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The First Mini-Quasar

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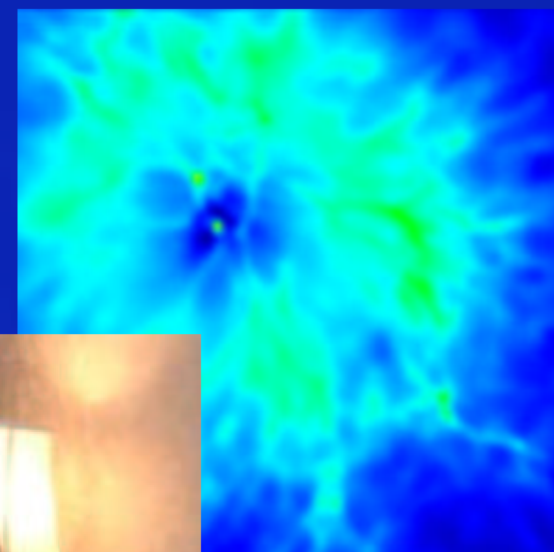


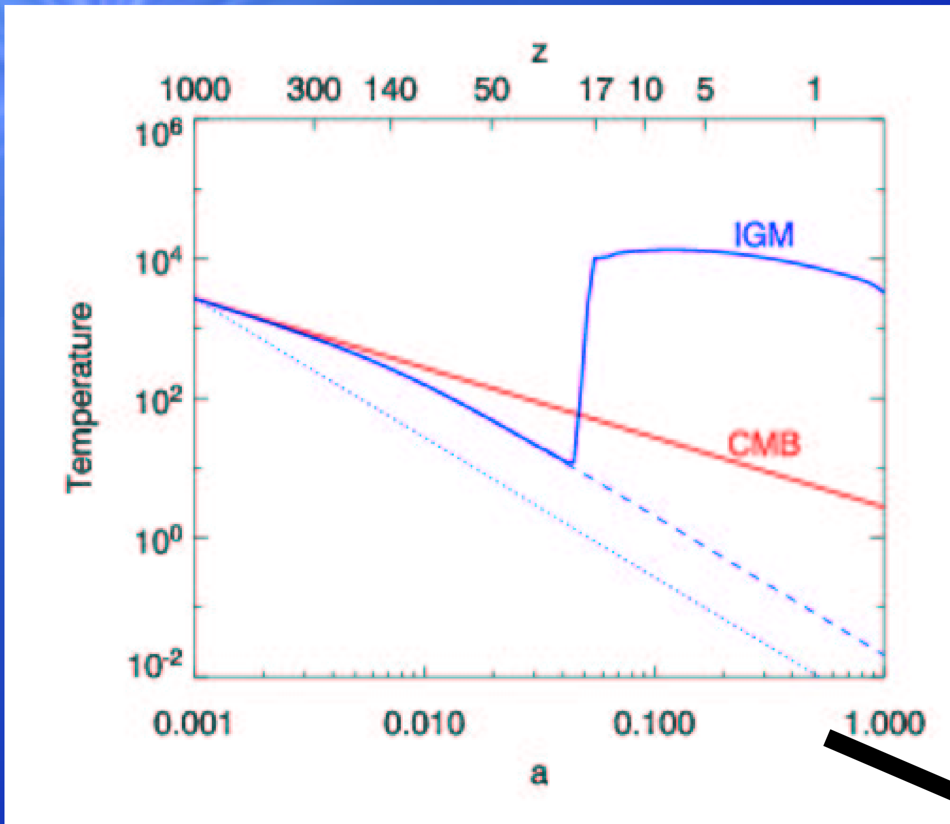
Overview

1. Background/Motivation

2. Numerical Simulations

3. Some Analysis (Work in Progress!!)

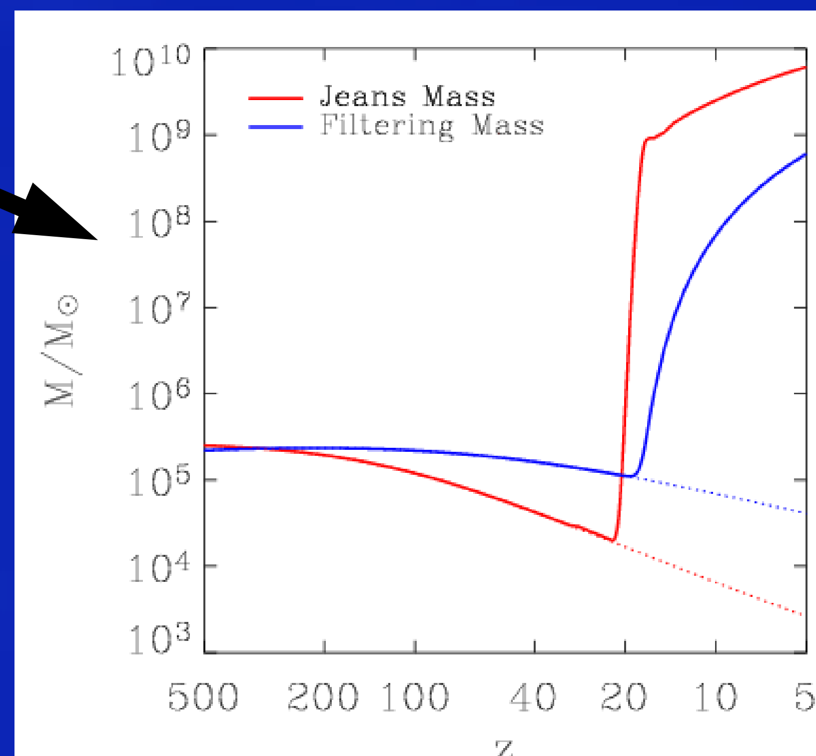
4. Conclusions/Future Work



Reminder:

T_{CMB} falls as 1/(1+z)
T_{IGM} falls as $1/(1+z)^2$

Reionization raises T_{IGM} to ~10^4 K.
Process is uncertain!

