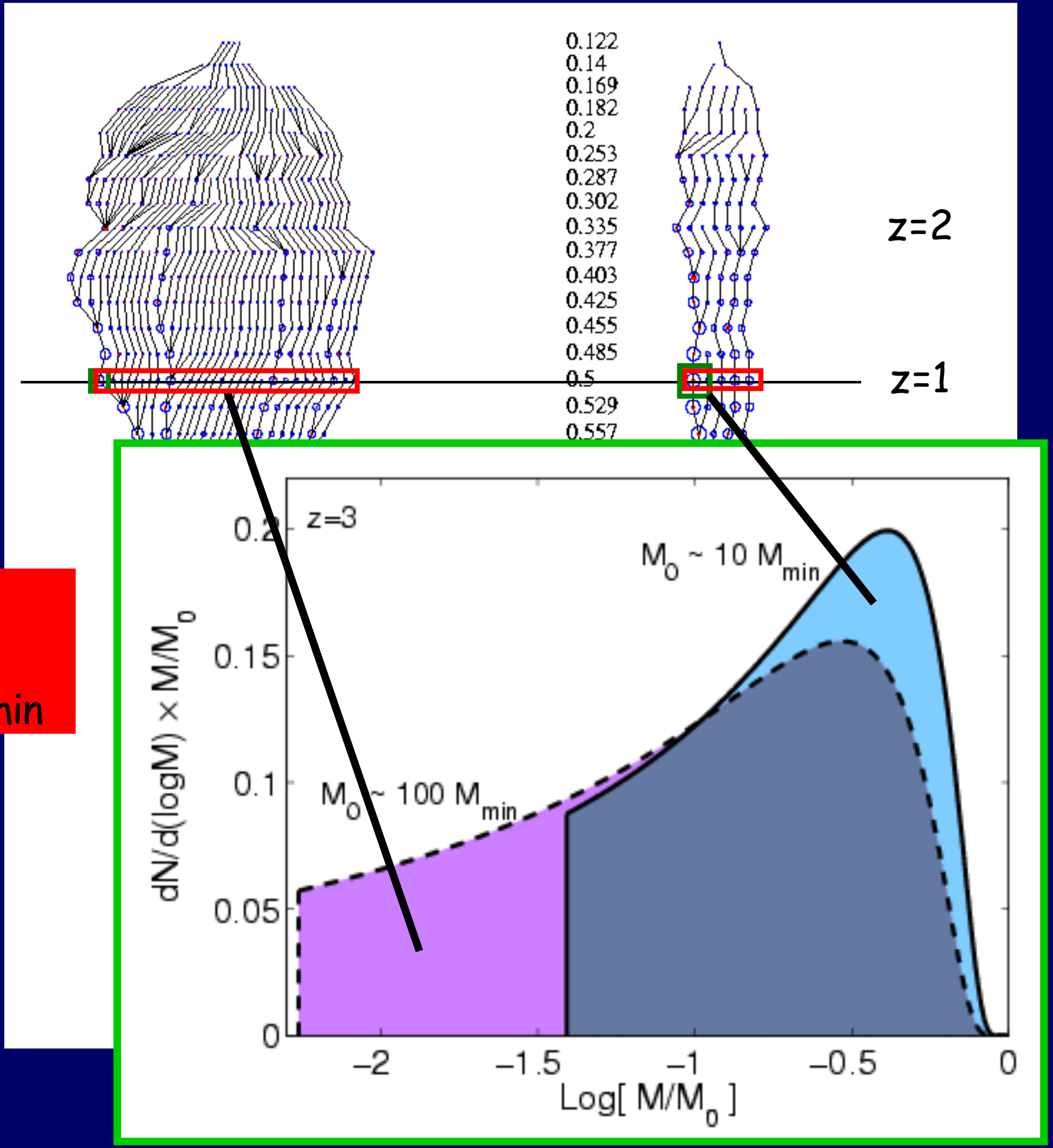


Regulated SFR, keeps gas for later star formation in small halos

Shutdown of star formation earlier in massive halos, later in satellites

Is Downsizing Anti-hierarchical?

