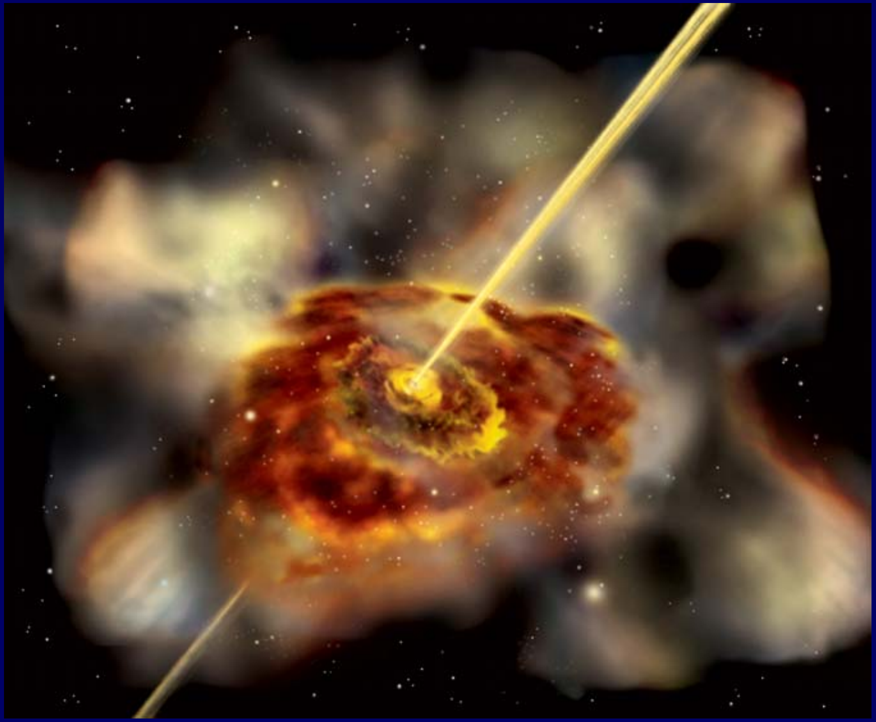
What Could AGN Feedback Do for Galaxy Formation

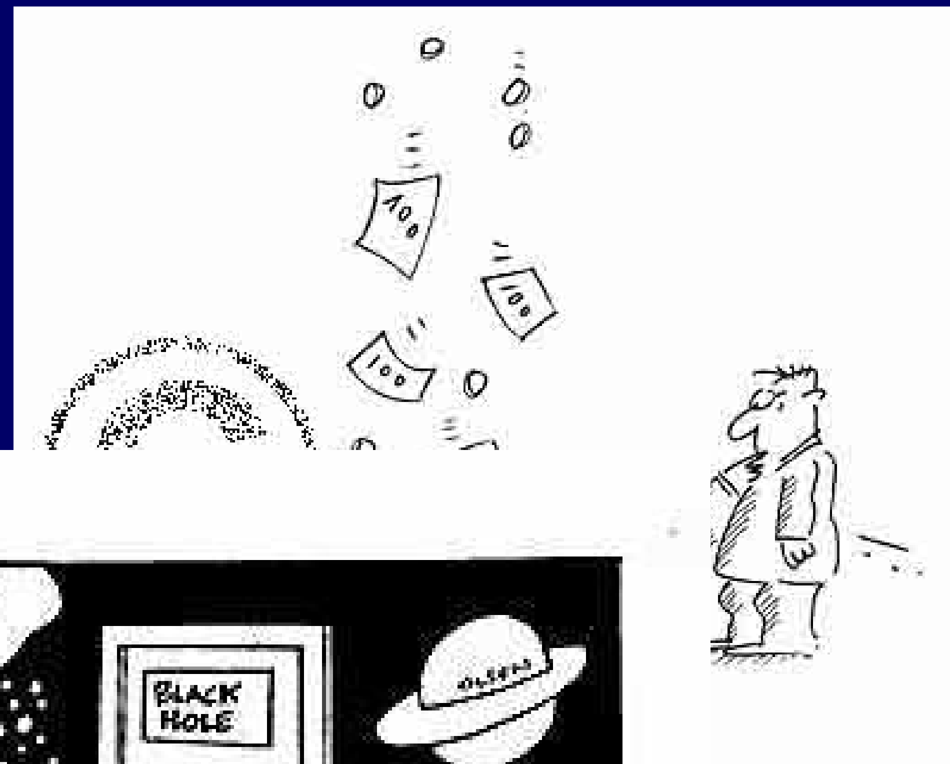
Avishai Dekel

HU Jerusalem

Hagai60, February 2006



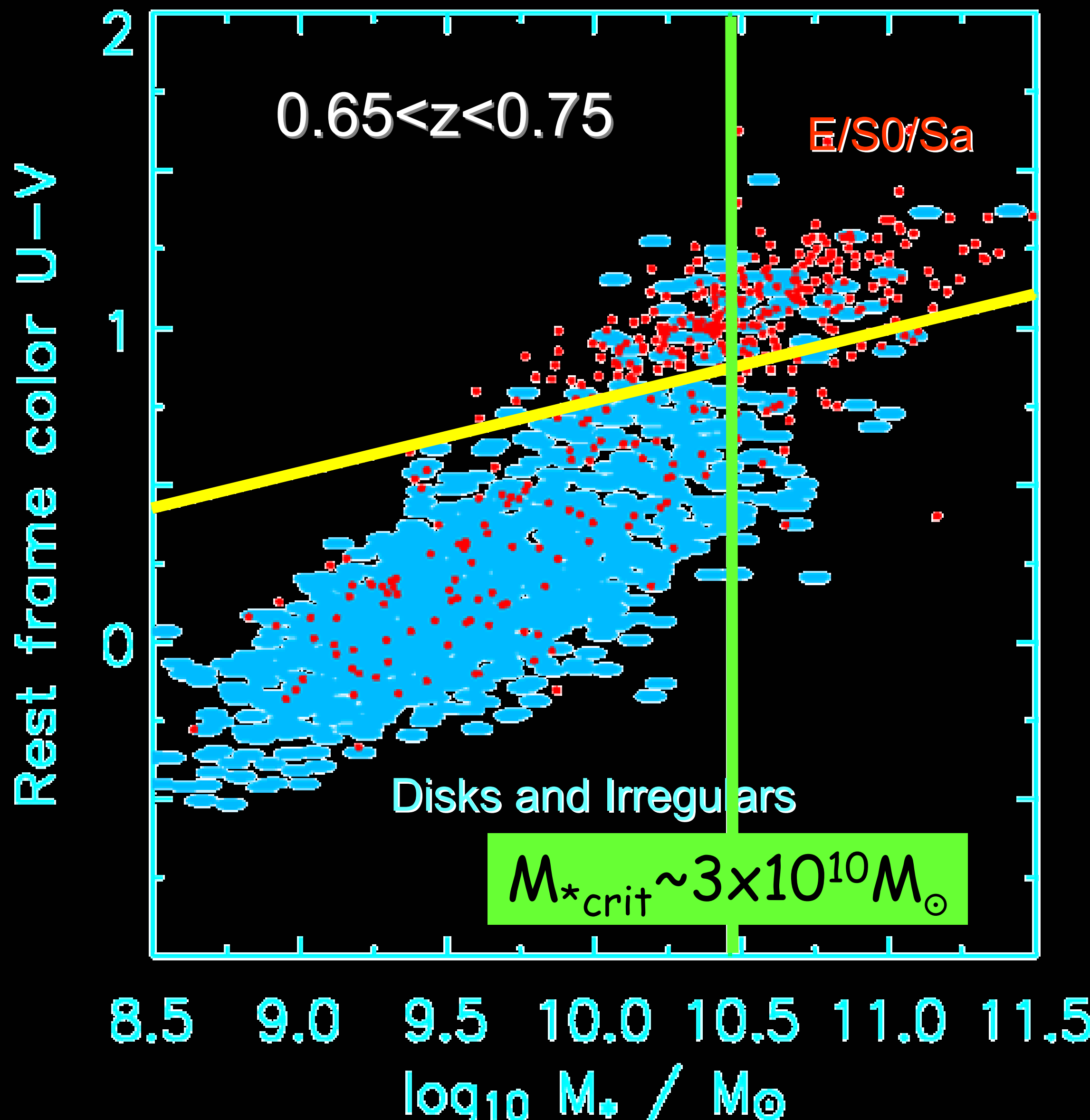
Black holes in israel?



Outline

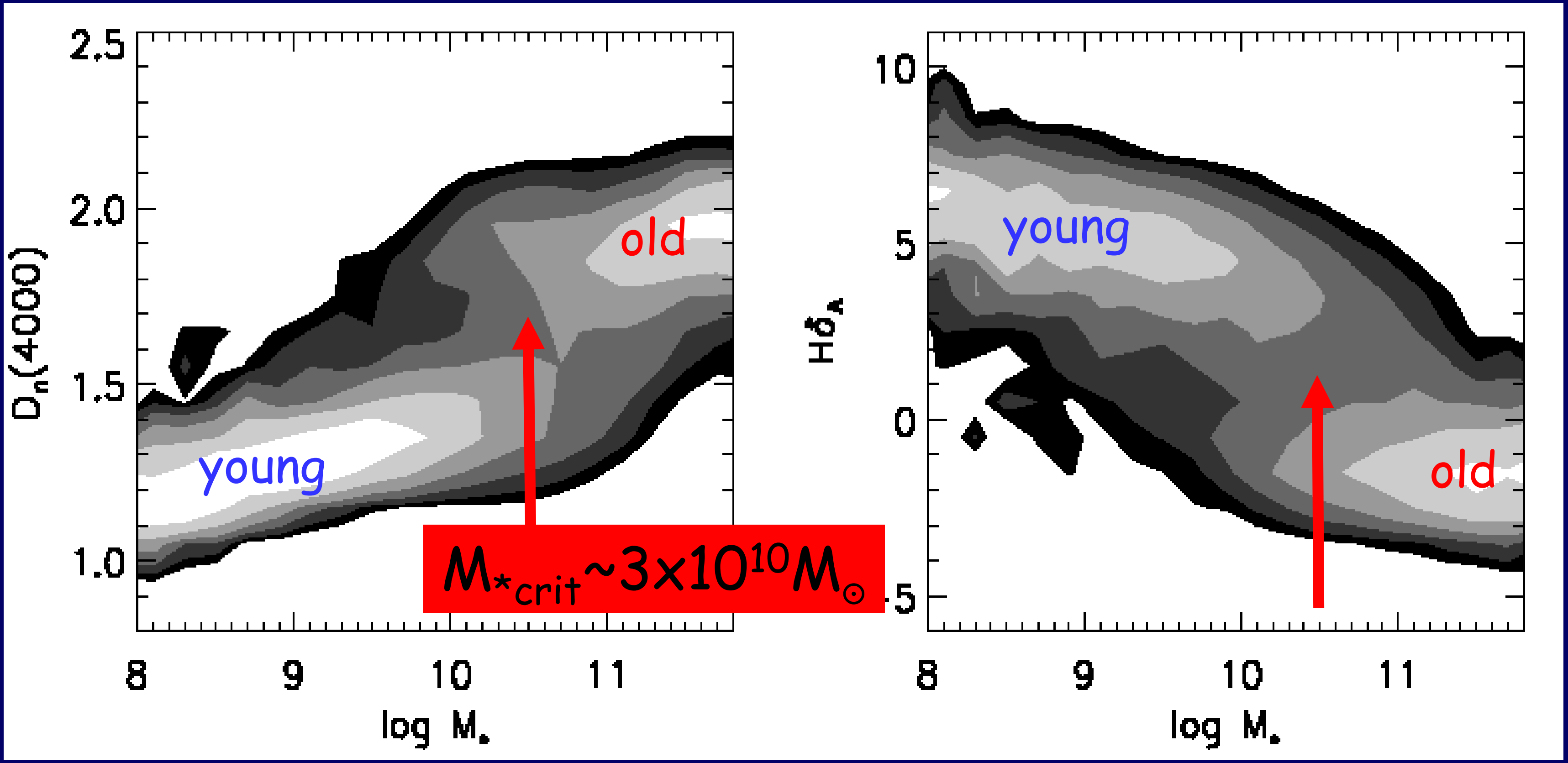
- Galaxy bimodality: shutdown in big galaxies
- Shock heating vs cold flows: threshold mass
- AGN vs supernova feedback: maintenance
- Origin of the bimodality

Bi-modality in color and bulge/disk



Bell

Bi-modality: Age vs Stellar Mass

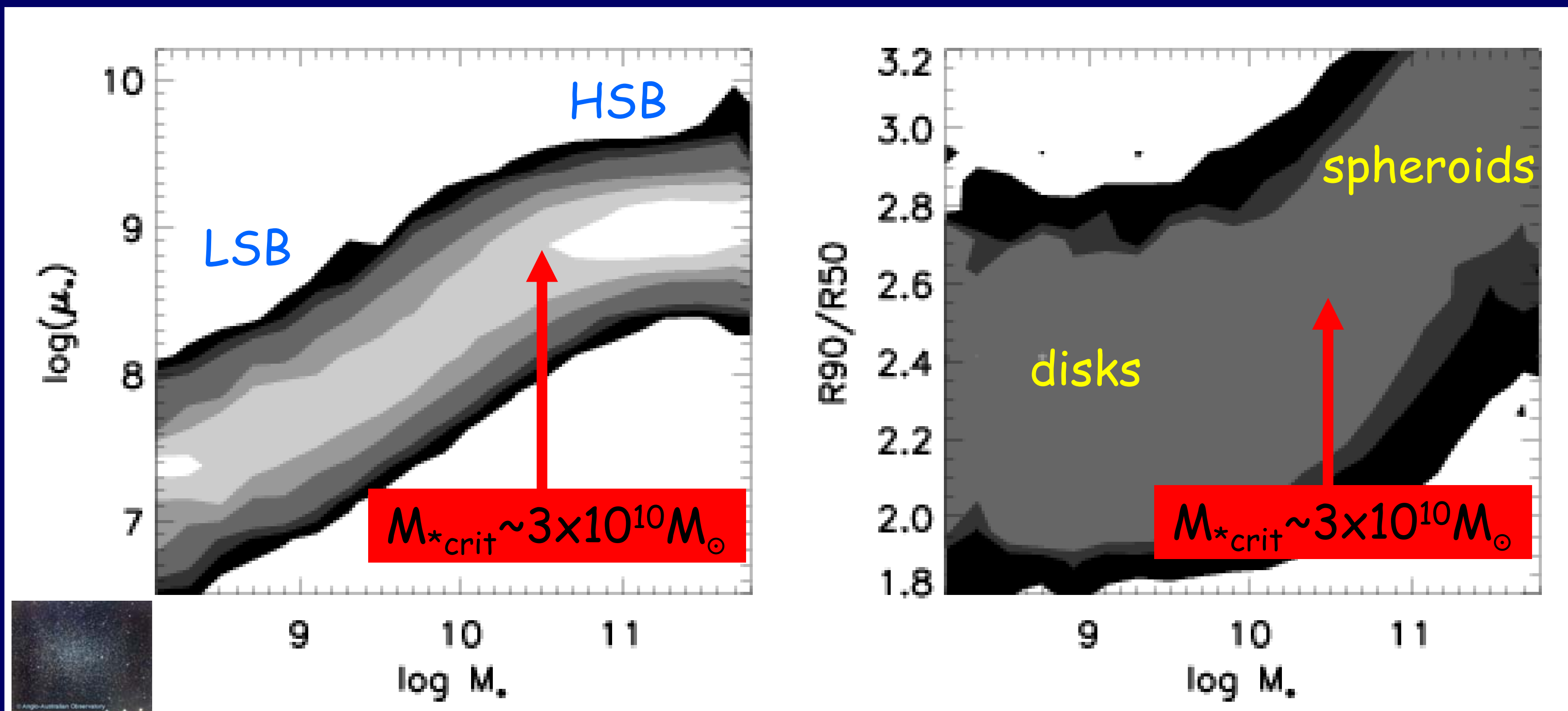


SDSS Kauffmann et al. 03

gas fraction: Sheila Kannappan

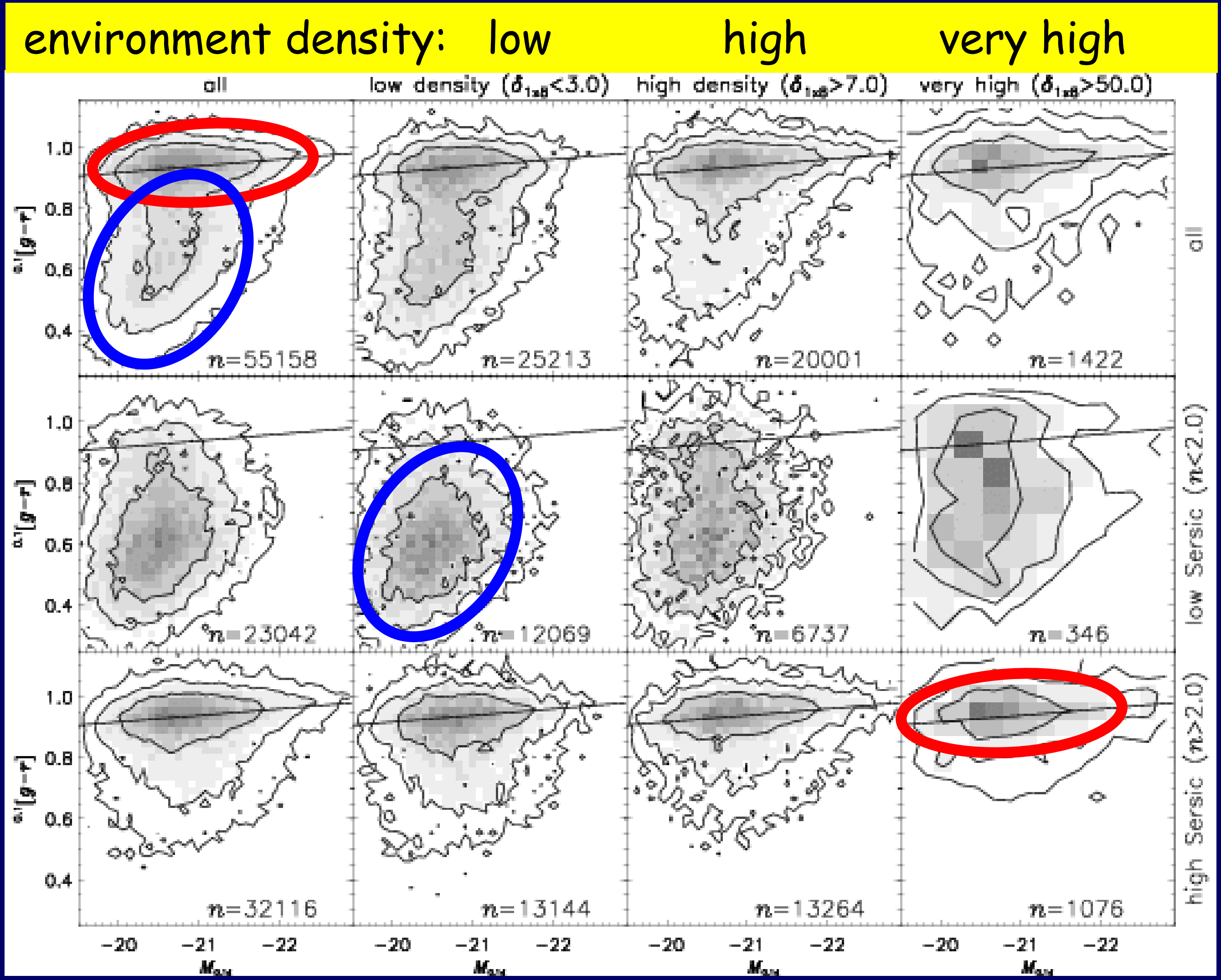
Transition Scale

Surface Brightness　　　　Bulge/Disk



SDSS Kauffmann et al. 03

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

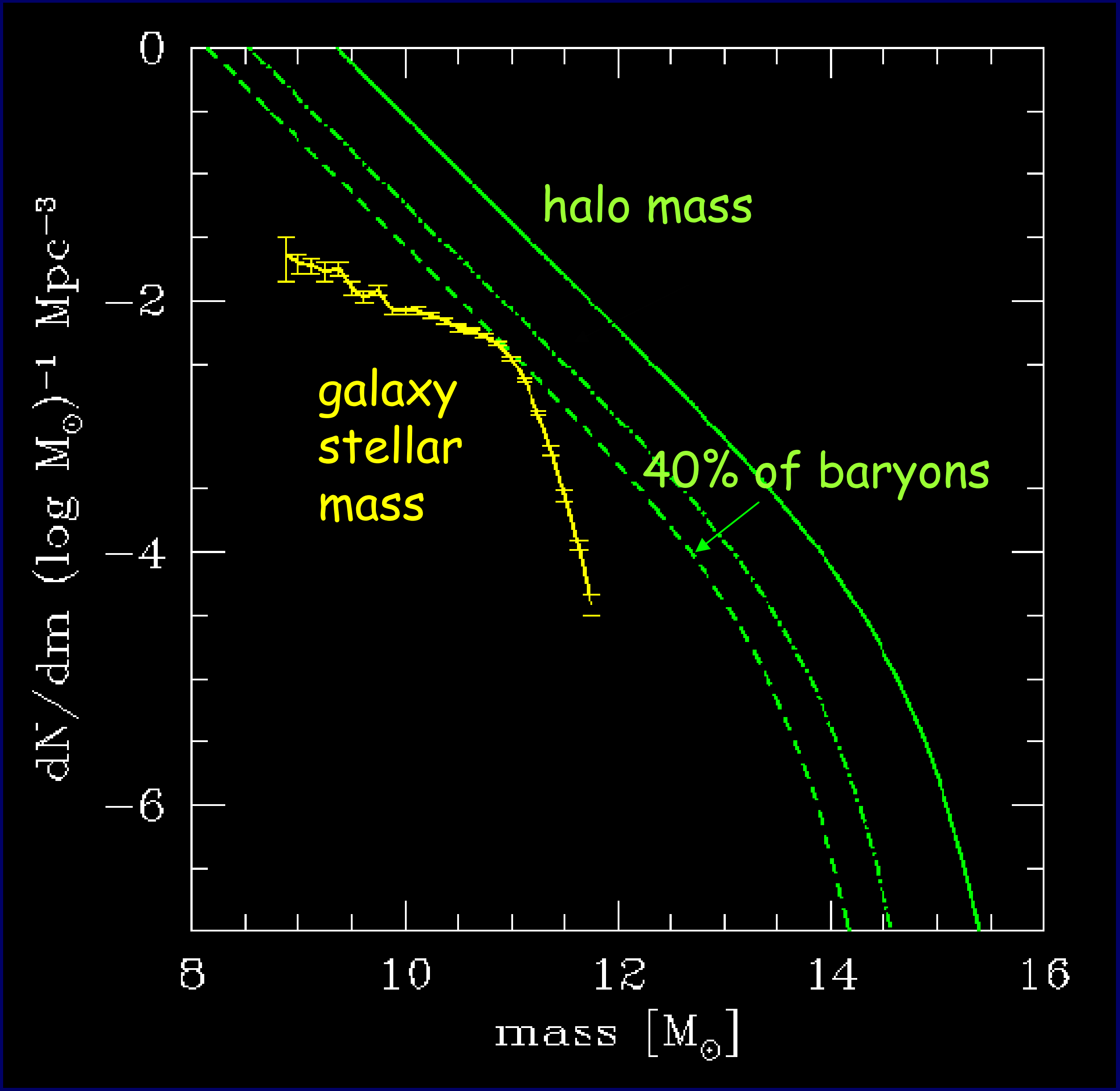


$M_{halo}<6\times10^{11}$
"field"

