The effect of feedback and reionization on low-mass dwarf galaxy halos

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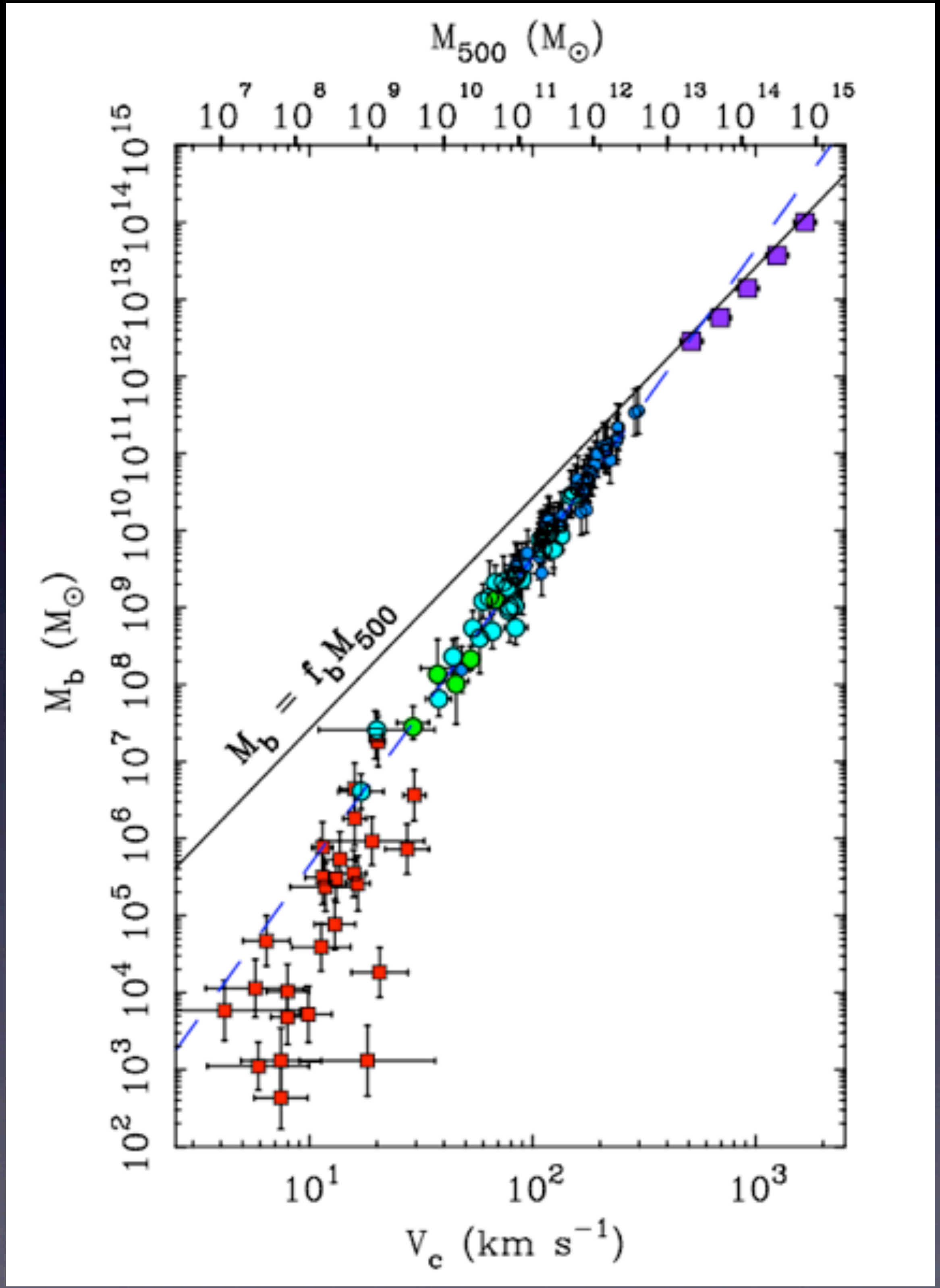
Goals

- Understand the physics regulating star formation in low-mass halos ($M_{halo} \sim 10^9\ M_\odot$)
- Test the relative importance of reionization and supernova feedback
- Use high resolution zoom-in AMR simulations to explore these issues



McGaugh et al. 2010

Simulation Set-up

- Enzo - Adaptive Mesh Refinement (AMR) code
- $1.55 \times 10^9 M_\odot$ at $z = 0$ in isolated environment
- 4 comoving Mpc h^{-1} cosmological box with 2 nested refinement grids ($m_{dm} = 5353 M_\odot$)
- Adaptive refinement based on dm & gas density (12 levels, Δx_{min} = 11 comoving pc)
- Non-equilibrium H_2 cooling (Anninos et al. 1997, Abel et al. 1997)
- Metal line cooling & heating rates (Smith et al. 2008)
- Cosmic UV backgrounds (photoionizing & photodissociating) (Hardt & Madau 2001, 2011)
- Self-shielding prescription from photoionization & photodissociation (Simpson et al. 2012 in prep, Shang, Bryan & Haiman 2010)
- Star formation ($m_* = 100 M_\odot$) (Cen & Ostriker 1992)
- Thermal supernova feedback (assume $150 M_\odot$ stars make 10^{51} ergs injected over 10 Myrs) (Cen & Ostriker 1992)