Merger trees
of dark-matter
halos $M>M_{min}$



Upsizing of mass
in **main** progenitor

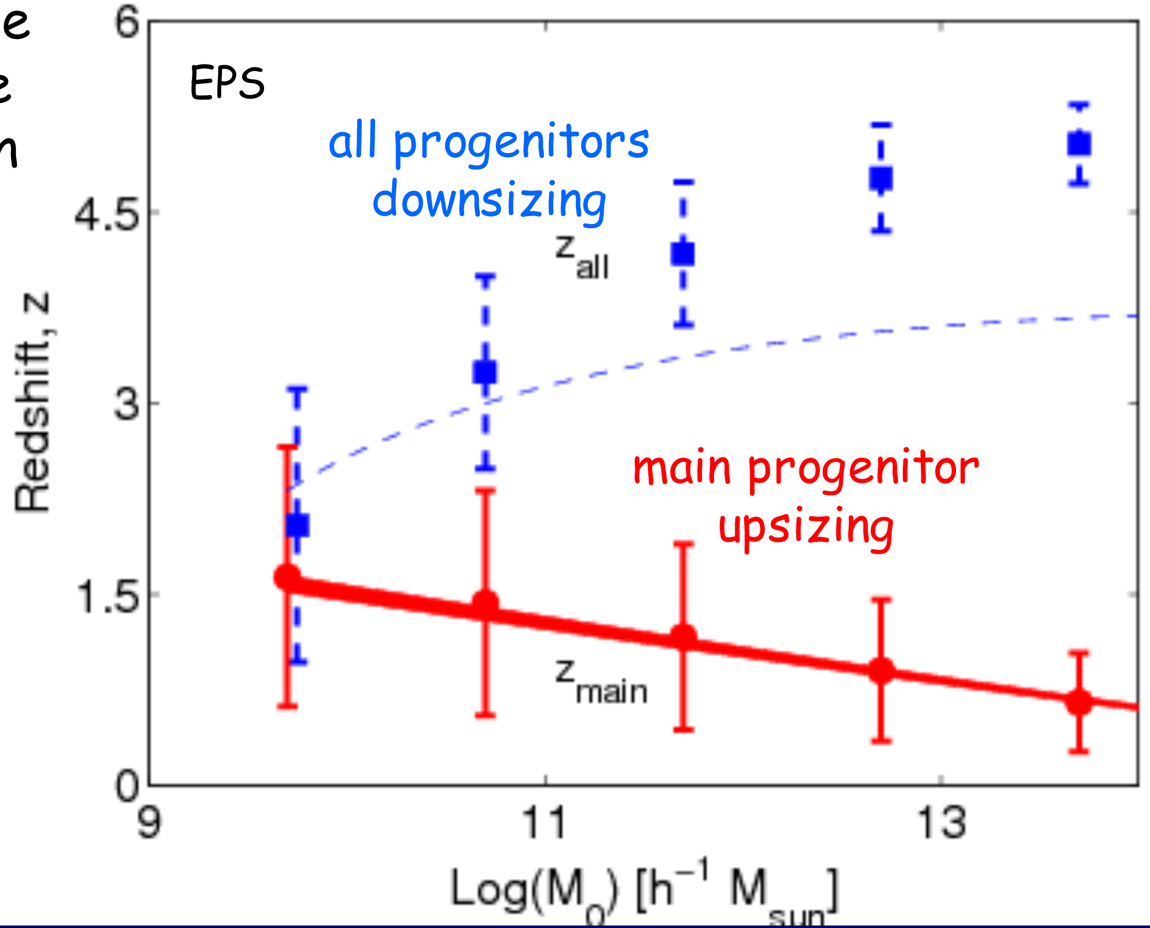
Downsizing of mass
in **all** progenitors $>M_{min}$

Neistein, van den
Bosch, Dekel 2006

Natural Downsizing in Hierarchical Clustering

Neistein, van den Bosch, Dekel 2006

Formation time
when half the
mass has been
assembled



Conclusions

1. Galaxy type is driven by dark-halo mass:
   $M_{crit} \sim 10^{12} M_\odot$ by shock heating (+feedback & clustering)

2. Disk & star formation by cold flows riding DM filaments

3. Early ($z>2$) big halos ($M \sim 10^{12}$)
   big high-SFR galaxies by cold flows in hot media

4. Late ($z<2$) big halos $M>10^{12}$ (groups):
   virial shock heating triggers "AGN feedback"
   → shutdown of star formation → red sequence