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

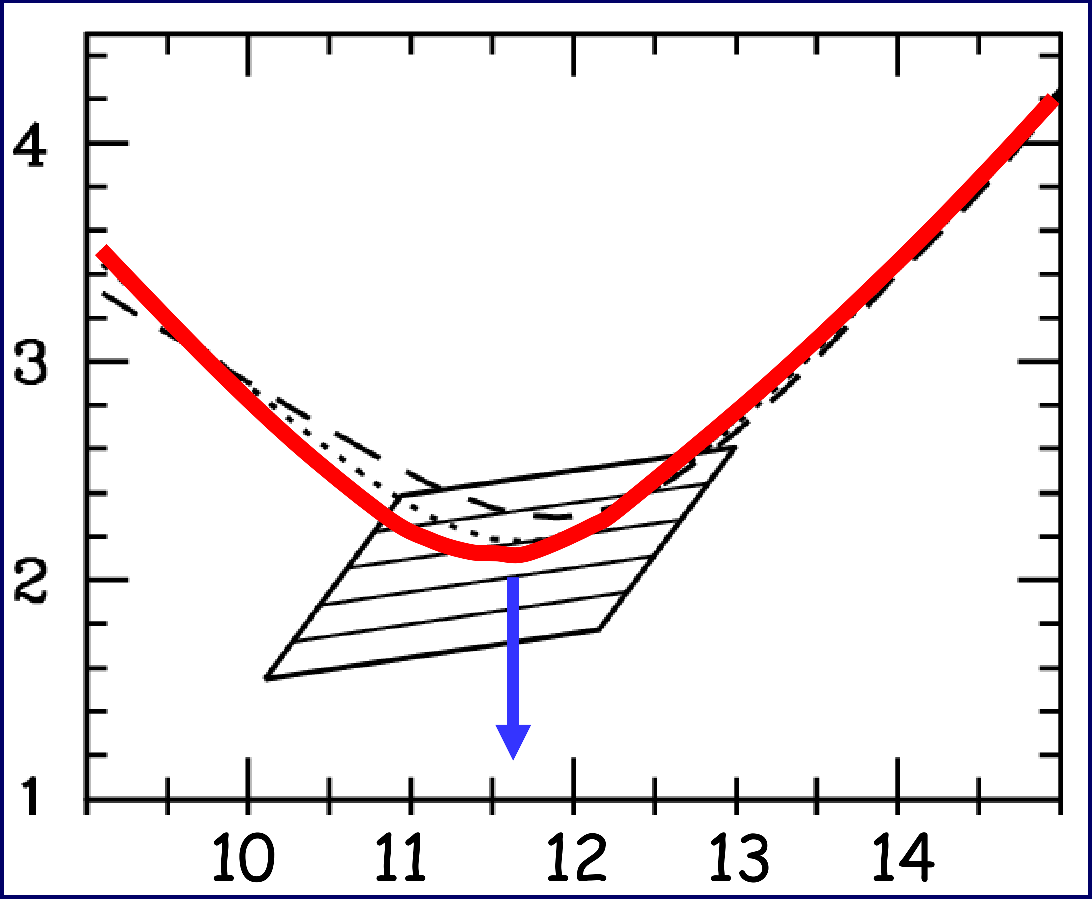
SDSS: Hogg et al. 03

Mass versus Light Distribution



‹M/L› vs M for halos in 2dF assuming ΛCDM

M/L



M

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

Observed Characteristic Scale

- bi-modality/transition at

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

below: disks, blue, star forming,
in field (small halos)

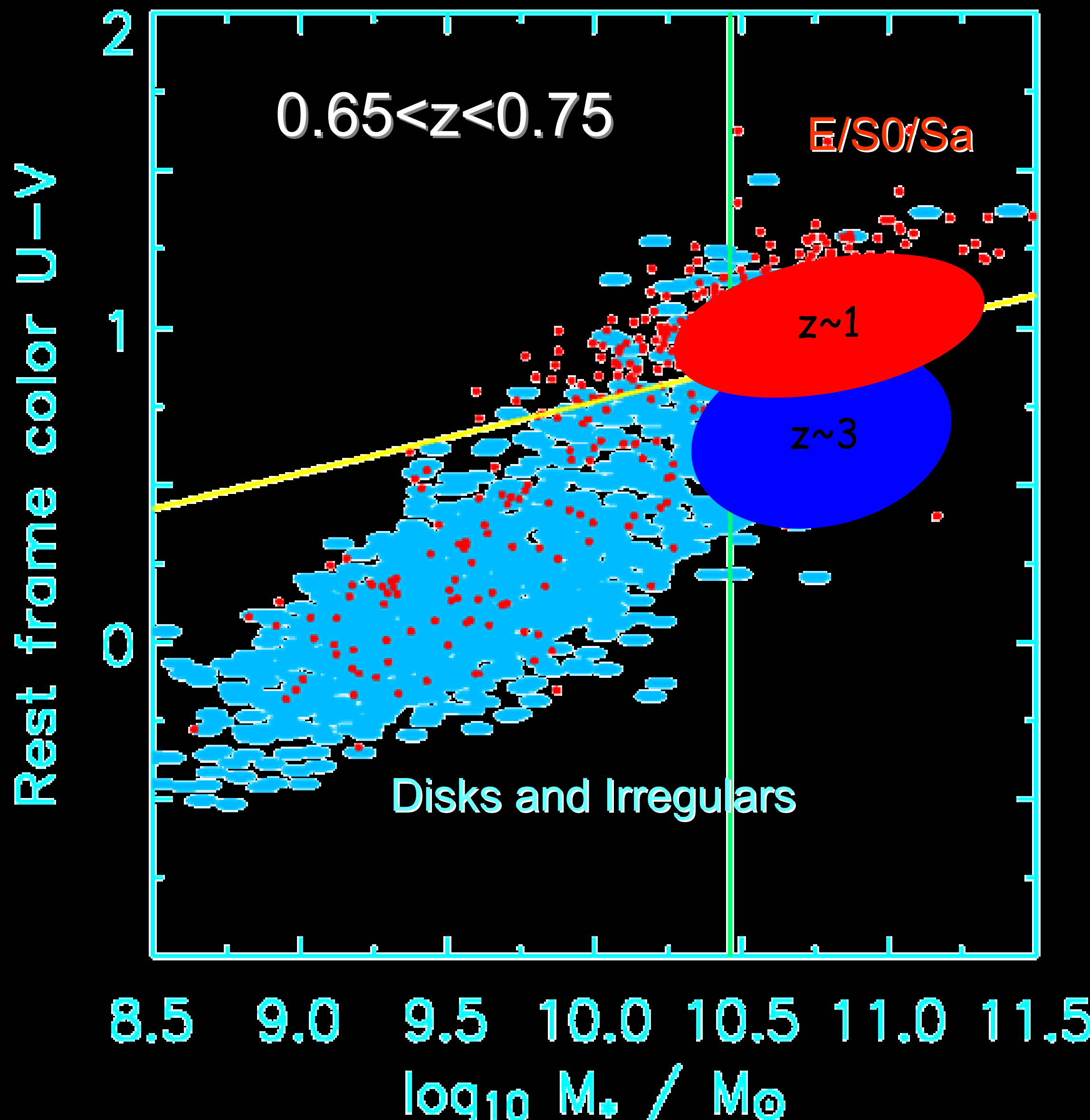
above: spheroids, red, old stars,
clustered (massive halos)

- very blue gal's → **regulated** starbursts

- big blue galaxies at very early times z~2-3
→ **early** star formation in big objects

- luminous red galaxies at early times z~0-1
→ early star formation, then **shutdown**

Bi-modality in color and bulge/disk



Bell

2. Shock-Heating vs Cold Flows: Threshold Mass

Birnboim & Dekel 2003; Dekel & Birnboim 2006

Standard Picture of Infall to a Disk

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

Perturbed expansion

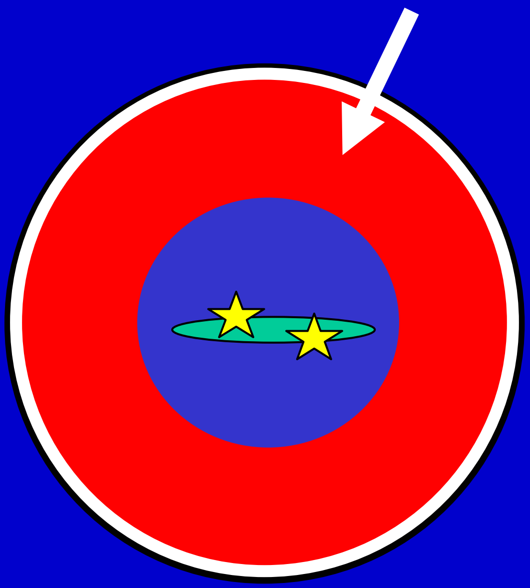
Halo virialization

Gas infall, shock heating at the virial radius

Radiative cooling

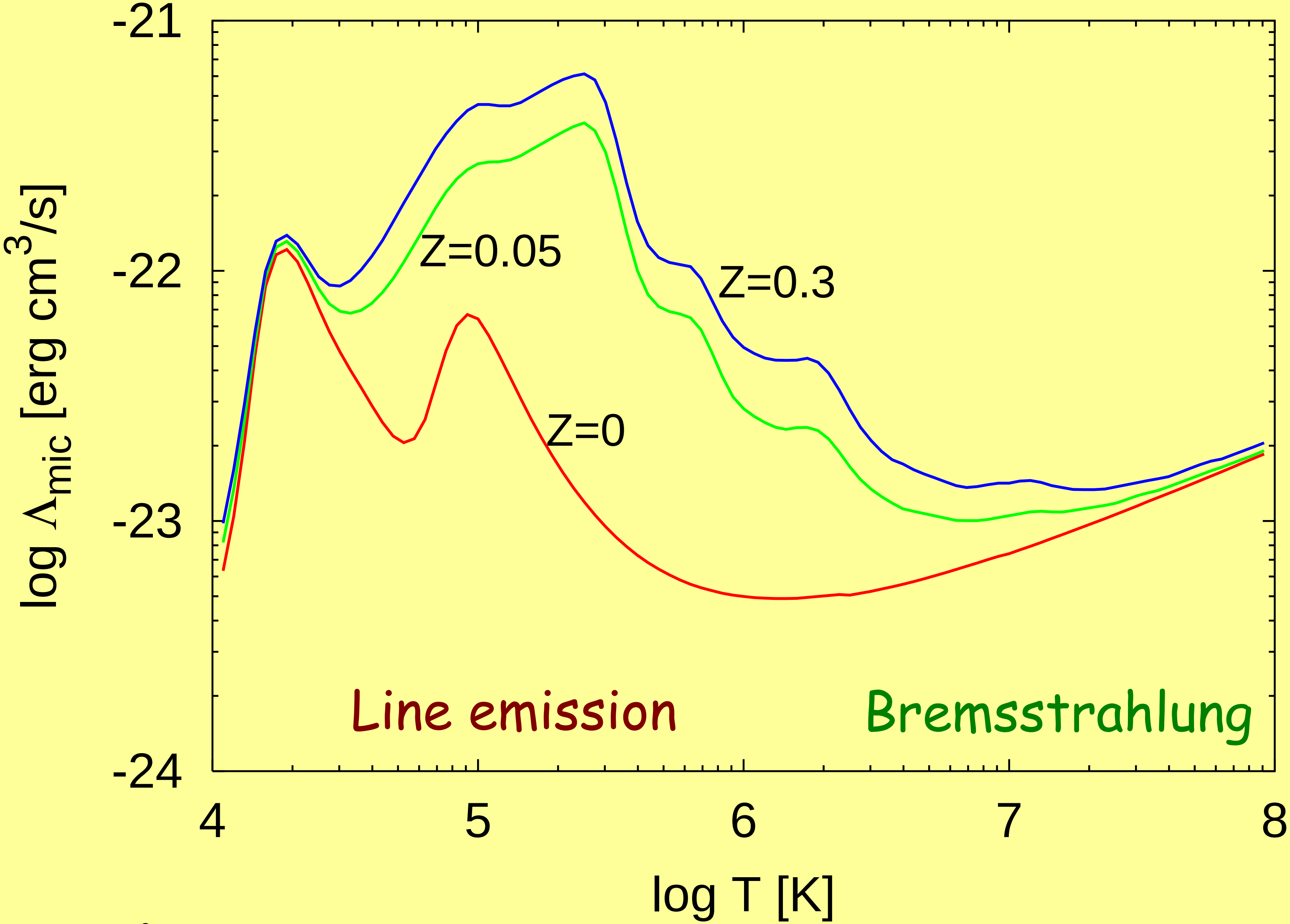
Accretion to disc if $t_{cool} < t_{ff}$

Stars & feedback



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

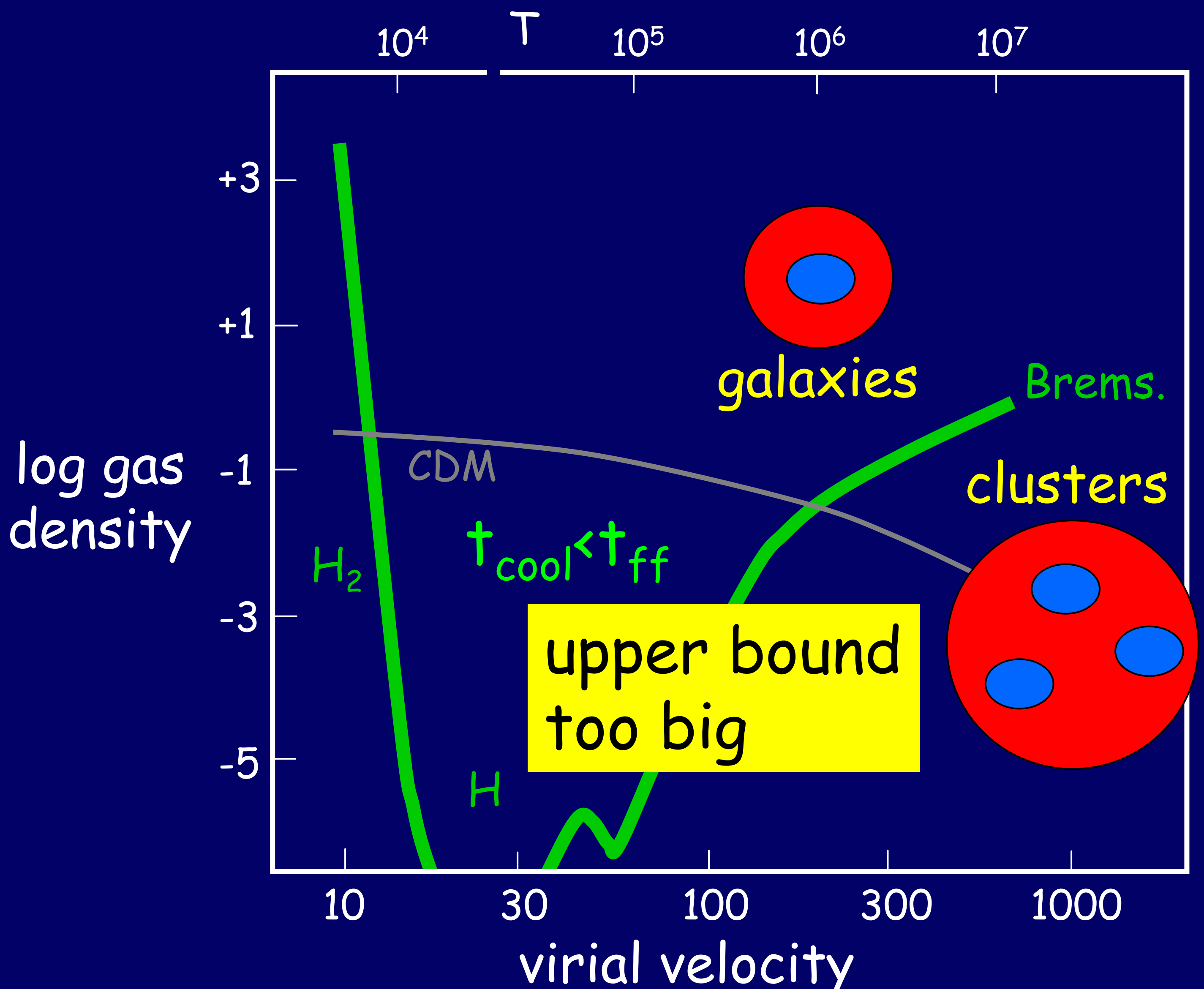
Cooling rate



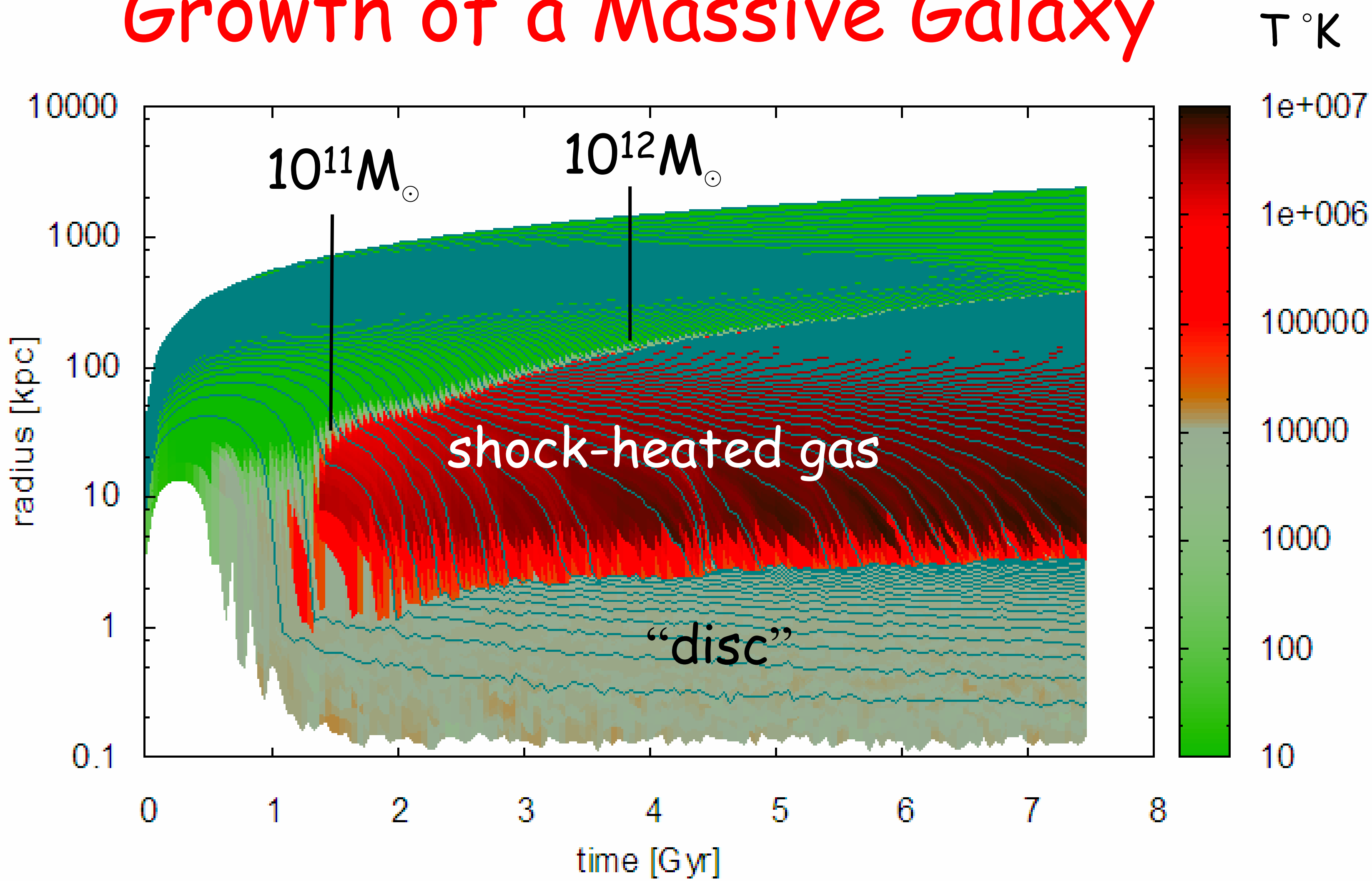
$$q = \frac{N_A{}^2 \chi^2}{\mu^2} \Lambda(T) \rho \quad [\text{erg g}^{-1}\ \text{s}^{-1}] \qquad N_A / \mu \ \text{molecules per g} \qquad \chi\ \text{e}^- \ \text{per particle}$$