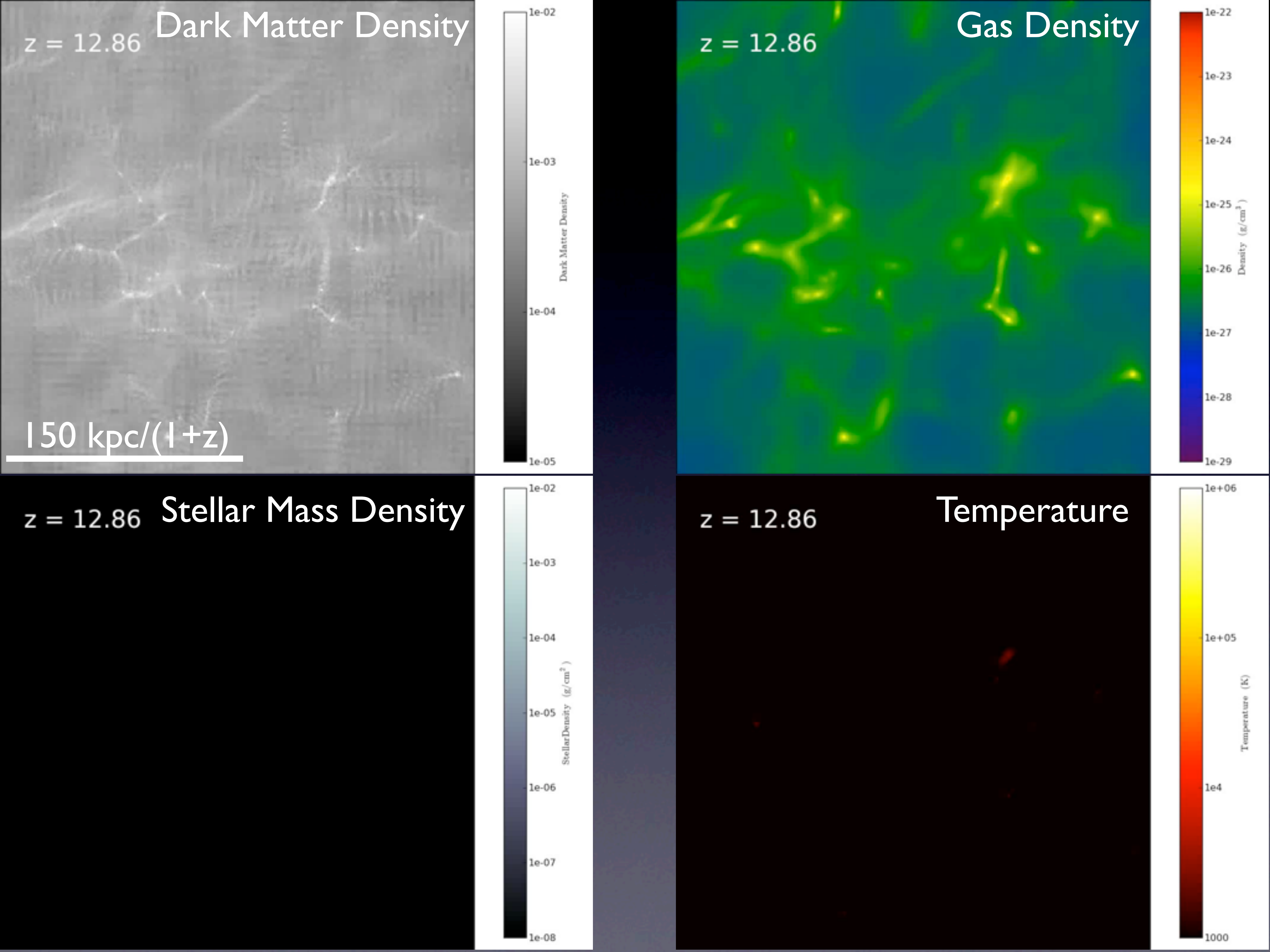
Dark Matter Density

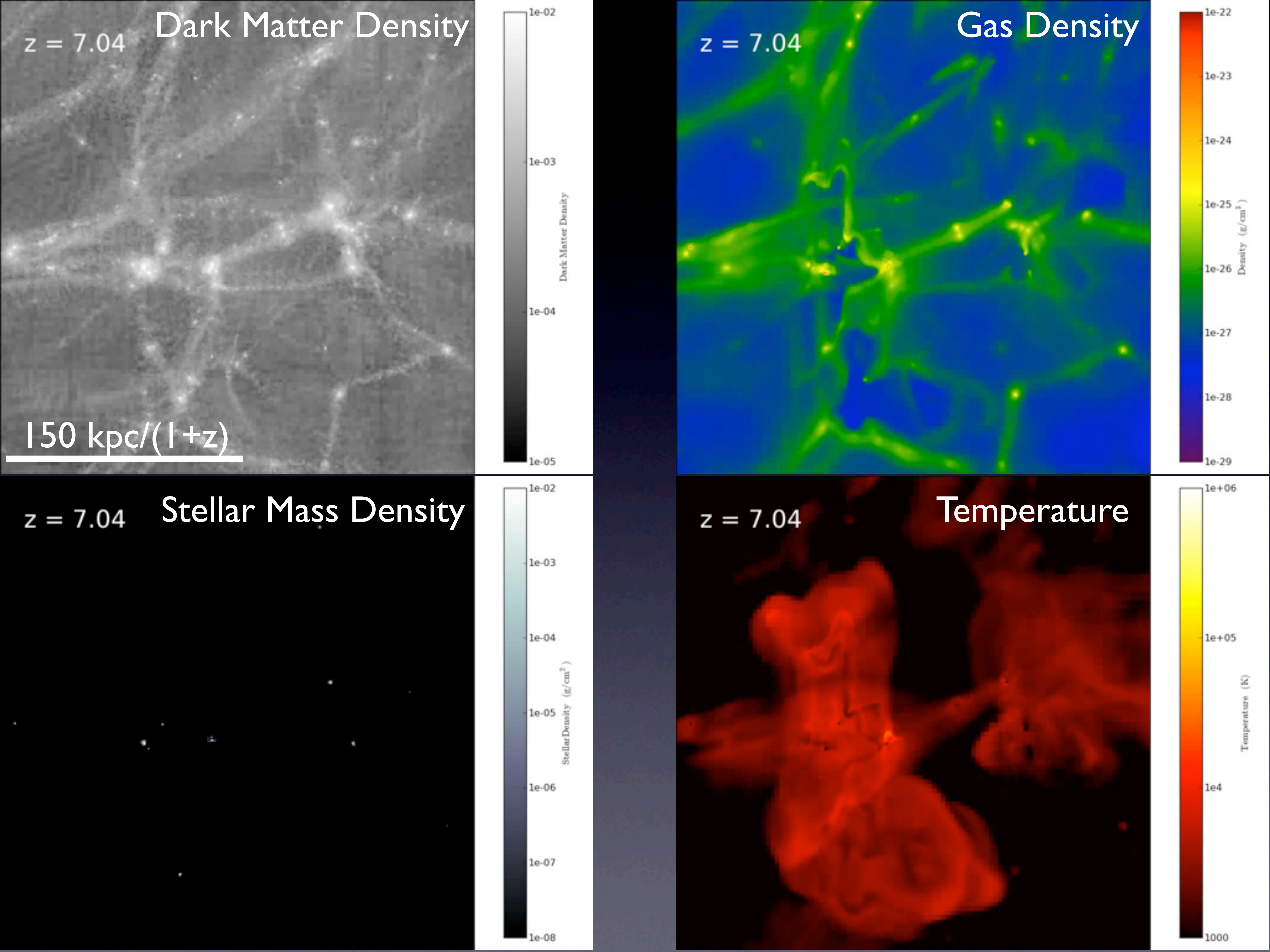
Gas Density

150 kpc/(1+z)