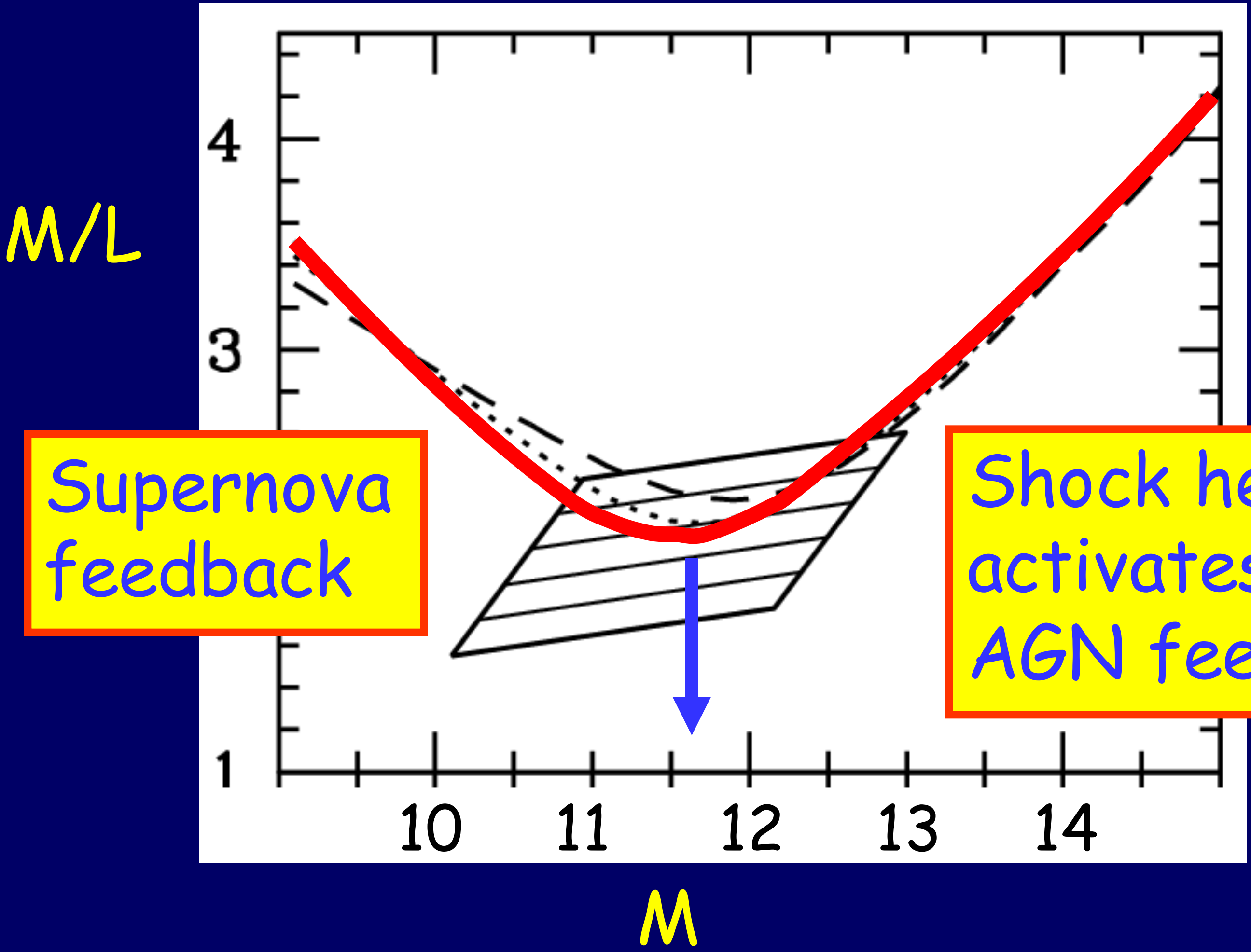
5. Late ($z<2$) small halos $M<10^{12}$ (field): blue disks $M_* < 10^{10.5}$

