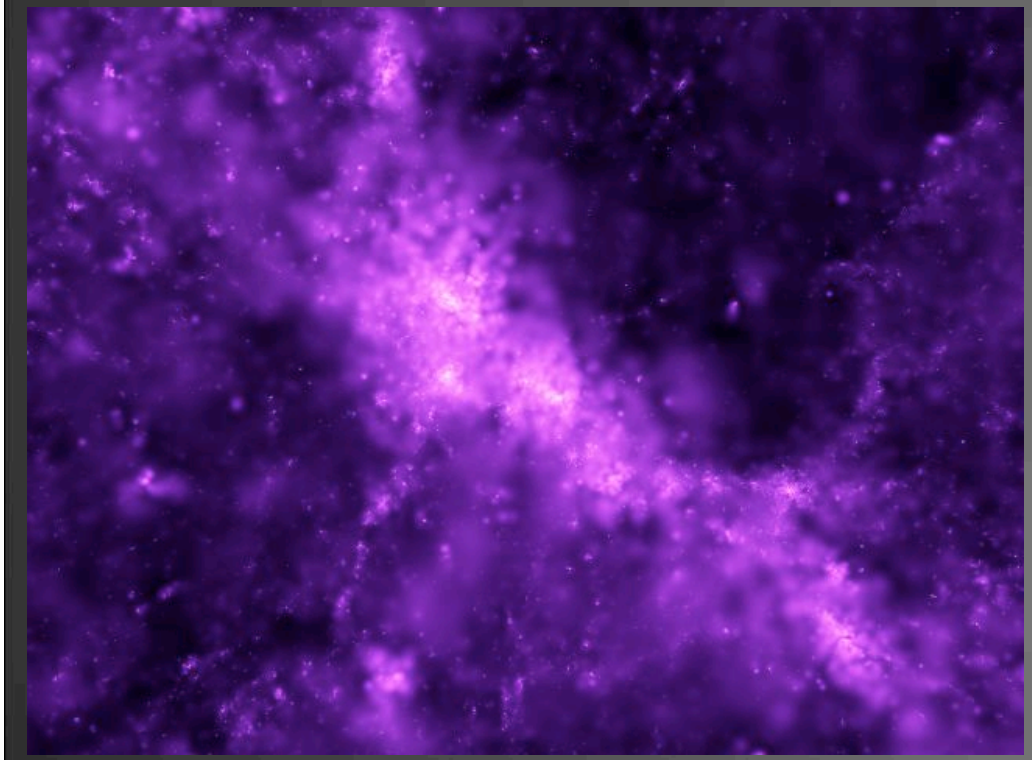
From the *very* first stars to z~6 supermassive black holes



Michele Trenti

SPACE TELESCOPE SCIENCE INSTITUTE
Operated for NASA by AURA

A Century of Cosmology

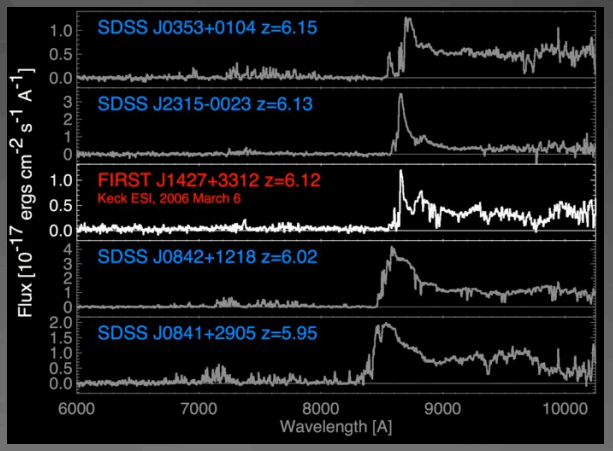
August 27, 2007

In collaboration with M. Stiavelli

PopIII stars

- Stars formed from collapse of metal “free” ($Z < 10^{-4}\ Z_\odot$) gas
- At very high redshift ($z>30$) form within 10^5-$10^6\ M_\odot$ halos cooled by H_2
- No fragmentation
  - very massive [O(100) $M_\odot$]
- Drive initial metal enrichment in the universe
- Provide Intermediate Mass Black Hole seeds

