The Growth of Galaxies by Cold Gas Accretion

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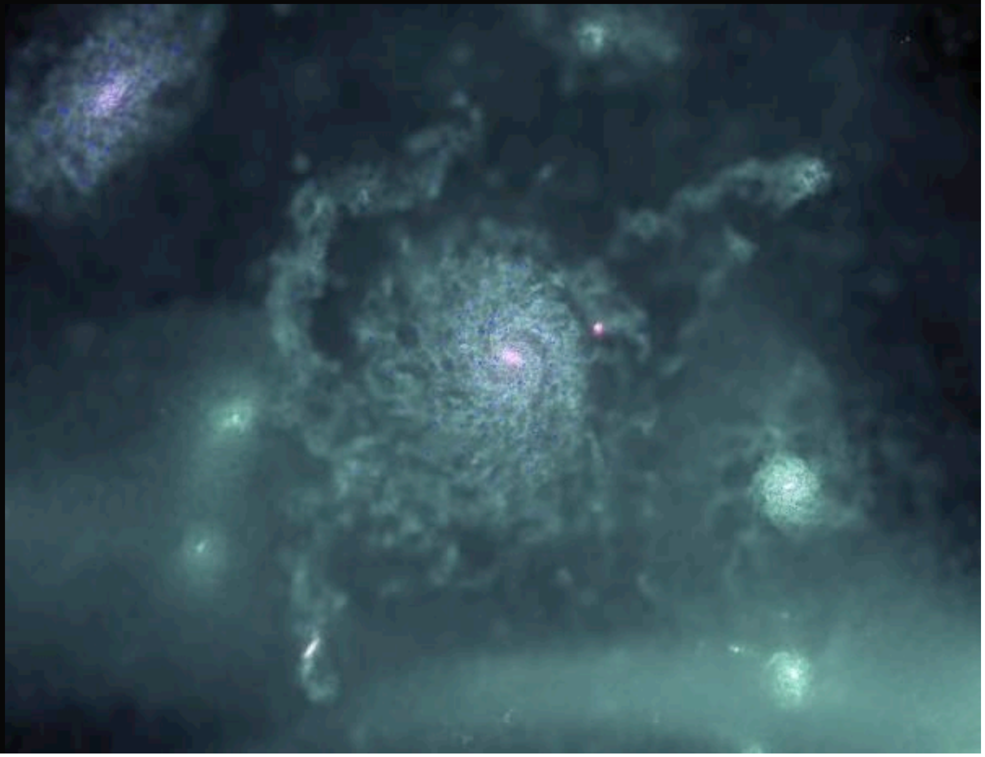
In collaboration with the UW's N-body Shop™
makers of quality galaxies

Outline

- The Simulations: Creating Realistic Disk Galaxies

- Cold Flow Gas Accretion
  -The Role of Cold Gas Accretion in Disk Star Formation
  -The Role of Cold Gas in Massive Galaxies at High z

- Conclusions



Gasoline

- PKDGRAV: Parallel N-body Tree Code
- Gasoline: PKDGRAV+gas using smoothed particle hydrodynamics (SPH)
- Physics: Gravity, Hydrodynamics, Shocks, Radiative Heating+Cooling, UV field
- Sub-grid Physics: Star Formation, Supernova Feedback, Stellar Winds, Metal Enrichment

Stadel (2001)
Wadsley *et al.* (2004)

SF/Feedback Model

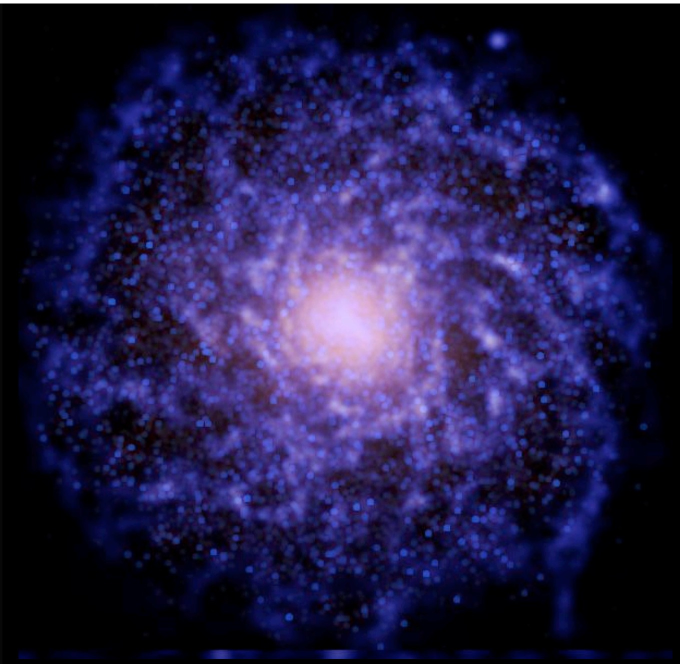
- Star Formation: reproduces the Kennicutt-Schmidt Law; each star particle a SSP with Kroupa IMF

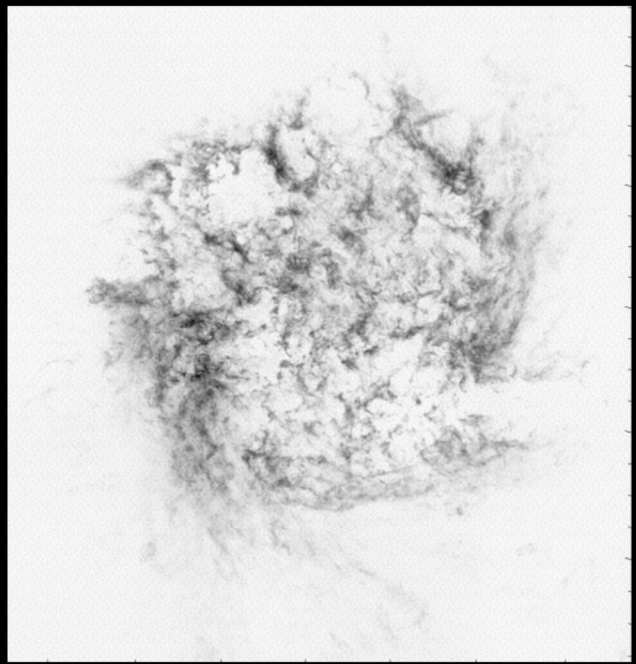
- Energy from SNII deposited into the ISM as thermal energy based on McKee & Ostriker (1977)

- Radiative cooling disabled to describe adiabatic expansion phase of SNe (Sedov-Taylor phase); ~2Myr (blastwave model)

- Only Free Parameters: SN & Star Formation efficiencies

Stinson *et al*. (2006), Governato *et al*. (2007)





LMC HI distribution (Stavely-Smith 2003)

The Formation of a Milky Way-Mass Galaxy

30 kpc on a side

Green = gas

Blue/Red = age/metallicity weighted stars

Our Simulations

SDSS gri-composite images from three galaxy simulations at z=0

At z=0 our disk galaxies simultaneously:

- Have a realistic satellite Luminosity Function
- Reproduce the observed trend in “Downsizing”
- Land on the Tully-Fisher relation
- Match the observed Mass-Metallicity relation for galaxies

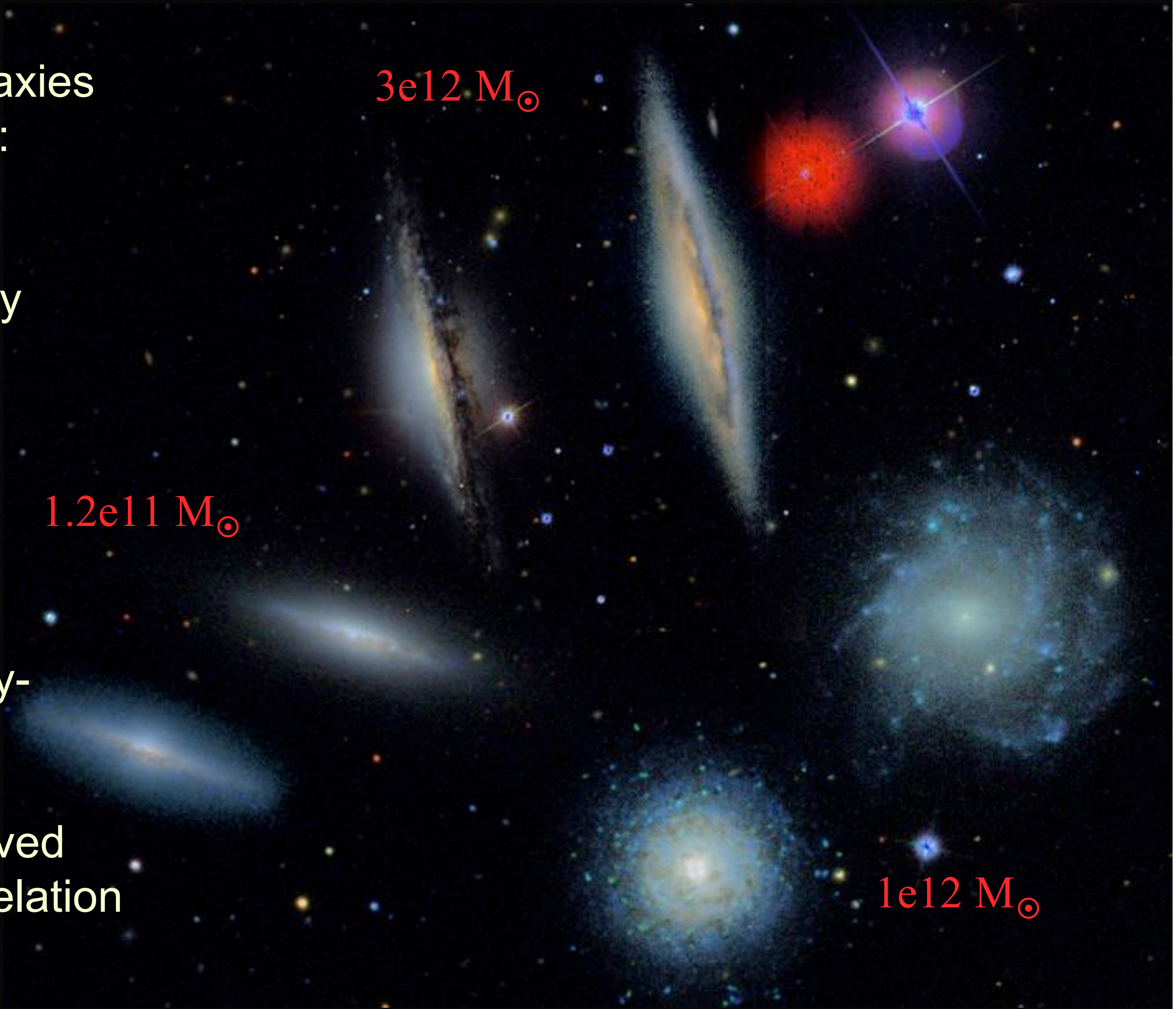


Image by C. Brook, using mock broadband “observations” created with Sunrise, courtesy P. Jonsson.