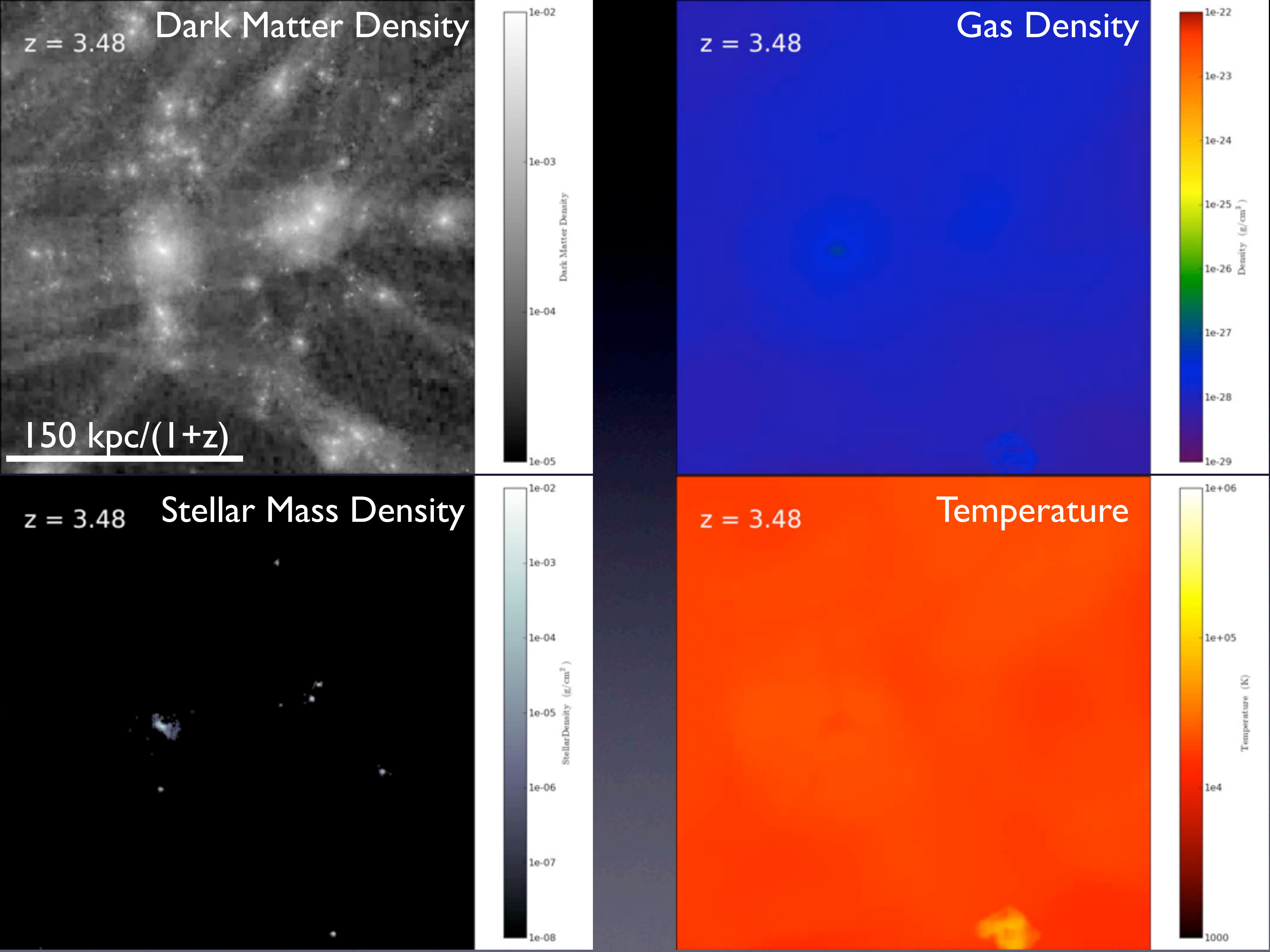
Stellar Mass Density

Temperature


z = 12.86
Dark Matter Density
150 kpc/(1+z)
1e-02
1e-03
1e-04
1e-05
Dark Matter Density
z = 12.86
Gas Density
1e-22
1e-23
1e-24
1e-25
1e-26
1e-27
1e-28
1e-29
Density (g/cm^3)
z = 12.86
Stellar Mass Density
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-08
StellarDensity (g/cm^2)
z = 12.86
Temperature
1e+06
1e+05
1e4
1000
Temperature (K)

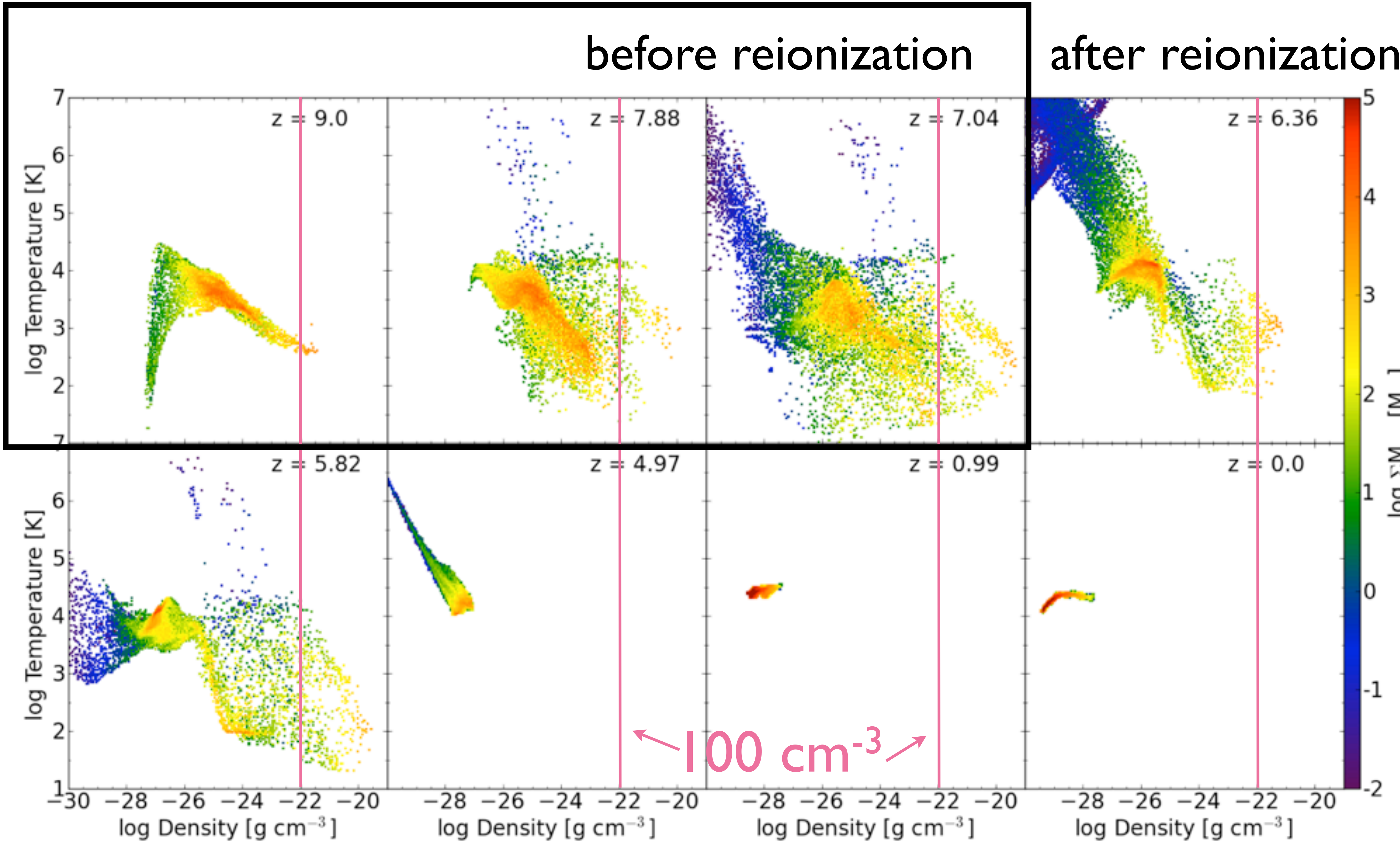


Dark Matter Density
z = 7.04
150 kpc/(1+z)
1e-02
1e-03
1e-04
1e-05
Dark Matter Density
Gas Density
z = 7.04
1e-22
1e-23
1e-24
1e-25
1e-26
1e-27
1e-28
1e-29
Density (g/cm^3)
Stellar Mass Density
z = 7.04
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-08
StellarDensity (g/cm^3)
Temperature
z = 7.04
1e+06
1e+05
1e4
1000
Temperature (K)



Dark Matter Density
z = 3.48
150 kpc/(1+z)
1e-02
1e-03
1e-04
1e-05
Dark Matter Density
Gas Density
z = 3.48
1e-22
1e-23
1e-24
1e-25
1e-26
1e-27
1e-28
1e-29
Density (g/cm³)
Stellar Mass Density
z = 3.48
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-08
StellarDensity (g/cm²)
Temperature
z = 3.48
1e+06
1e+05
1e4
1000
Temperature (K)