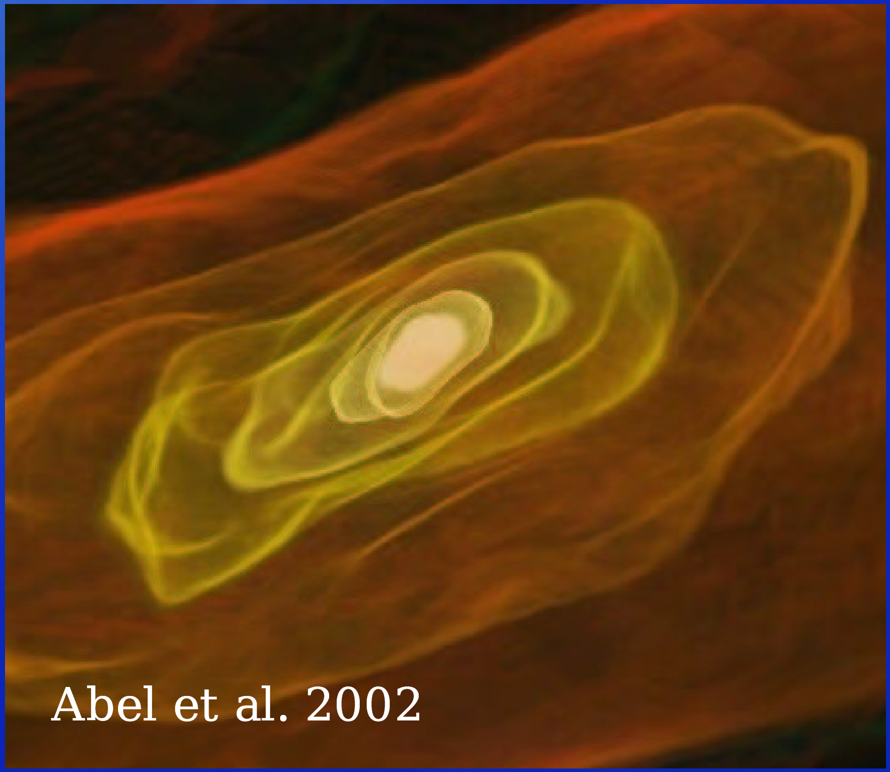


Baryonic collapse if $M > M_J$

$$\lambda_J = \sqrt{\frac{\pi}{G\rho}}\, c_s \qquad M_J = \frac{6}{\pi}\rho_{\rm crit}\Omega_b(1+z)^3\lambda_J^3$$

