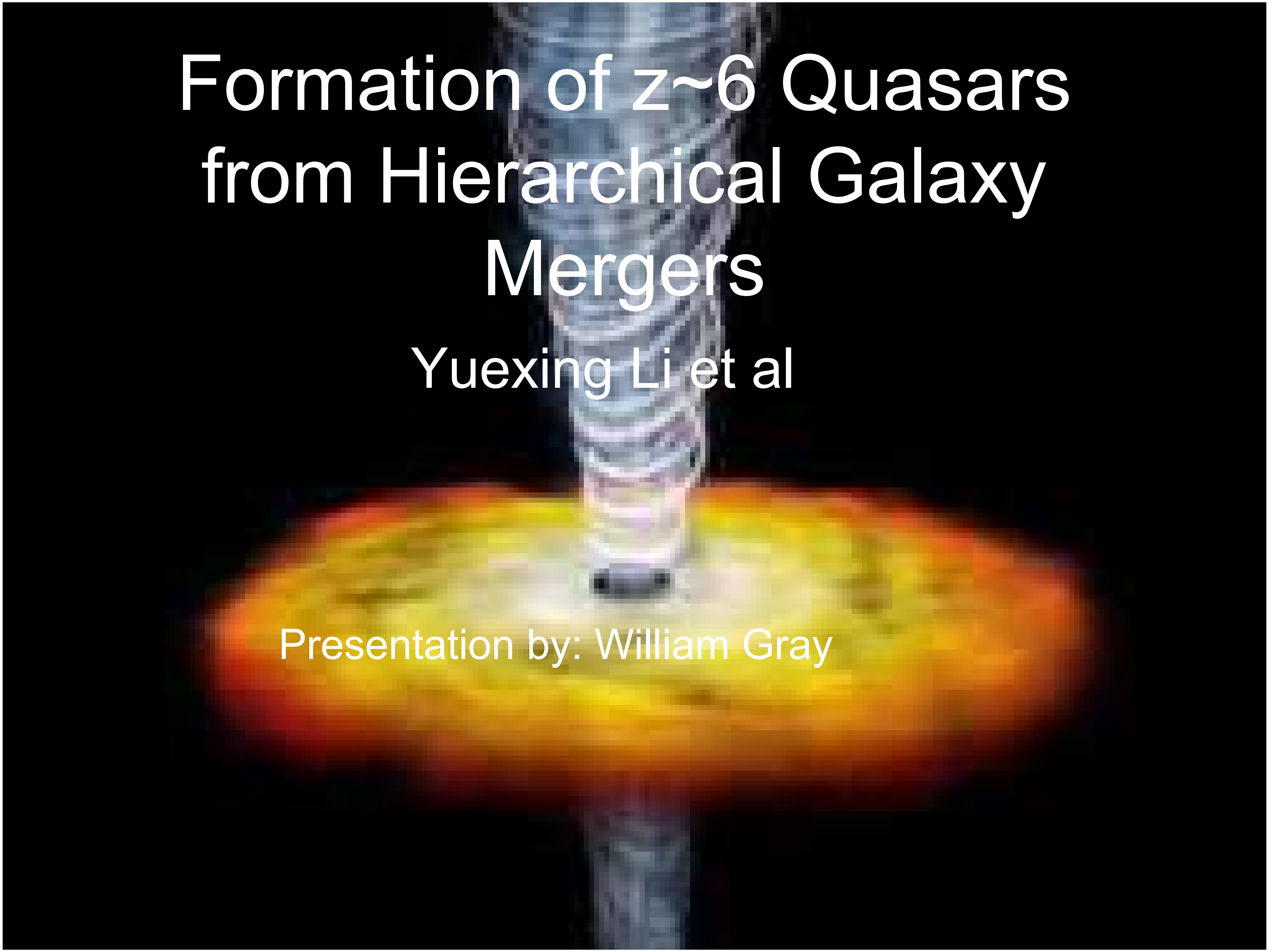
Formation of z~6 Quasars from Hierarchical Galaxy Mergers

Yuexing Li et al



Presentation by: William Gray

Definitions and Jargon

- QUASAR stands for QUASI-stellAR radio source
- Extremely bright and active nucleus of a young galaxy
- Z~6 = about 800 million years after Big Bang.
- SED - Spectral Energy Distribution
- FIR Galaxy - Far InfraRed Galaxy
- BH / SMBH - Black Hole/ Super Massive Black Hole