Multiphase ISM

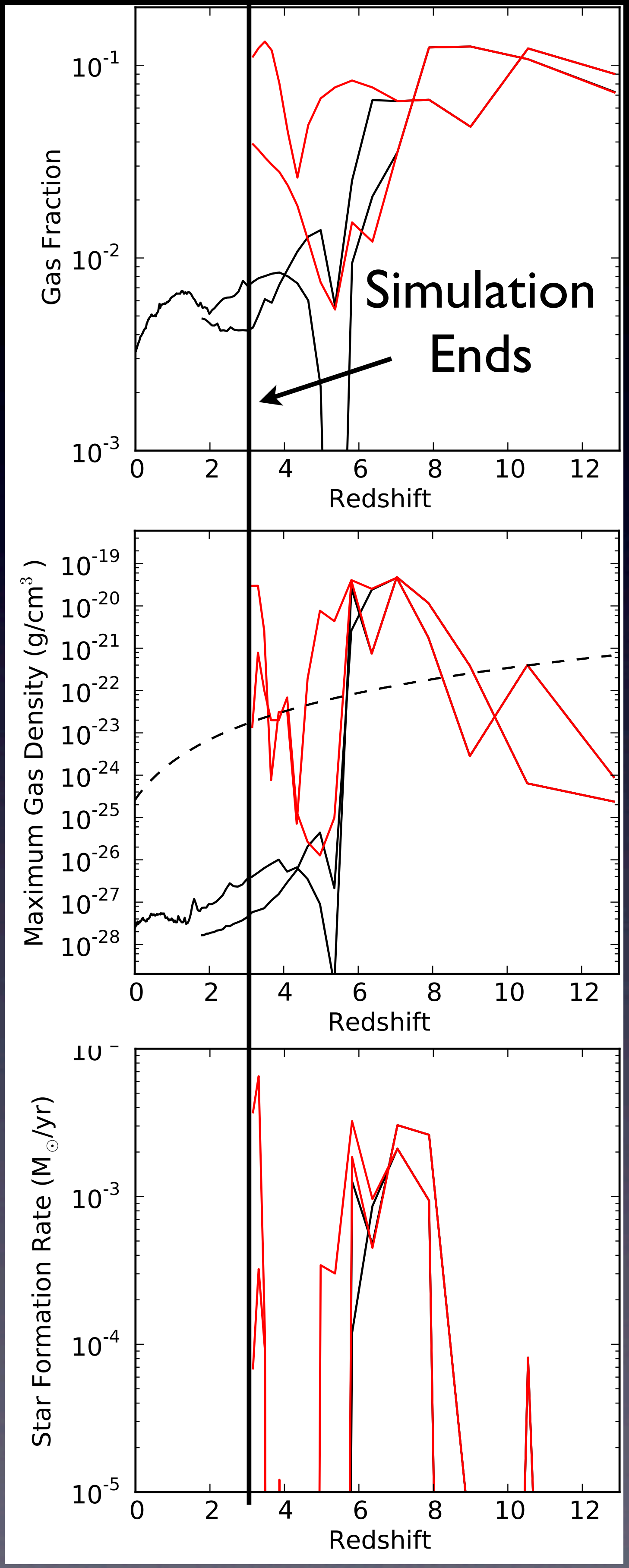


Gas with r_{200} of a progenitor

Reionization vs. SN feedback

No UV Background

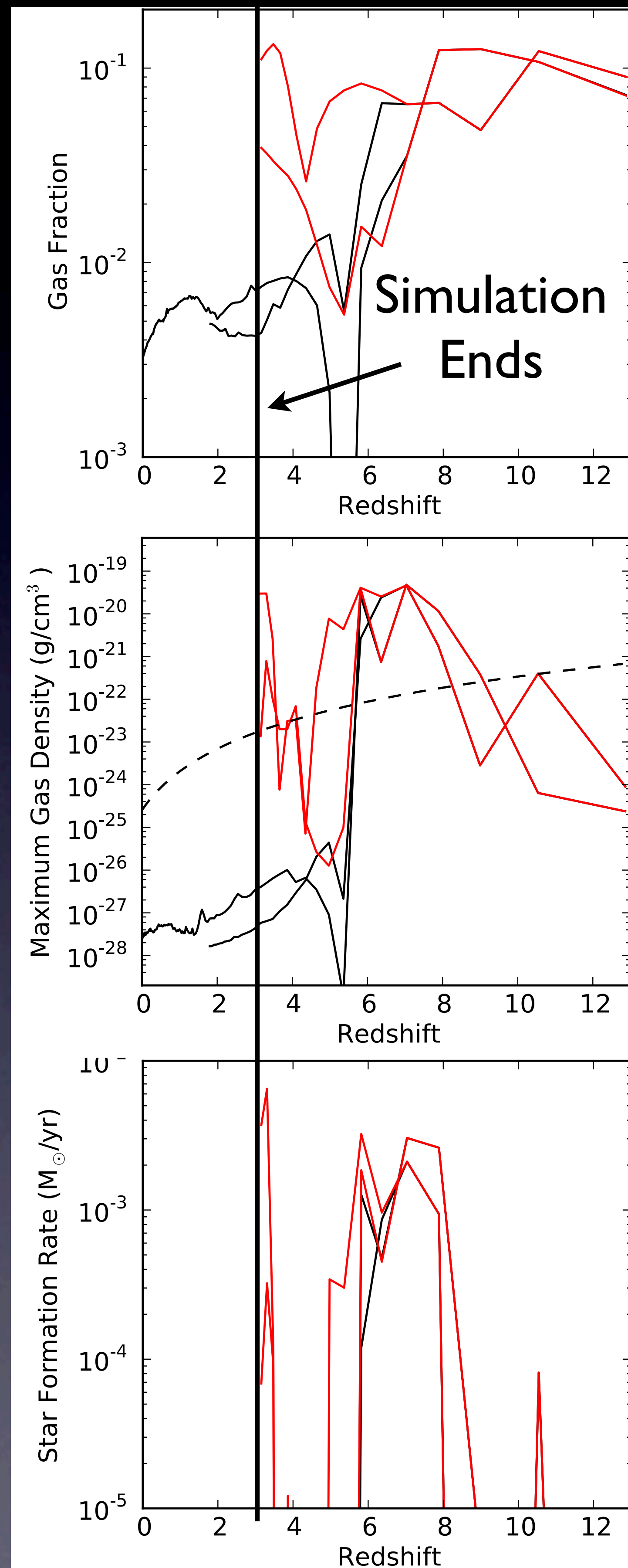
black: full physics
red: No UV bg

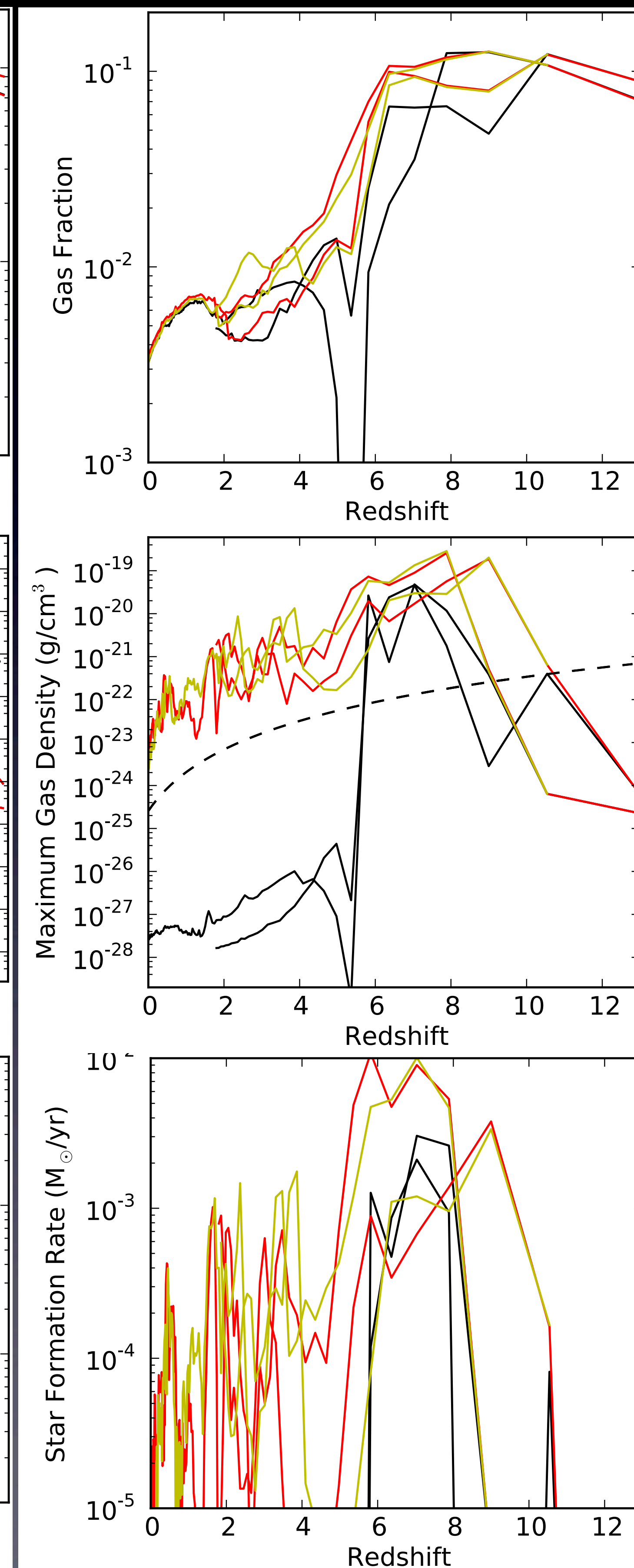


Reionization vs. SN feedback

No UV Background