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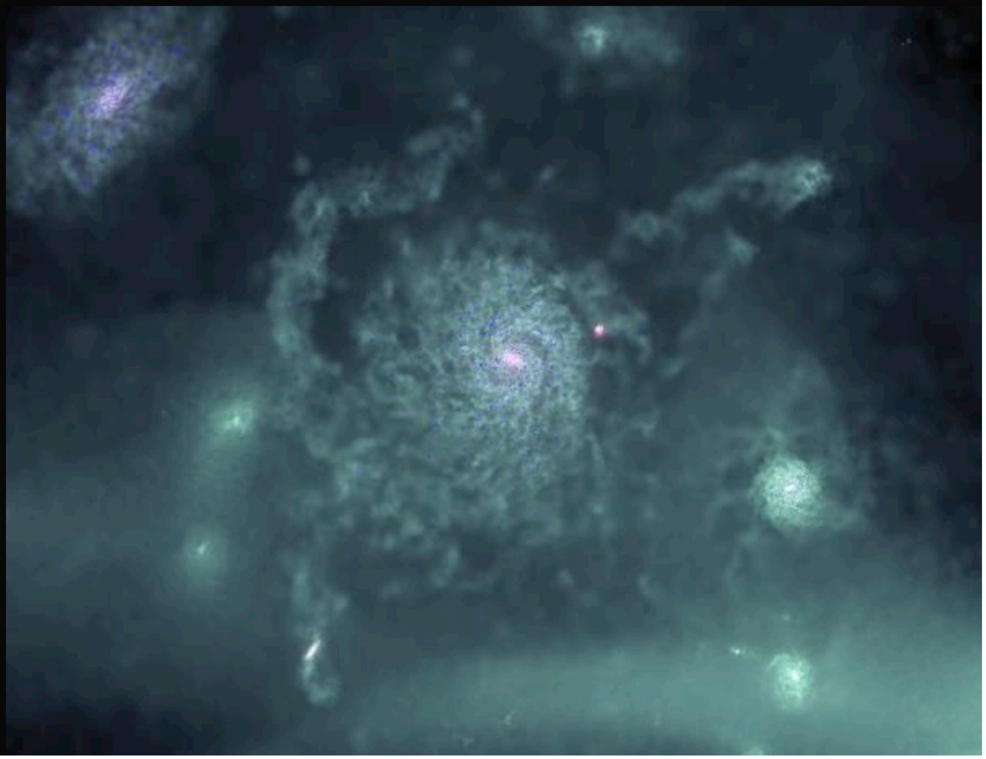
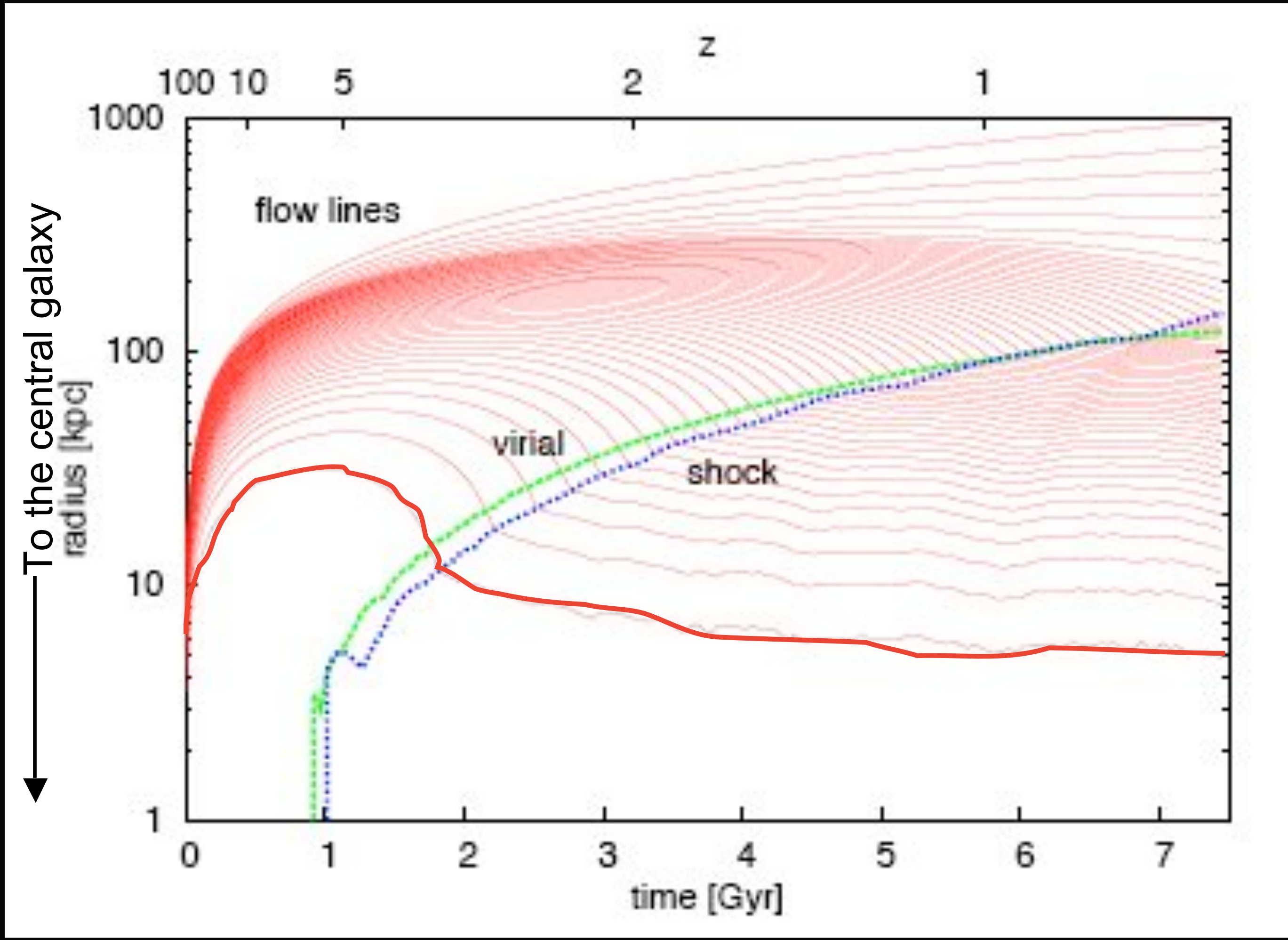
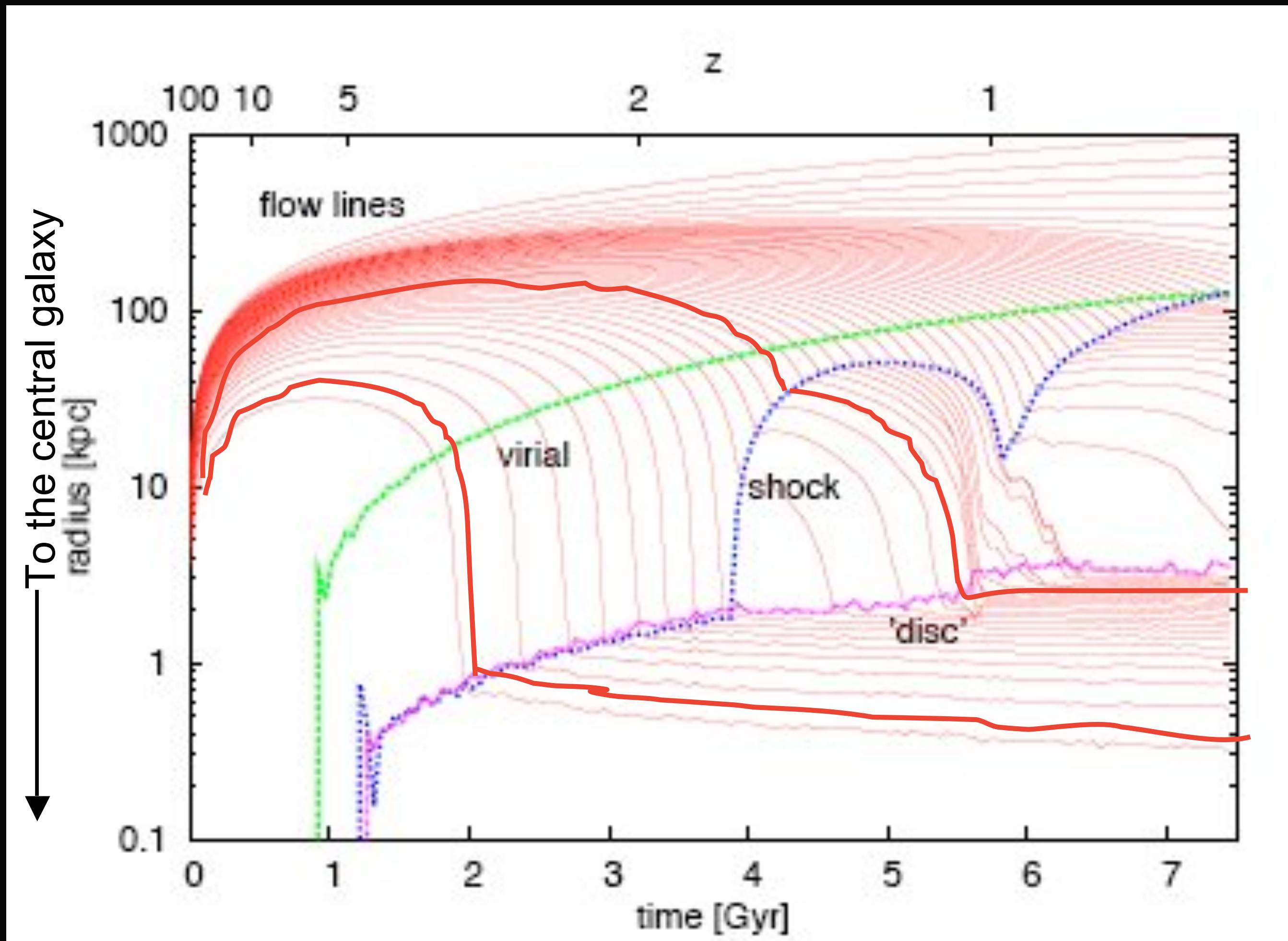