Cooling vs Free Fall

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

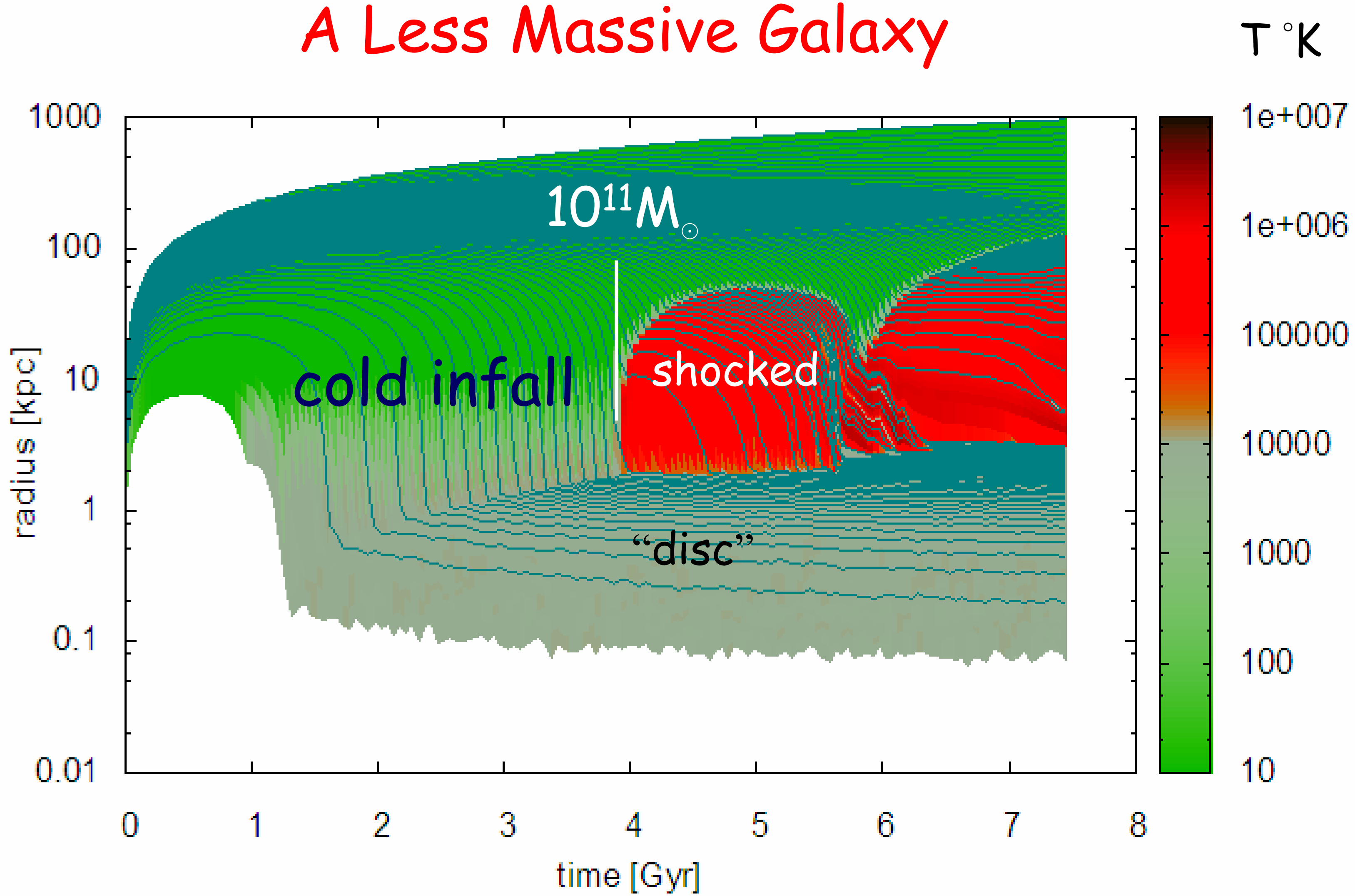


Growth of a Massive Galaxy



Spherical hydro simulation Birnboim & Dekel 03

A Less Massive Galaxy



Spherical hydro simulation

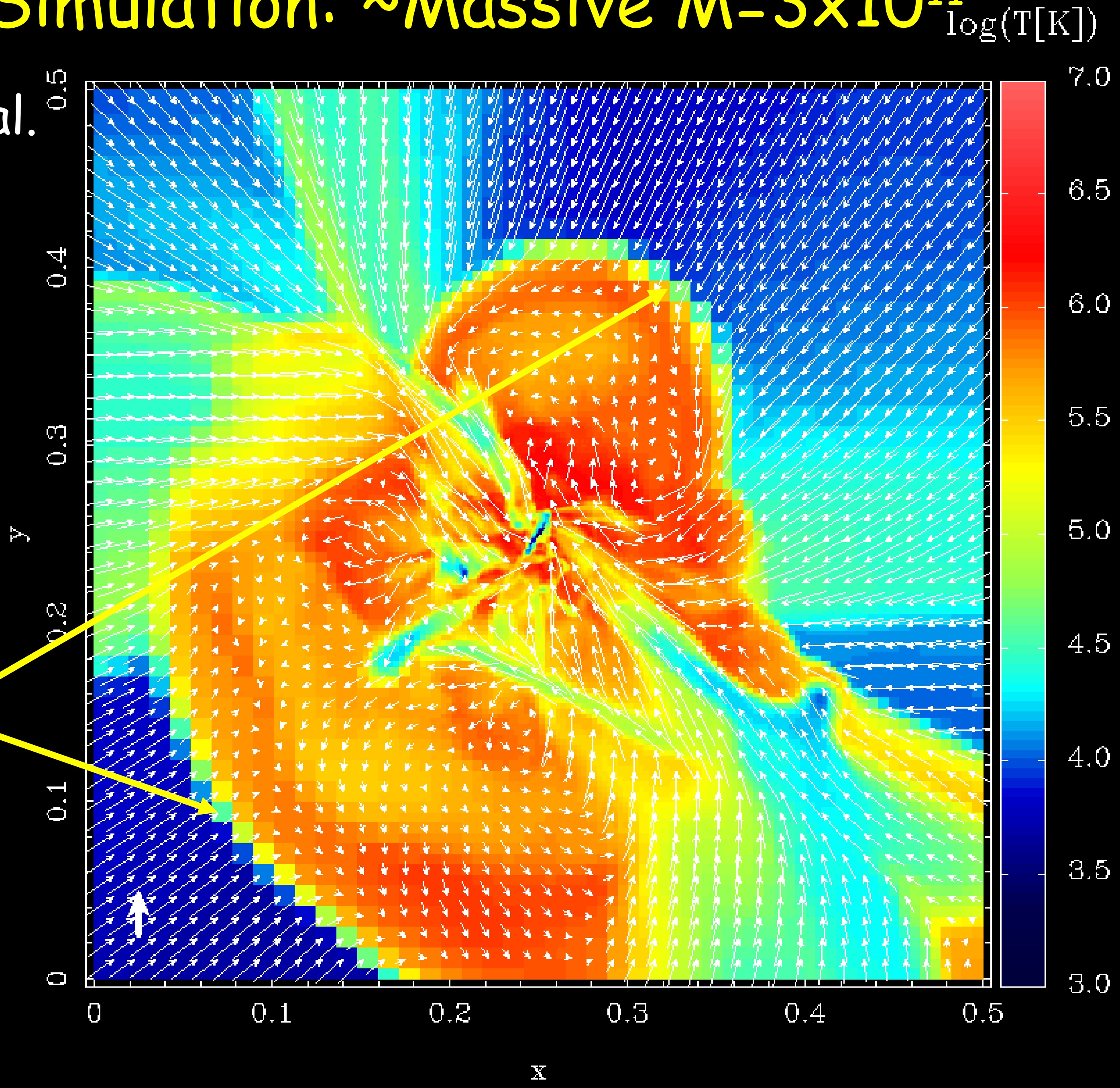
Birnboim & Dekel 03

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

Kravtsov et al.

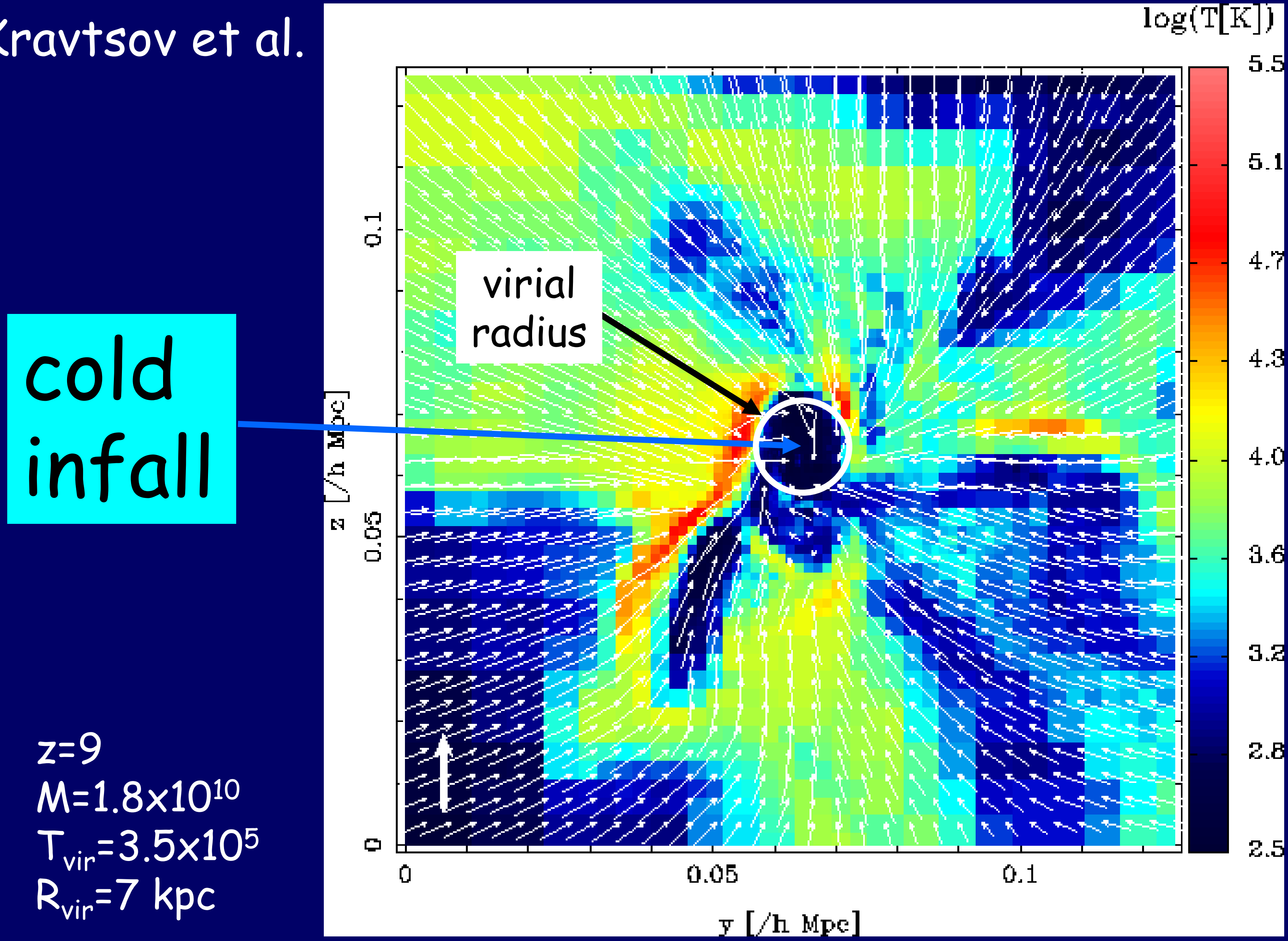
$z=4$
$M=3\times10^{11}$
$T_{vir}=1.2\times10^{6}$
$R_{vir}=34$ kpc

virial shock



Less Massive $M=1.8\times10^{10}$

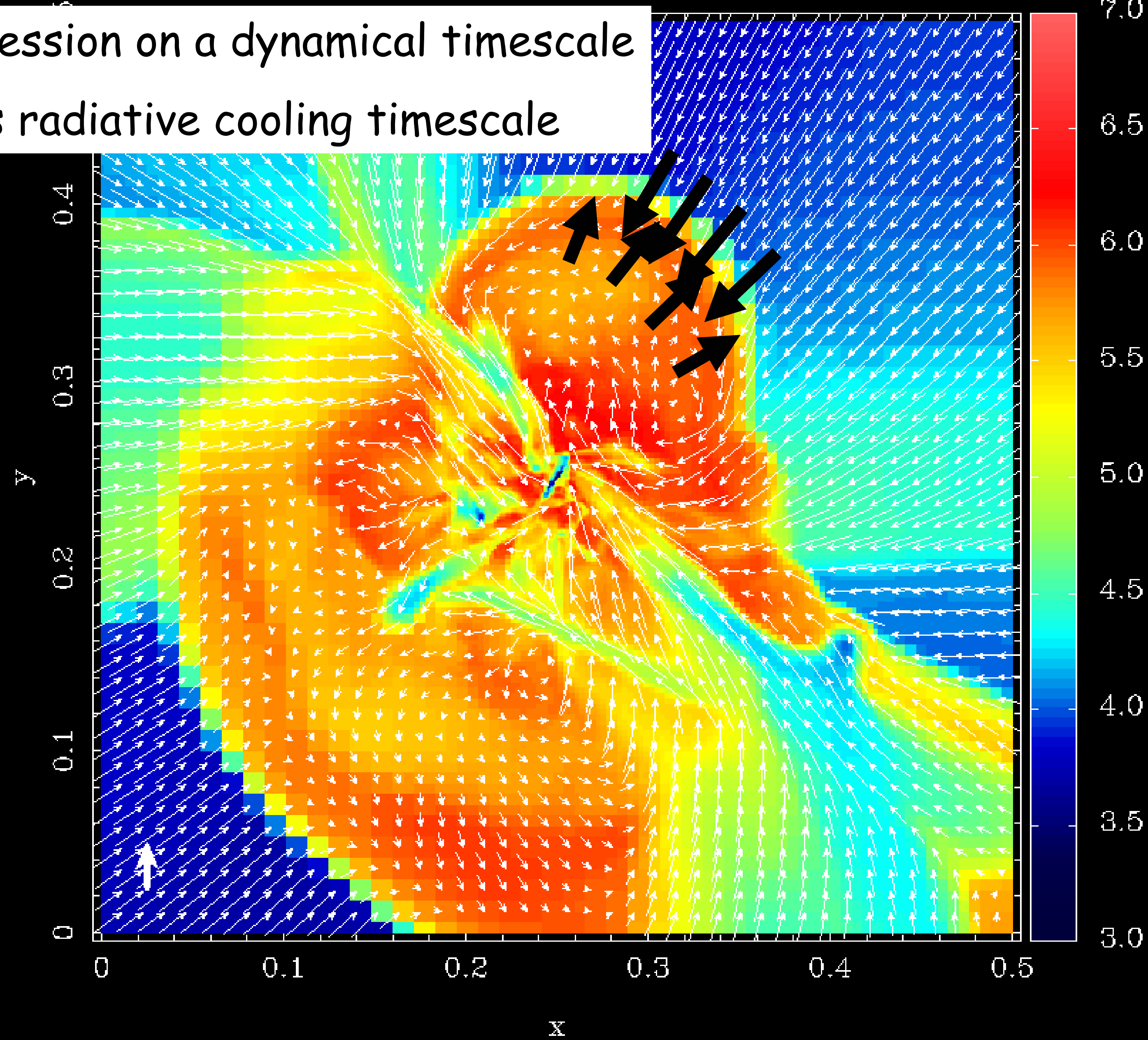
Kravtsov et al.



$z=9$
$M=1.8\times10^{10}$
$T_{vir}=3.5\times10^5$
$R_{vir}=7$ kpc

Gas through shock: heats to virial temperature

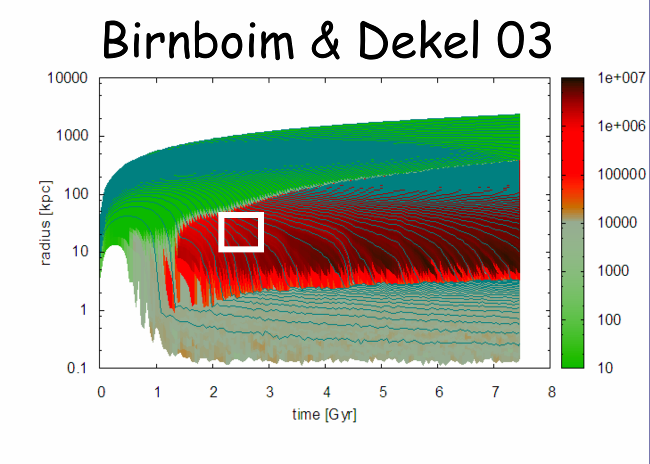
compression on a dynamical timescale
versus radiative cooling timescale



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):

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

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

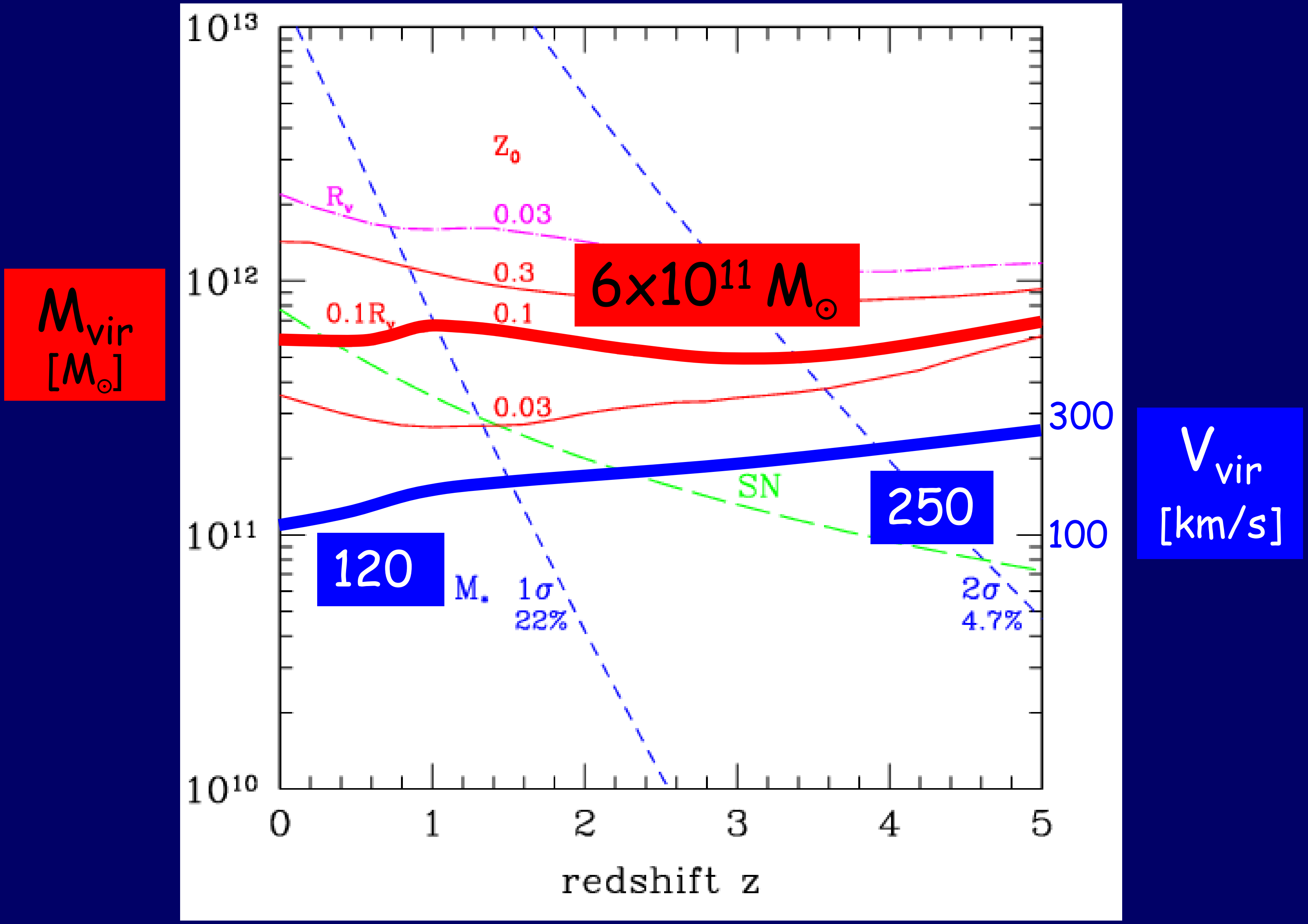
$$t_{comp} \equiv \frac{21}{5} \frac{\rho}{\dot{\rho}} \approx \frac{4}{3} \frac{R_s}{V}$$