Bright z≈6 Quasar



Courtesy of R. White, STScI

- Extremely rare objects:
  - on the sky one every ≈ 200 deg^2 (Fan et al. 2004)
  - A simulation of ≈0.5 (Gpc/h)^3 is needed just to have one such object
- Their luminosity (M_B ≈ -27) is powered by accretion onto supermassive black hole
- Expected to sit at the center of the biggest proto-clusters at that time (e.g., Springel et al. 2005)

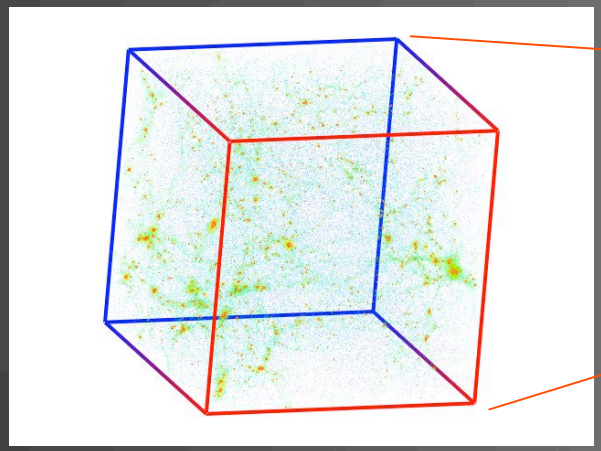
Bright z≈6 Quasar and PopIII

- What is the relation between the very first PopIII stars and the bright z≈6 quasars?
- When are the QSO BH seeds formed?
- Is the quasar progenitor the first PopIII formed in the typical QSO volume?
- How do QSO seeds grow?

Bright z≈6 Quasar and PopIII

- 10^{13} dynamic range from a PopIII halo to the typical cosmic volume of a z ≈6 QSO
  - Outside the current capability of a cosmological simulation

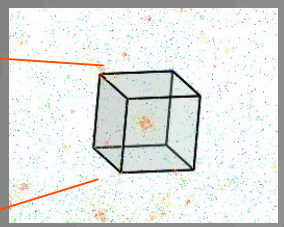
Bright z~6 QSO typical volume



10^{19} M.

10^{13}

Pop III DM halo



10^{6} M.