Properties of Z~6 Quasar

- Low space density (~10$^{\wedge-9}$ MPC$^{\wedge-3}$)
- High luminosities ($M_{1450Å}$ < -26)
- Gunn-Peterson absorption troughs in their spectra (places them at the end of the epoch of reionization)
- Lack of evolution in their SED compared to low redshift Quasars

SDS J1148+5251

- Most distant quasar know. Discovered by the Sloan Digital Sky Survey.
- $Z = 6.42$. $M_{1450Å} = -27.8$
- $L_{bol} = 10^{14}\ L_{sun}$
- SMBH = (1-5)*10^9 Msun
- Near Solar metallicity in Quasar host

Very rare Quasar

- Low abundance of such quasars.
- Hosted by massive halos ($>10^{13}M_{sun}$) in rare density peaks
- ΛCDM cosmology suggests that small objects form first and merge - “hierarchical assembly”
- Originates in highly overdense regions in the initial dark matter density distribution.
- Quasar and host form from many gas-rich mergers.

Cosmological Parameters

Wilkinson microwave Anistropy Probe

WMAP1 - (Ω_m = 0.3, Ω_b = 0.04, Ω_Λ = 0.7, h = 0.7, n_s = 1, σ_8 = 0.9)

WMAP3 - (Ω_m = 0.236, Ω_b = 0.042, Ω_Λ = 0.759, h = 0.732, n_s = 0.95, σ_8 = 0.74)

For the purpose of this paper, the simulations used WMAP1 values because WMAP3 predicts lower halo masses and longer formation time. Although they do compare results using WMAP3.

Little Methodology

- 1: Perform a coarse dark matter sim of volume of 1 h^{-3} Gpc^3 to find candidate halo for quasar.
- 2. Largest halo is candidate for formation of quasar at z= 6.5
- 3. “Zoom-in” on candidate region and simulation is rerun with higher resolution