Temperature dependence

Pop.III Stars and Their Remnants

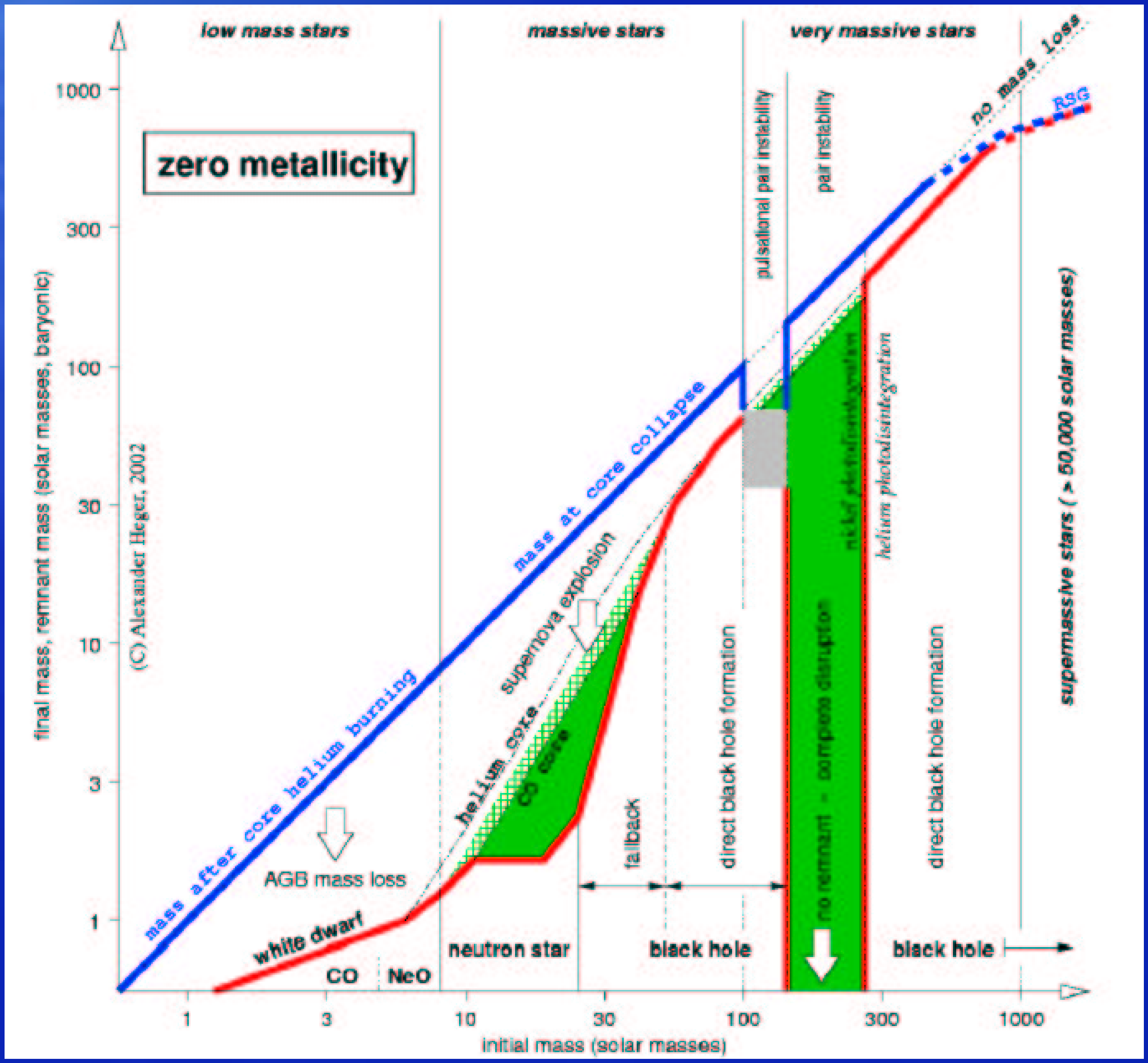


Need cooling to lower M_j

Z=0, have to rely on inefficient H_2 cooling

Simulations (Abel et al. 2002, Bromm et al. 2002) show that Z=0 IMF is likely to be top-heavy:

$M \sim 100\text{-}1000\ M_\odot$



Heger & Woosley 2002

The First MiniQuasar

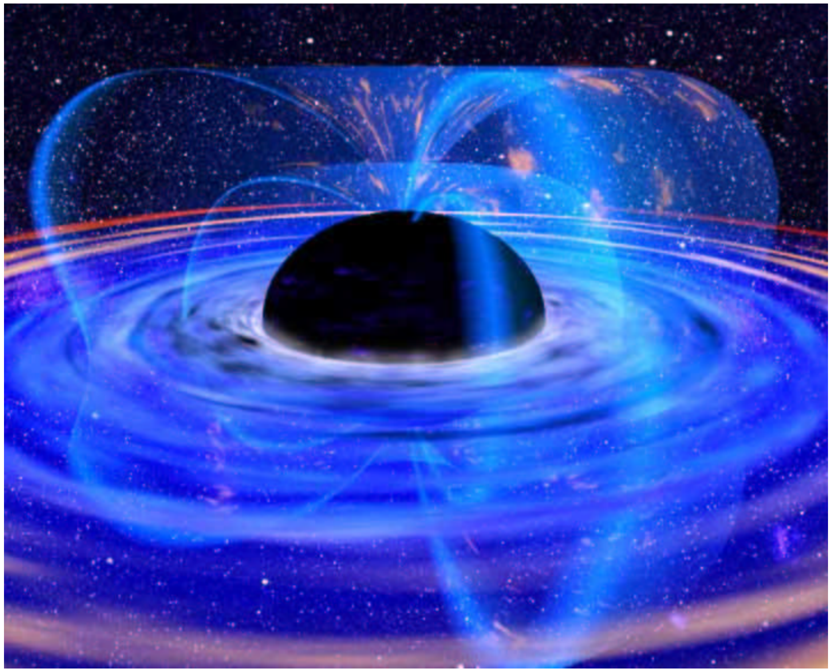
SN explosion probably unbinds all the gas in the host halo.

Halo continues to merge, gas supply is replenished.

Gas is accreted onto BH: a MiniQSO begins to shine!

Hard x-rays can escape the host halo and affect the IGM:

- contribute to re-ionization
- heat gas, raise Jeans/Filtering mass
- destroy (create) H_2, inhibit (enhance) SF



NASA Goddard

Enzo Cosmological Simulation Code

Laboratory for Computational Astrophysics
University of California, San Diego

- Written by Greg Bryan and Mike Norman
- publically available: astro-ph/0403044
- Structured Adaptive Mesh Refinement
- Baryon Hydrodynamics: PPM with dual-energy formalism
- Dark Matter Dynamics: Adaptive Particle-Mesh
- 9-species chemistry network (Anninos, Abel):