black: full physics
red: No UV bg

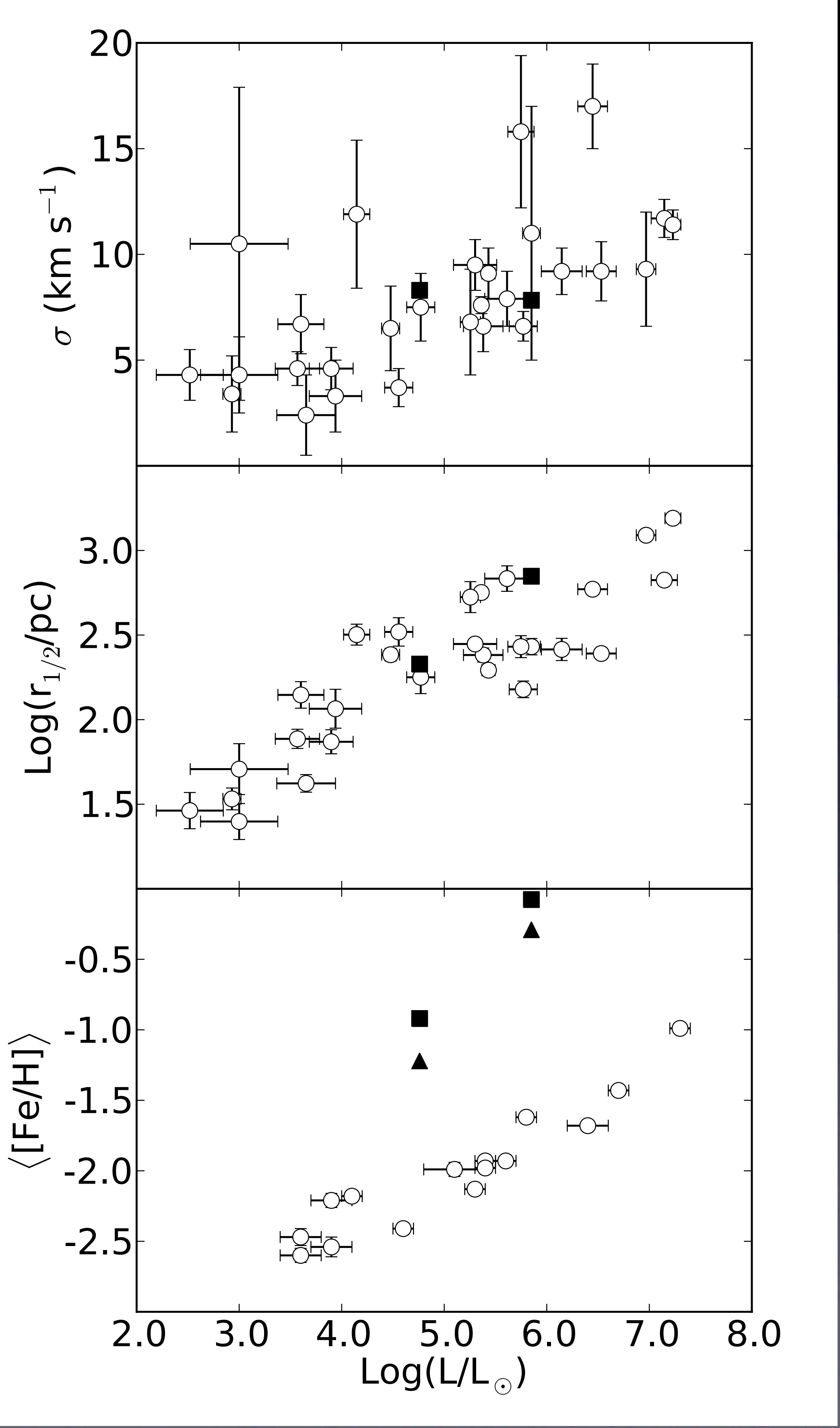




No Thermal Feedback

black: full physics
red,yellow:
No SN feedback

Comparison to MW dSphs

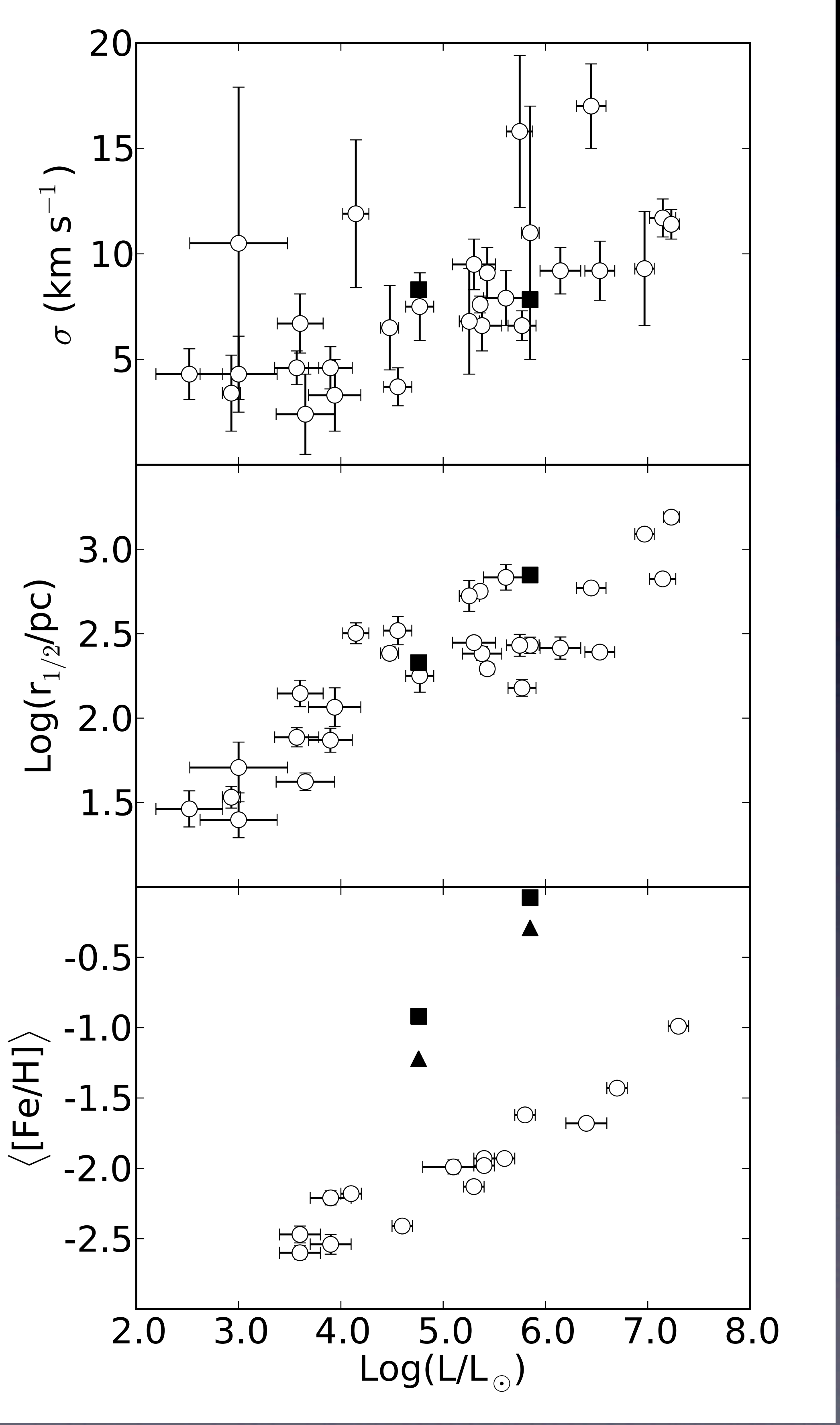


Reionization z=6-7 | Reionization z=8-8.9

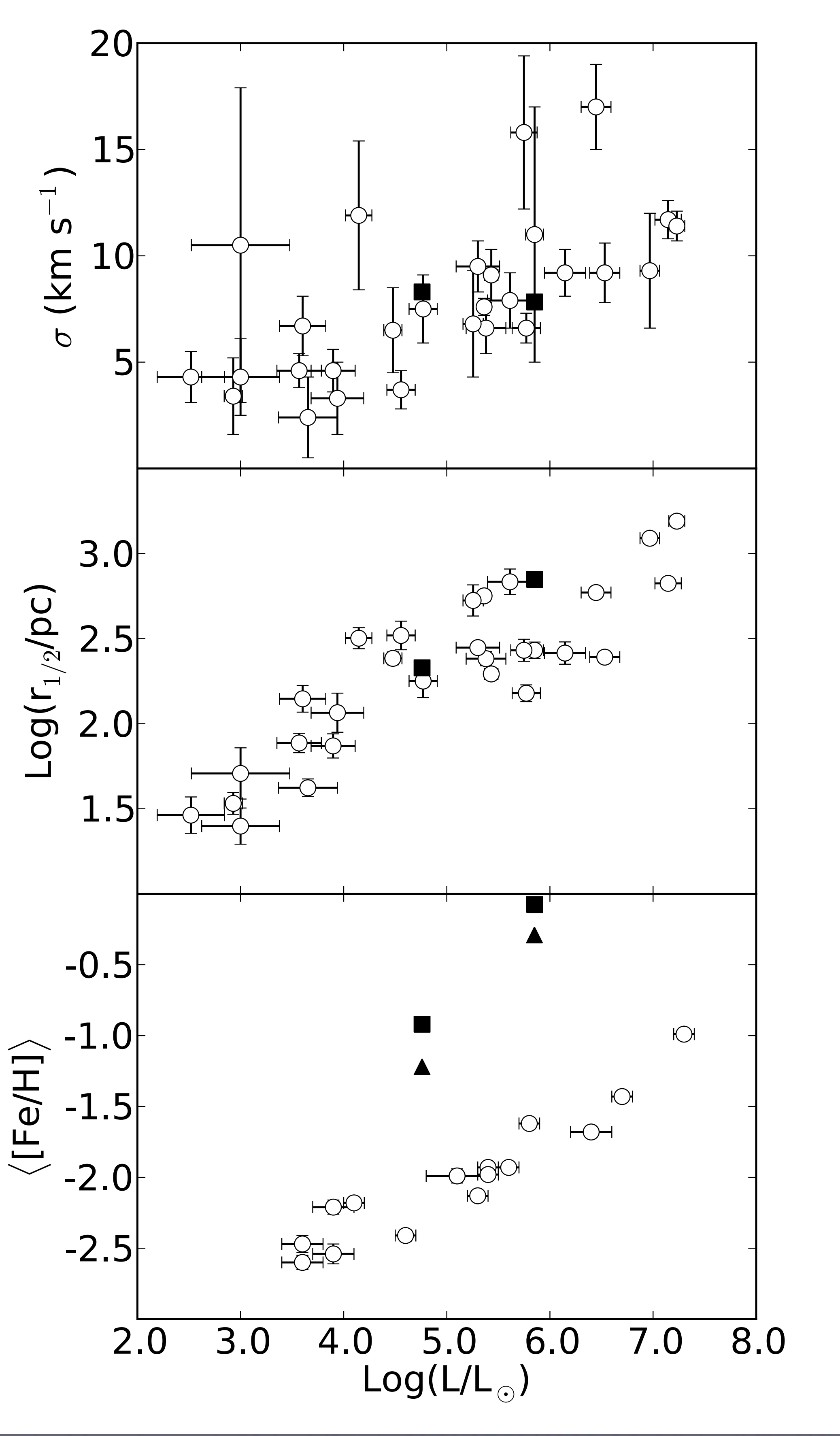
	R10	R10-earlyUV
$M_{tot}/M_\odot$	1.55×10^9	1.55×10^9
$M_*/M_\odot$	1.43×10^6	1.16×10^5
r_{200} (kpc)	23.7	23.9
$r_{1/2}$ (pc)	704	213
$M_{1/2}/M_\odot$	3.05×10^7	3.86×10^6
$M_{300}/M_\odot$	7.53×10^6	7.41×10^6
$\sigma_{1/2}$ (km/s)	7.83	8.30
$\langle Z/Z_\odot \rangle$ (median)	0.51	0.06