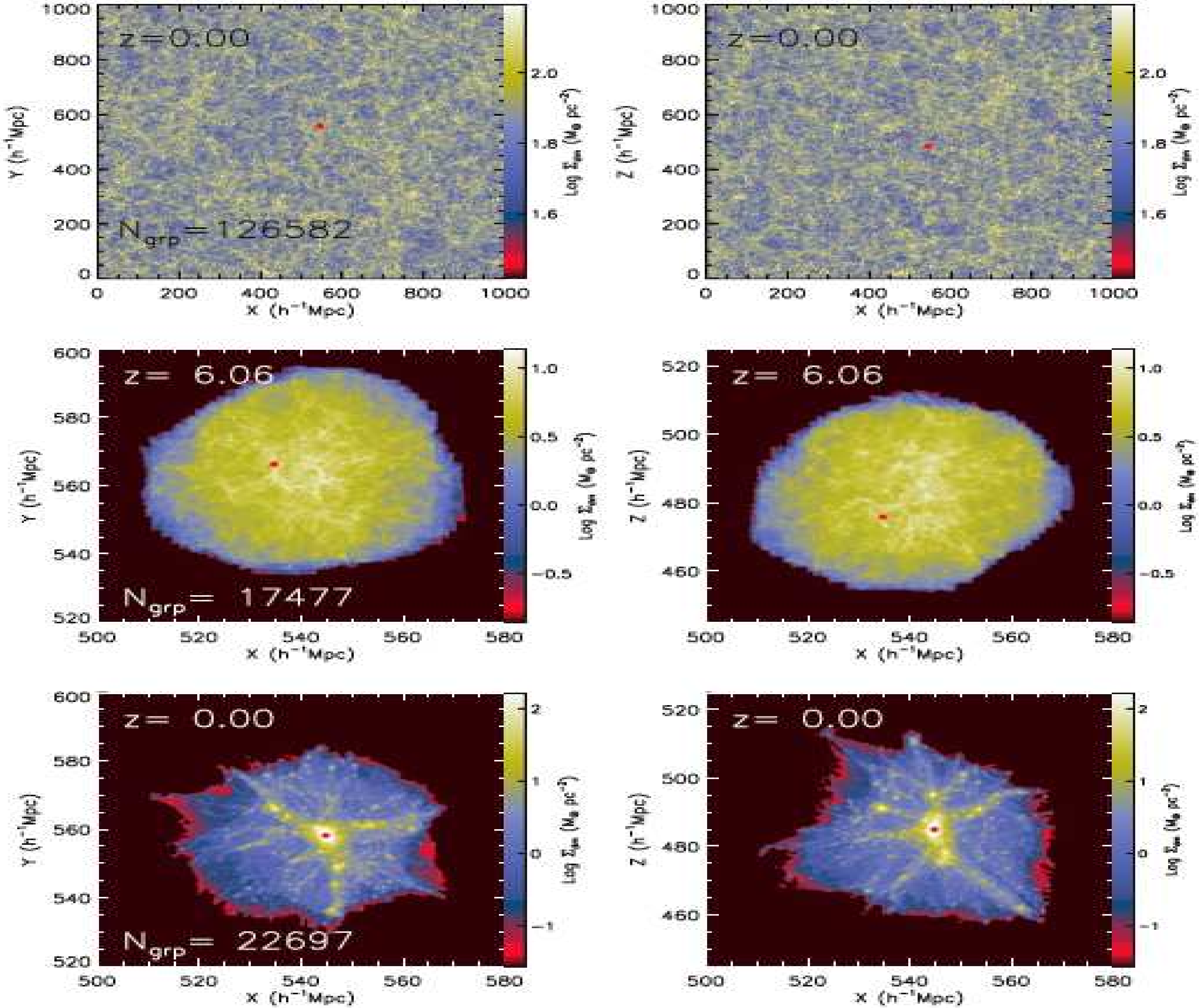
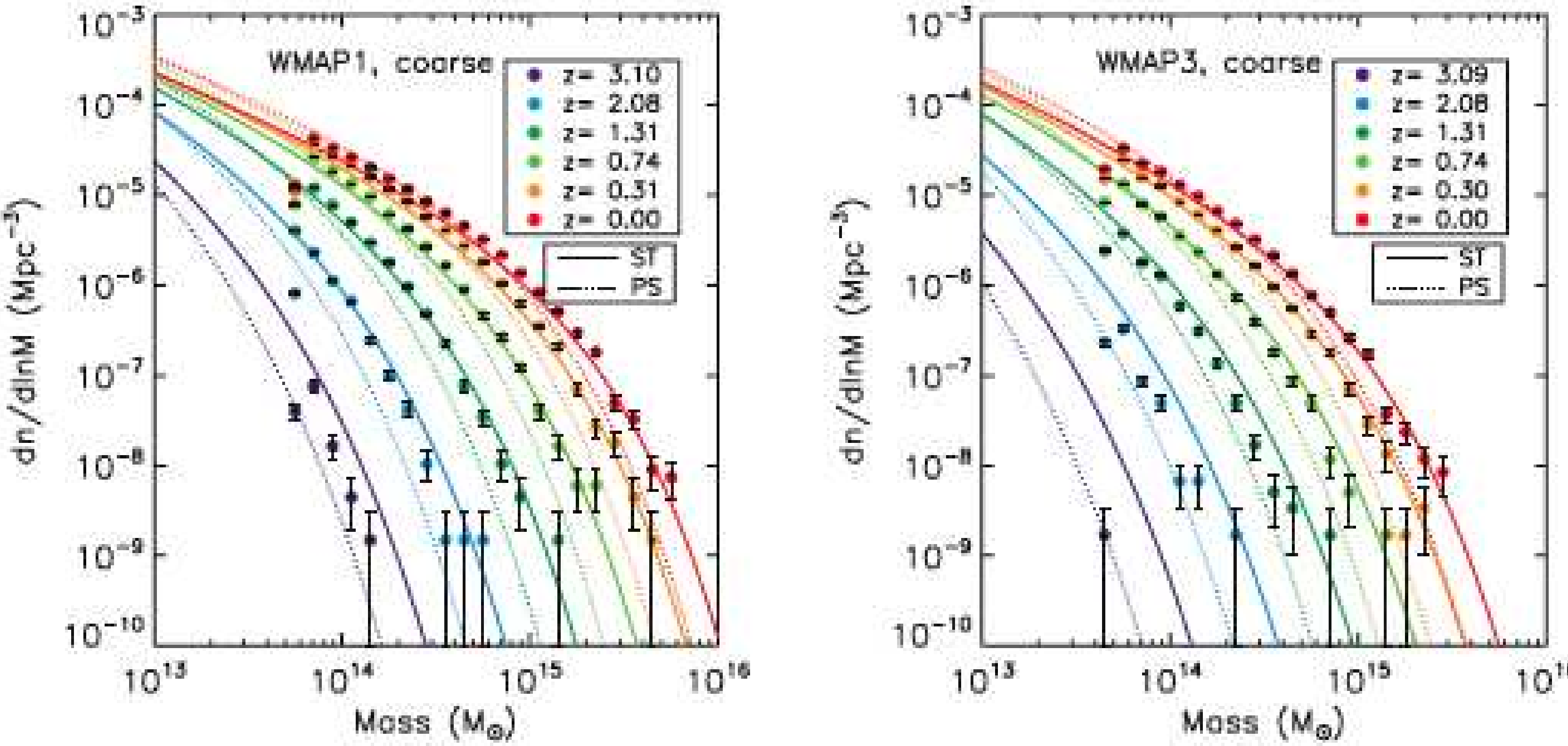