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

Stability criterion: $\gamma_{eff} > \frac{10}{7}$ $\longrightarrow$

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

Shock-Heating Scale



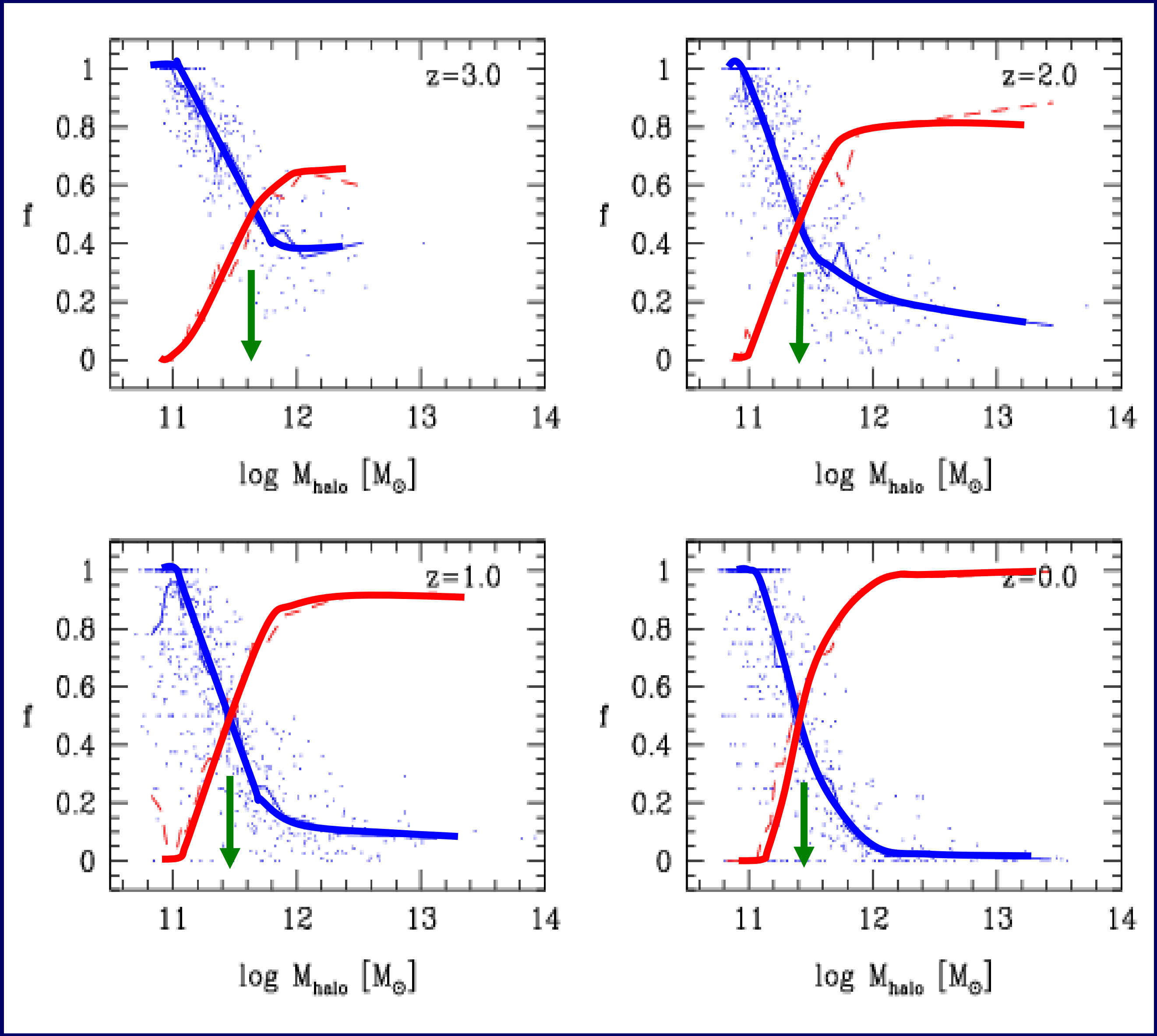
Fraction of cold/hot accretion

SPH simulation

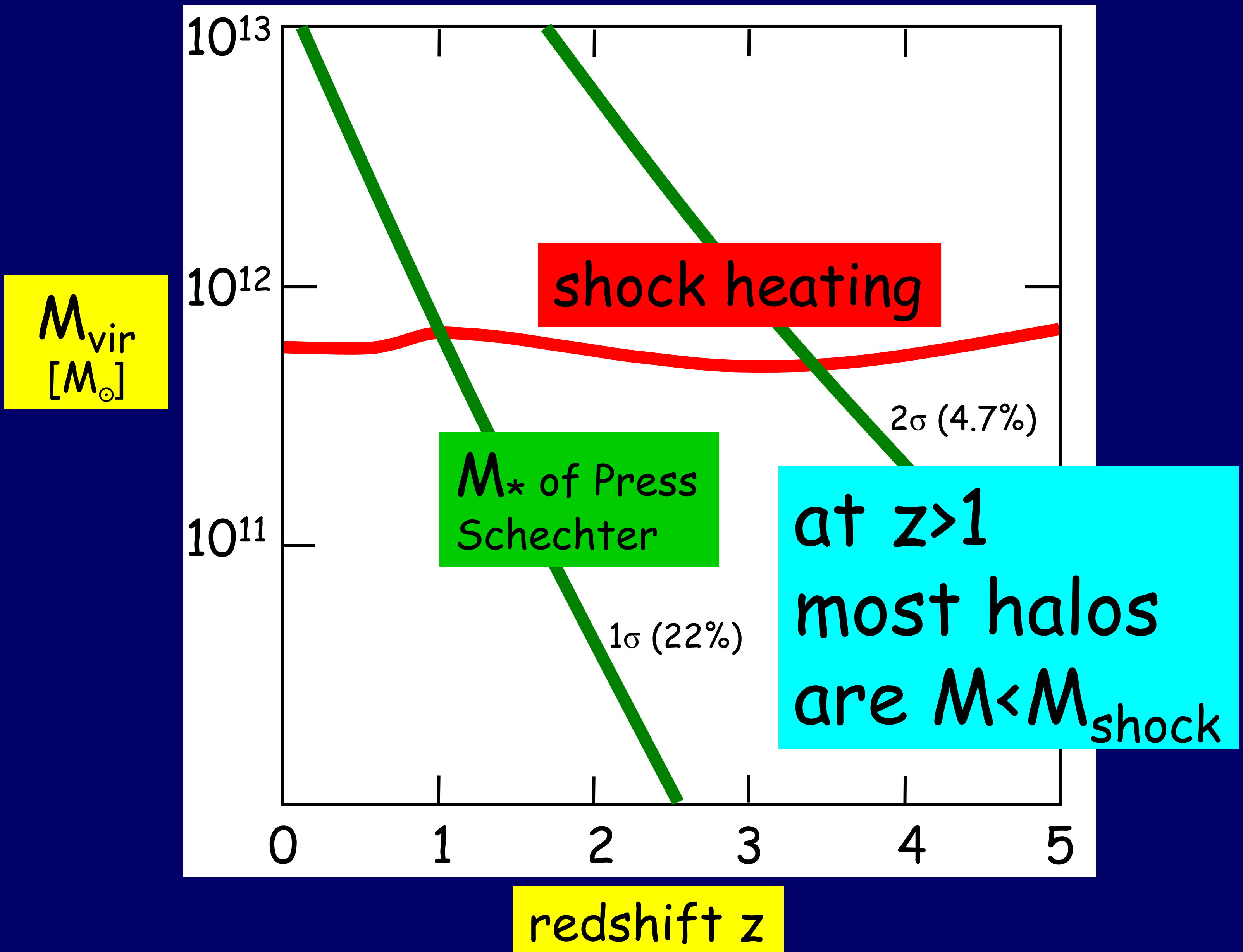
Keres, Katz, Weinberg, Dav'e 2004

Z=0, under-estimating M_{shock}

sharp transition



Cold Flows in Typical Halos

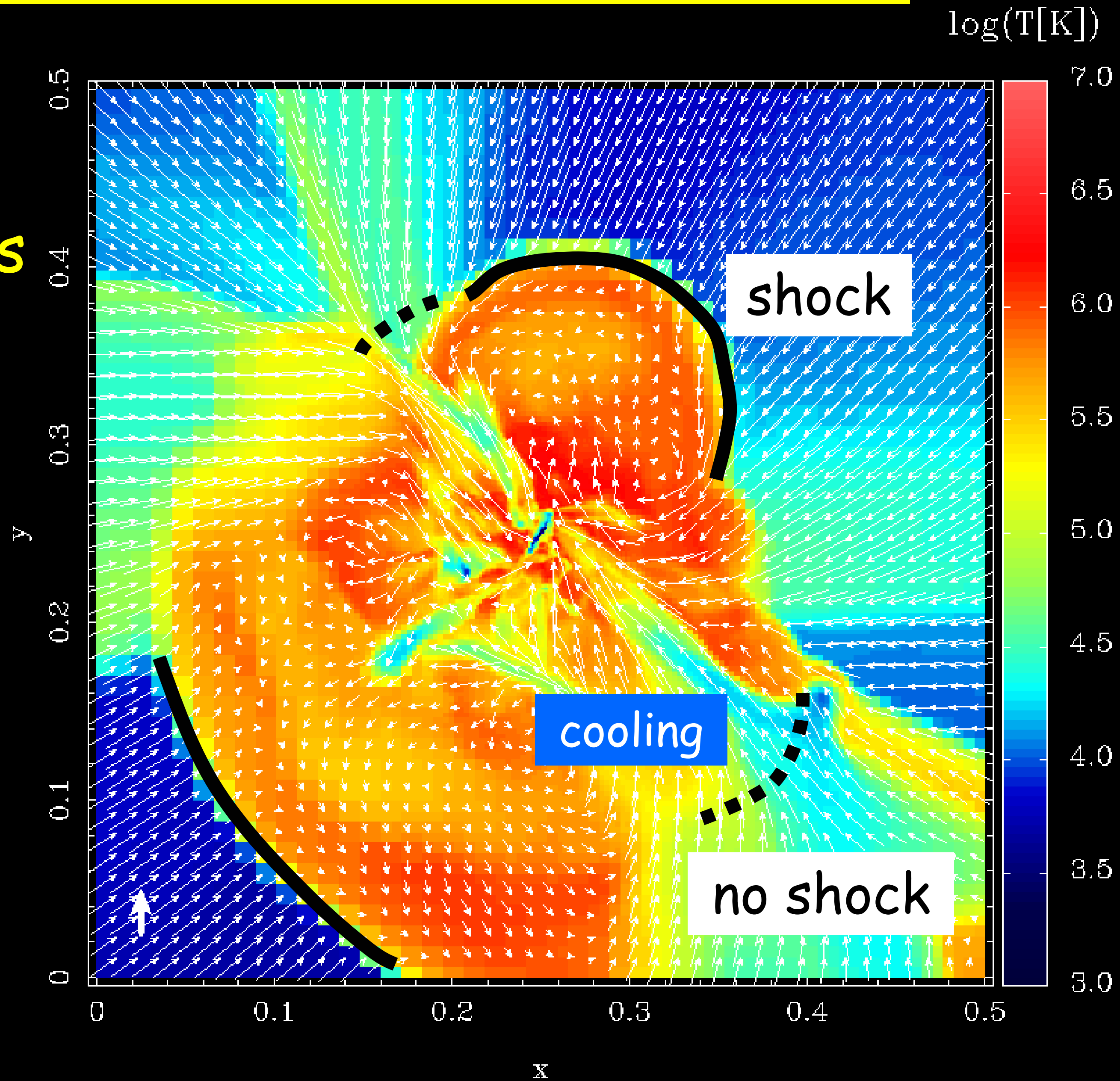


Cold Streams in a Hot Medium

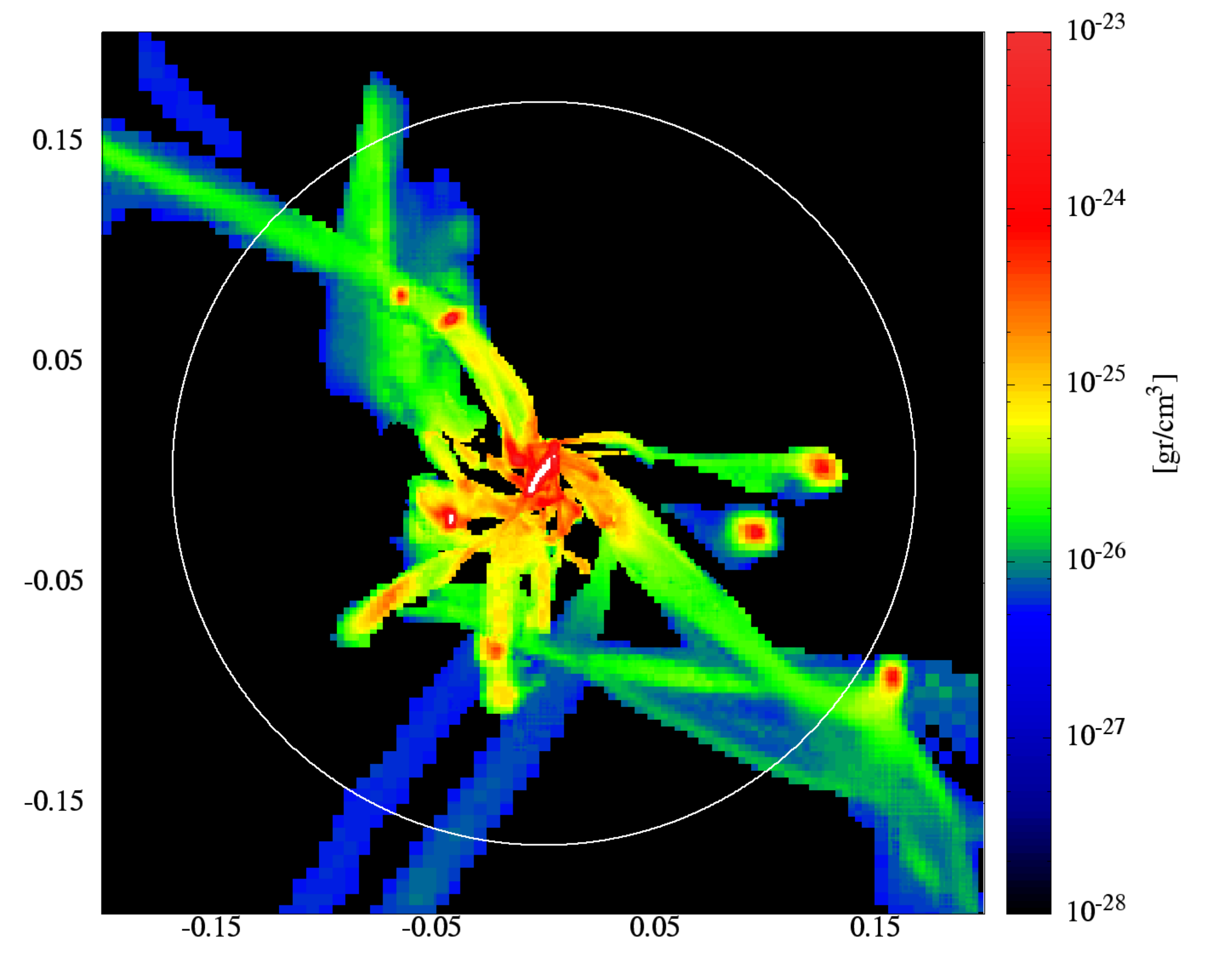
$M > M_{shock}$

Cold streams at z>2

Totally hot at z<1



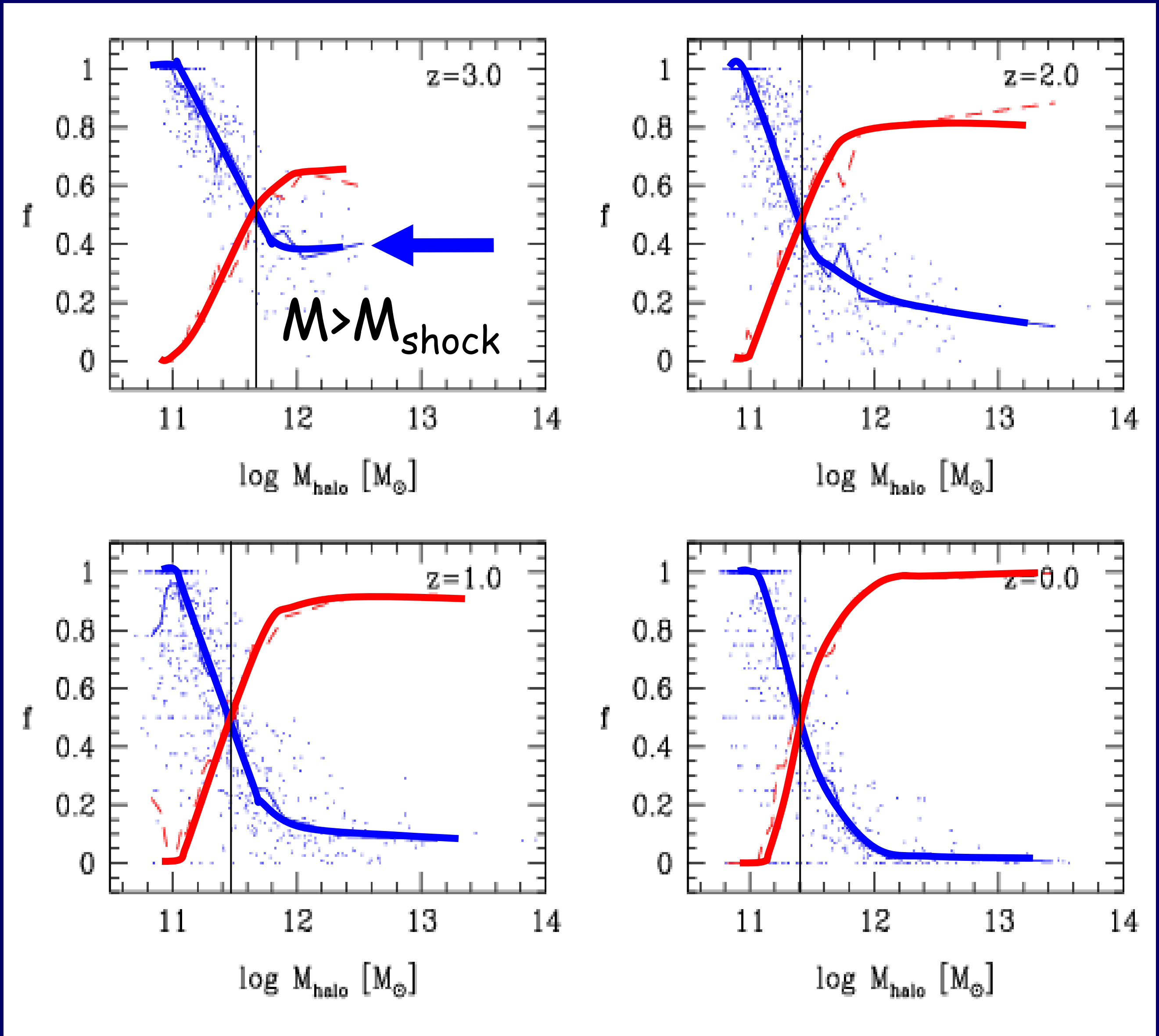
Cold, dense filaments and clumps (50%) riding on dark-matter filaments and sub-halos