Data from Walker et al. 2009, Kirby et al. 2008 & Kirby et al. 2011

Comparison to MW dSphs

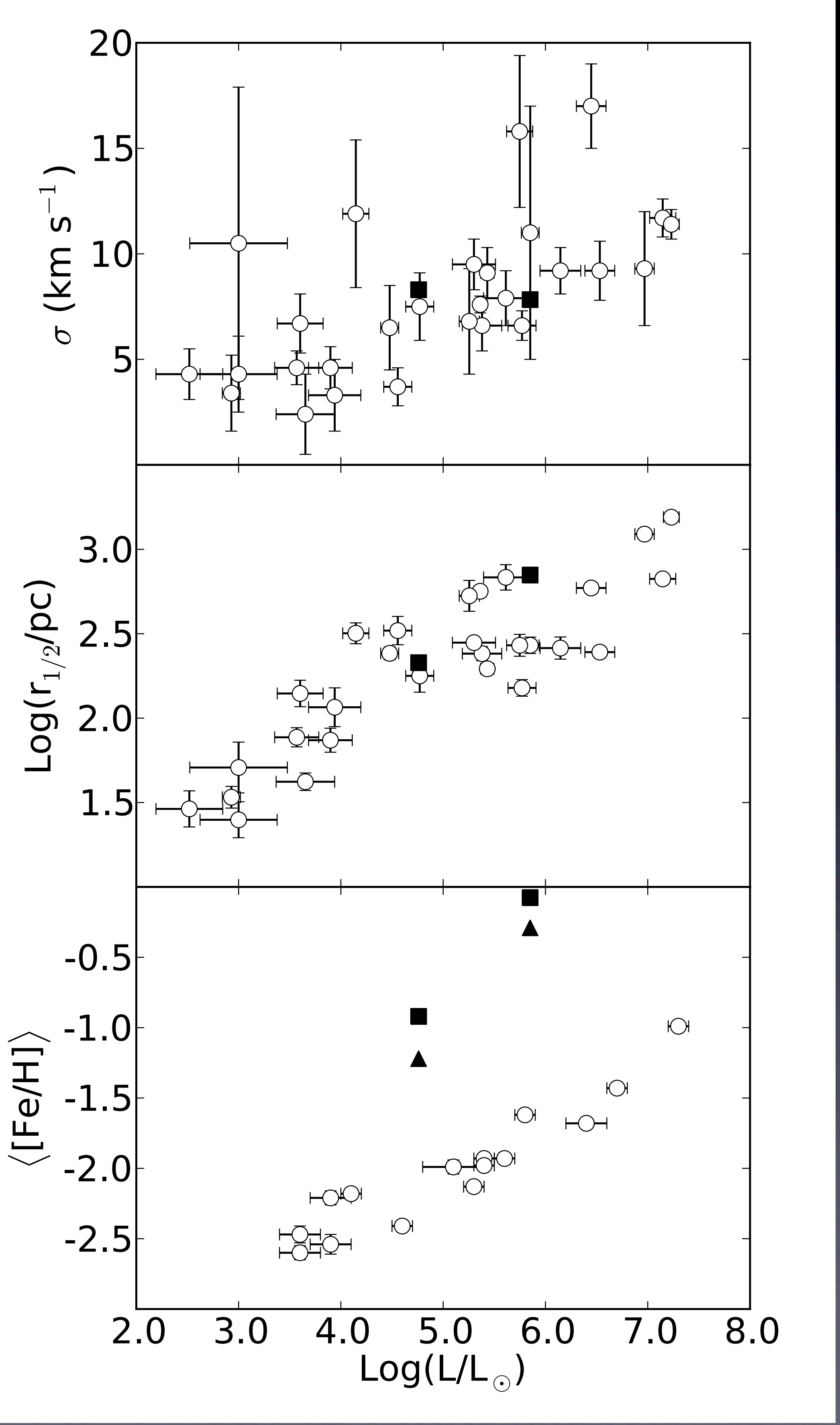


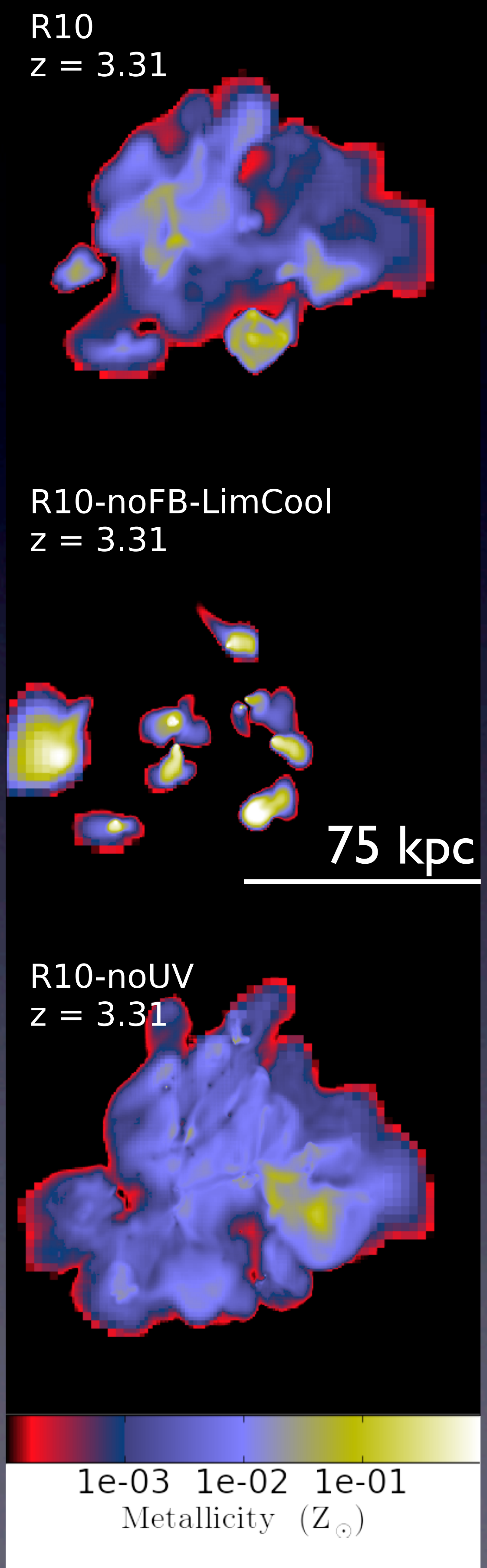
Comparison to MW dSphs



Data from Walker et al. 2009, Kirby et al. 2008 & Kirby et al. 2011

Comparison to MW dSphs



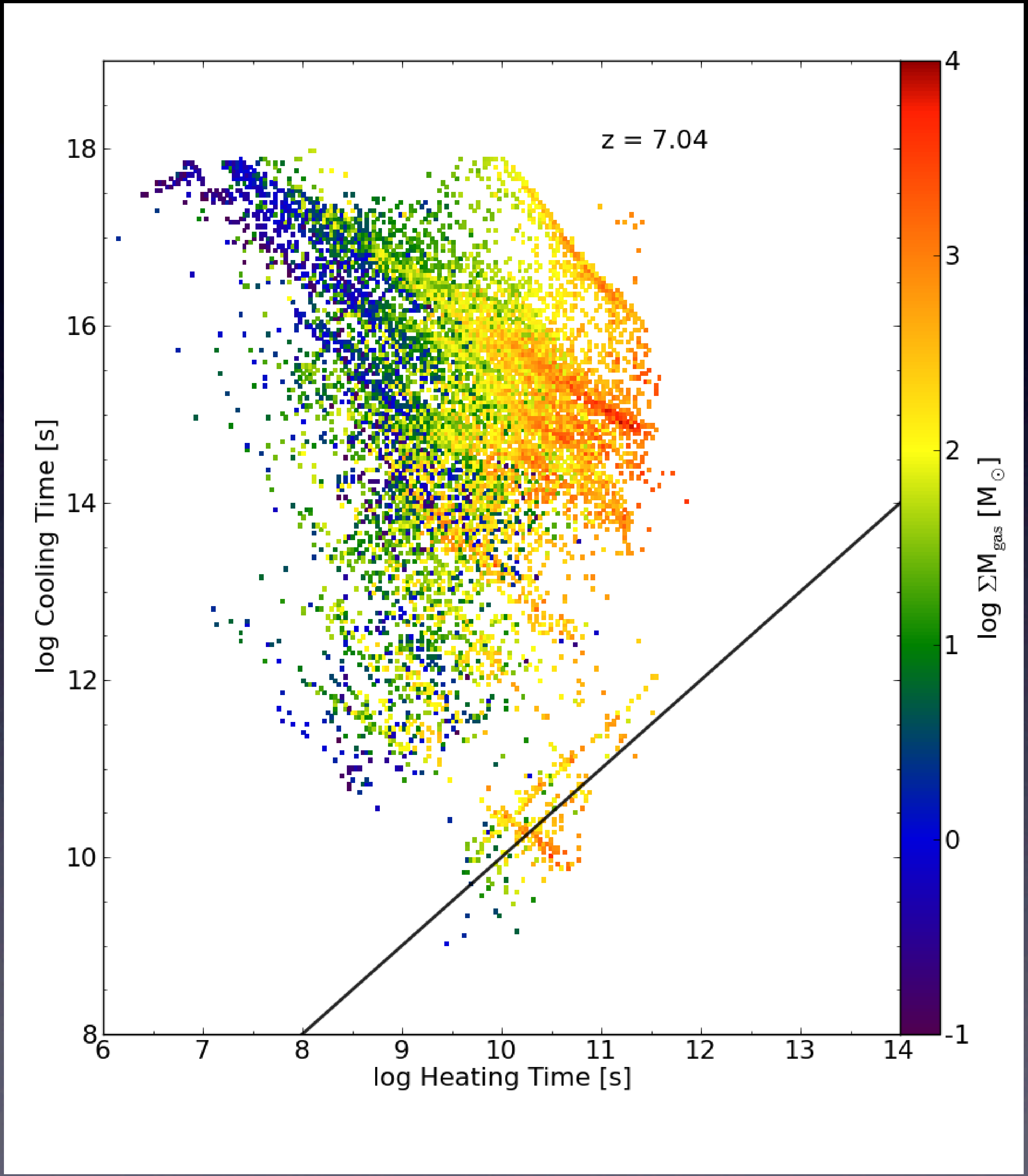


Full Model

No Feedback

No UV Background

Why? *an old story*



We assume
150 $M_\odot$ of stars
produce 10^{51} ergs
in *thermal energy*

$$t_{heat} = \frac{3}{2}\frac{m_{cell}kT_{cell}}{\mu_{cell}m_H}\frac{t_f}{e_{SN}M_*c^2}$$

10 Myrs

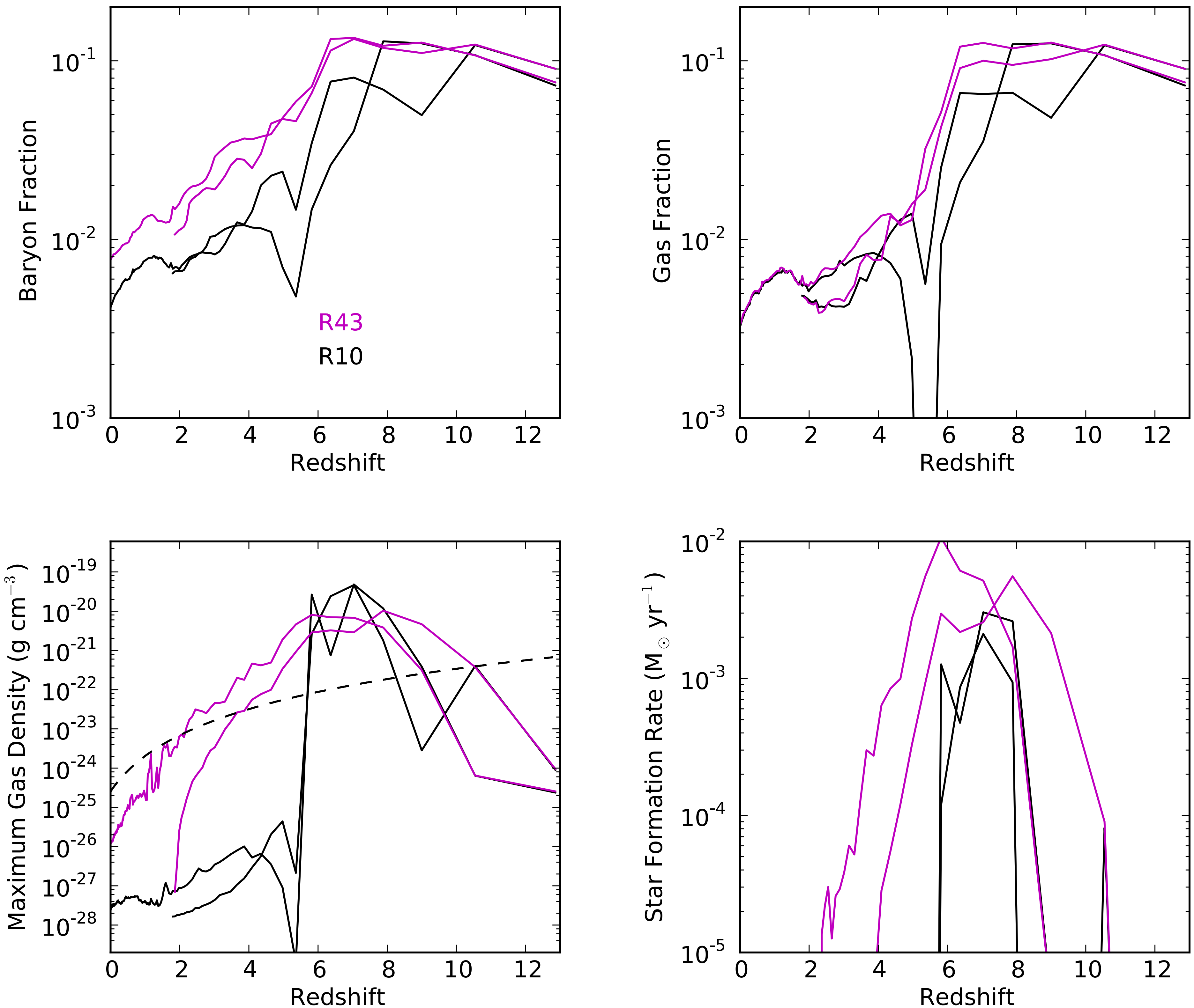
3.7e-6

100 $M_\odot$

Spatial resolution

Black: Δx_{min} = 11 pc/(z+1)

Magenta: Δx_{min} = 43 pc/(z+1)



Conclusions

- We have performed a series of high resolution, cosmological simulations of the formation of a low-mass dwarf halo
- We find that our halo forms hierarchically, with multiple star forming progenitors at high redshift
- The timing of reionization can produce a difference in stellar mass of an order of magnitude
- The UV background and SN feedback work together to suppress star formation; the UV background by suppressing the overall gas fraction, and SN by destroying self-shielded dense gas
- We form an object consistent in mass and luminosity to MW dwarfs
- We do not find good agreement with stellar metallicities for such objects, indicating the need for a more realistic feedback model
- The low masses of dwarfs make them attractive laboratories for simulators to tackles these types of issues at high resolutions