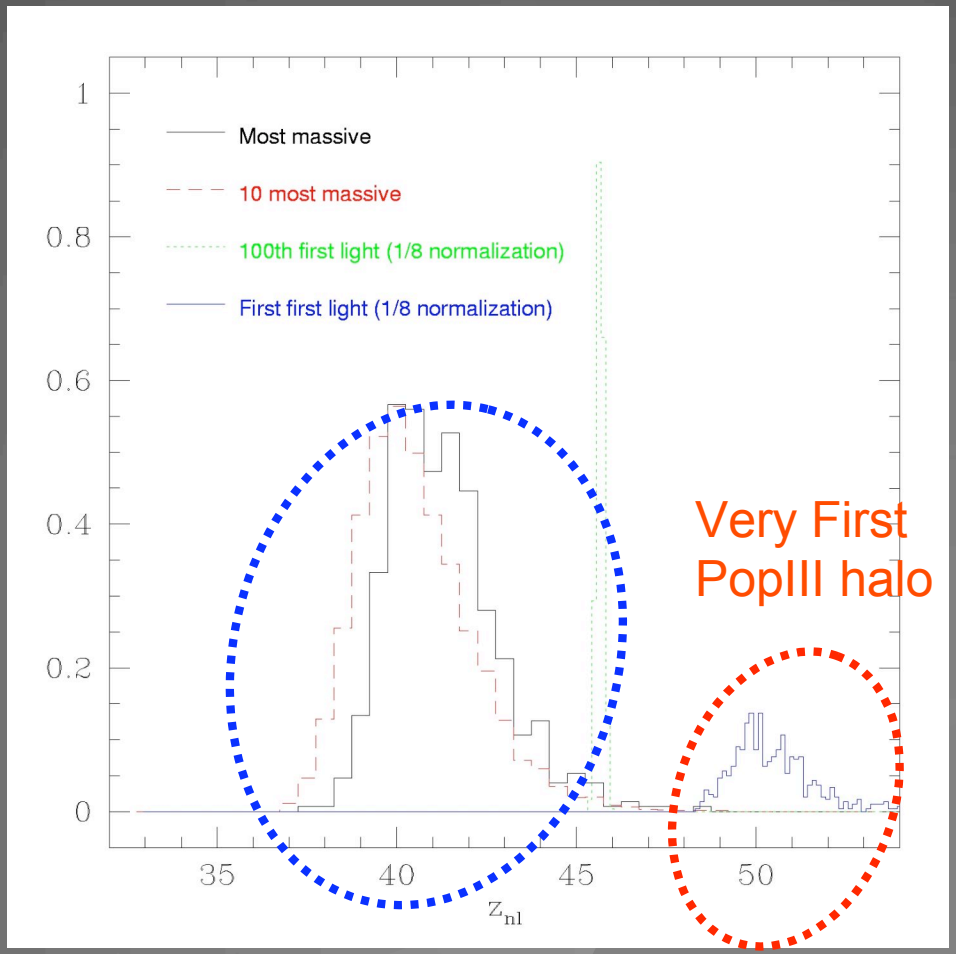
From PopIII to Bright z~6 Quasars

- We developed an original method, coupling N-body simulations with a linear theory Monte Carlo code
  - Details in Trenti & Stiavelli (2007), ApJ in press
    - (astro-ph/0705.4223)
  - DM halos at z=6 identified from the cosmological simulation
  - MC sampling of subgrid fluctuations provides the formation time of the first PopIII progenitor for every particle in the simulation

Results: large volume I

- (720Mpc/h)^3, WMAP3 cosmology but σ_8=0.9
- PopIII halo mass assumed: 10^6 M$_\odot$/h
- First PopIII halo in the box formed at z>49
- PopIII halo progenitor of most massive z=6 halo formed at z~41

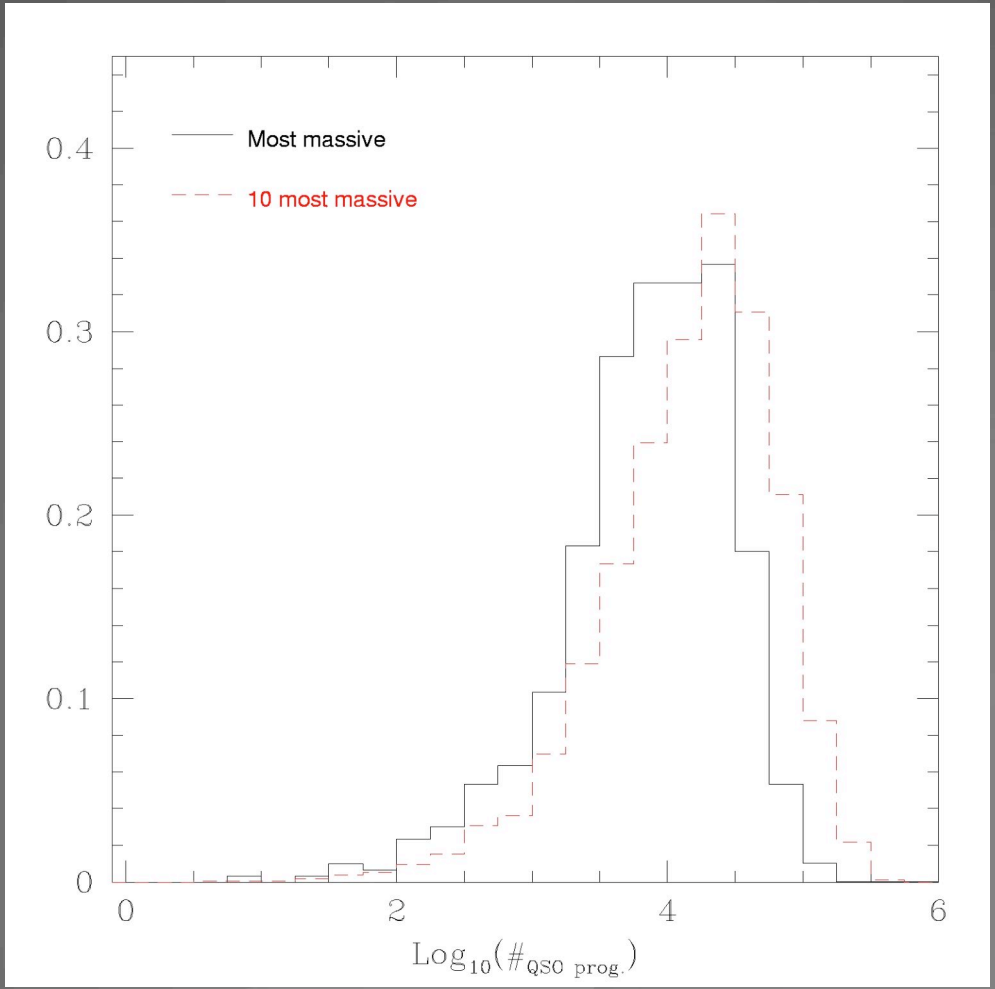
Trenti & Stiavelli (2007)