Birnboim, Zinger, Dekel, Kravtsov

Fraction of cold/hot accretion

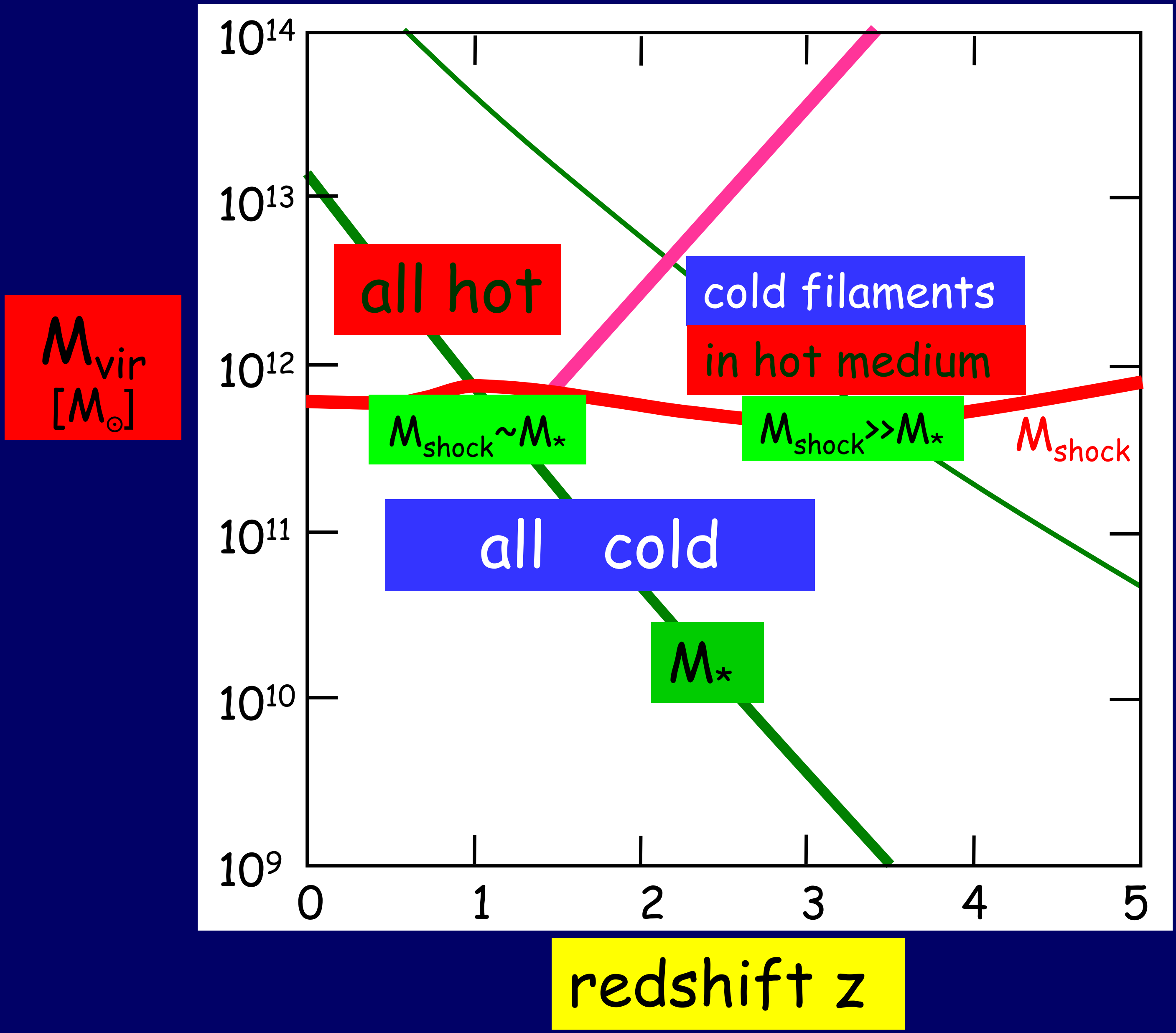
cold streams in hot media at high z



SPH simulation

Keres, Katz, Weinberg, Dav'e 2004

Shock-Heating vs Clustering Scale



Once the halo gas is shock heated, what keeps it hot?

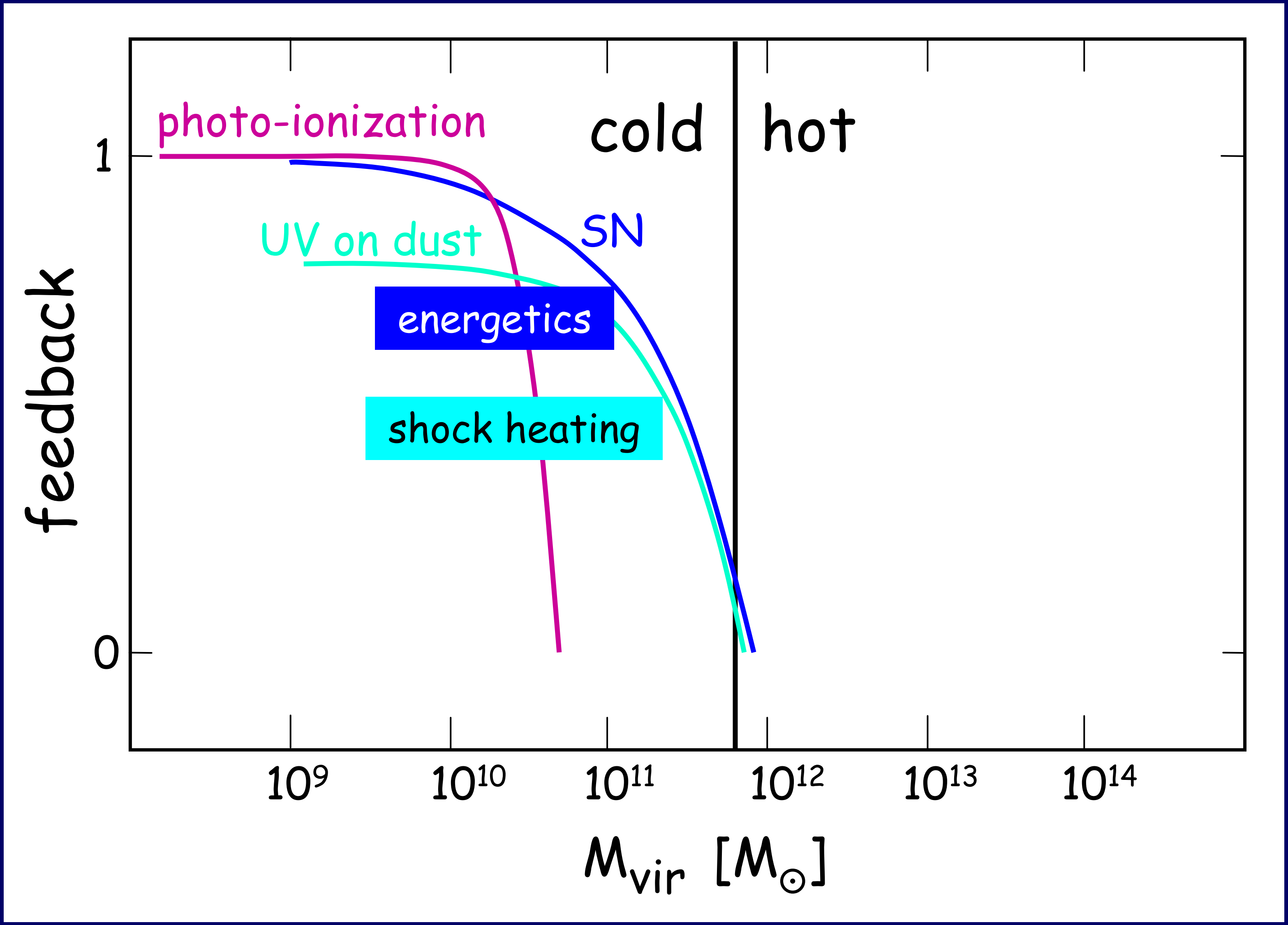
3. Feedback Processes

and the shock-heating scale

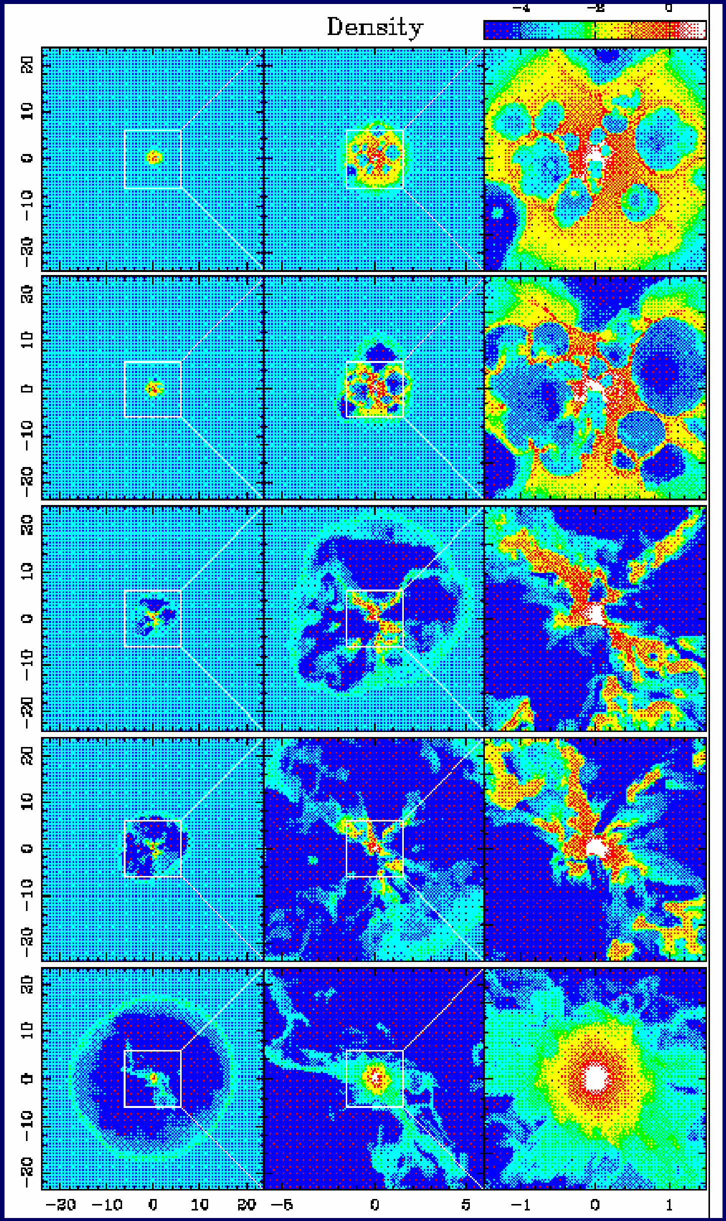
Supernova feedback

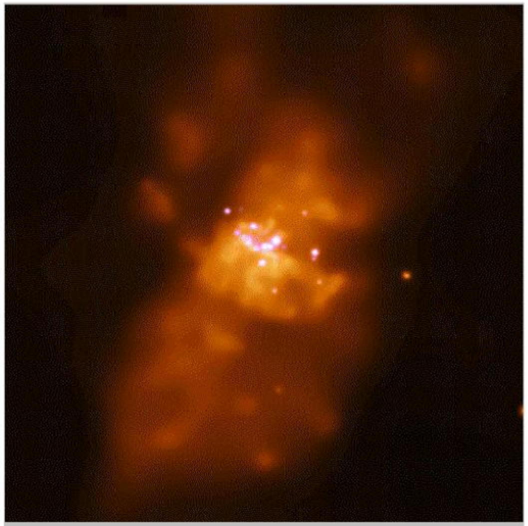
AGN feedback

Below the Shock-Heating Mass



Supernova Feedback



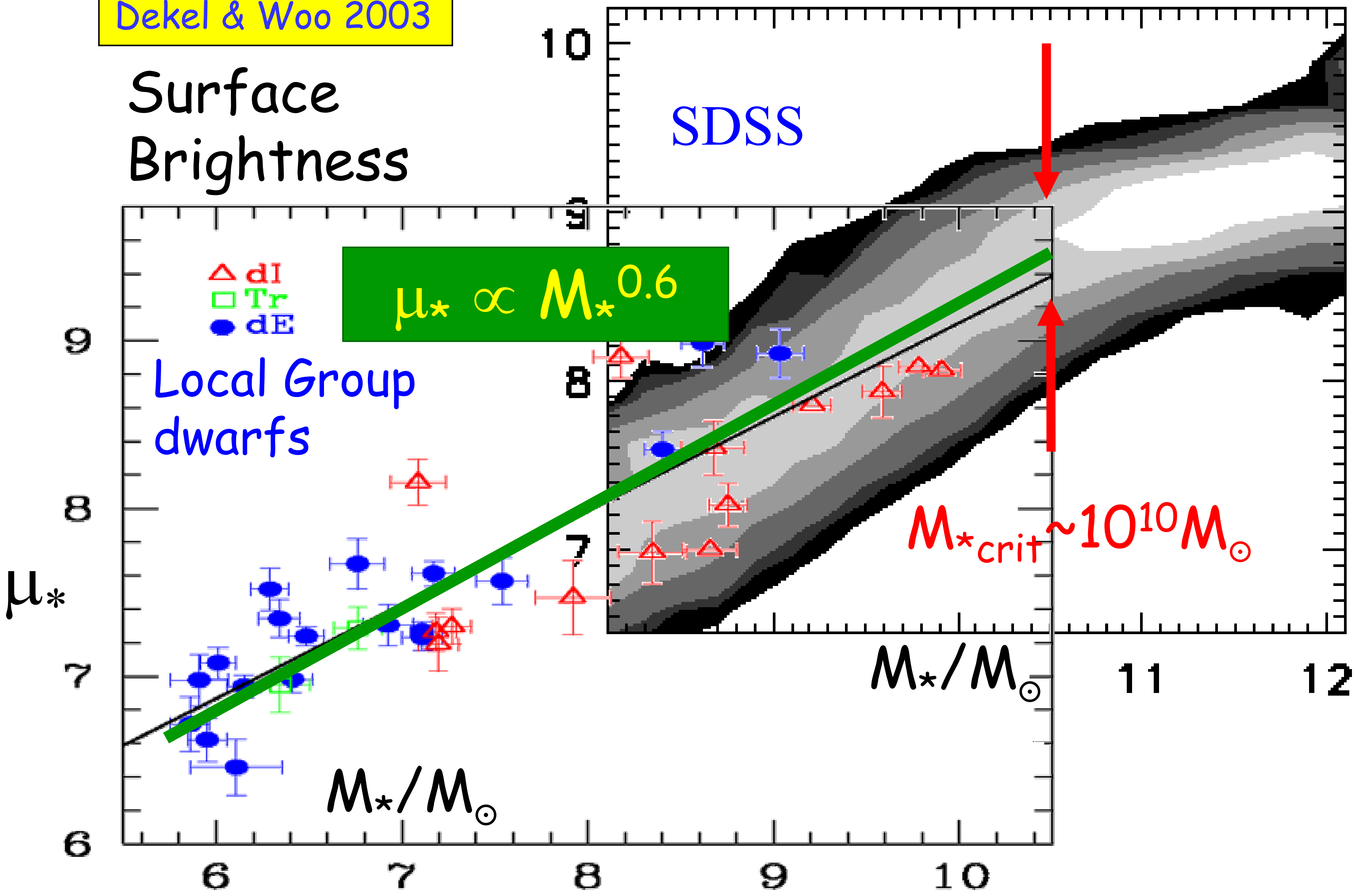


Chandra X-Ray Observatory image of M82

Mori et al.

"Fundamental Line" of LSB/Dwarfs

Dekel & Woo 2003



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 $T \sim 10^5 K$

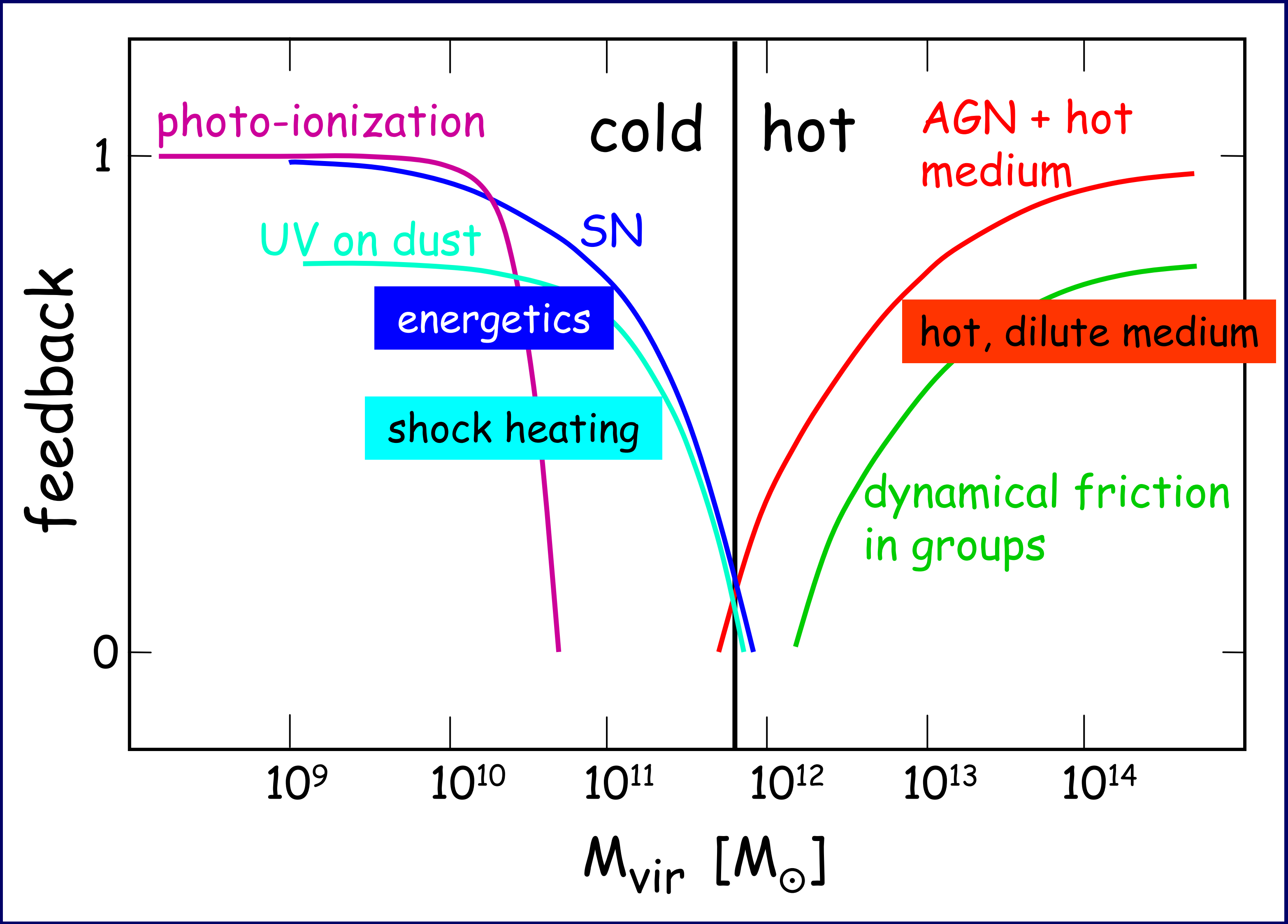
Energy required for blowout:

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

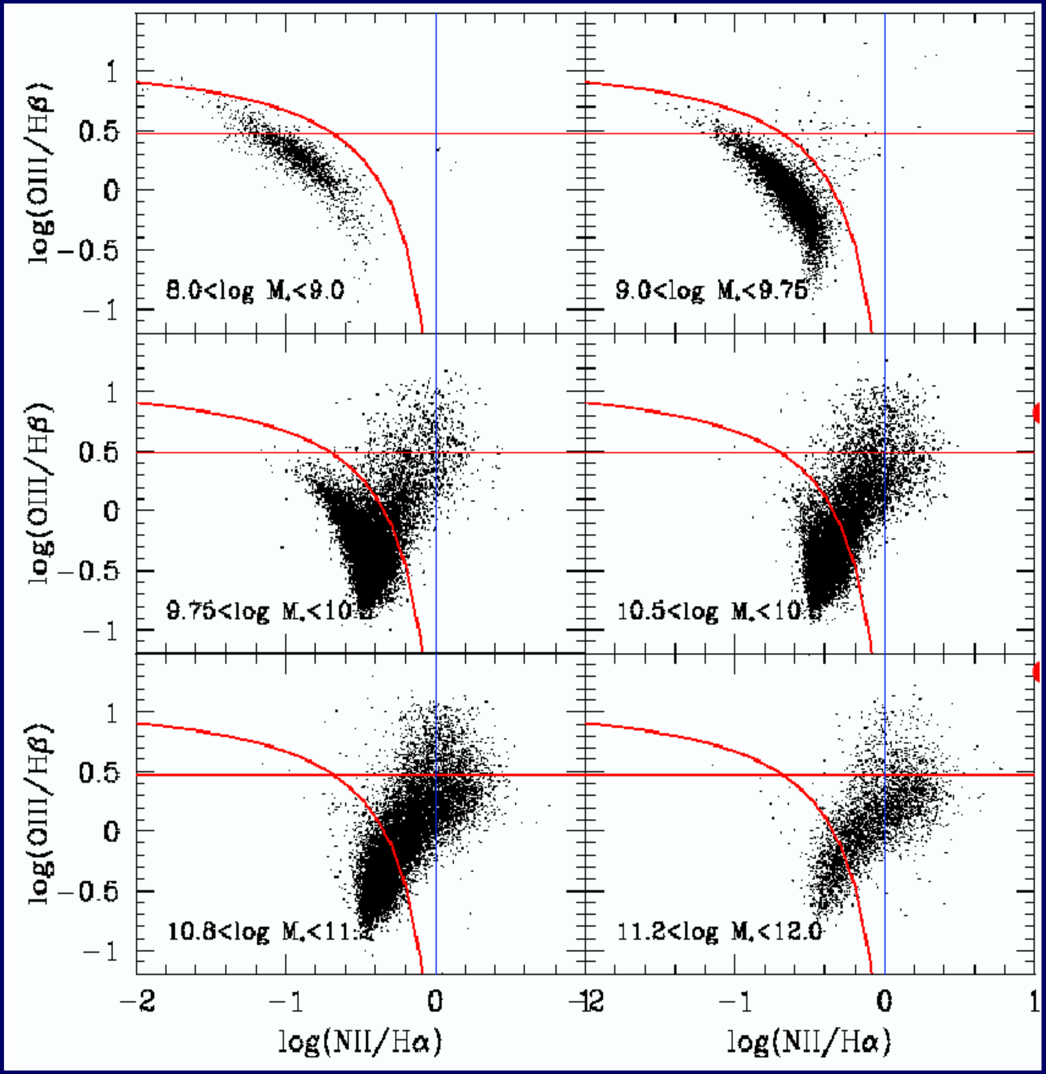
$$\rightarrow \quad V_{\rm crit} \approx 120 \text{ km/s} \quad \rightarrow \quad M_{\rm crit} \approx 7\times 10^{11} M_\circ$$