6. Downsizing is seeded in the DM hierarchical clustering

7. Downsizing is shaped up by feedback & shutdown $M>10^{12}$

8. Two different tracks from blue to red sequence

‹M/L› has a minimum at M_{crit}

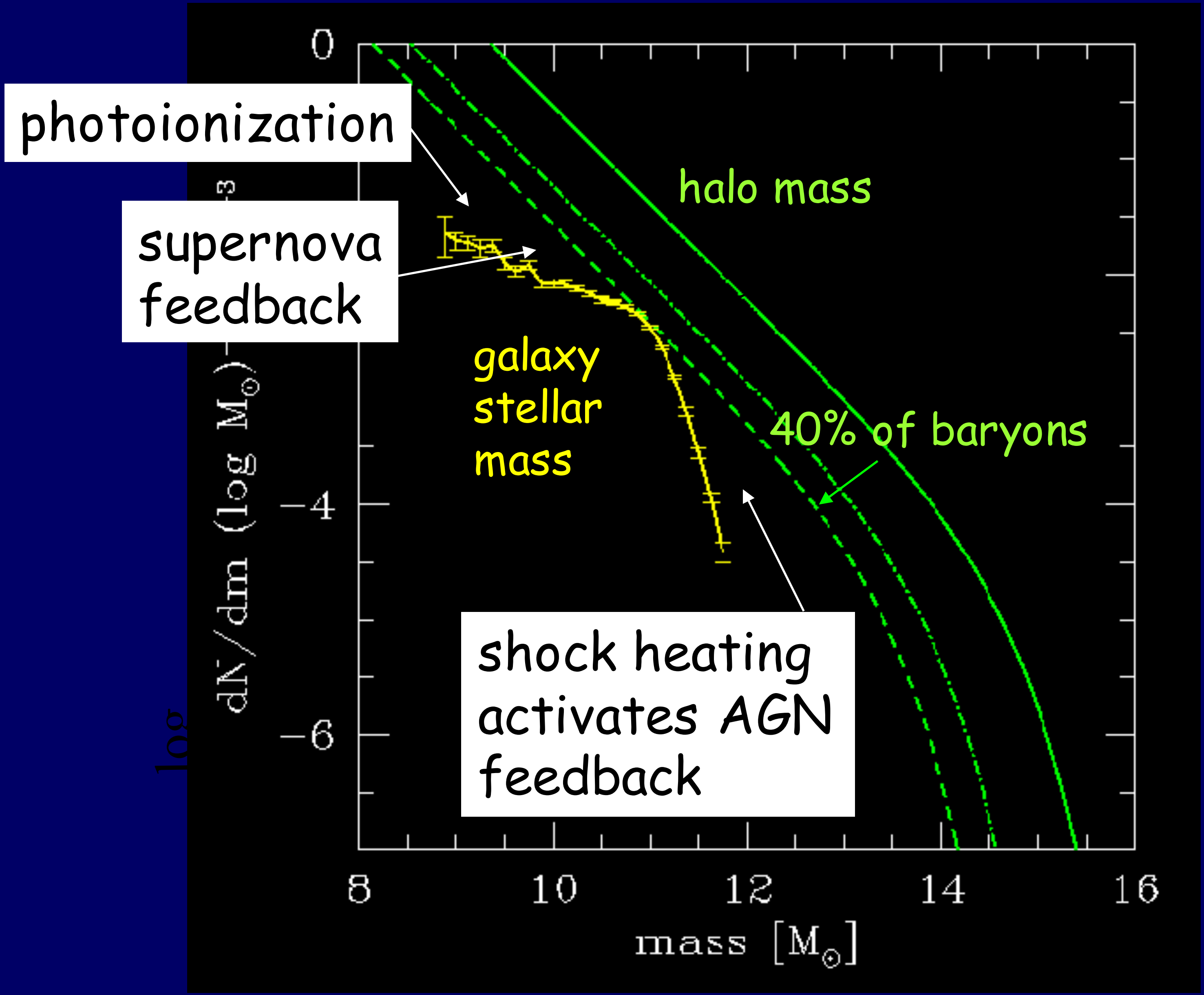


Supernova feedback

Shock heating activates AGN feedback