The Adiabatic Case



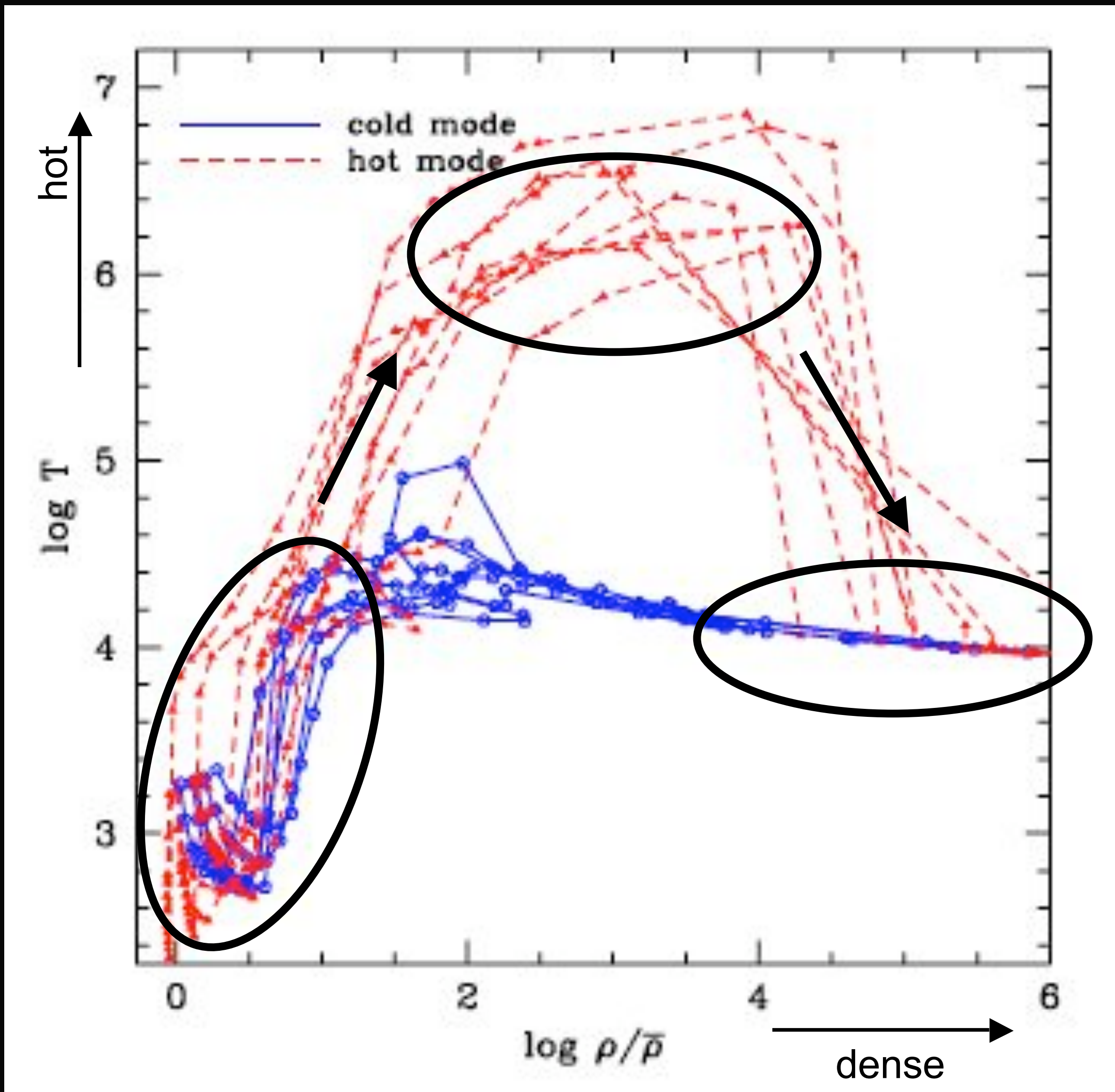
Dekel & Birnboim (2006)

Mass Dependent Stable Shocks



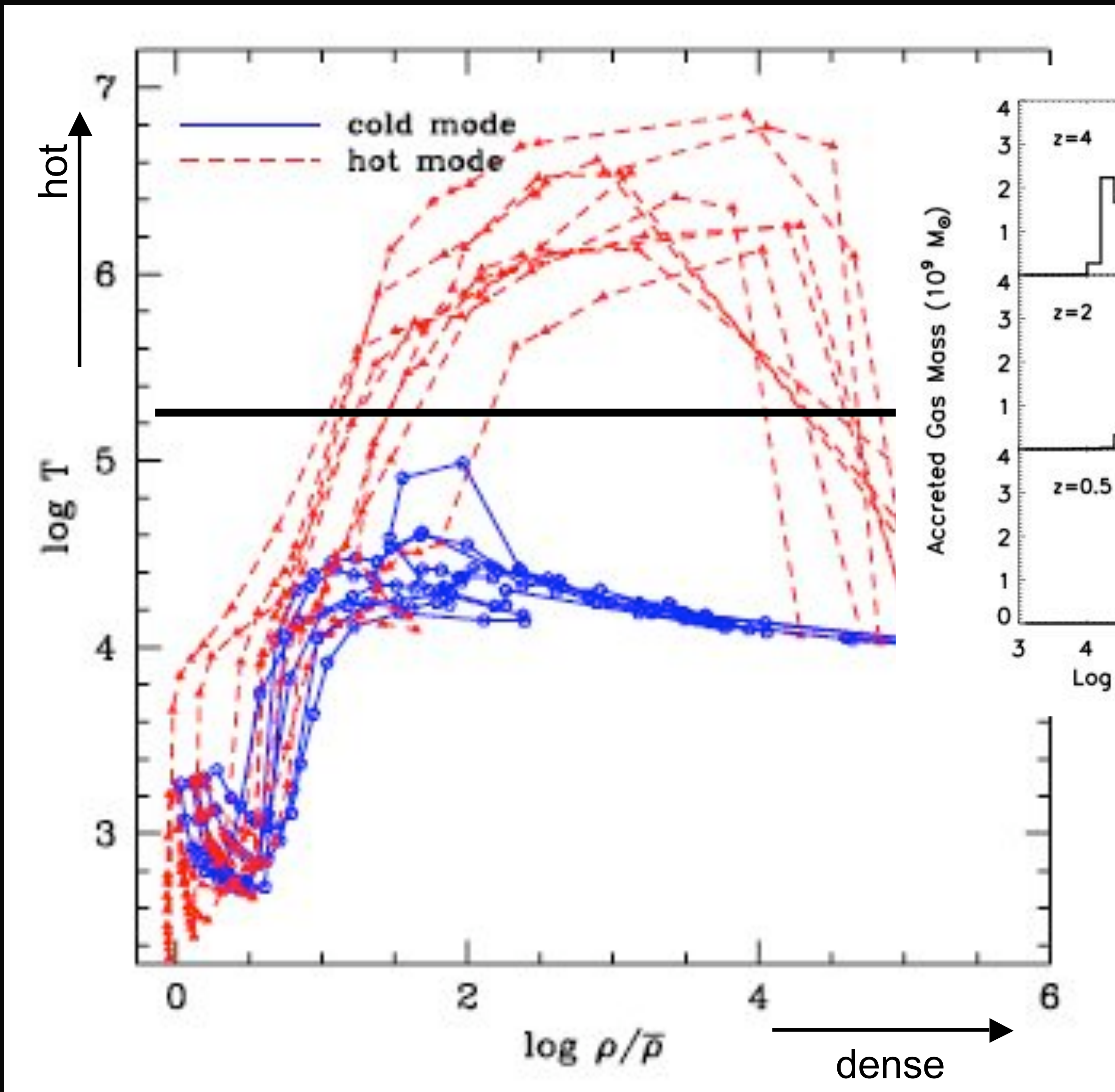
Dekel & Birnboim (2006)

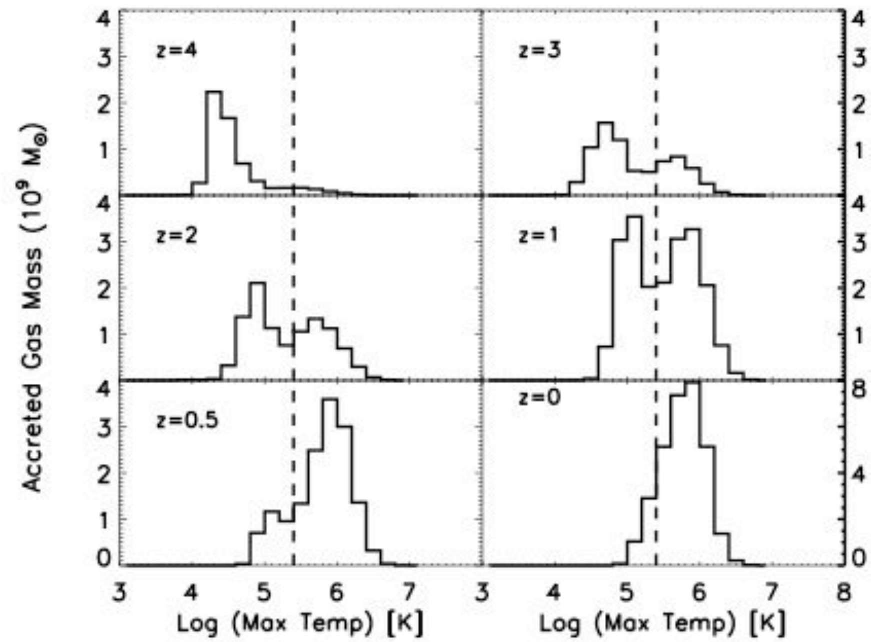
Hot vs Cold



Keres et al. (2005)

Hot vs Cold



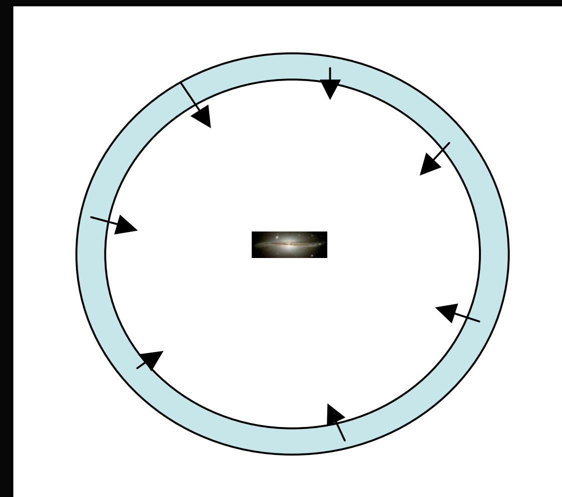


Maximum Temperature Reached by Gas Accreted to MW size galaxy in various redshift intervals