  H, H^+, H^-, H_2, H_2^+, He, He^+, He^{++}, e^-
- Non-equilibrium cooling rates

Simulation Set-Up

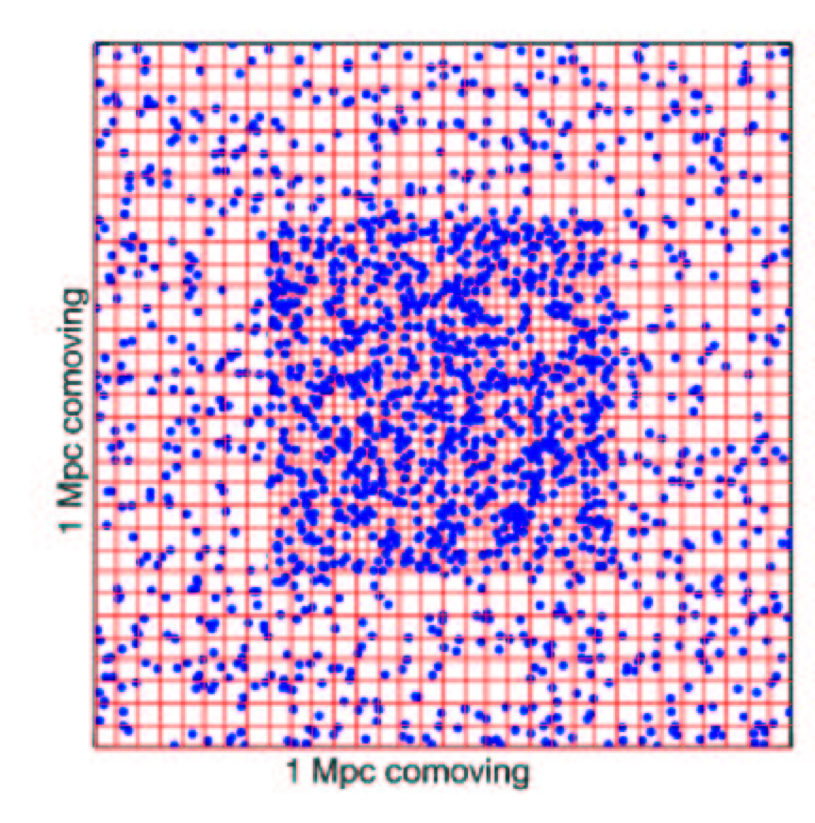
Concordance Cosmology with σ_8=0.85

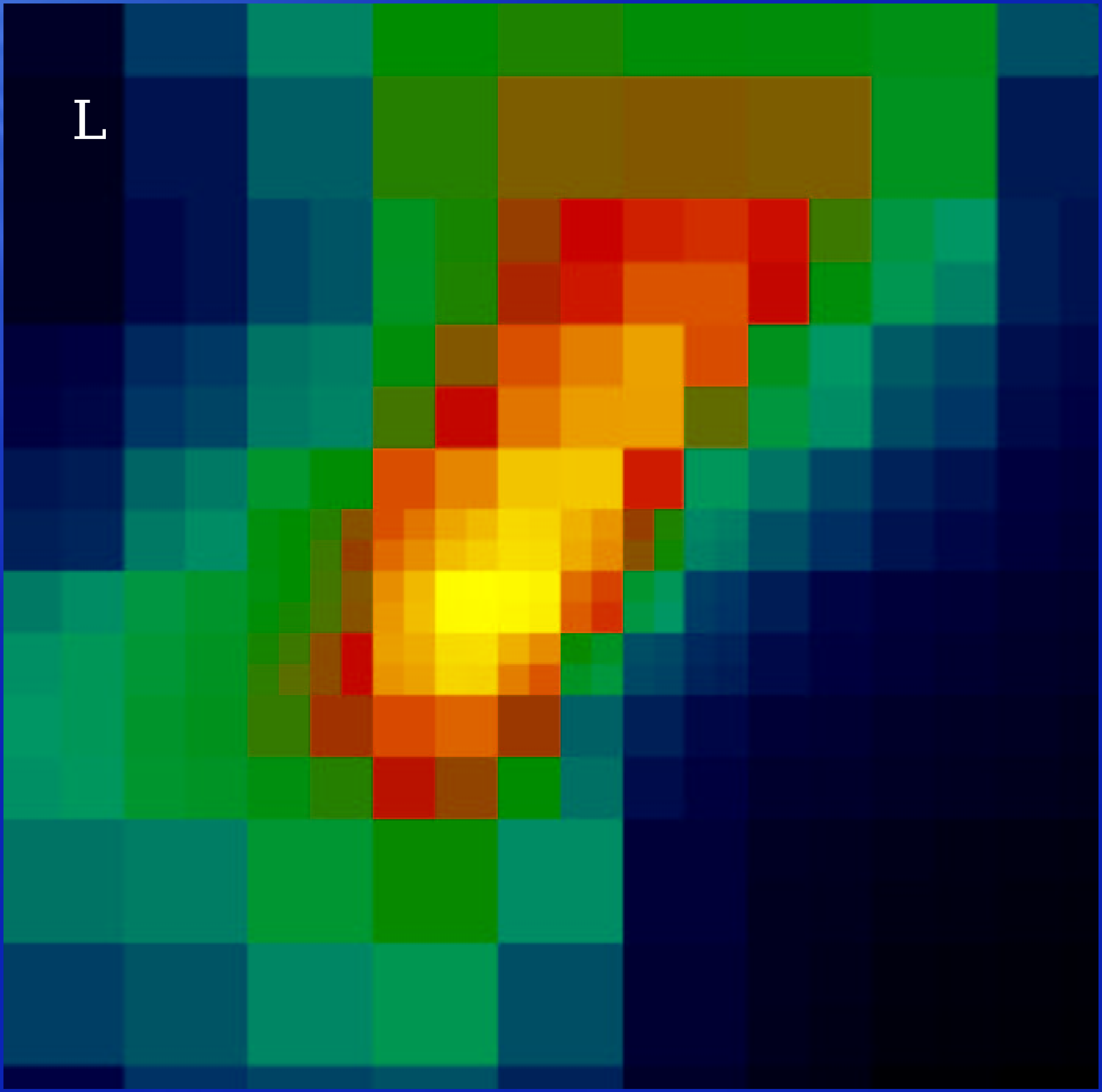
1 Mpc co-moving box, from z=99 to z=15.