Using conditional luminosity function: Van den Bosch, Mo, Yang 03

A Sharp knee in the luminosity function



photoionization

supernova feedback

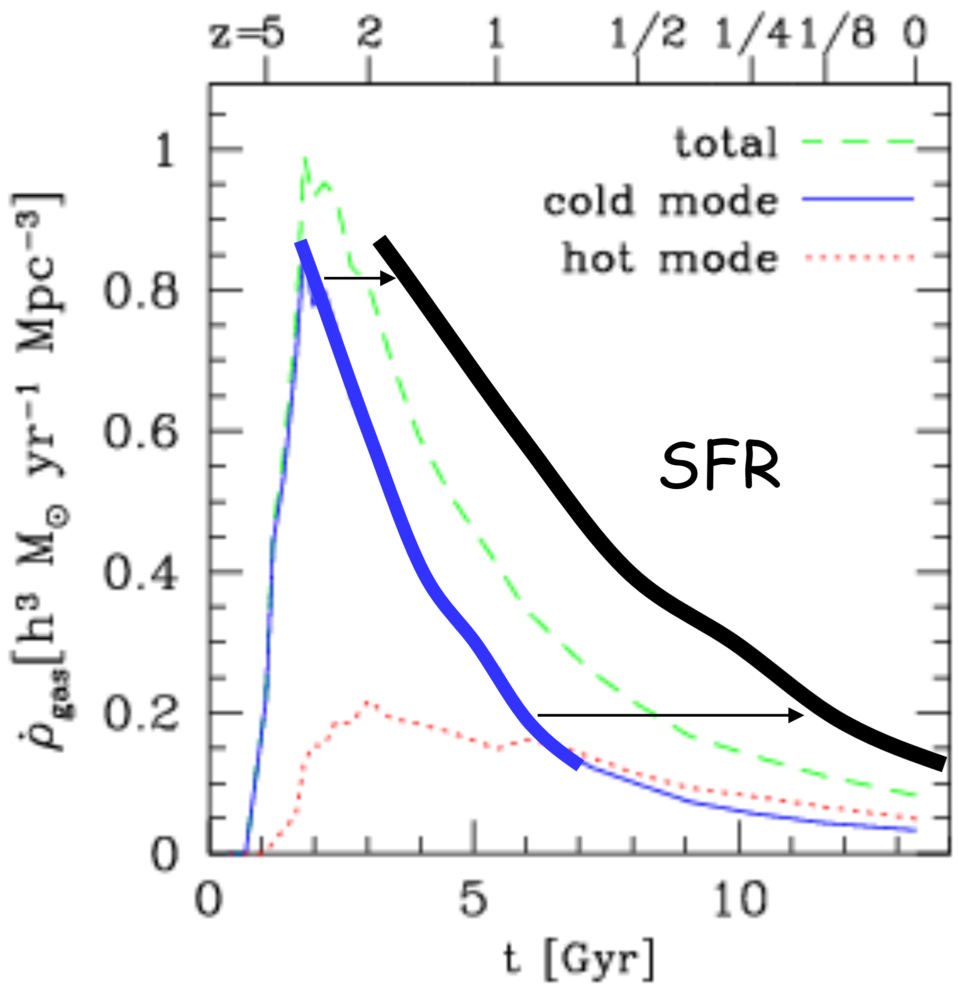
galaxy stellar mass

halo mass

40% of baryons

shock heating activates AGN feedback

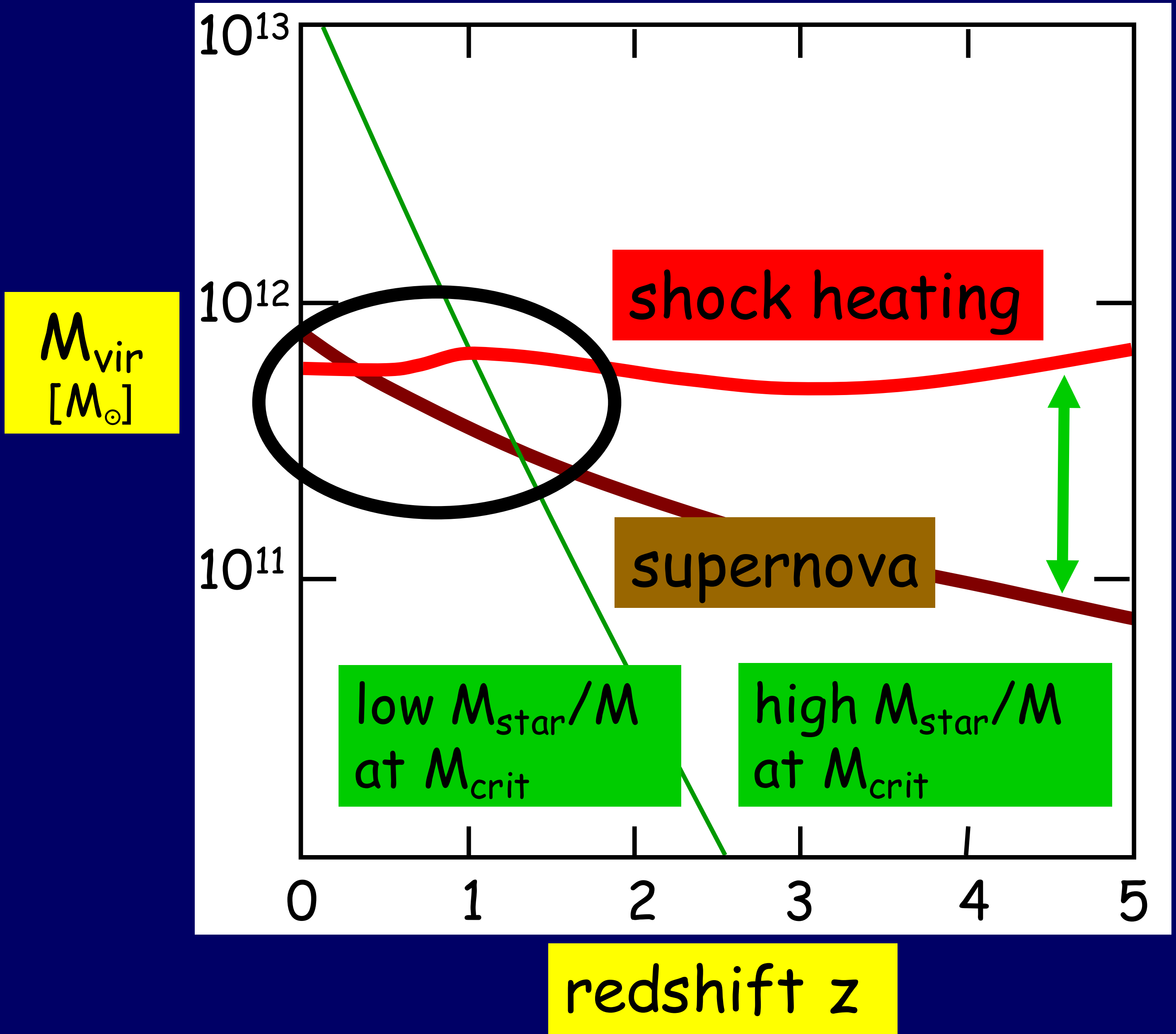
Cold infall history → Star formation history