Keres et al. (2005)

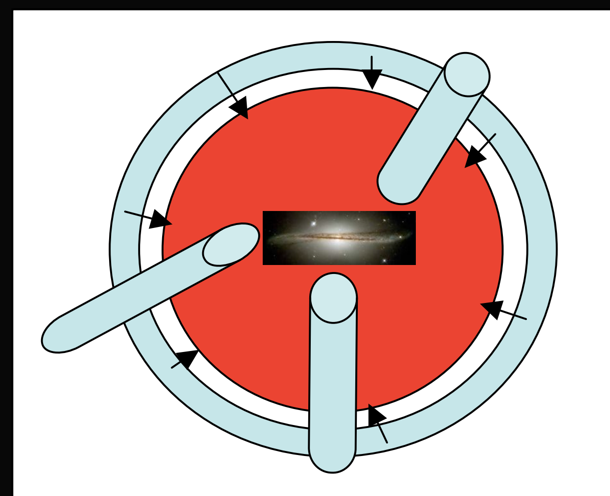
Shock Definitions

$T_{shock} \geq 3/8T_{vir}$



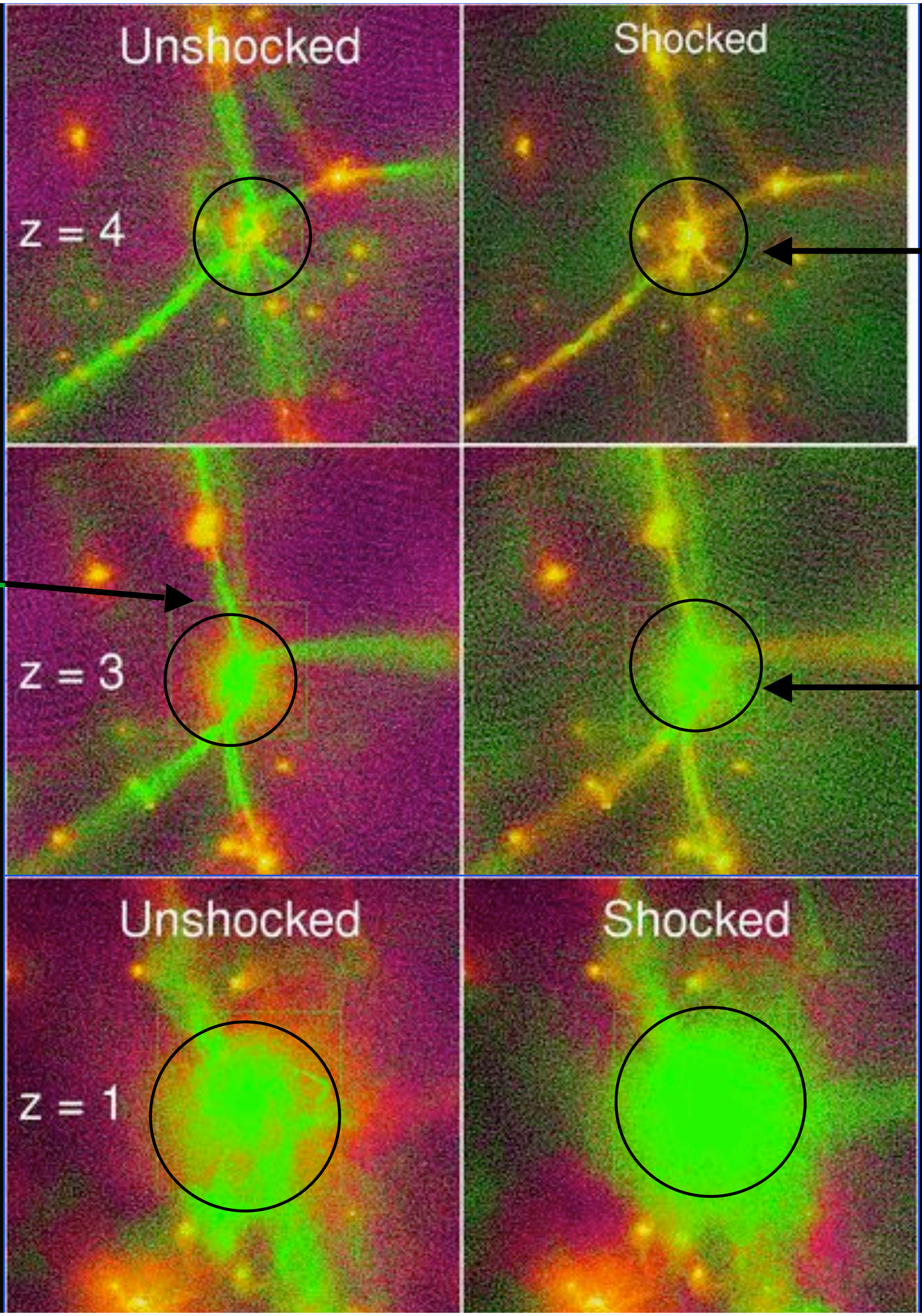
$T_{shock} \geq 3/8T_{vir}$

$S_{shock} \geq log_{10}[(3/8T_{vir})^{1.5}/4\rho_0]$



Birnboim & Dekel (2003)

Hot vs Cold



No shock yet

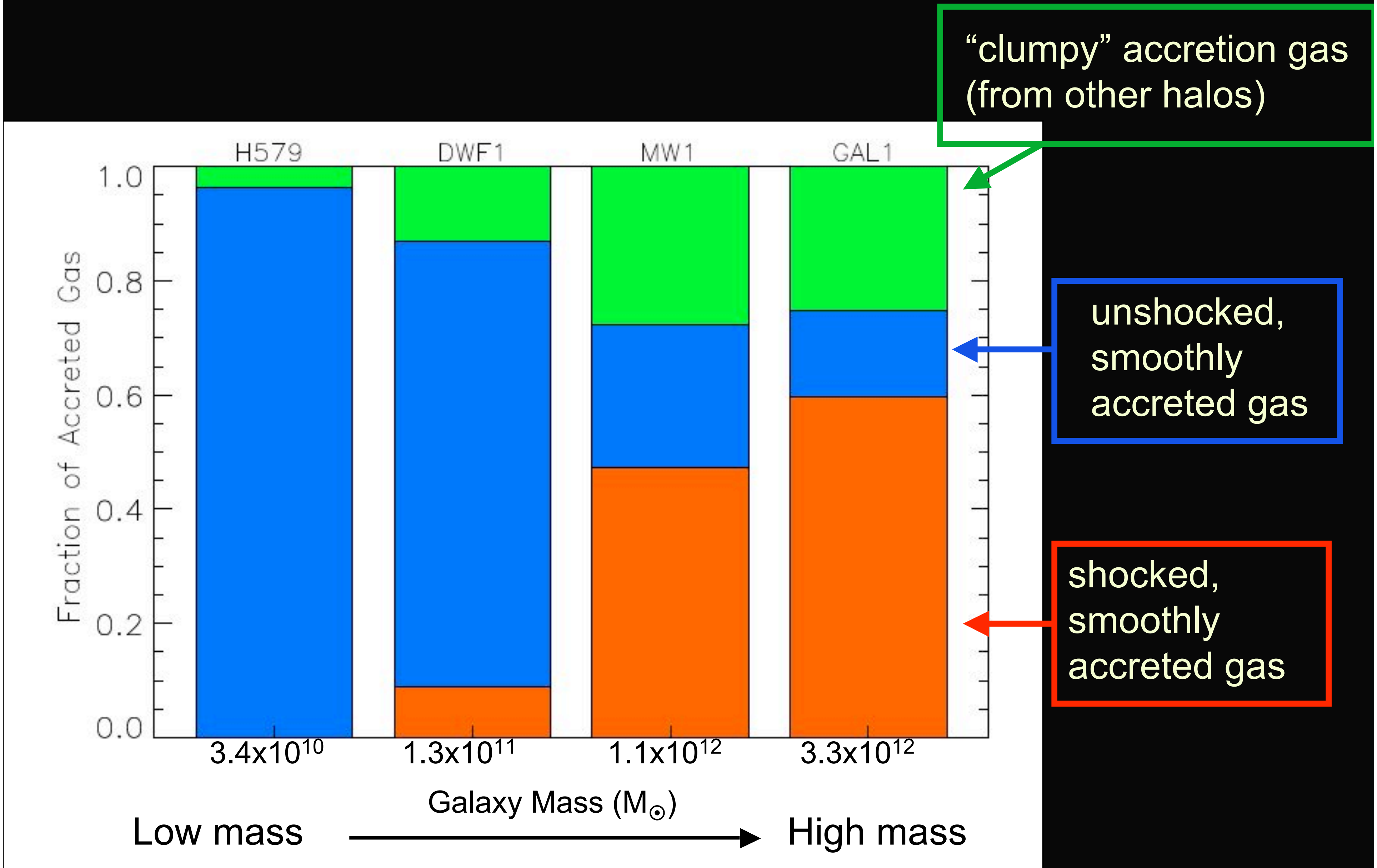
Shock exists

Unshocked gas in filaments

Definitions exclude “clumpy” accretion gas: gas that ever belonged to another galaxy halo