2-level initial conditions:

- outer region for larger-scale tidal field
- inner $(0.5\ \mathrm{Mpc})^3$ for analysis
  $M_{DM} = 2{,}000\ M_\odot$
  $D_{grid} = \sim 4$ kpc

- Plus 6 additional AMR levels
  $\Rightarrow D_{grid} = 60$ pc

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MiniQSO Radiation

Assume **only X-rays** are emitted: power-law from 0.2 to 10 keV.

Box is small enough that it remains, on average, optically thin
NO RADIATION TRANSPORT!

Source terms in energy conservation equation (heating),
and in species abundance equation (ionization).

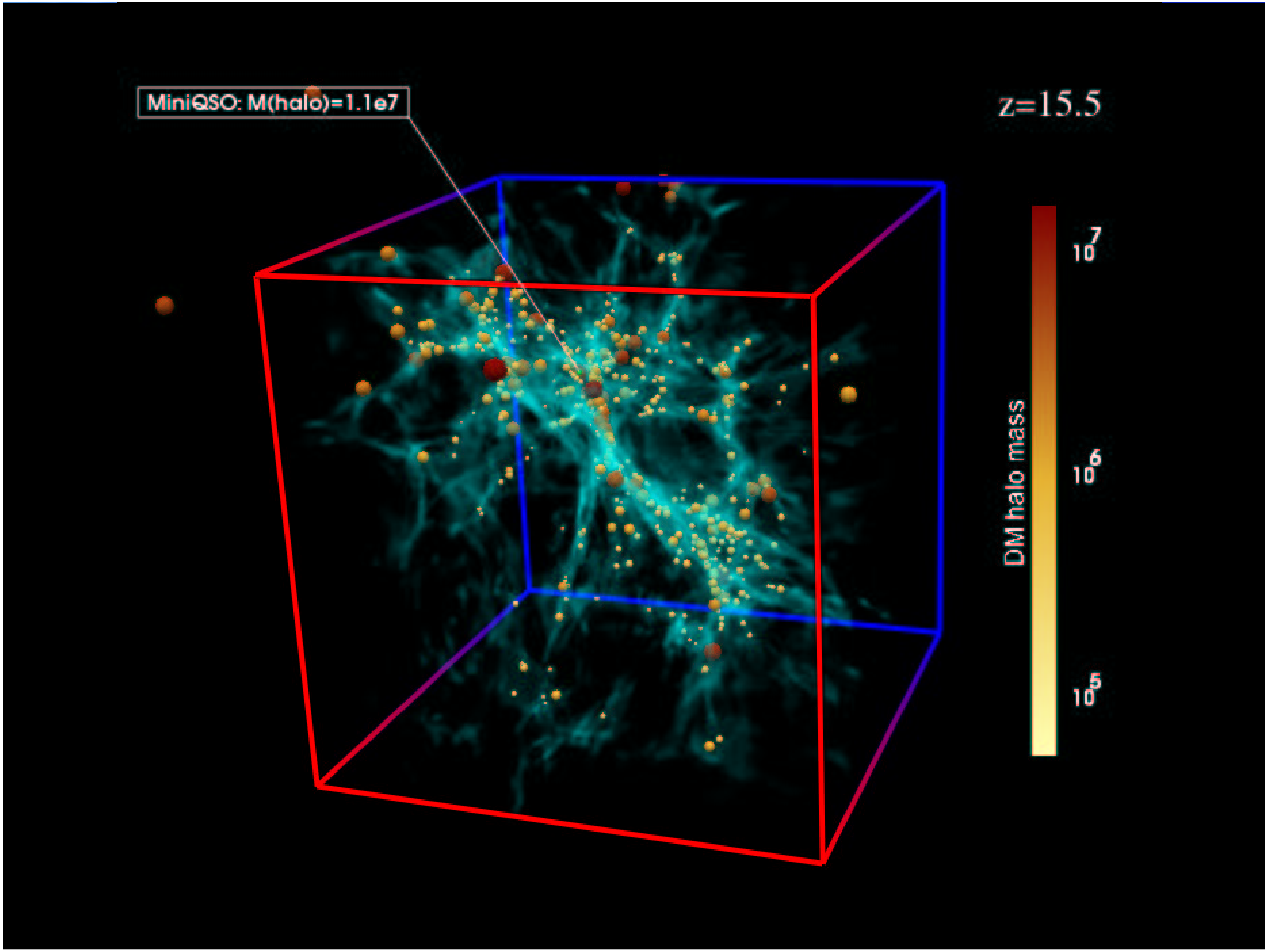
Pick the earliest, resolved (>100 DM particles) object above cosmological Jeans mass :