SPH simulation

Keres, Katz, Weinberg, Dav'e 2004

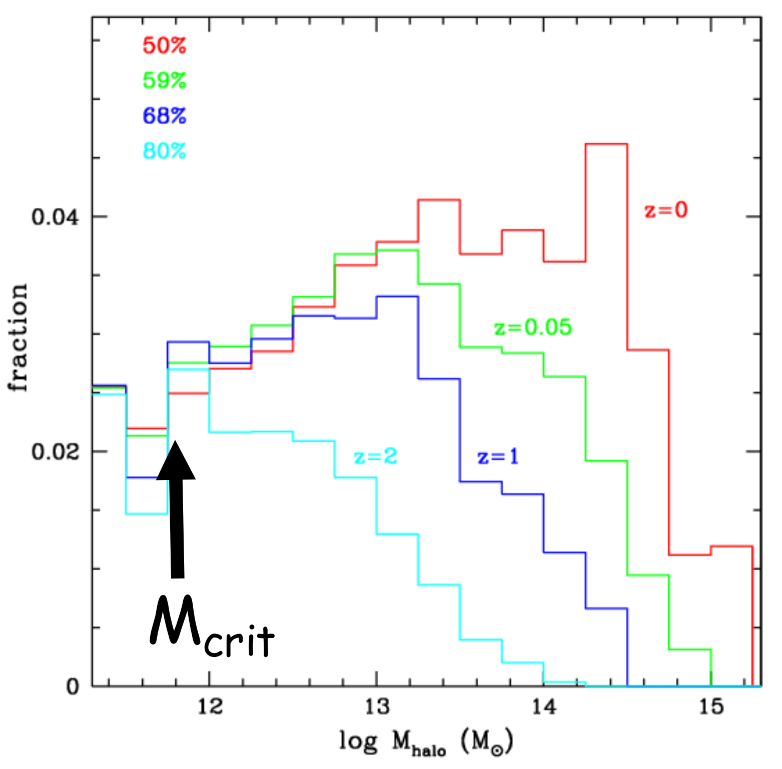
Shock-Heating vs SN Feedback at high z



History of Star Formation

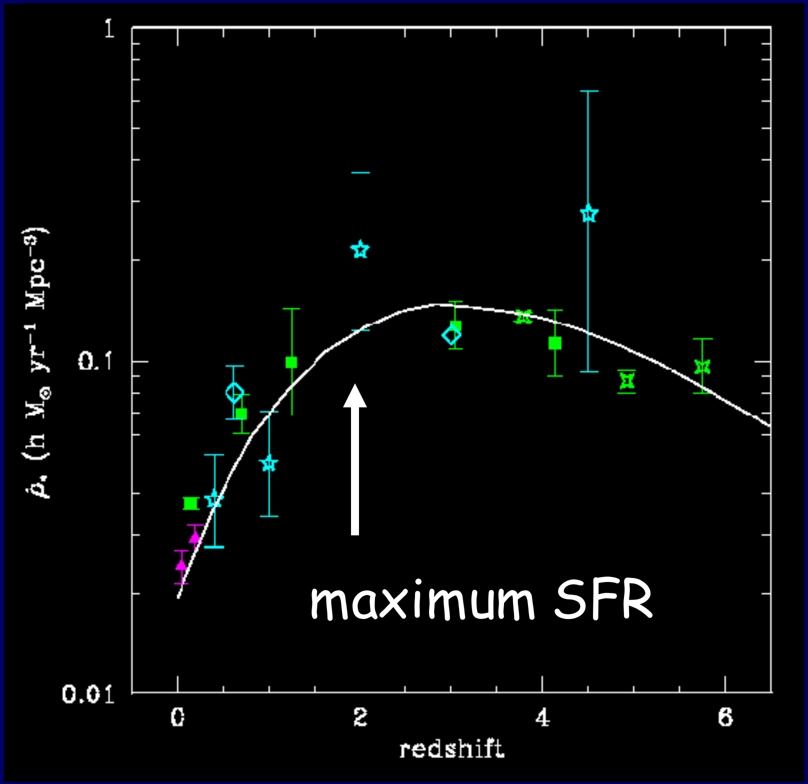
Most-efficient star formation near M_{crit}

evolution of
halo mass function



M_{crit}

evolution of
star formation rate



maximum SFR

The Angular Momentum problem

hydro simulations fail to produce large disks, over-produce bulges (Navarro, Steinmetz, …)

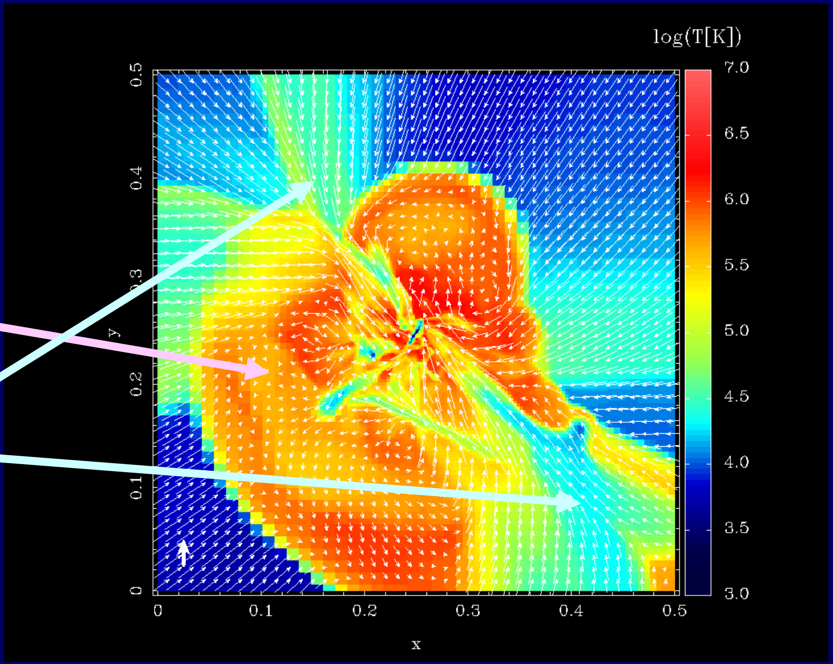
→ should get rid of low j tail

$M<M_{crit}$ SN blowout from dwarf halos, which enter as minor mergers (Maller & Dekel 02)