Results: large volume II

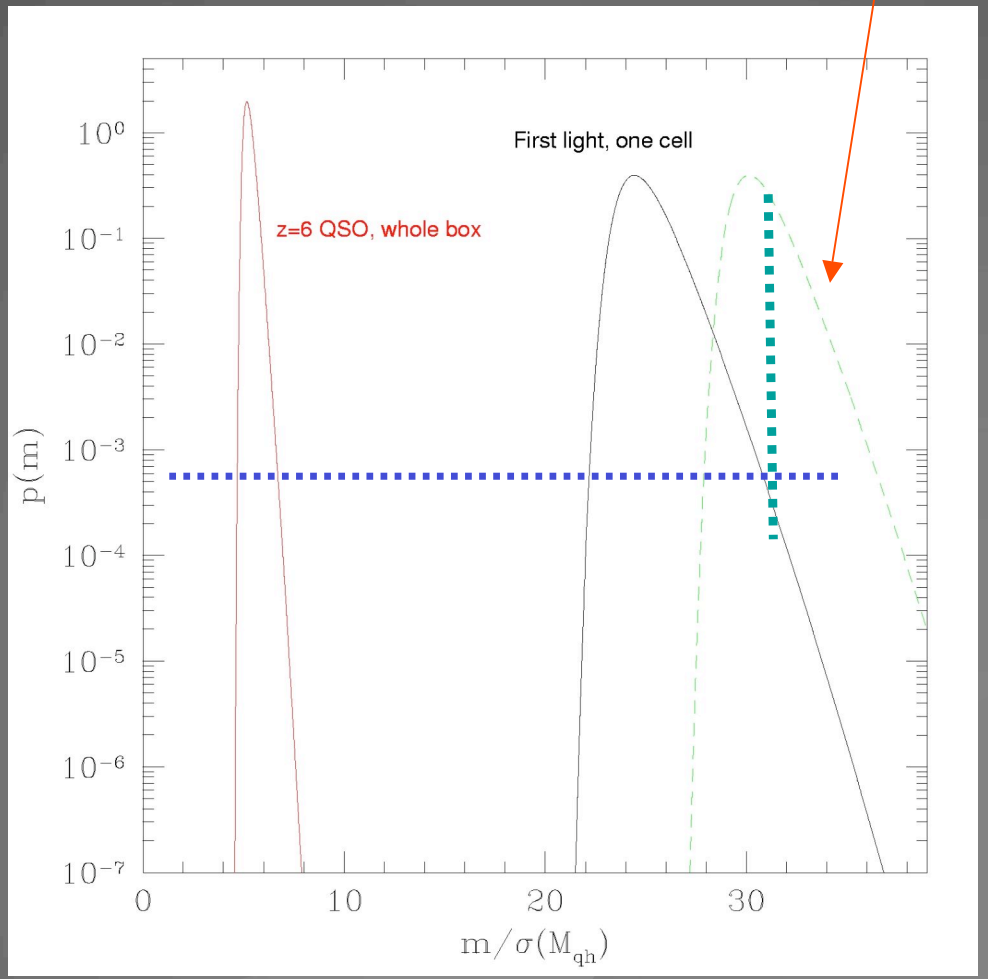
Trenti & Stiavelli (2007)