SN feedback only in small galaxies

Above the Shock-Heating Mass



Emission Properties vs. Stellar Mass



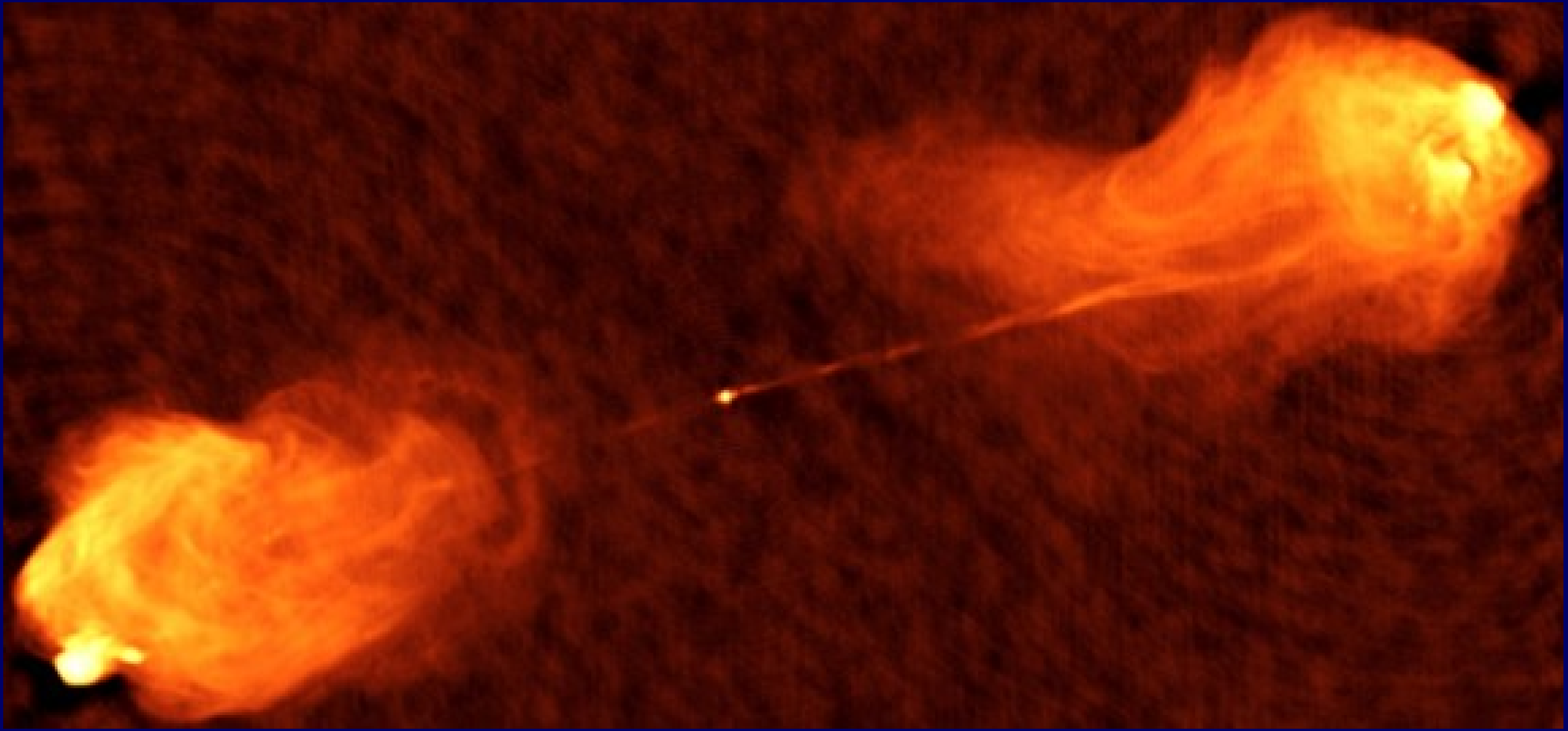
low-mass emission galaxies are almost all star formers

high-mass emission galaxies are almost all AGN

Kauffmann et al. 2004

AGN Feedback: how does it work?

How is the energy emitted from the "microscopic" black hole transferred to the gas on galactic scales?



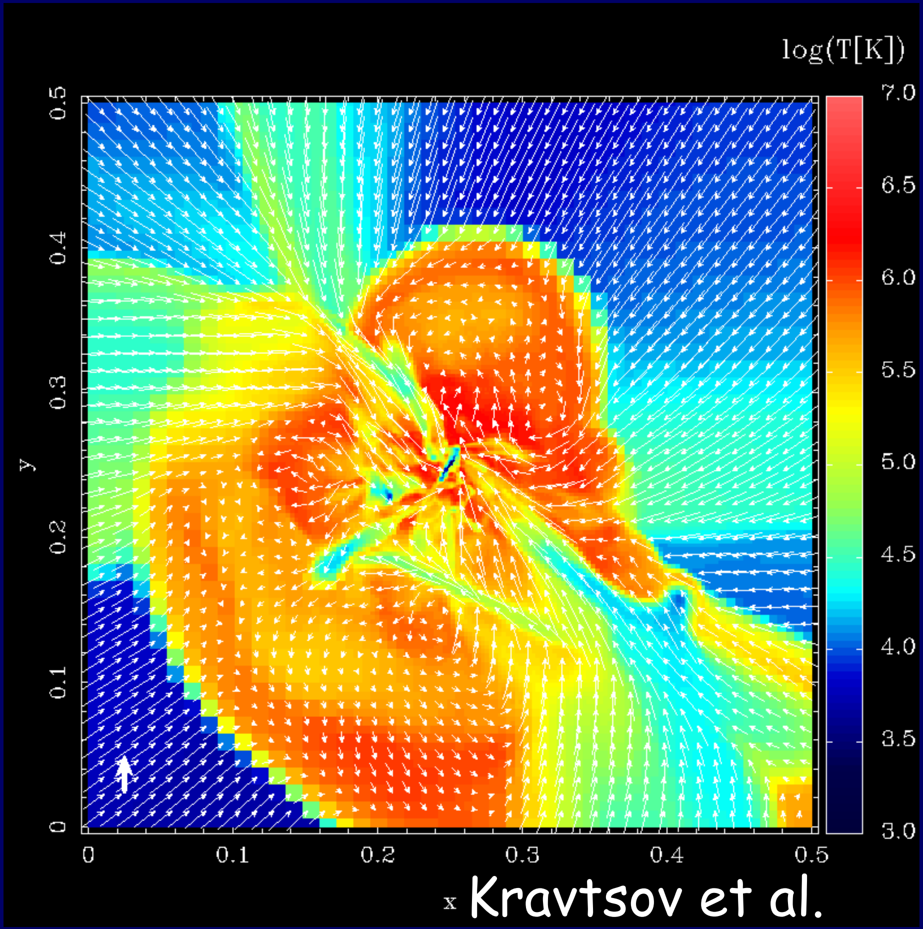
Shock Heating Triggers AGN Feedback

$M > M_{shock}$

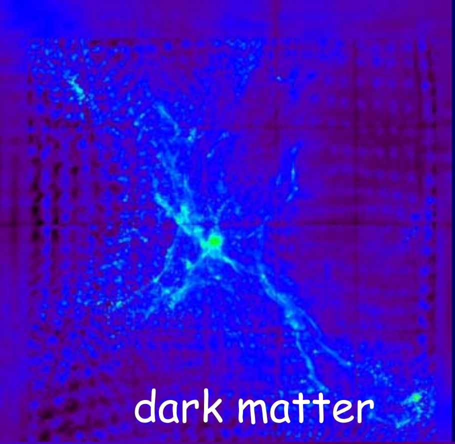
More than enough energy is available in AGNs

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

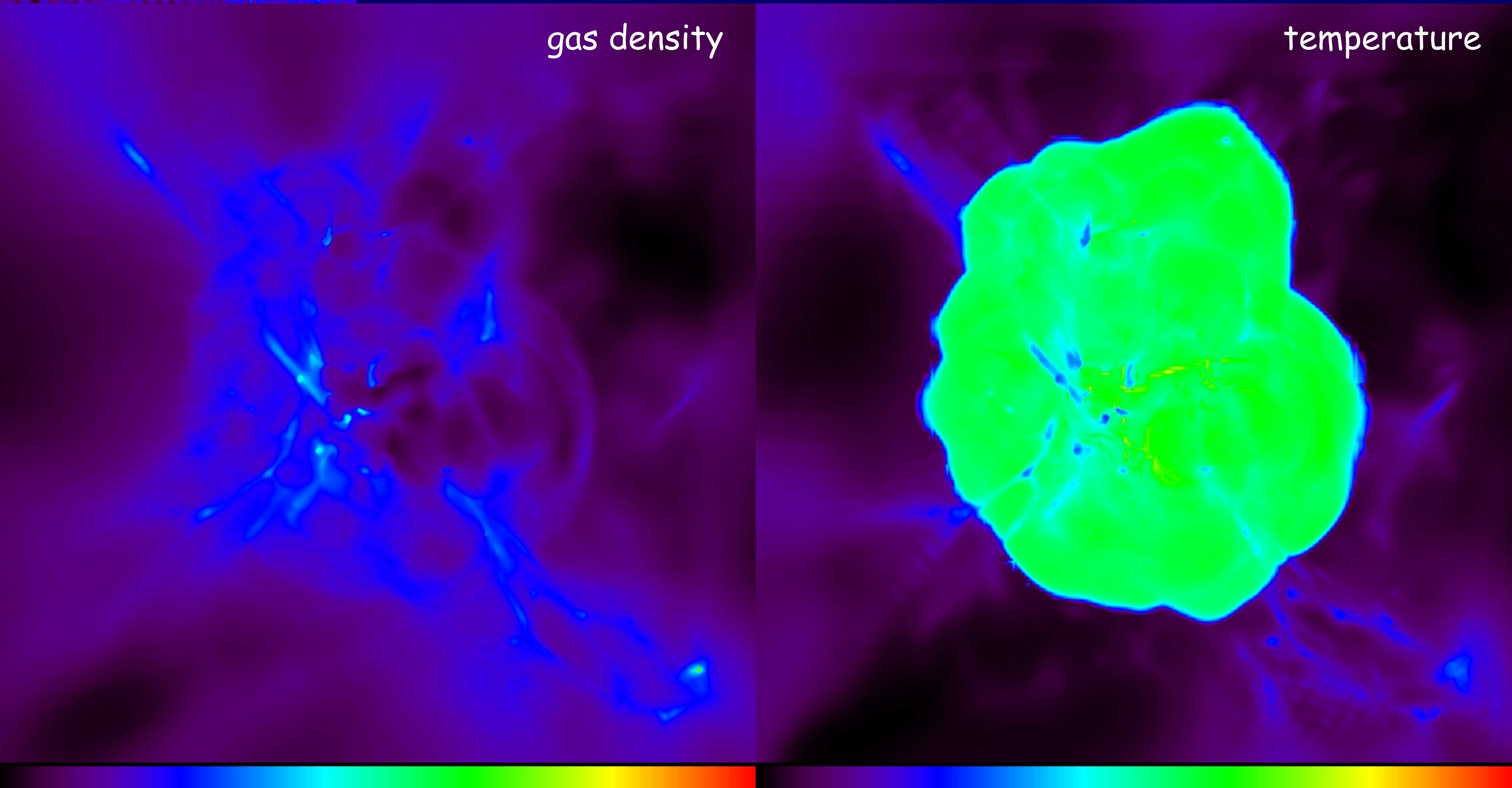
→Shock heating is the trigger for AGN feedback in massive halos



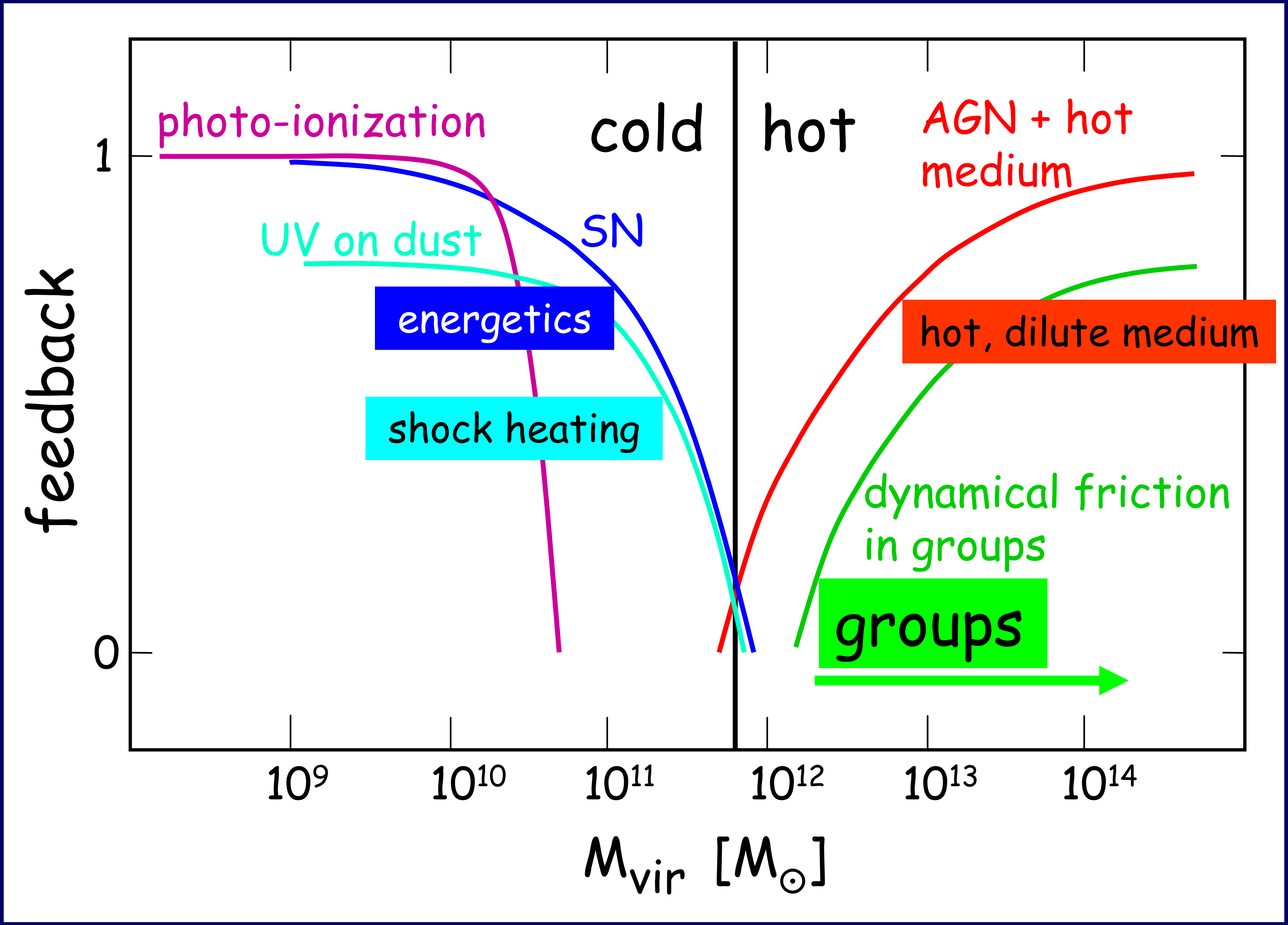
Introduces the necessary threshold mass



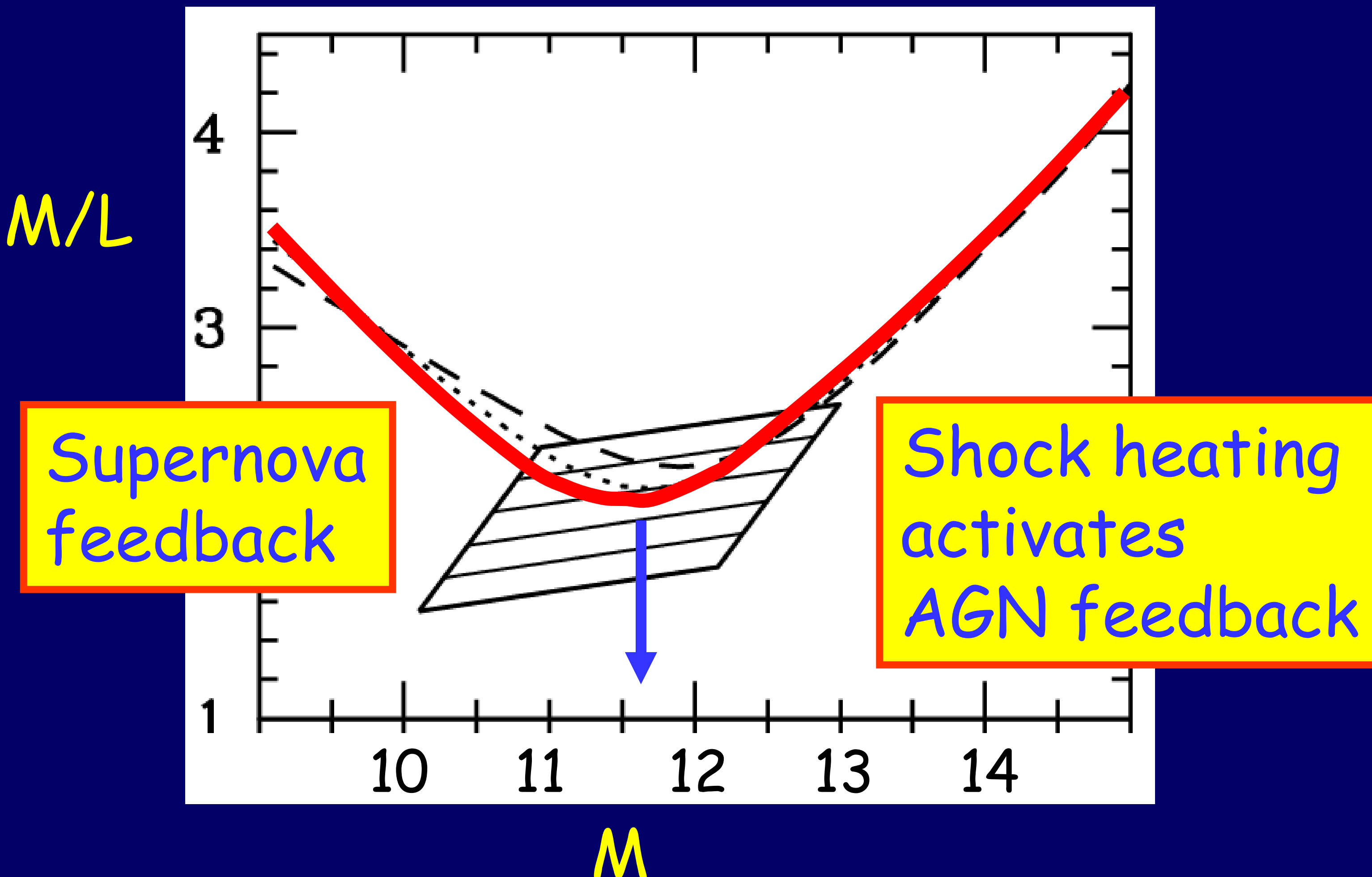
Dilute gas is heated and pushed away while dense clumps are shielded