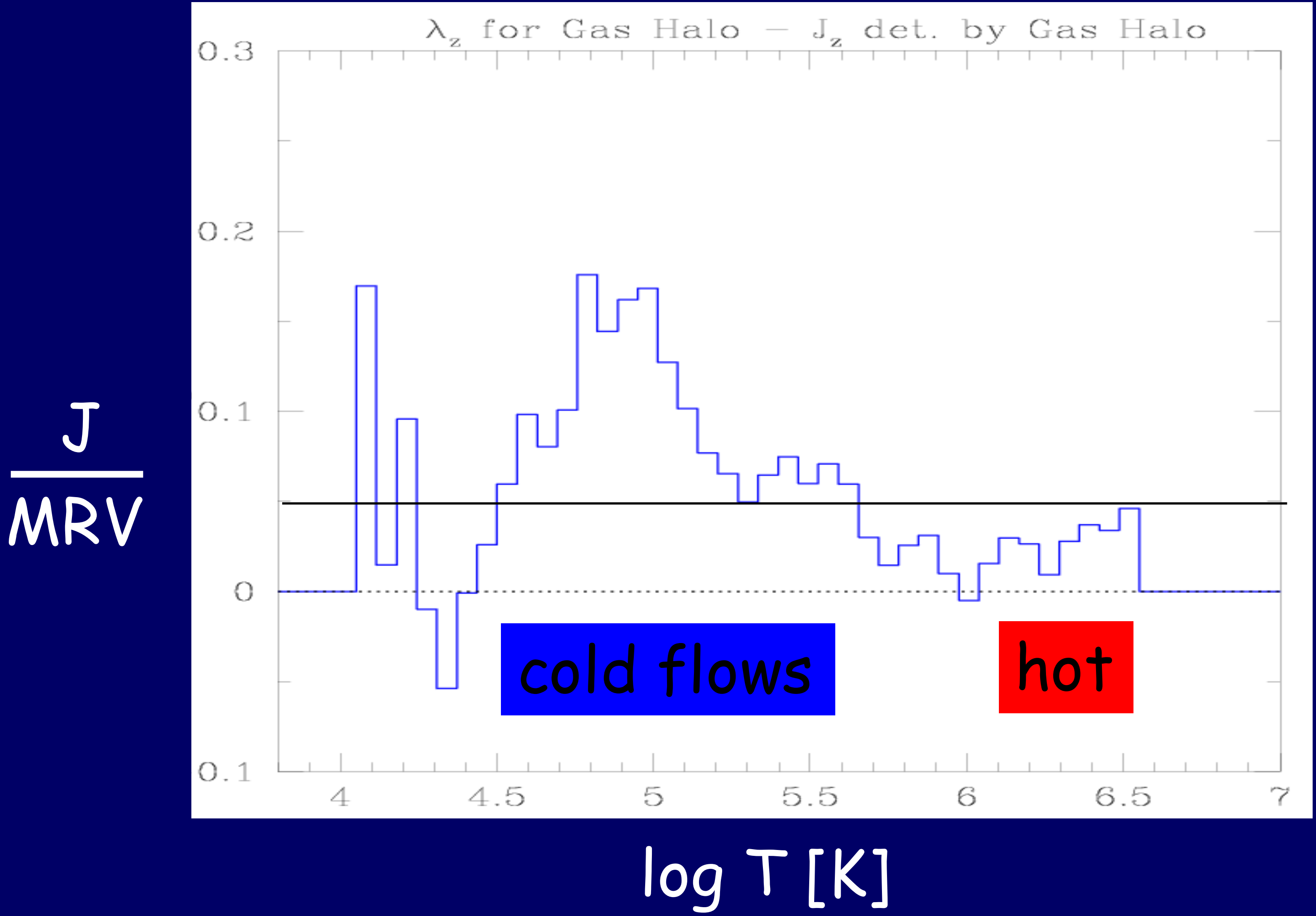
$M>M_{crit}$

AGN blowout of the low j hot medium

high j comes with cold streams



Angular Momentum: Cold vs Hot Gas



Zinger, Birnboim, Dekel, Kravtsov

Conclusions

Summary: Magic Scale
$M_* \sim 3\times10^{10} M_\odot$, $M_{vir} \sim 6\times10^{11} M_\odot$

$M < M_{crit}$

cold infall → disks

star bursts, field

SN feedback regulates SFR

→ blue, young pop

$M_*/M \propto V^2$ → LSB fundamental line

starves AGNs

Ly-α emitters

$M > M_{crit}$

hi-z progenitors < M_{crit} → disks

SF stops when > M_{crit} → red, old,
spheroids in groups

hot gas (+ cold flows at $z>2$)

AGN feedback prevents cooling
of shock-heated gas

X-ray

Origin of the Observed Features

Blue sequence & FL: Cold flows in $M<M_{shock}$ halos (+mergers); SFR regulated by SN fdbk

Big reds & no big blues at $z<1$: Shutdown SFR in $M>M_{shock}\sim 10^{12}$ due to coupling of hot gas with AGN fdbk; Mergers in groups --> spheroids help shutdown

Big blues at $z>2$: Cold streams in hot $M>M_{shock}$ before $z_{crit}\sim 2$

Color bimodality gap: Abrupt shutdown of SFR; Spheroids get red; Satellites

Environment dependence: HOD -- halo mass, $M_{group}\sim M_{shock}$

Bulge/Disk bimodality: Disks by cold flows in $M<M_{shock}\sim M_{group}$; Merger rate in groups --> spheroids + BH --> AGN fdbk

Minimum in M/L M_{shock}: Minimum in feedback efficiency

SFR peaks near $z\sim 1$: Maximum cold flow, minimum feedback

Angular momentum: By cold flows

To do (partial list) :