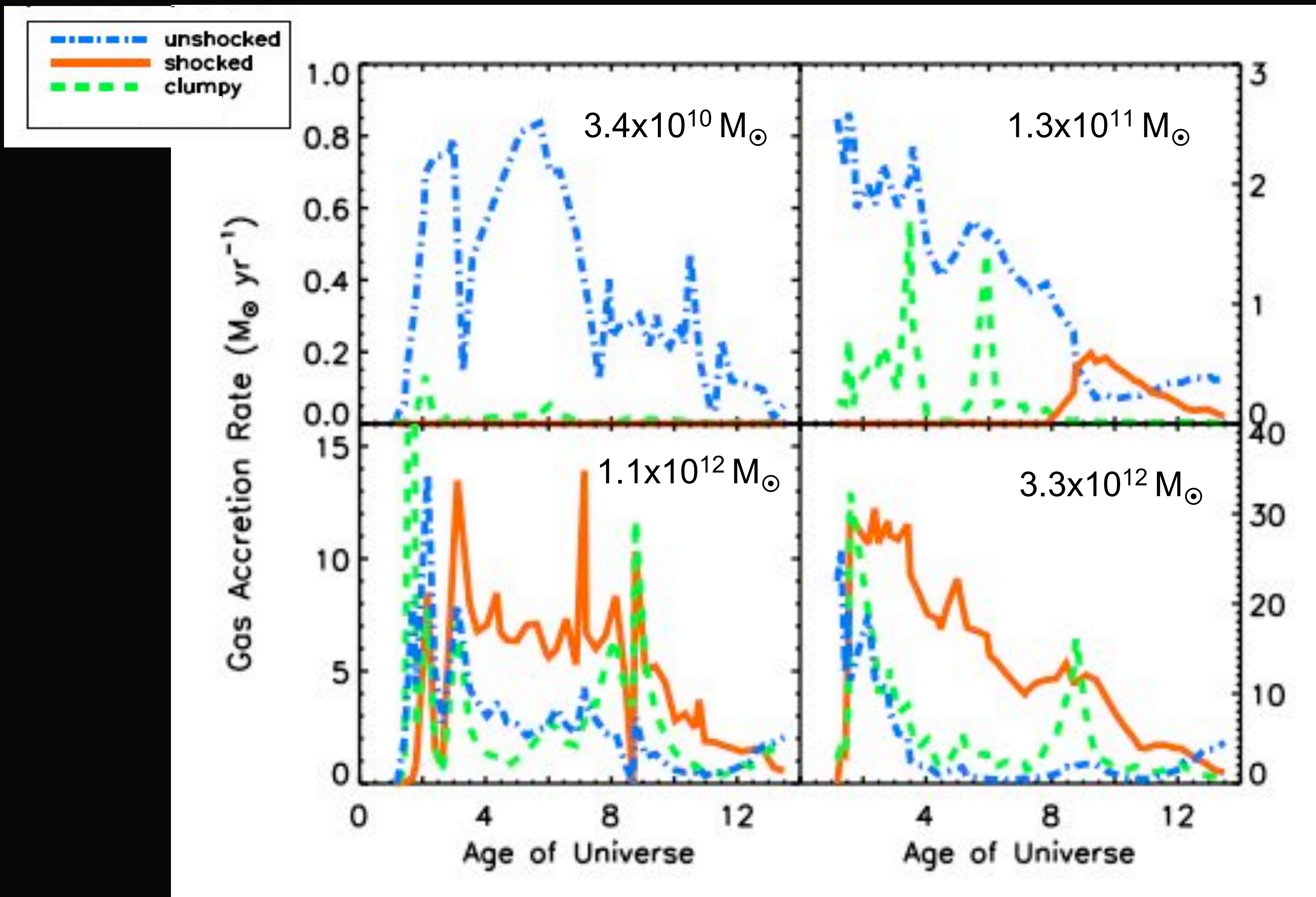
Hot vs Cold

Gas Accretion at the Virial Radius



Hot vs Cold

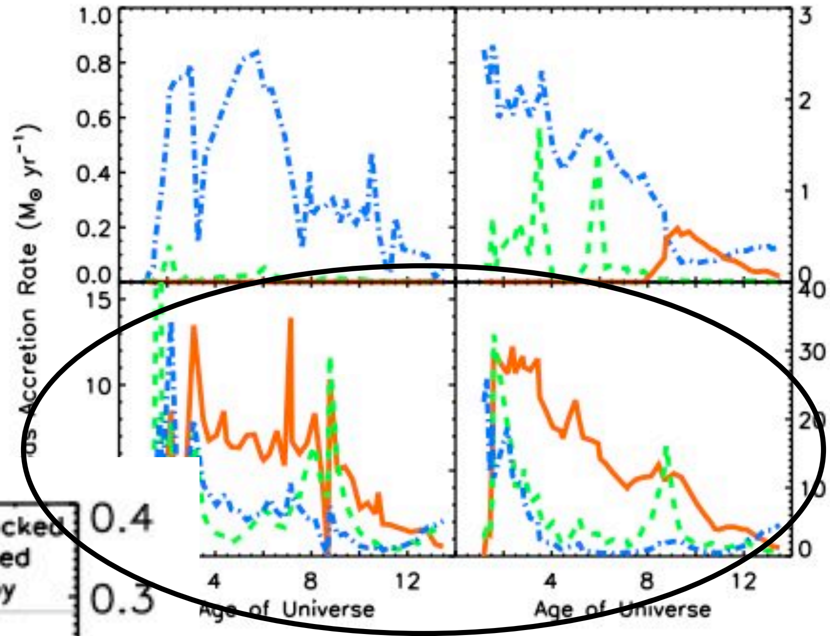
Gas Accretion Rates at the Virial Radius