- PopIII halo progenitor of most massive z=6 halo formed when there are already ~10^4 PopIII halos in the simulation box
- Sitting at the top of a large z=6 overdensity gives little relative advantage to PopIII halos formed at z>40



Understanding the result

- (720Mpc/h)^3 volume contains 180^3 cells of mass M_{qh} = $4 \cdot 10^{12} M_\odot/h$
- z=6 most massive halo has $\delta \sim 6\sigma(M_{qh})$
- Each M_{qh} cell has 160^3 subcells at PopIII minihalo mass
- ~ One in 10^3 cells has a PopIII progenitor formed earlier than the progenitor of the QSO
- Back of the envelope estimate gives ~ $6 \cdot 10^3$ PopIII formed before QSO progenitor

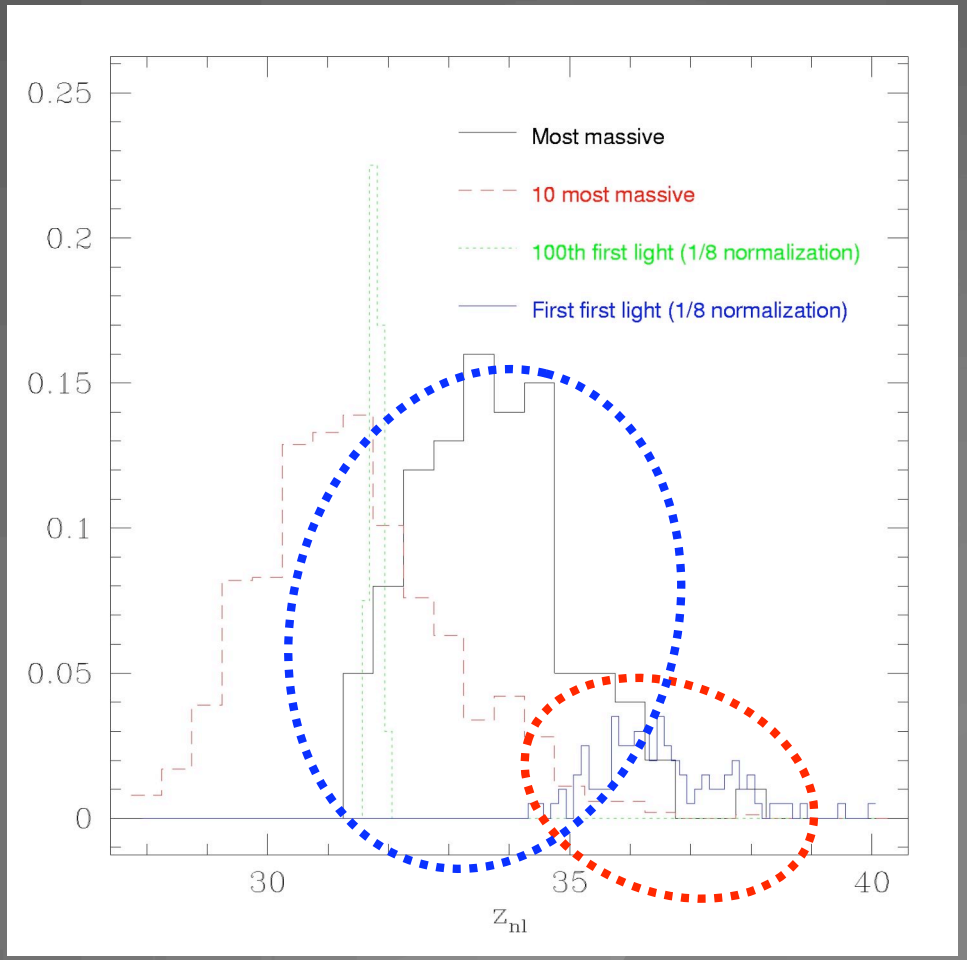


Trenti & Stiavelli (2007)