Cold flows: fate? star formation, SN feedback

Hot medium: two phases, AGN feedback

X-ray, Lα emission , external ionizing flux

Angular momentum

Star formation history

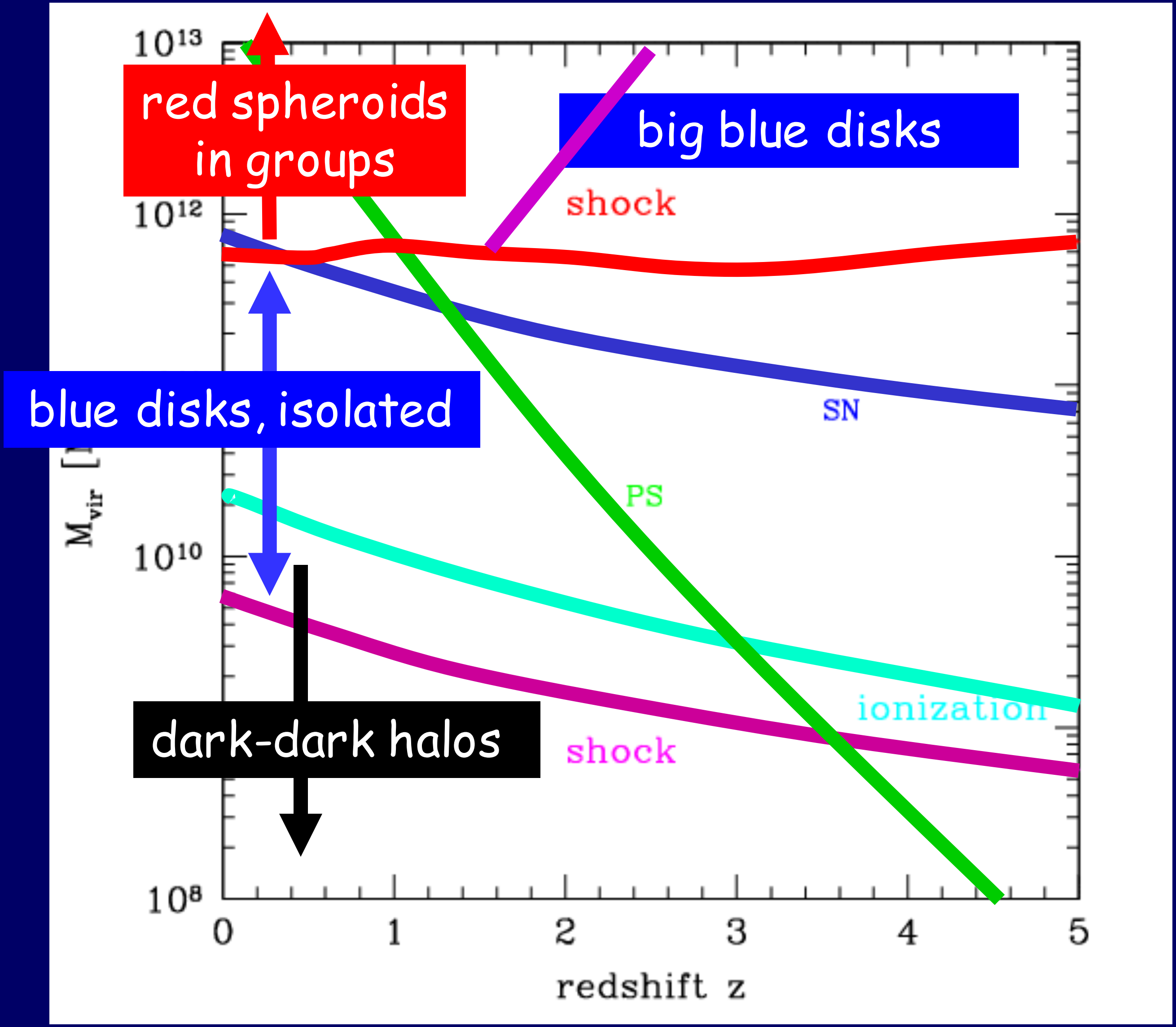
Implement in semi-analytic models

Theory vs. simulations

Re-engineering SAMs

- $M<M_{shockt}$: efficient early star formation by cold streams hitting disks
- $M>M_{shock}$ but $z>1.5$ (low HOD?): further star formation by cold streams
- $M>M_{shock}$ at $z<1.5$ in groups: shut off disk growth and star formation due to shock-heating + AGN feedback, preferably if big bulge
- no "cooling radius"; heating (not cooling) from the inside out

Characteristic Scales



red spheroids in groups

big blue disks

blue disks, isolated

dark-dark halos

Thank you

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Talks

Jan 2005, Lyon

Oct 03 Venice 30 min
Dec 03 IAP EARA workshop 30
Dec 03 Meudon 45
Dec 03 IAP 45
Dec 03 ETH Zurich 45

Jan 04 Oxford ddh+vf 30 and bimodality 45
Feb 04 DM Marina del Rey bimodality30
Apr 04 Texas A&M bimodality30 (45)
Apr 04 Berkeley colloq bimodality
Apr 04 LNLL
May 04 U of Arizona
May 04 CfA colloq
May 04 UCSB physics colloq
May 04 Caltech colloq
May 04 UCSC astronomy colloq
June 04 KIPAC Stanford colloq
July 04 Plumian 300 IoA bi30 (30)
August 04 UCSC workshop bi30 (30)
August 04 UVic bi50
Oct 04 KITP bi50