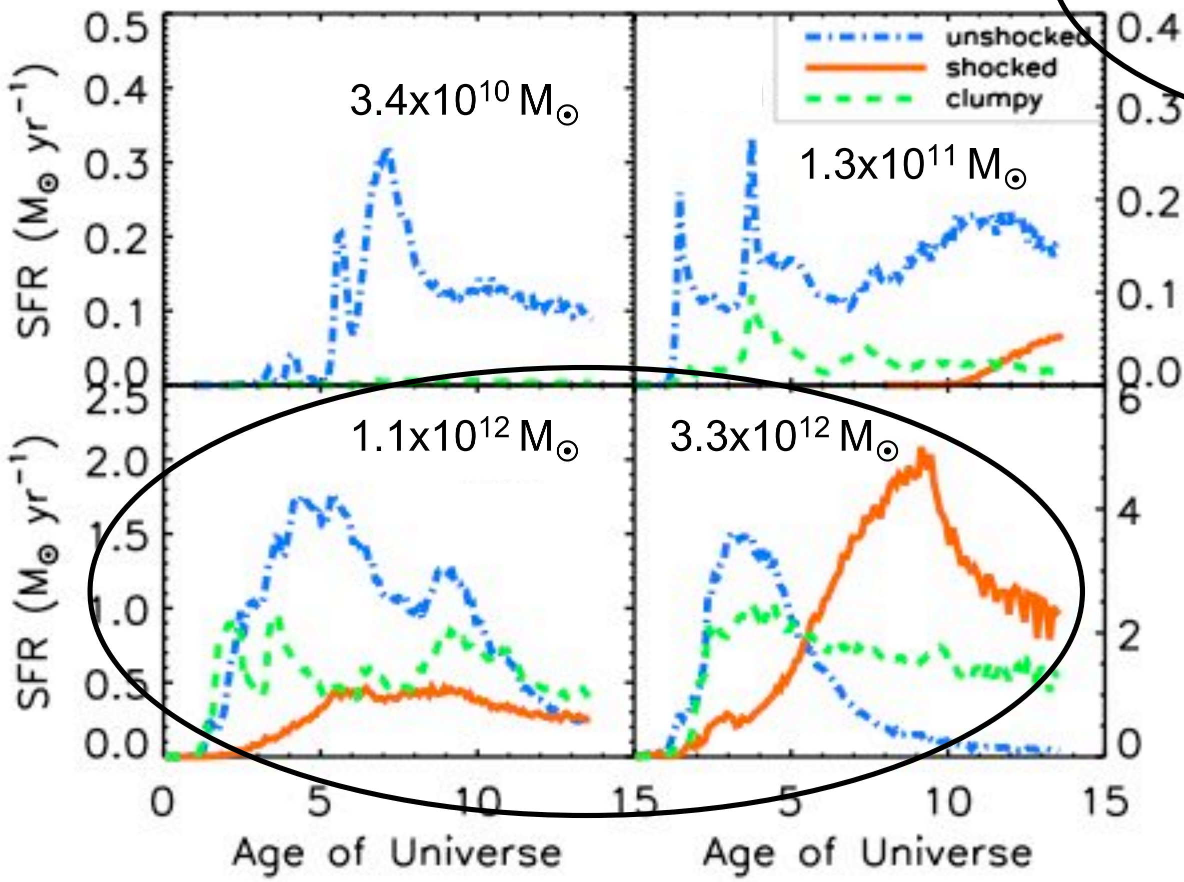


Disk Growth

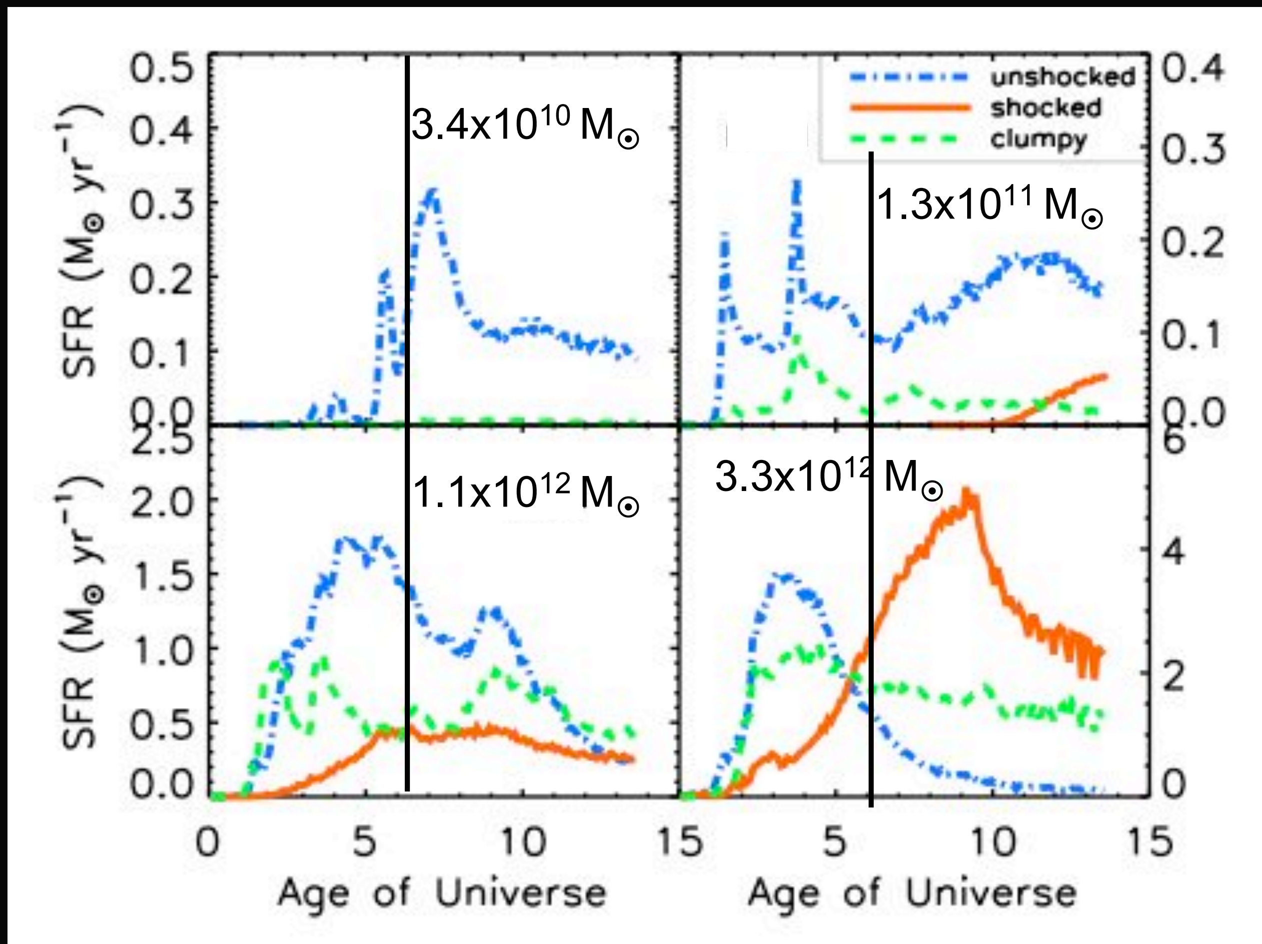
Gas Accretion Rates →

Disk Star Formation Rates



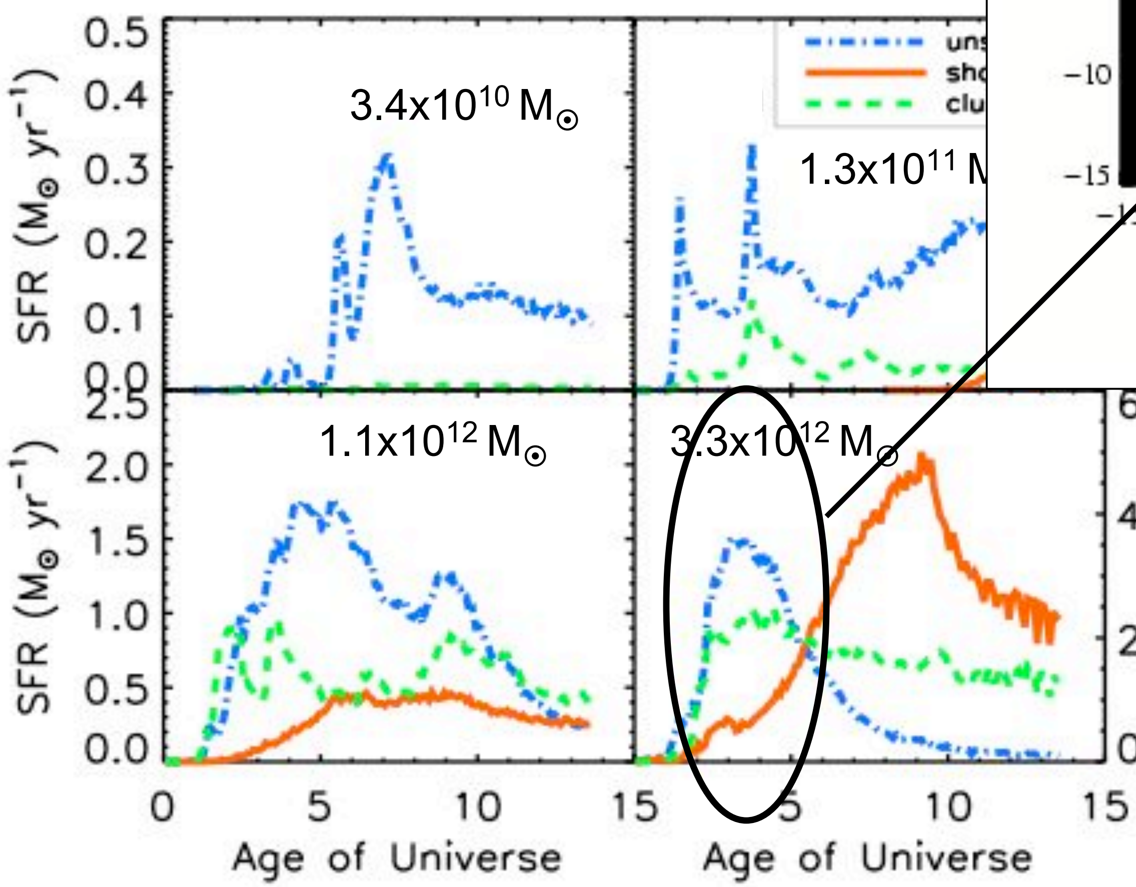


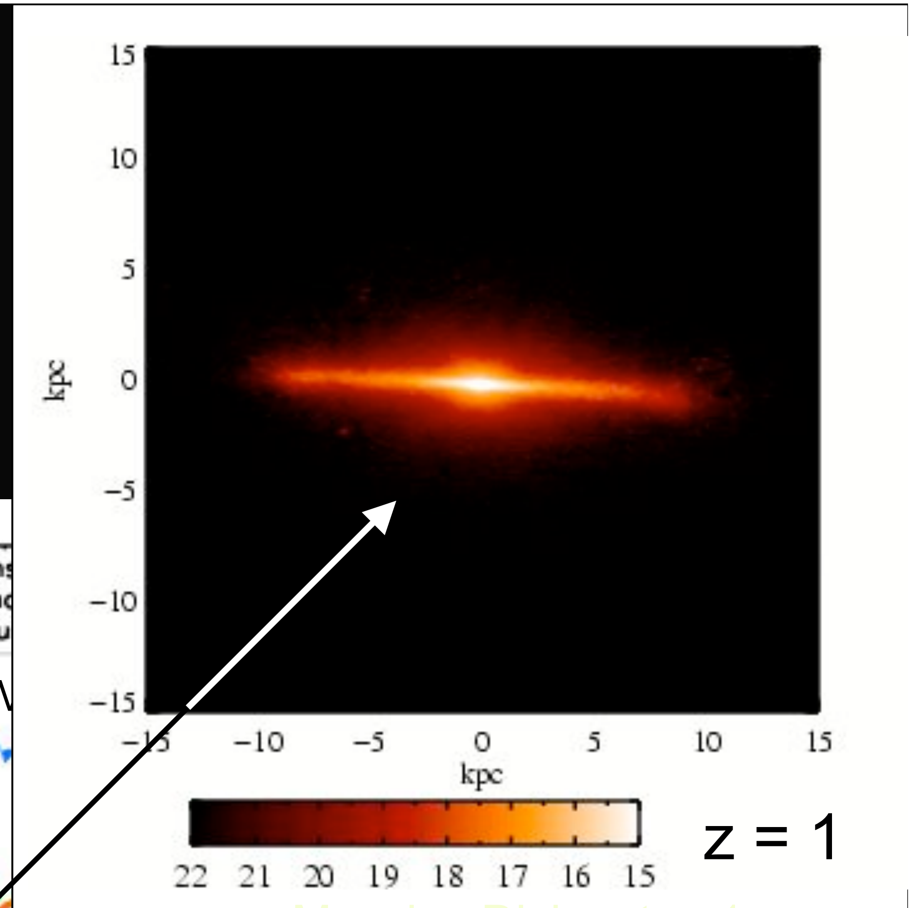
Historic Problem : Disk Growth *After* z=1



Mo et al. (1998); Mao et al. (1998);
van den Bosch (1998);
Somerville et al. (2008)

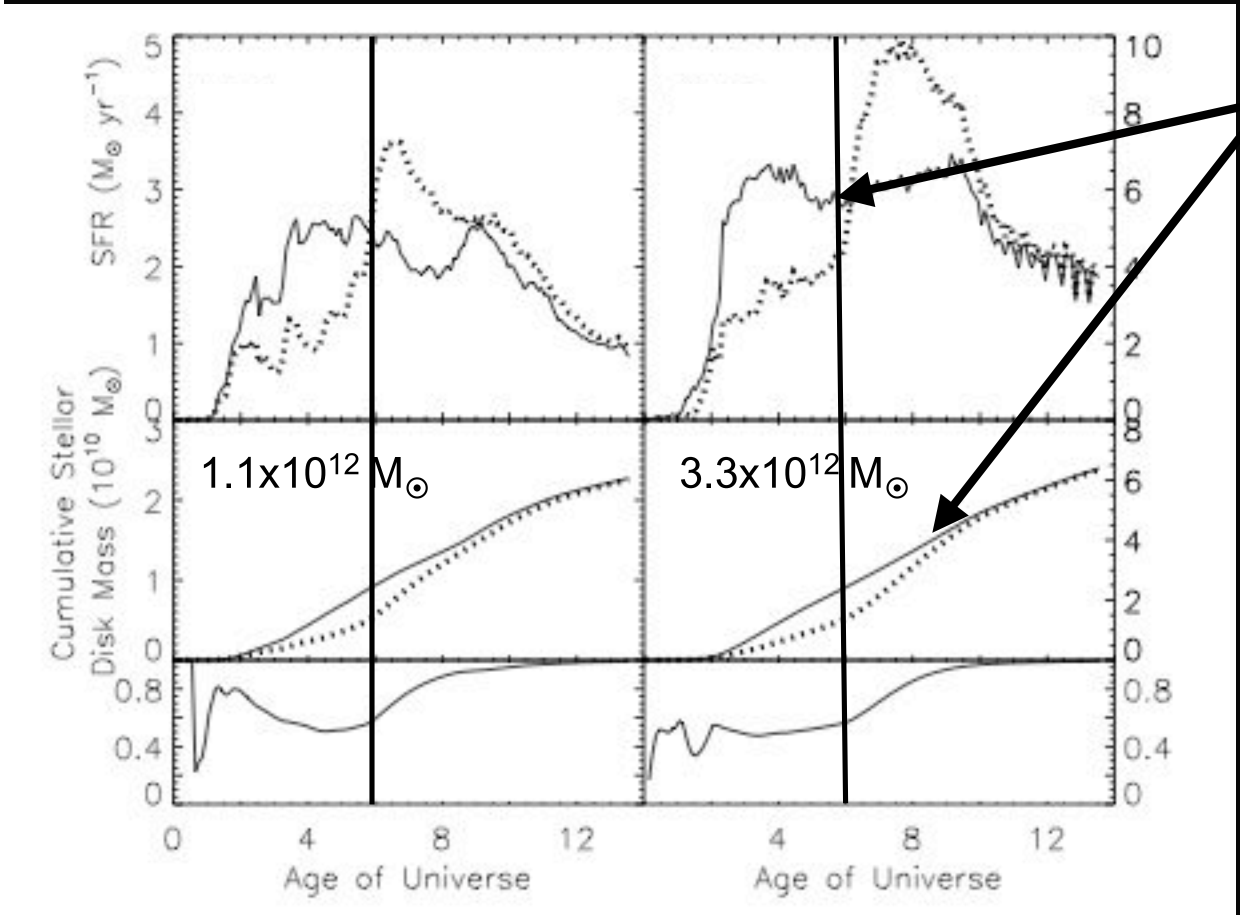
Disk Growth





Massive Disks at z=1: Vogt et al. (1996); Roche et al. (1998); Lilly et al. (1998); Simard et al. (1999); Labbe et al. (2003); Ravindranath et al. (2004); Ferguson et al. (2004); Trujillo & Aguerri (2004); Barden et al. (2005); Sargent et al. (2007); Melbourne et al. (2007); Kanwar et al. (2008); Forster-Shreiber et al. (2006); Shapiro et al. (2008); (2008); Genzel et al. (2008)