$M_{tot}=7\times10^5\ M_\odot$ at $z=25$ ($M_{J,b}=2.2\times10^4\ M_\odot$, $M_{F,b}=1.3\times10^5\ M_\odot$)

At z=21: turn on **150/500$M_\odot$** accreting BH MiniQSO:

$$F_x(r) = 6.7\times10^{-22}\ \mathrm{erg\ s^{-1}\ cm^{-2}\ Hz^{-1}}\ (r/1\mathrm{kpc})^{-2}\ (h\nu/1\mathrm{keV})^{-1}$$

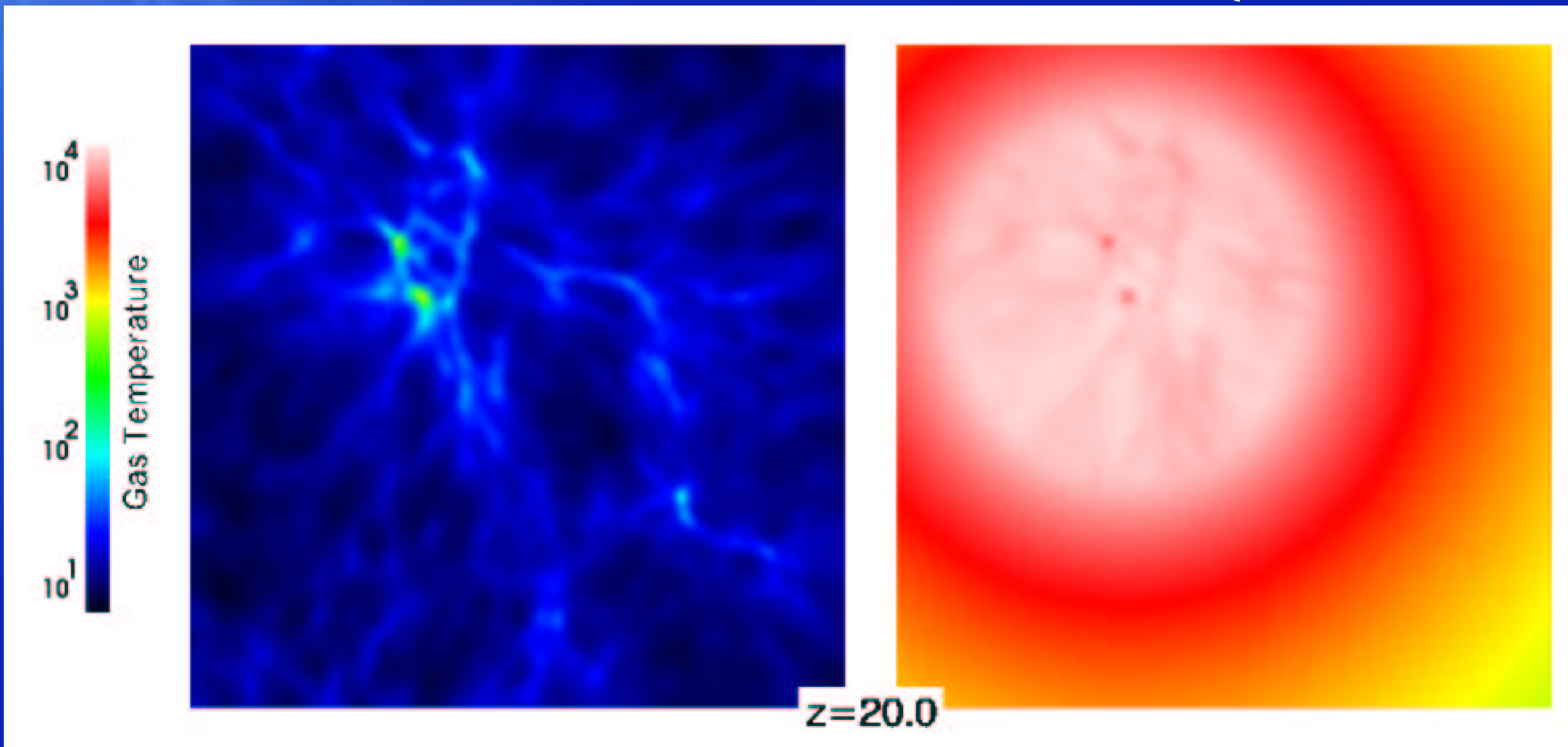
Let it shine for a few Salpeter times (~45 Myr): **down to z~15**.