Minimum Feedback Efficiency at Critical Mass



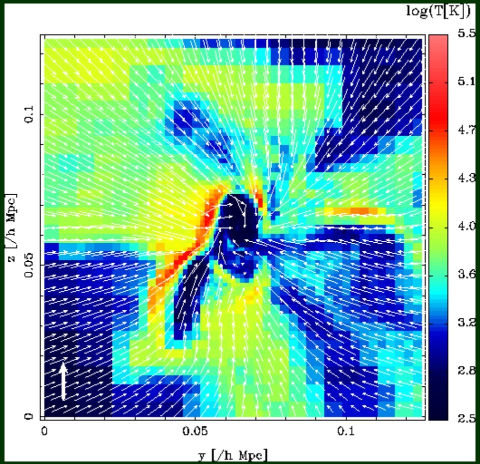
$\langle M/L \rangle$ has a minimum at M_{crit}

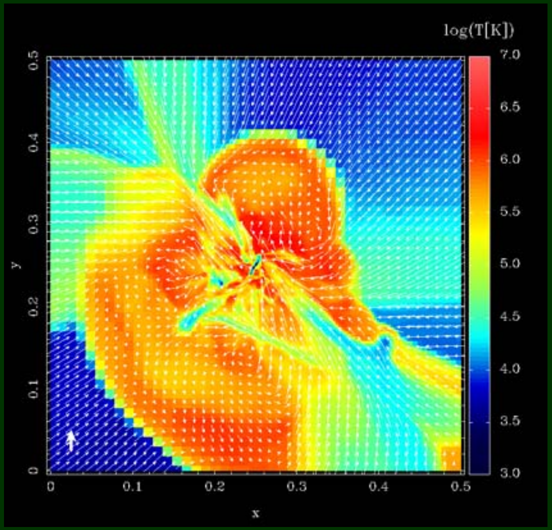


Using conditional luminosity function: Van den Bosch, Mo, Yang 03

4. Origin of the Bi-modality

Dekel & Birnboim 06





cold	vs	hot
ungrouped	vs	grouped
SN feedback	vs	AGN feedback

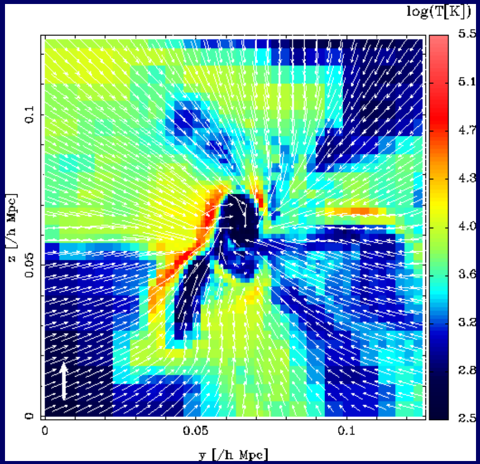
Key Ideas:

Cold flows → star burst

supersonic streams collide near center --

efficient cooling behind isothermal shock

→ dense, cold slab → star burst

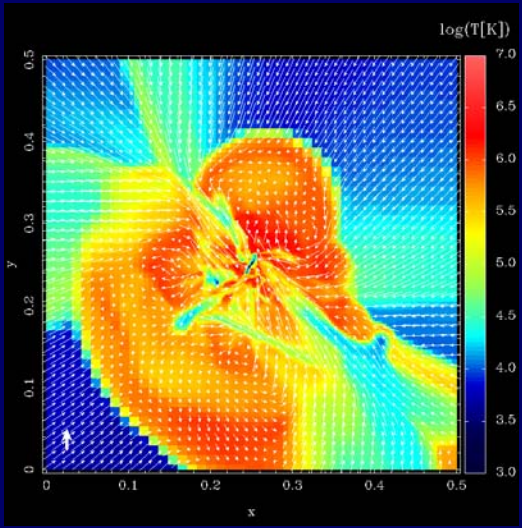


Hot medium → halt star formation

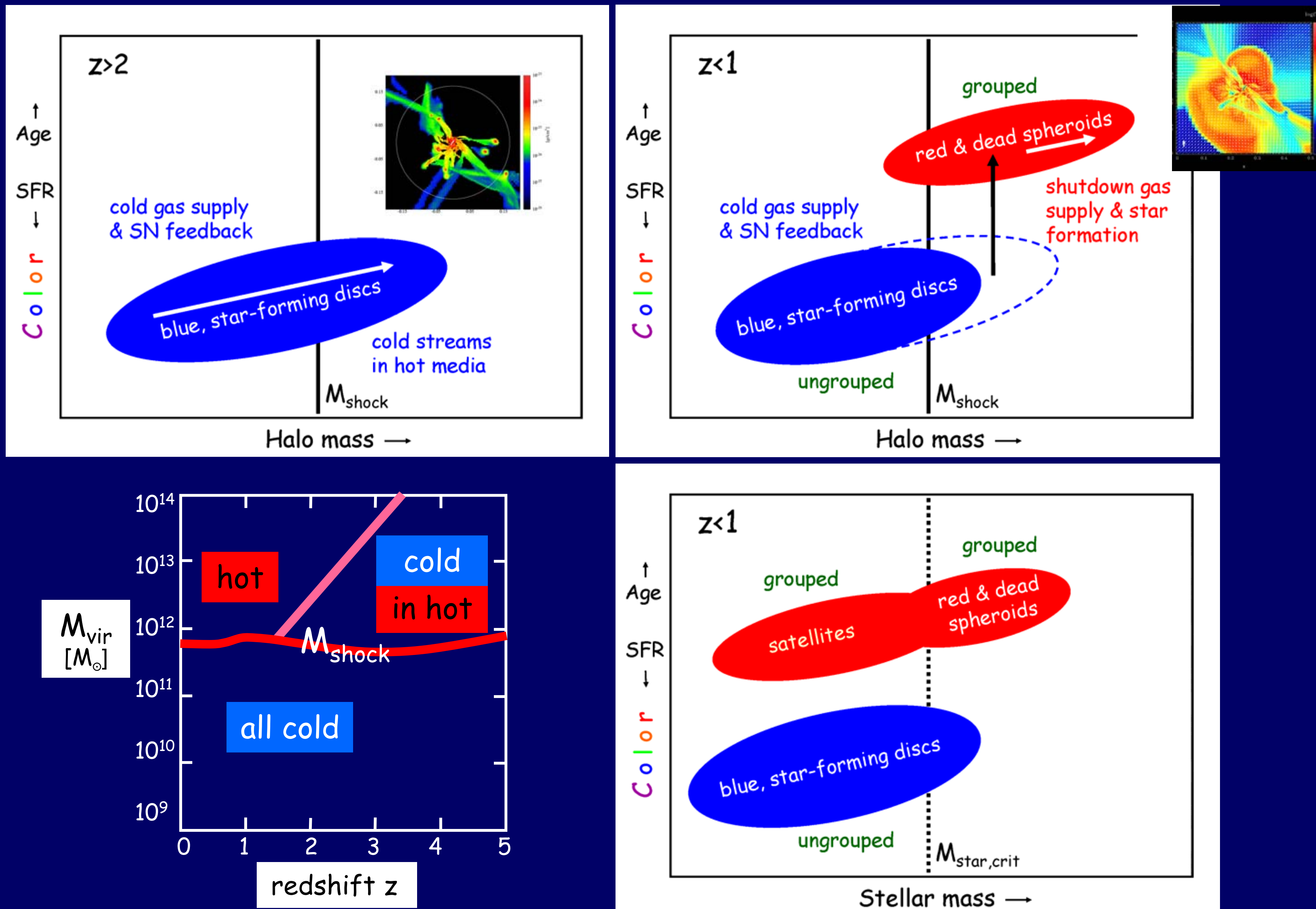
dilute medium vulnerable to AGN fdbk

→ shock-heated gas never cools

→ shut down disk and star formation



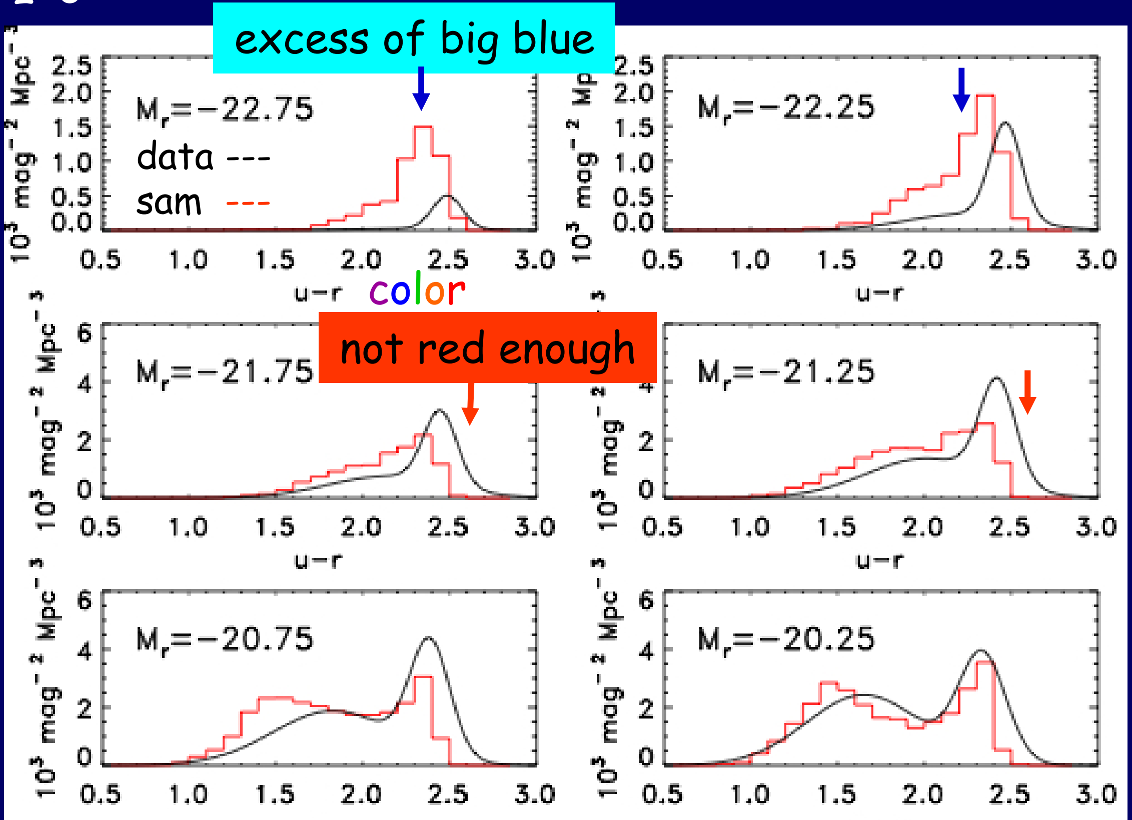
From blue sequence to red sequence

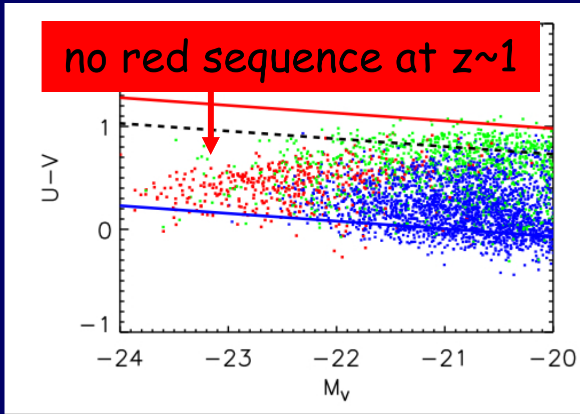


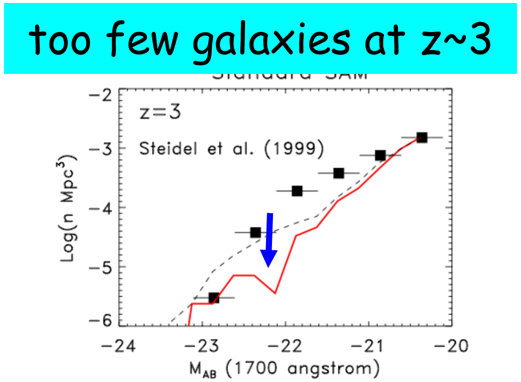
In a standard Semi Analytic Model (GalICS)

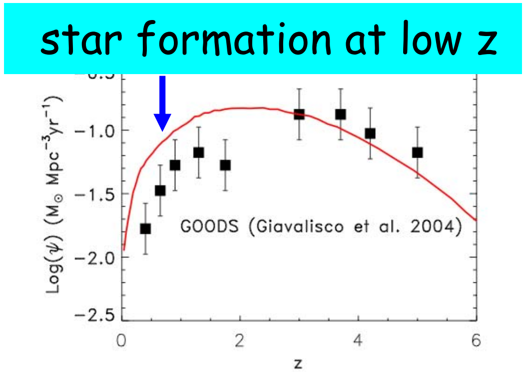
Cattaneo, Dekel, Devriendt, Guiderdoni, Blaizot 05

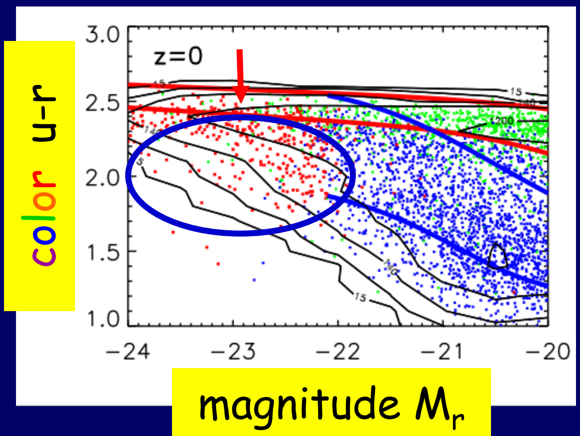
z=0

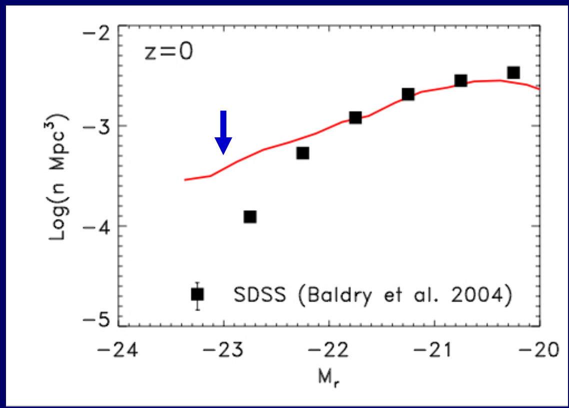




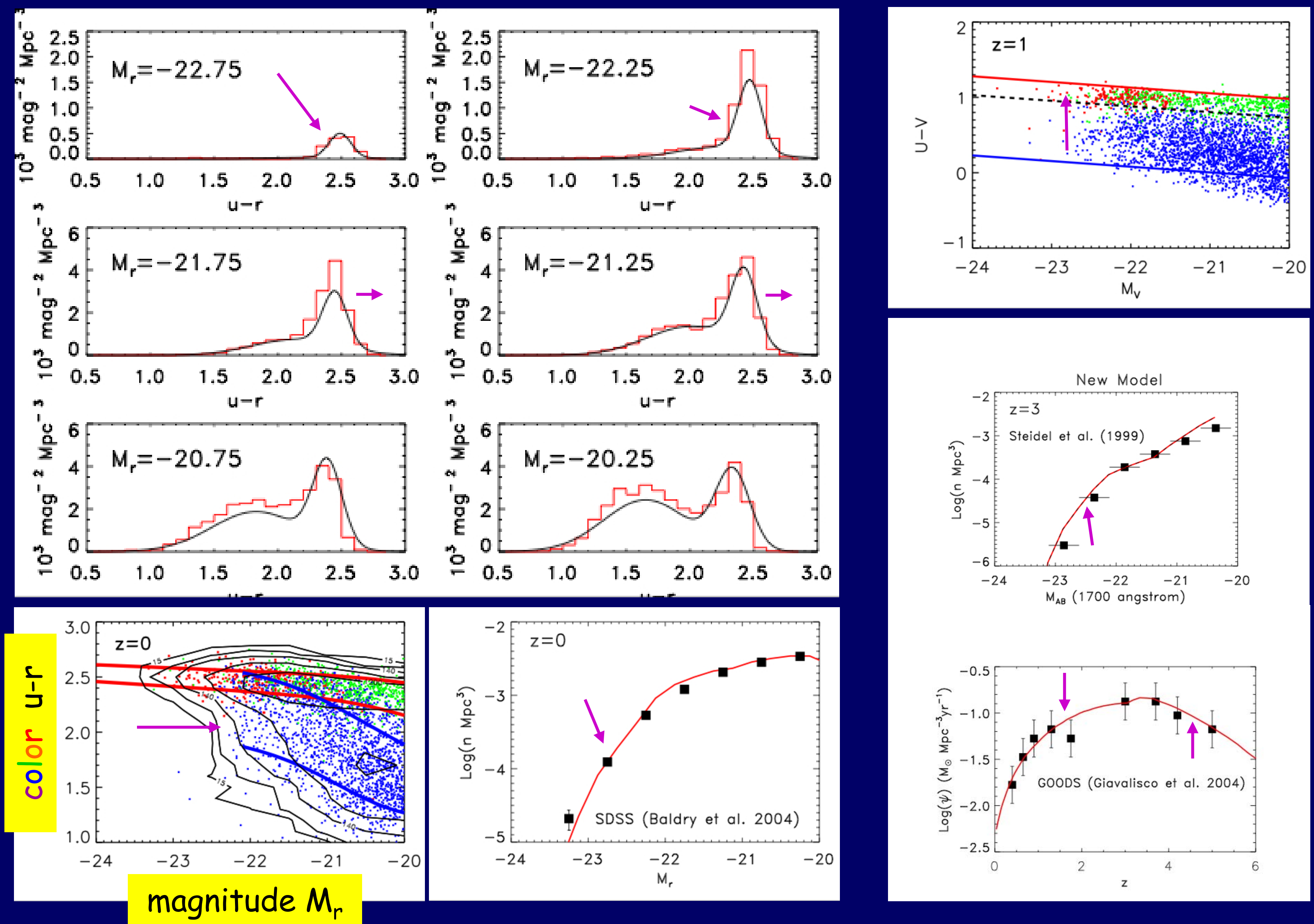




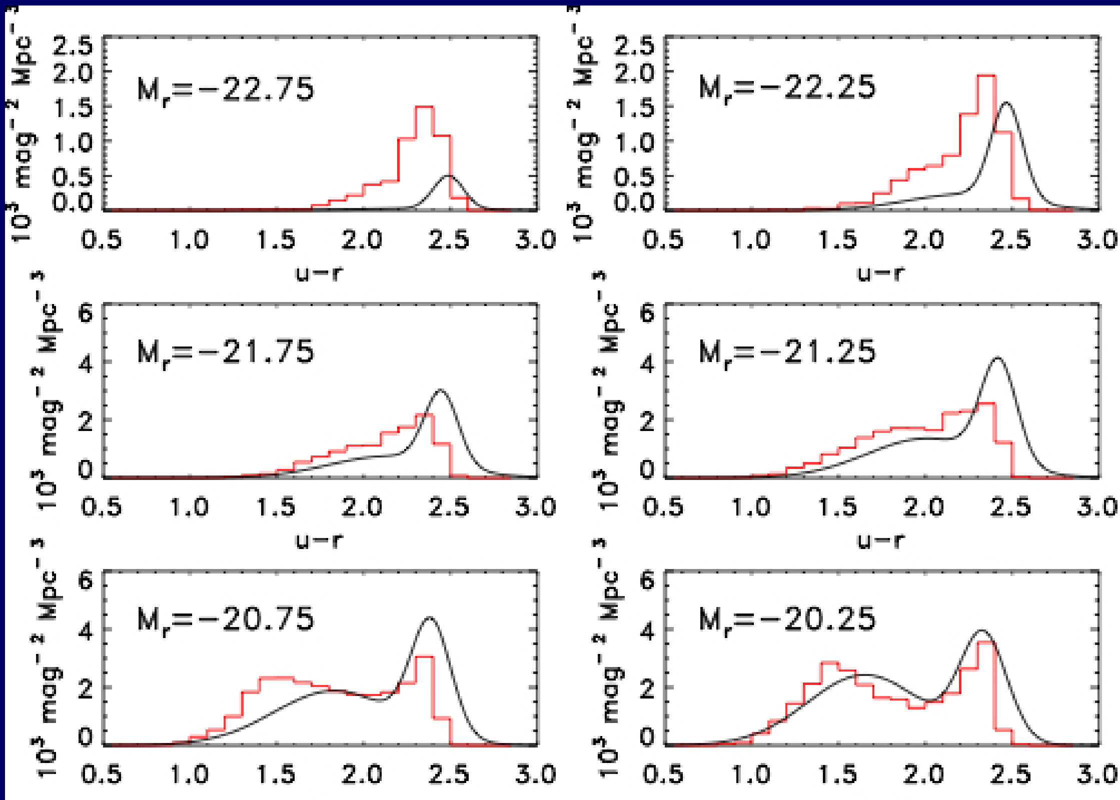




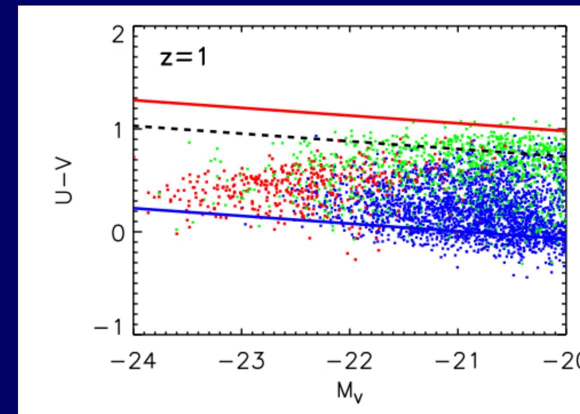
With Shutdown Above 10^{12} $M_\odot$



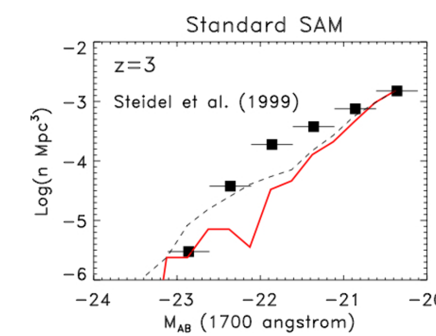
Standard



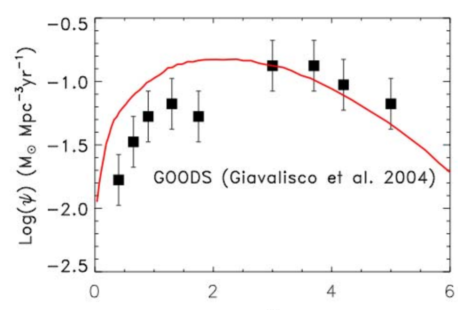
M_r=−22.75
M_r=−22.25
M_r=−21.75
M_r=−21.25
M_r=−20.75
M_r=−20.25
10^3 mag^-2 Mpc^-3
u−r