Results: small volume I

- $(60 Mpc/h)^3$
- PopIII halo mass assumed: 10^6 $M_\odot/h$
- First PopIII halo in the box formed at z~36
- PopIII halo progenitor of most massive z=6 halo formed at z~33

Trenti & Stiavelli (2007)



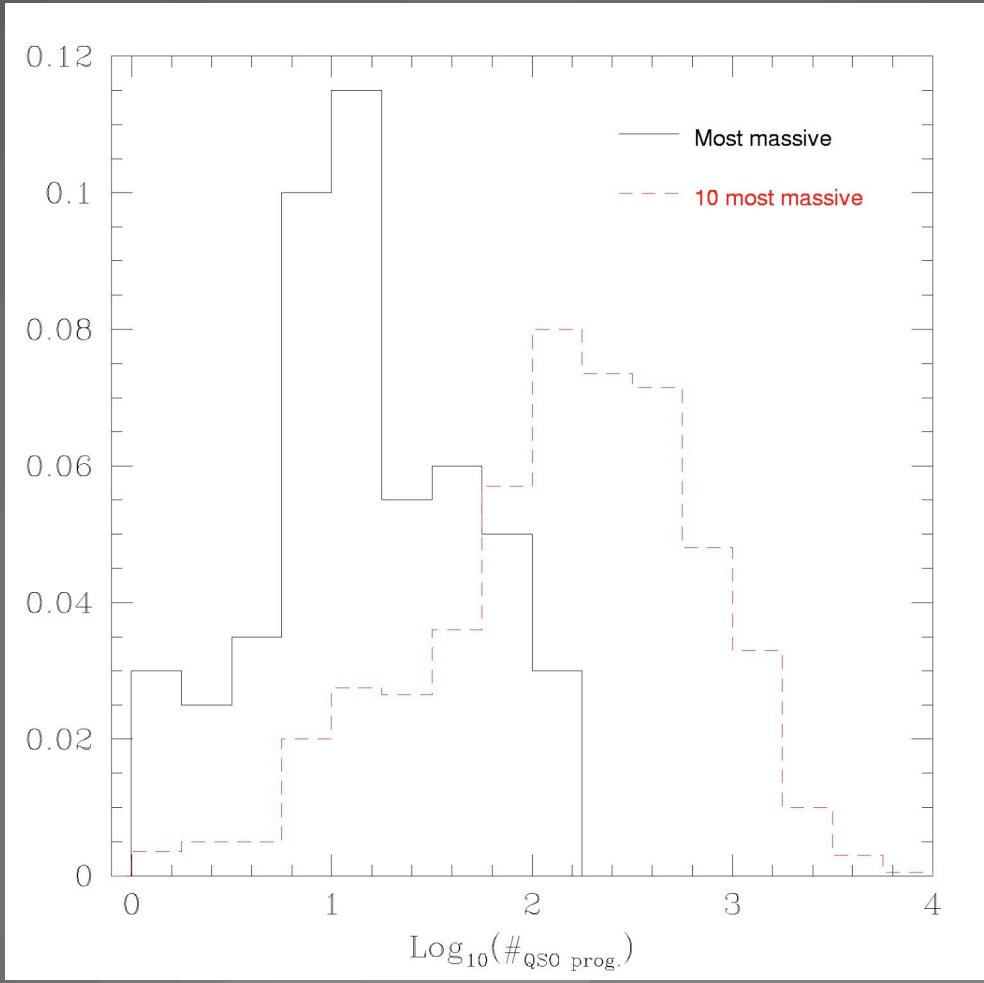
First progenitor of most massive z=6 halo