MiniQSO: M(halo)=1.1e7
z=15.5
DM halo mass
10^7
10^6
10^5

Movies, Movies, Movies …

Some Effects

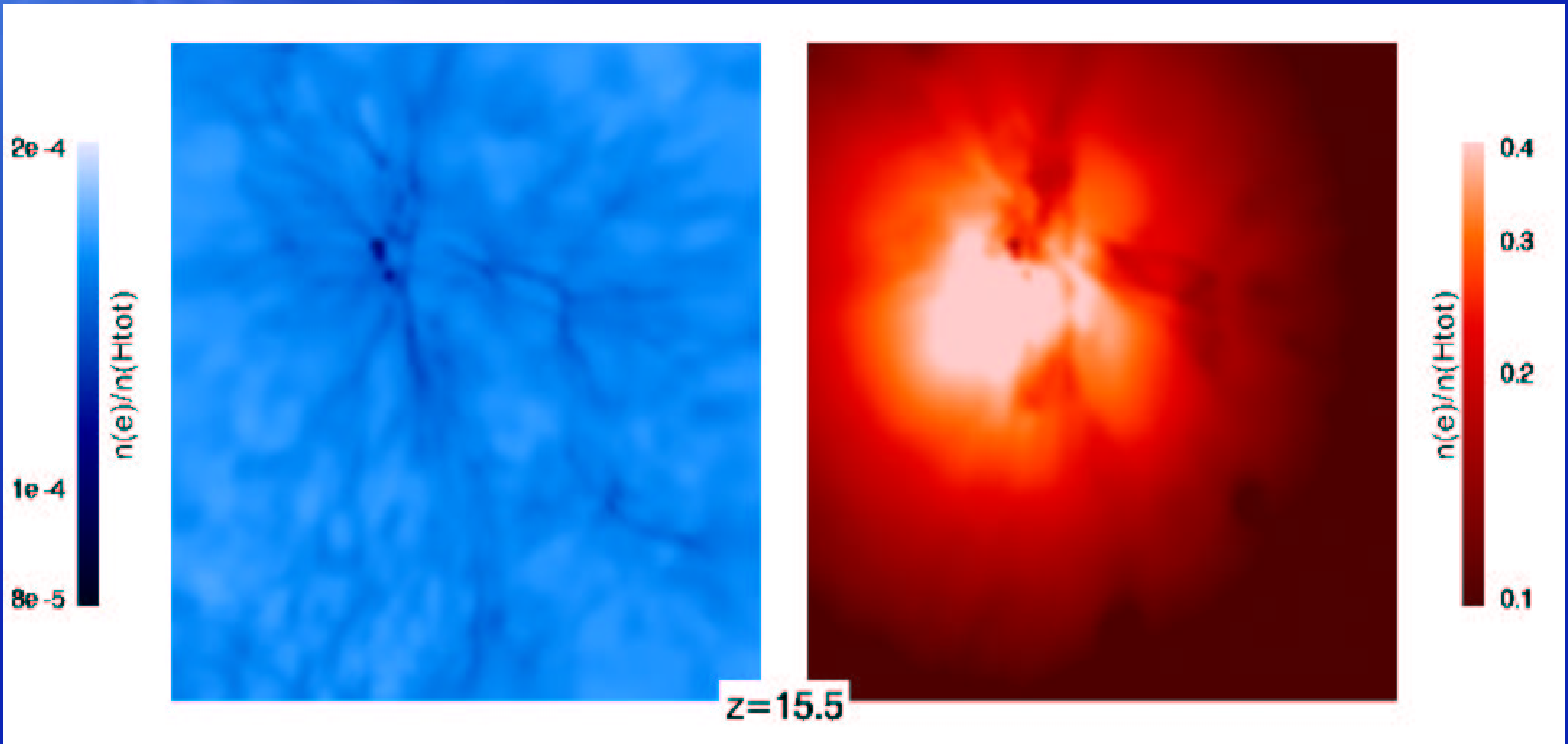
No Radiation MiniQSO



Gas is almost instantly heated to ~10^4 K everywhere

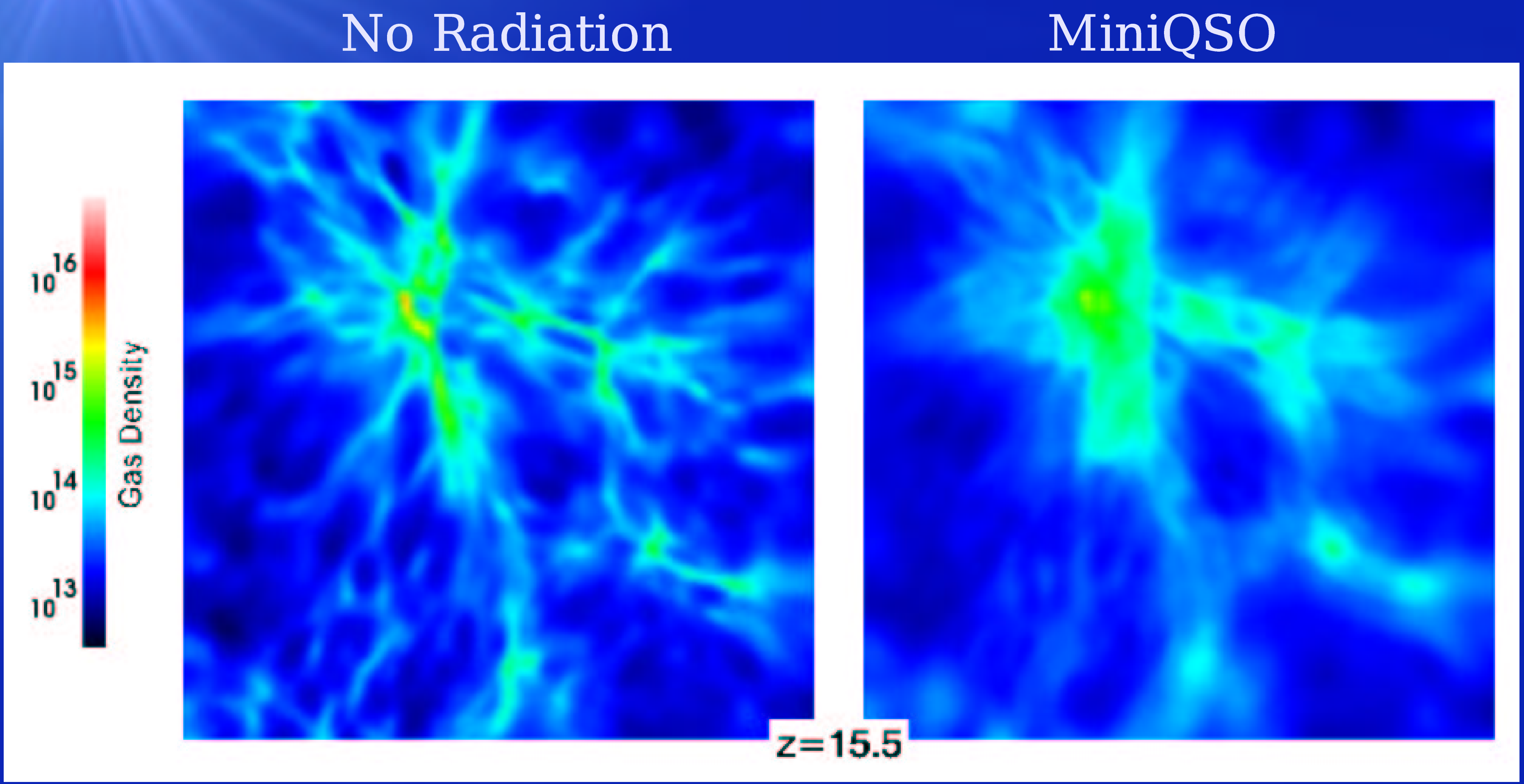
Some Effects

No Radiation | MiniQSO



Gas is partialy ionized: $x_e \sim 0.1$ in most of box.

Some Effects

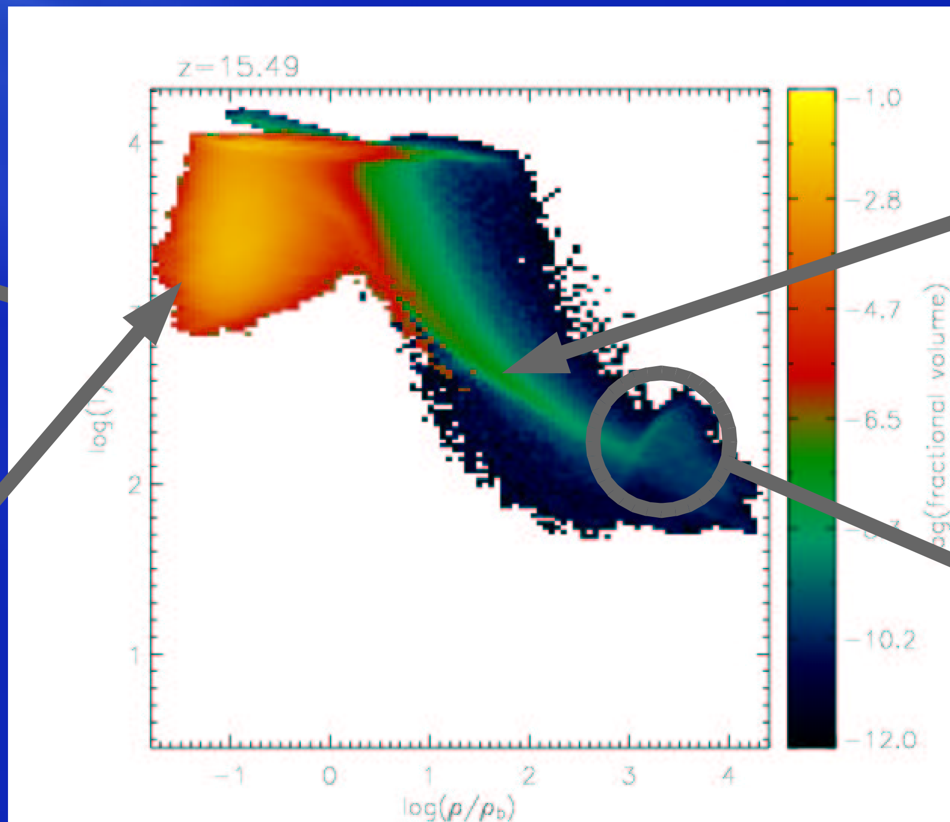


Jeans smoothing: Gas distribution is “puffed up”, further infall will be delayed.

Phase Diagrams

Shock Heated

Heated by MiniQSO radiation



H_2 cooling

Artificial adiabat

Adiabat: $S \propto \rho^{-2/3}\, T = \text{const.}$

Conclusions / Future Work

An early population of mini-quasars would have a serious impact on near-by small halos:

- T_{IGM} is heated to 10^4 K
- Ionization fraction is small ($x \sim 0.1$)
  - $\Rightarrow$ 21cm in emission against CMB?
- Gas collapse in neighboring halos is delayed.

Need to look in detail at how the baryonic halo mass function is affected.

Pre-process gas in host halo to mimic the radiative effects of the SN and its progenitor. Include Lyman-Werner H_2-dissociating flux.