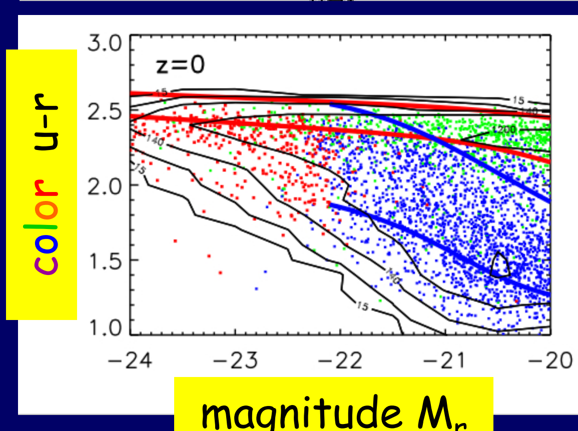
z=1
U−V
M_V



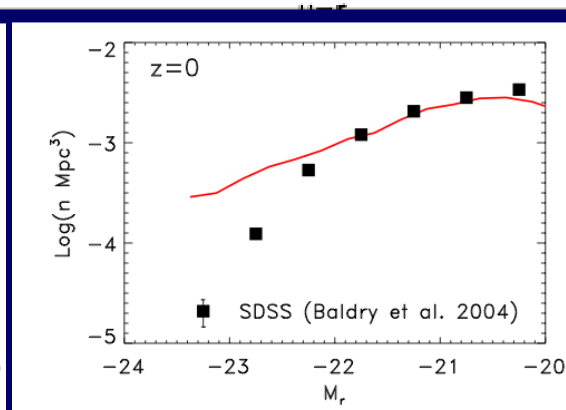
Standard SAM
z=3
Steidel et al. (1999)
Log(n Mpc^3)
M_AB (1700 angstrom)



GOODS (Giavalisco et al. 2004)
Log(ψ) (M_⊙ Mpc^-3 yr^-1)
z

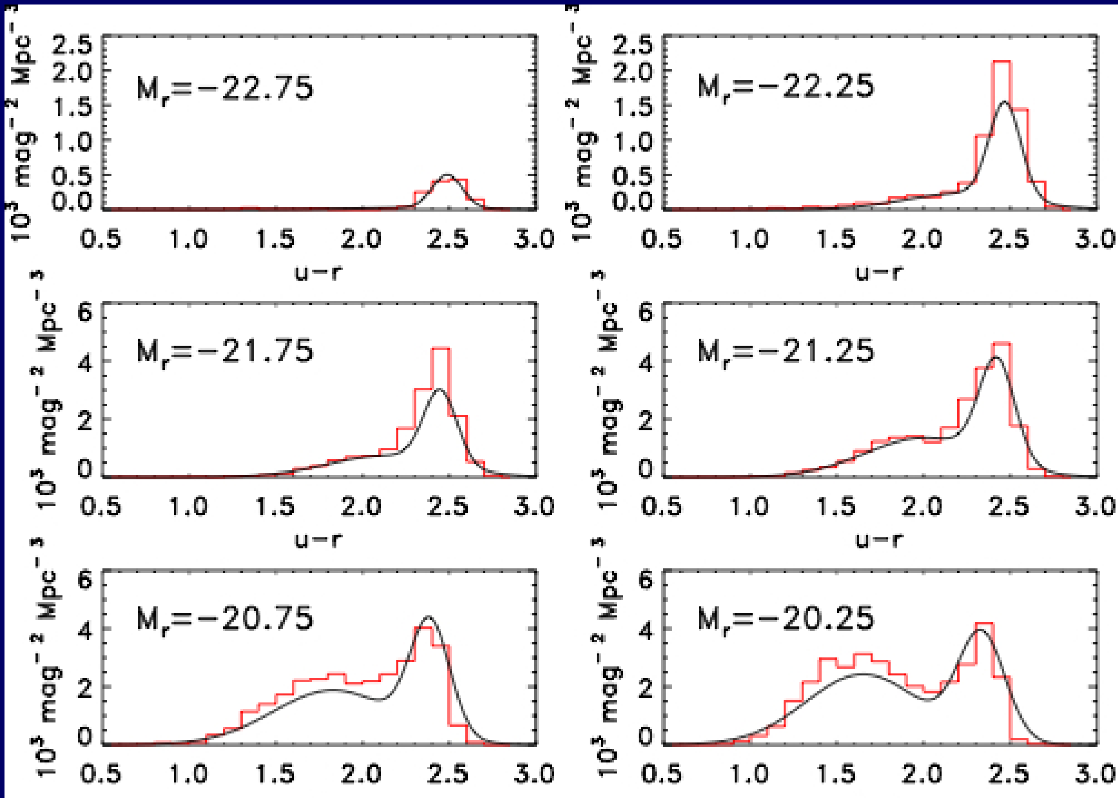


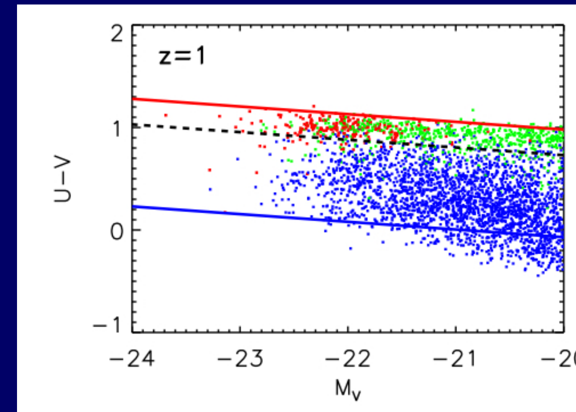
z=0
color u-r
magnitude M_r

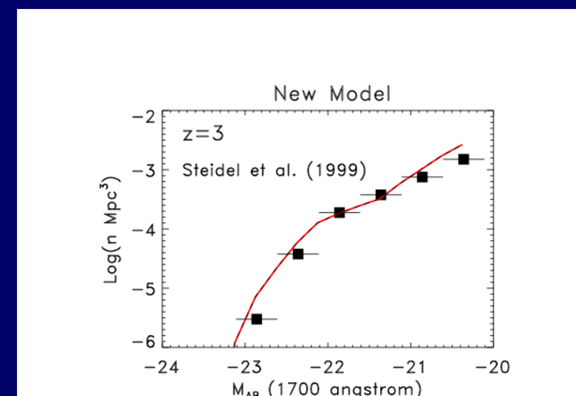


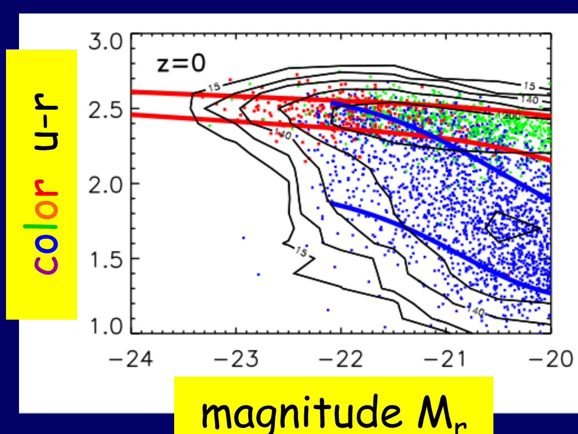
z=0
SDSS (Baldry et al. 2004)
Log(n Mpc^3)
M_r

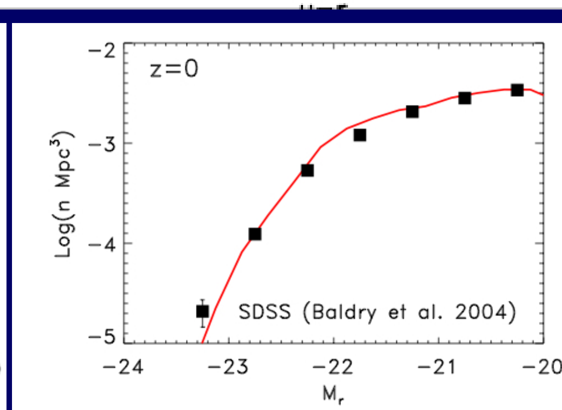
With Shutdown Above $10^{12}\ M_\odot$

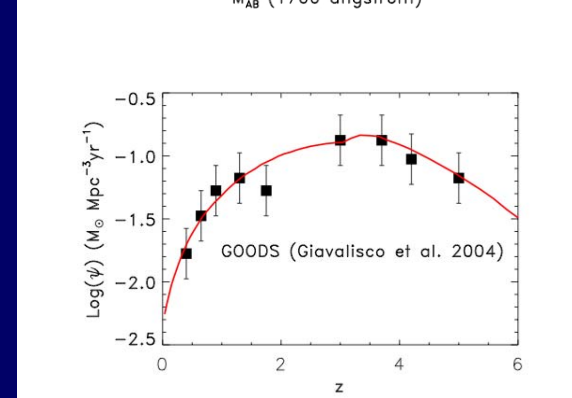




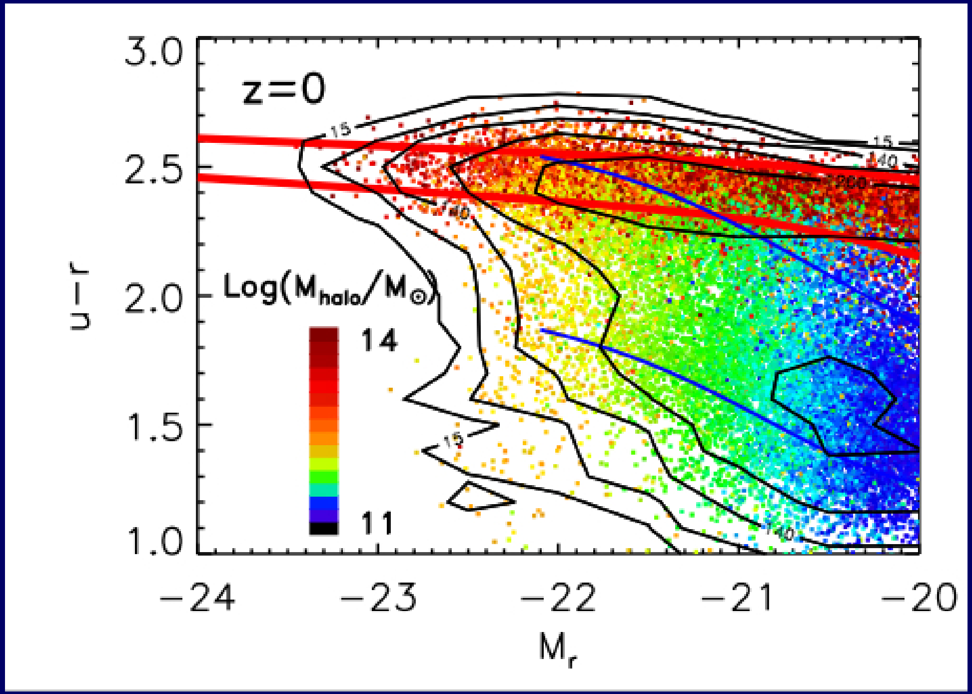




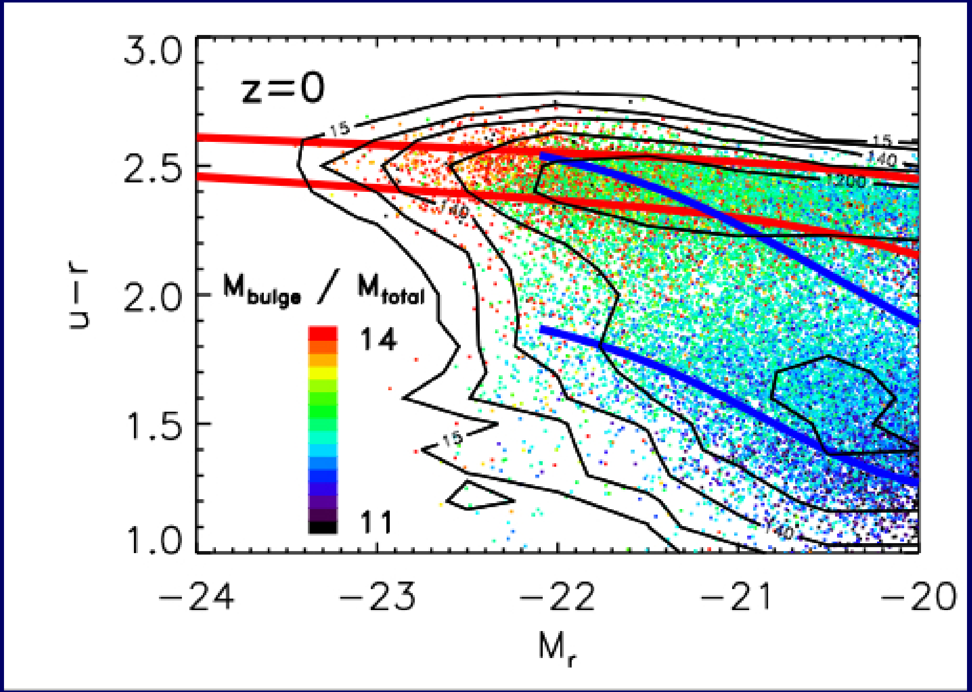




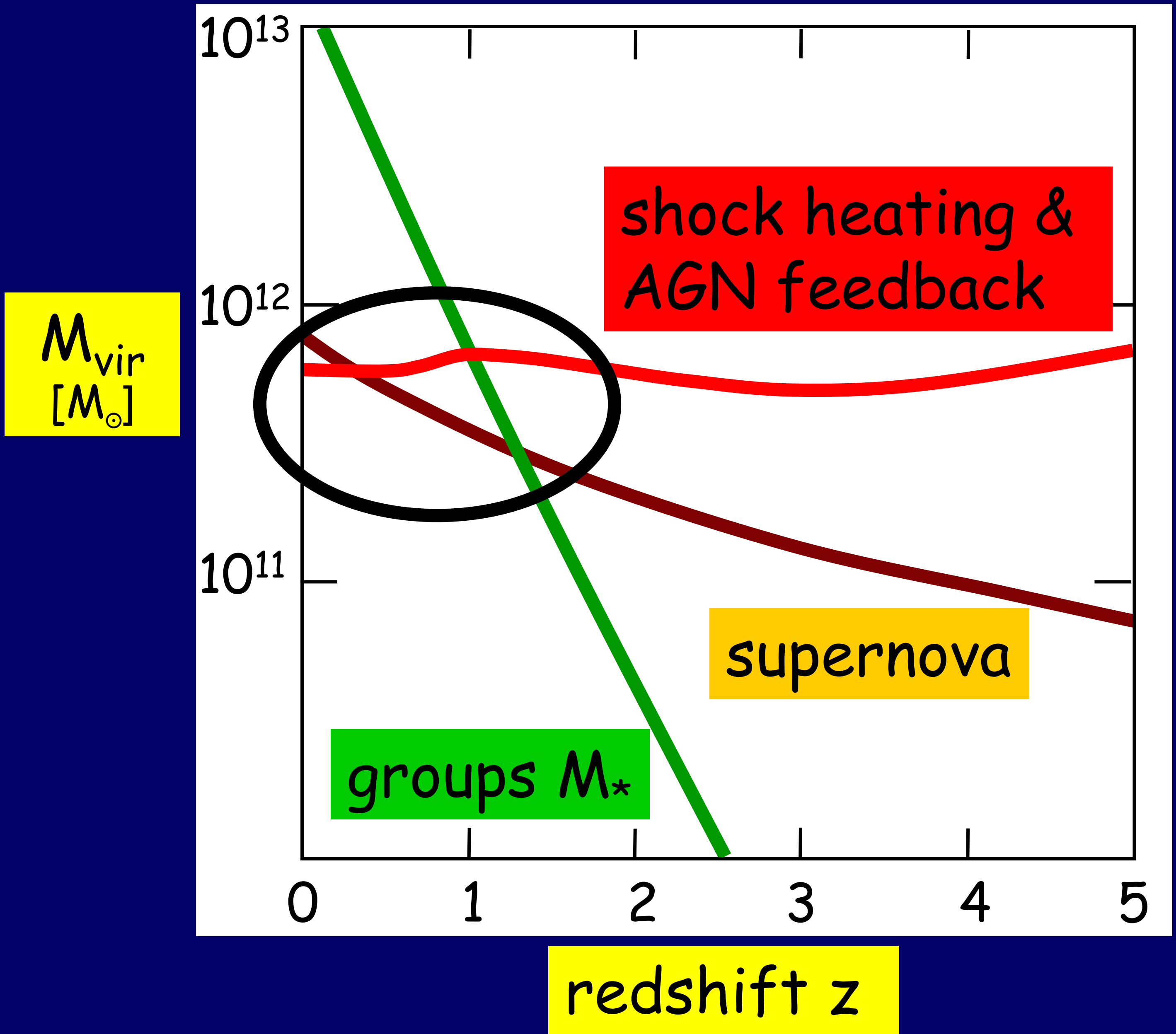
Environment dependence via halo mass



Bulge to disk ratio



Scales Roughly Coincide

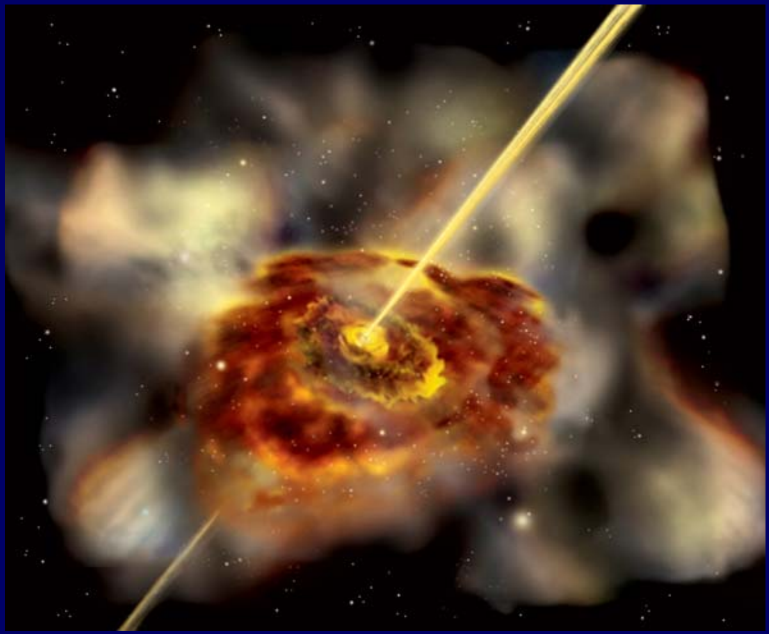


Conclusions

- Dark-halo mass drives galaxy type:
  $M_{crit} \sim 10^{12} M_\odot$: shock heating, feedback, clustering
- Disk buildup & star formation: ...by cold flows riding dark-matter filaments
- Early $(z>2)$ in big halos $M>10^{12}$:
  big blue galaxies by cold flows in hot media
- Late $(z<2)$ in big halos $M>10^{12}$ (groups):
  virial shock heating triggers AGN feedback
  → shutdown of star formation → red sequence
- Late $(z<2)$ in small halos $M<10^{12}$ (field):
  blue disks $M_* < 3\times10^{10} M_\odot$
- Explains other open puzzles

Questions for AGN Feedback

- Energy of outflow (vs binding energy of galactic gas)?
- Persistence over Hubble time?
- Mechanism for spreading the effect across the galaxy?
- origin of threshold mass?



Thank you