Very First PopIII halo

Results: small volume II

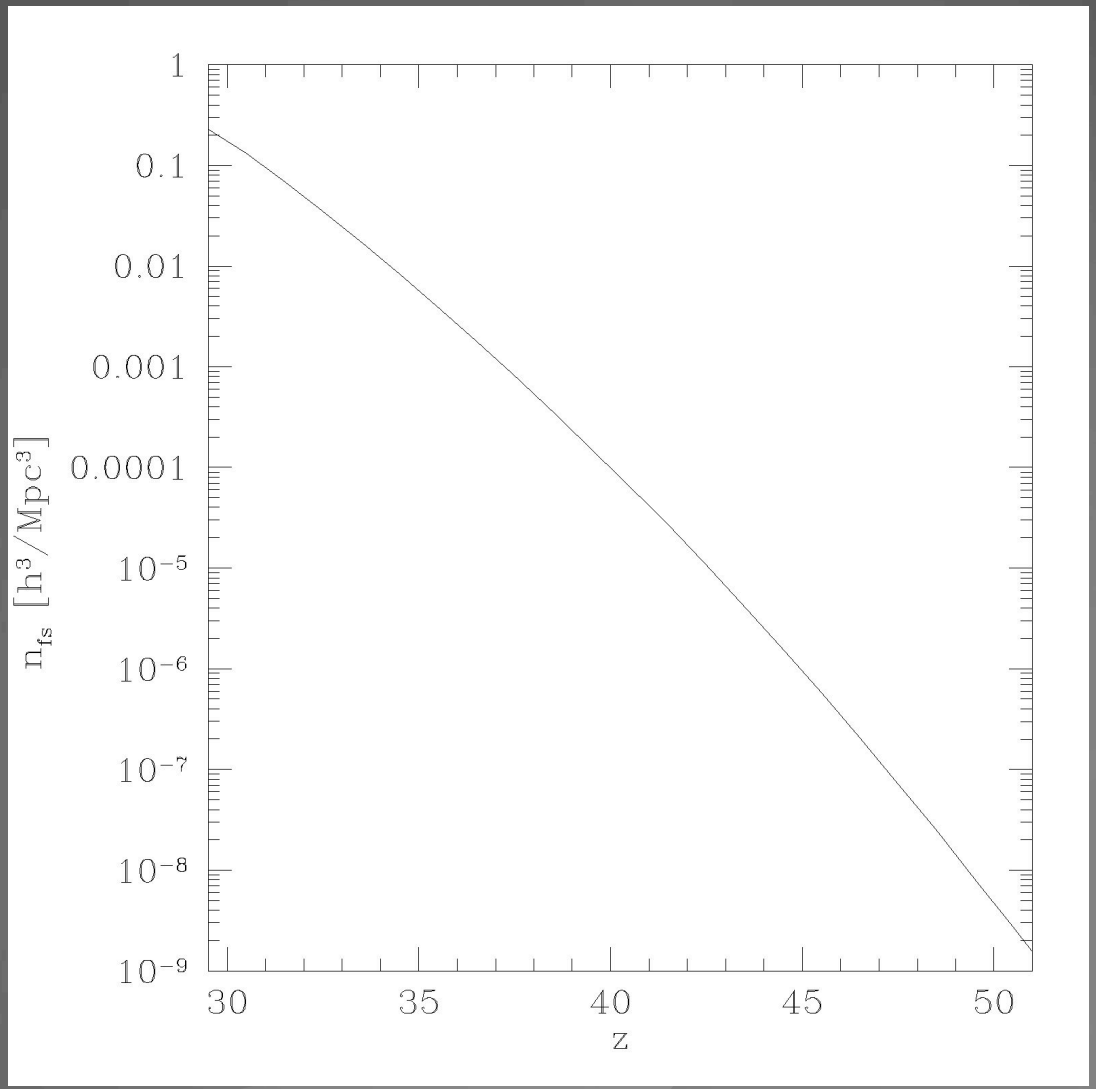
Trenti & Stiavelli (2007)

- PopIII halo progenitor of most massive z=6 halo formed within the first ~10^2 PopIII halos virialized in the simulation
  - Not infrequent to be within the first 10
- Sitting at the top of a large z=6 overdensity gives a relative advantage when the total volume considered is small



Formation rate of the very first PopIII

- Number of PopIII halos per unit z per $(Mpc/h)^3$
- By z~30 enough PopIII halos to photo-dissociate all primordial H_2 in the box (10^{-4} abundance assumed)
  - LW background may lead to delay of further PopIII formation, if feedback is negative