Problem 1: Disk Growth *After* z=1



Heating gas shifts SF to z < 1, as models predict

Models also predict dramatic change in scale lengths since z=1

The Formation of a Massive Galaxy to z=4

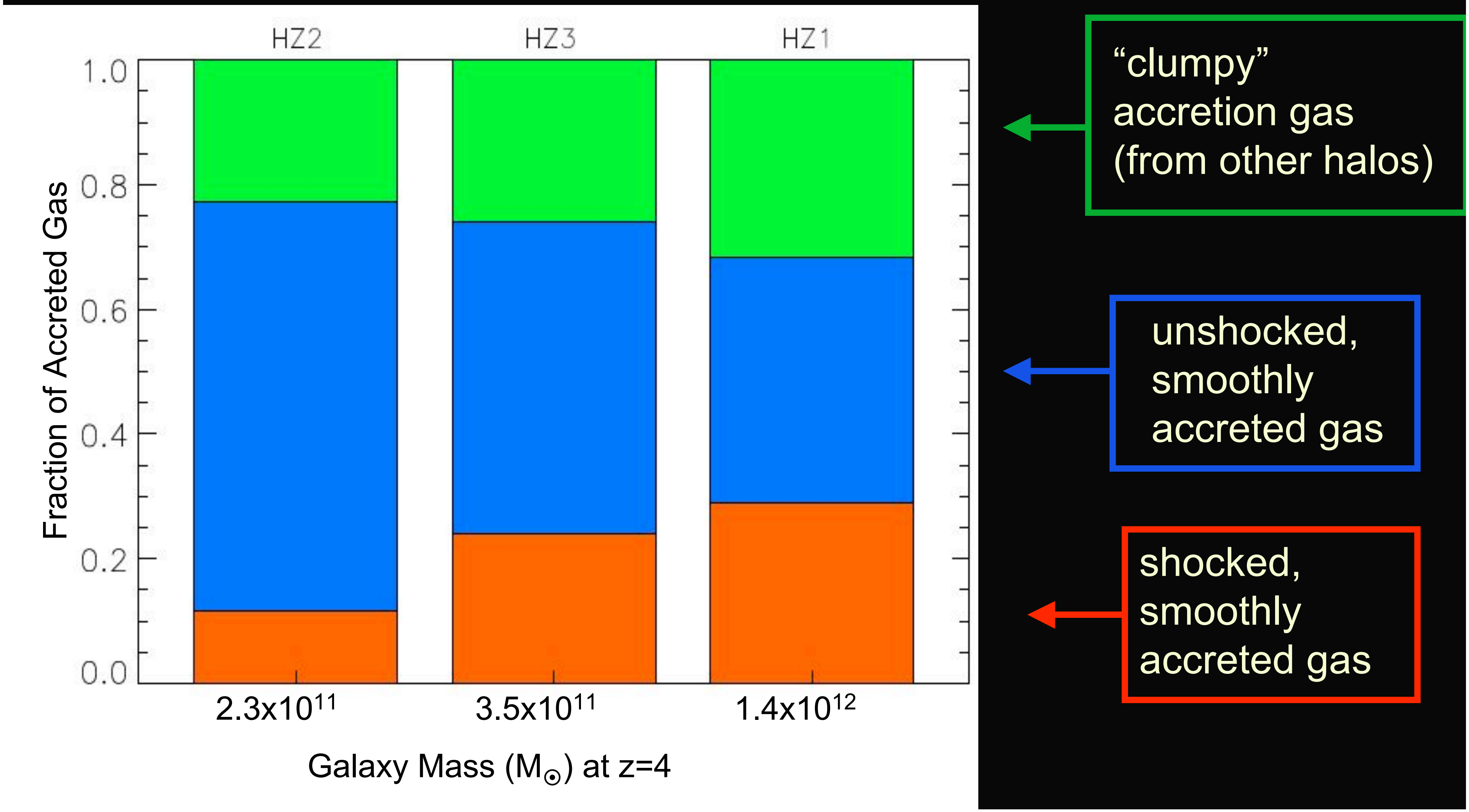
$2\times10^{13}\ M_\odot$
at z=0
(small cluster)

30 kpc on a side

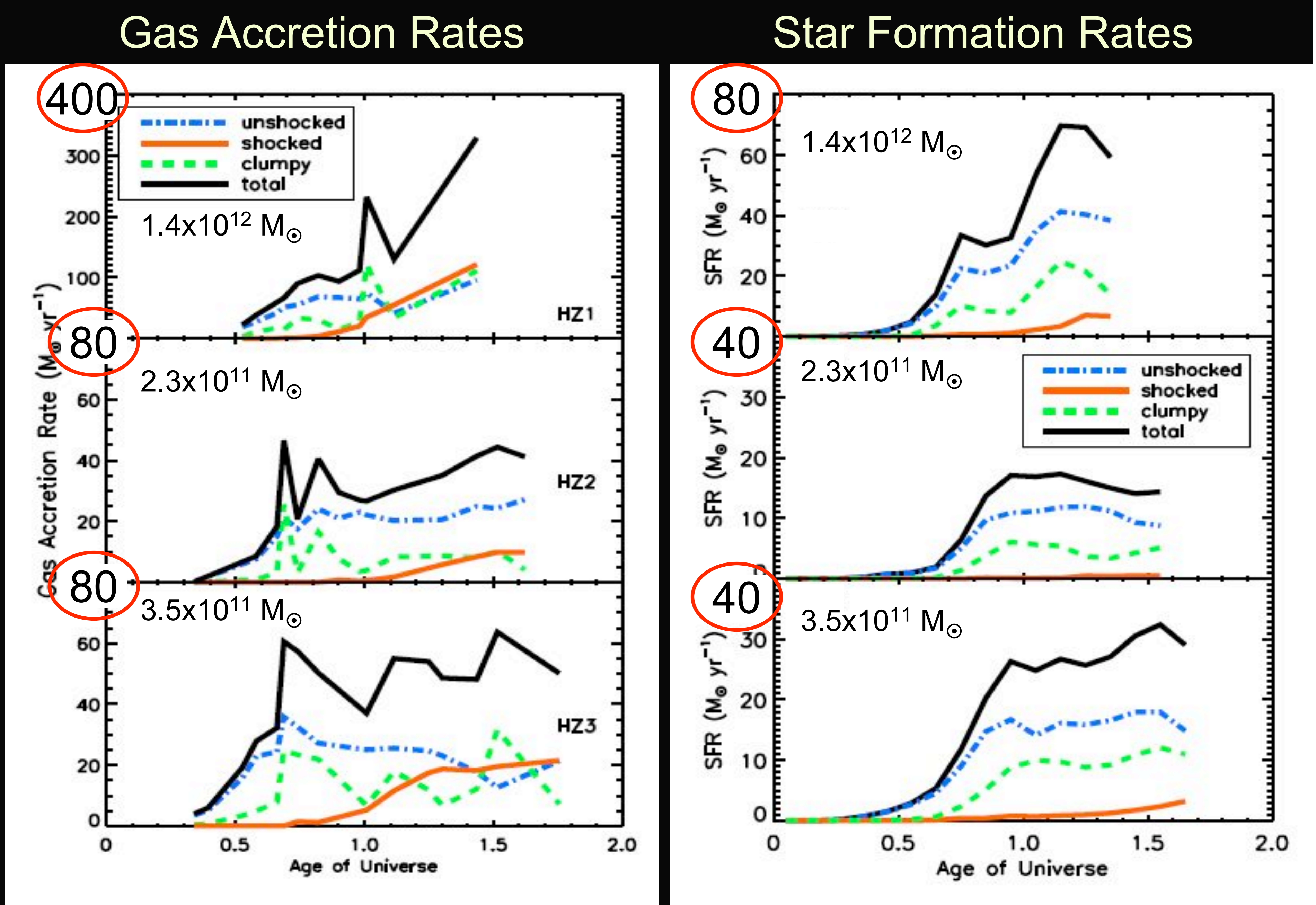
Green = gas

Blue/Red =
age/metallicity
weighted stars

Gas Accretion at the Virial Radius

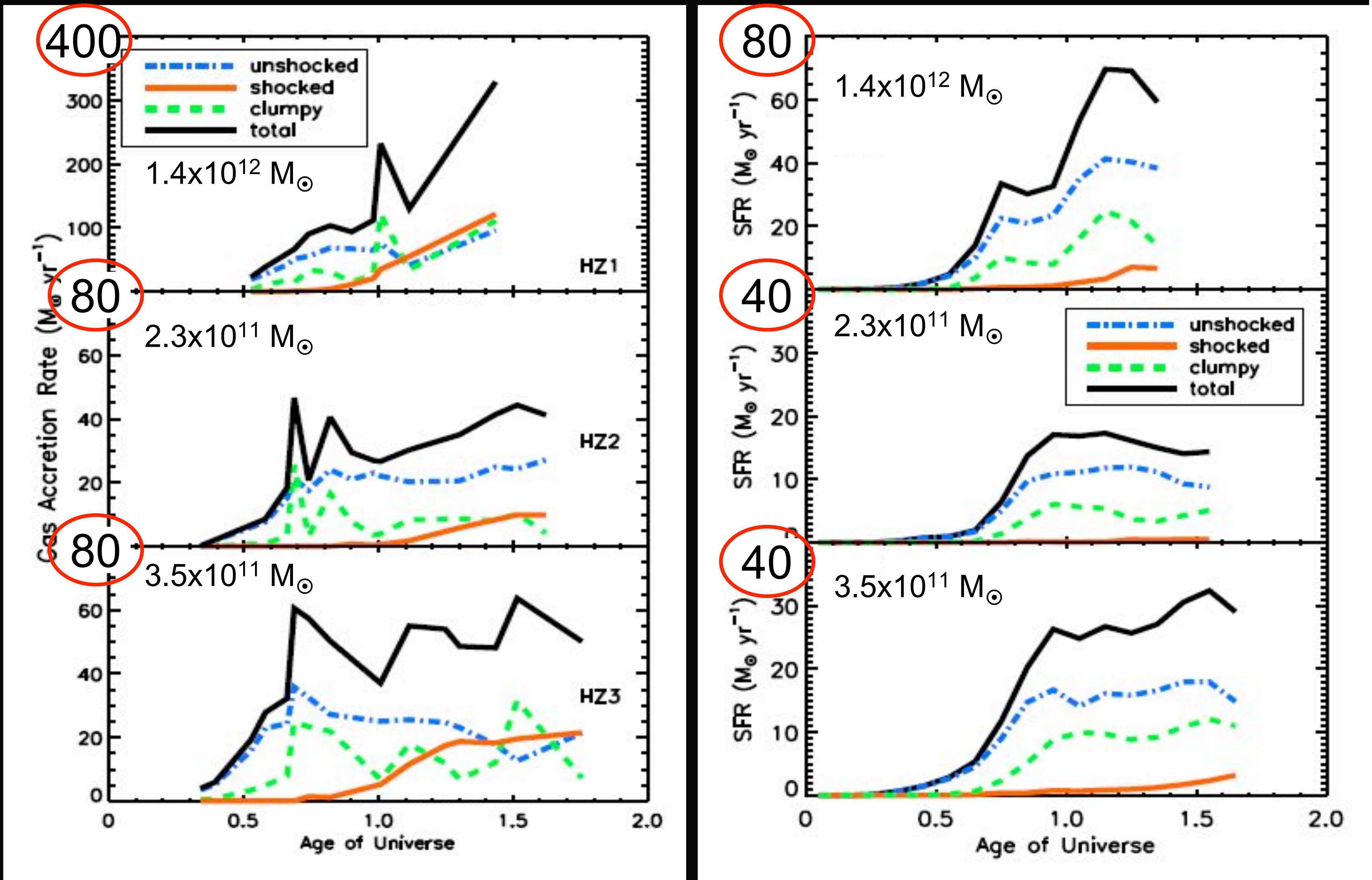


Massive Galaxies



Massive Galaxies

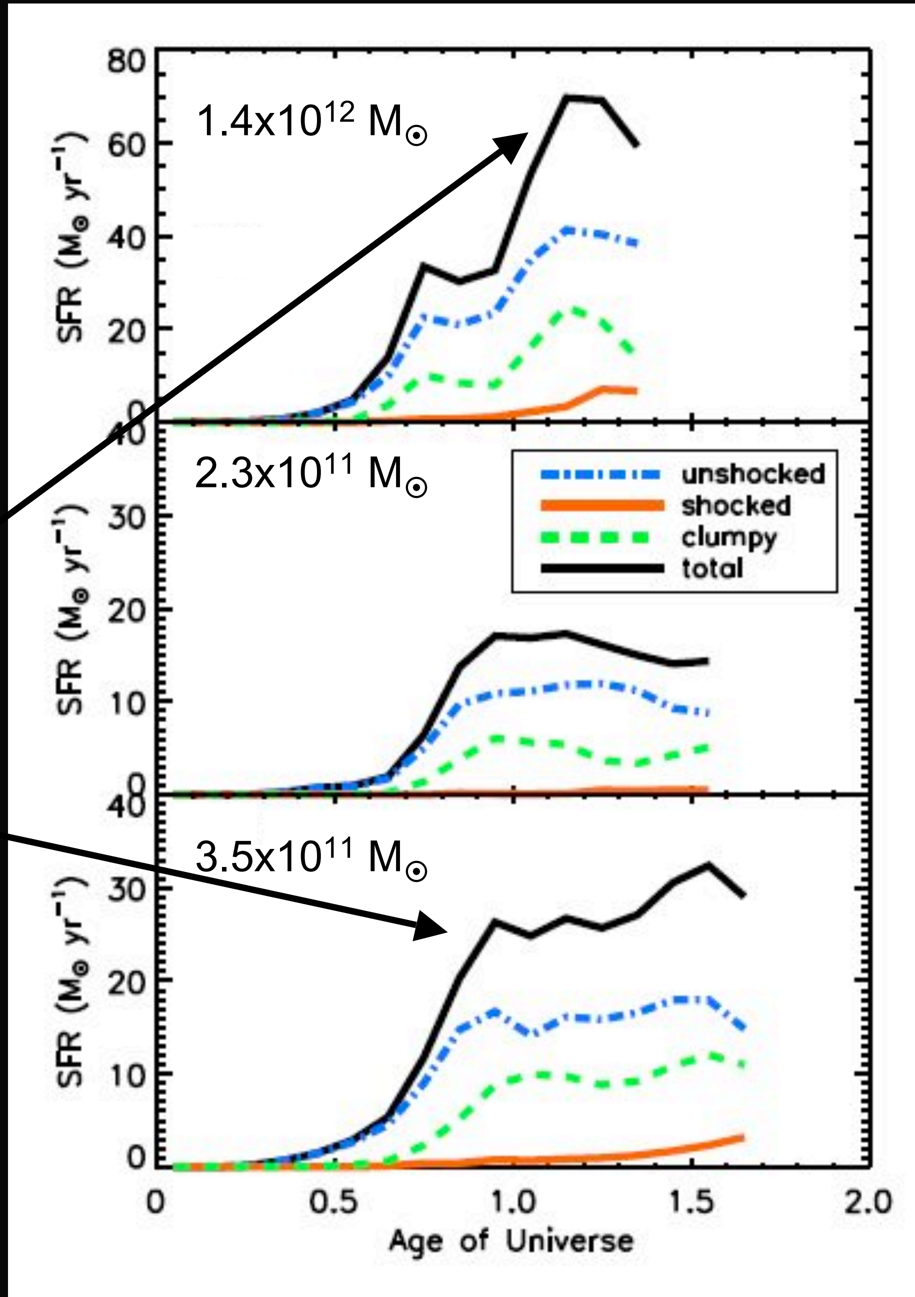
SF bursts in mergers?



Top Heavy IMF in burst?

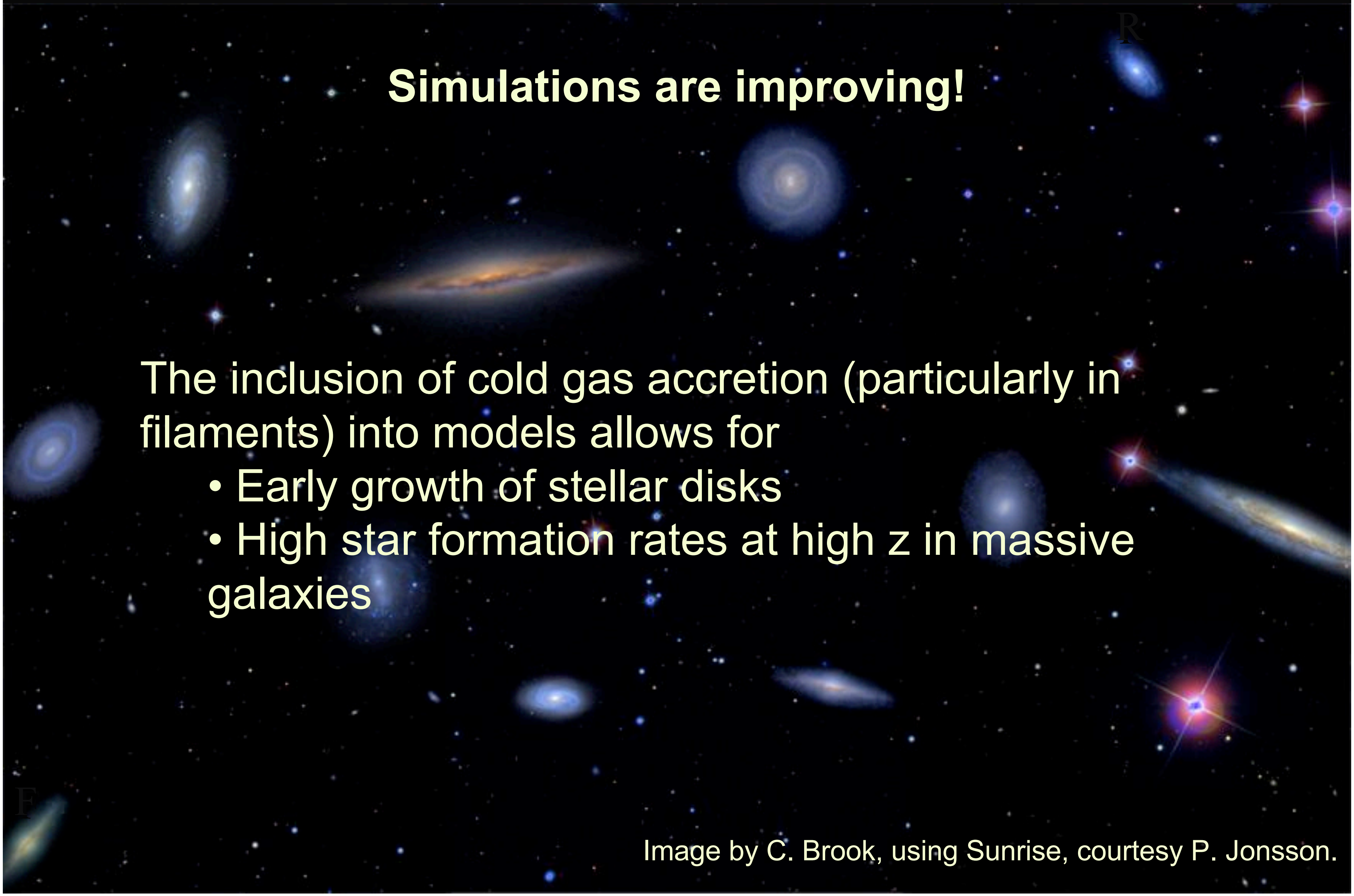
SFRs comparable to LBGs (30-100 $M_\odot$/yr)

[Fe/H] ~ -1.0



Baugh et al. 2005
Steidel et al. 1999; Shapley et al. 2001

Conclusions



Simulations are improving!

The inclusion of cold gas accretion (particularly in filaments) into models allows for

- Early growth of stellar disks
- High star formation rates at high z in massive galaxies

Image by C. Brook, using Sunrise, courtesy P. Jonsson.