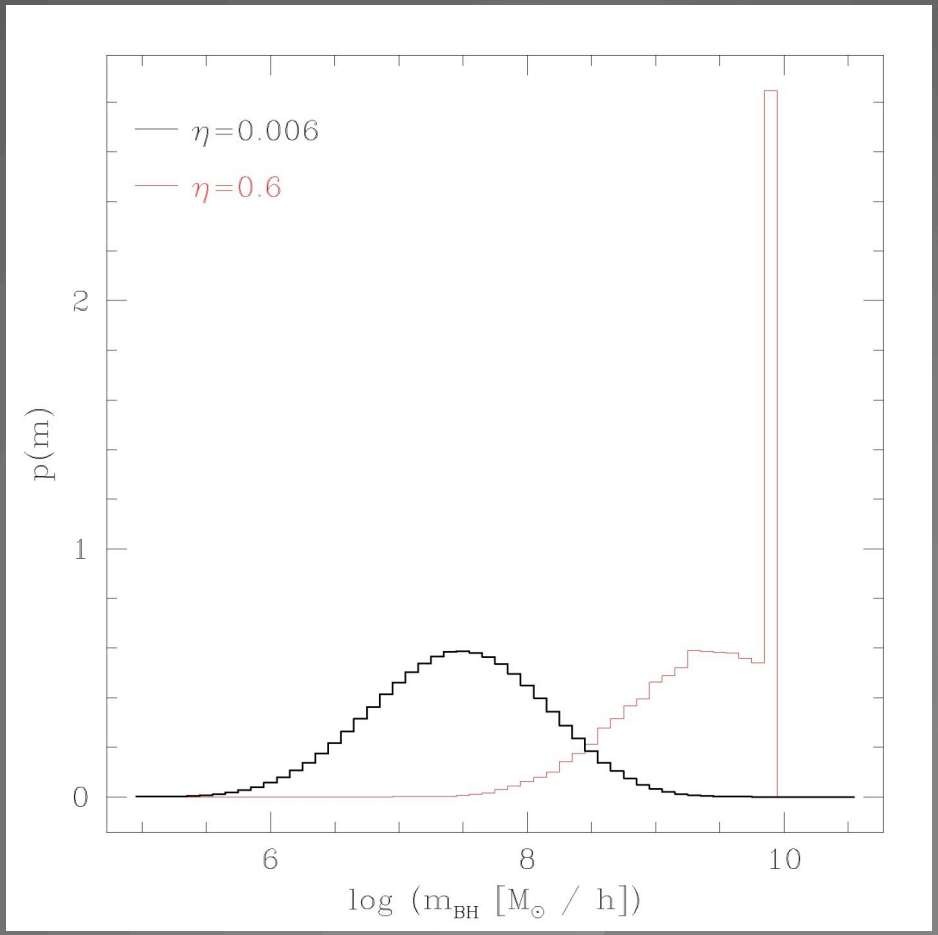


Do we have too many BH seeds?

- Given the typical volume of a bright z=6 QSO about 10^4 IMBH seeds from PopIII stars are formed before the first QSO progenitor
- All these seeds have enough time, if accreting at Eddington rate with ε~0.1, to reach $M_{BH}>10^9 M_\odot$ by z~6
- What makes the QSO progenitor so special?

IMBH accretion: a simple model

- Press-Schechter merger tree code
- Seeds start growing at z=40 and are limited to accrete up to a fraction η of the gas supply of their halo
- Limiting accretion to η~0.005 produces a reasonable z=6 QSO luminosity function



Conclusions

- The most massive halos at $z_1 >> z_2$ do not evolve into the most massive at z_2
  - The very first PopIII stars in the universe are not correlated with the largest halos at z~6, considered to host bright QSOs
- QSO progenitors are still formed within the early era of PopIII, when LW background is unlikely to influence the minihalo evolution
- A realistic QSO luminosity function can be obtained starting from the very first IMBH seeds assuming that accretion is limited up to a fraction of the total gas mass in the halo