FIG. 1.— Snapshots from a cosmological simulation run with WMAP1 parameters. The images show projected density of dark matter in *x-y* (*left column*) and *x-z* (*right column*) planes; the red dot represents the center of mass of the quasar halo, which is the largest halo at both $z = 0$ and 6. The top panels show the coarse run at $z = 0$. The middle and bottom panels show the zoom-in run at $z = 6.06$ and 0, respectively; the number at the lower left corner indicates the number of groups identified at that redshift.

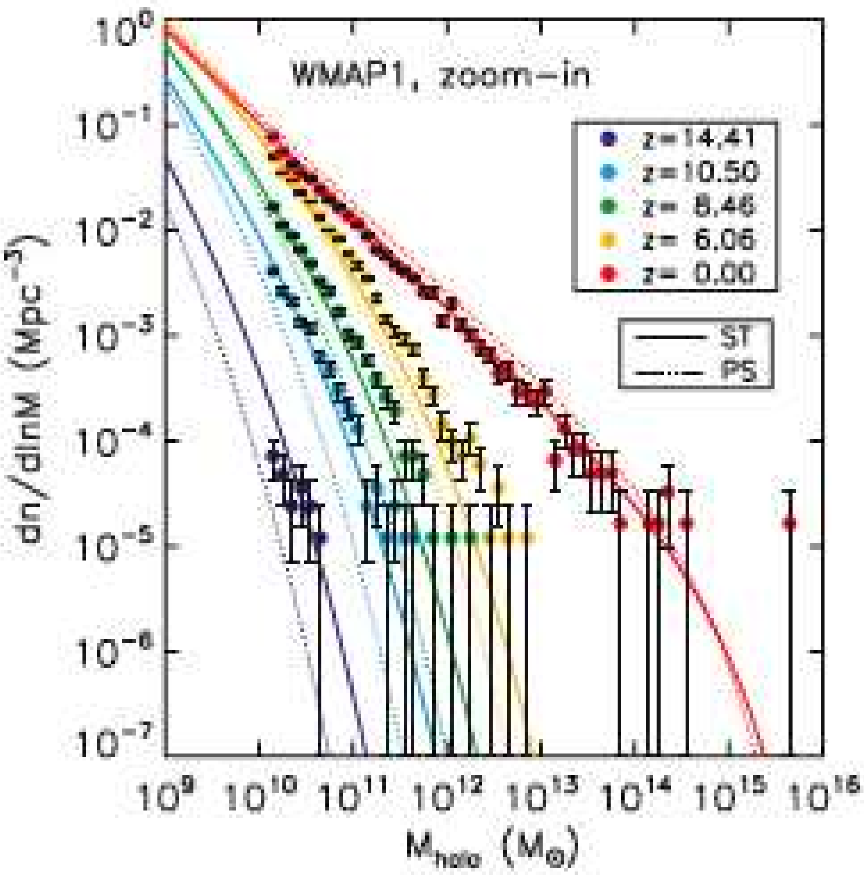
Merger Trees

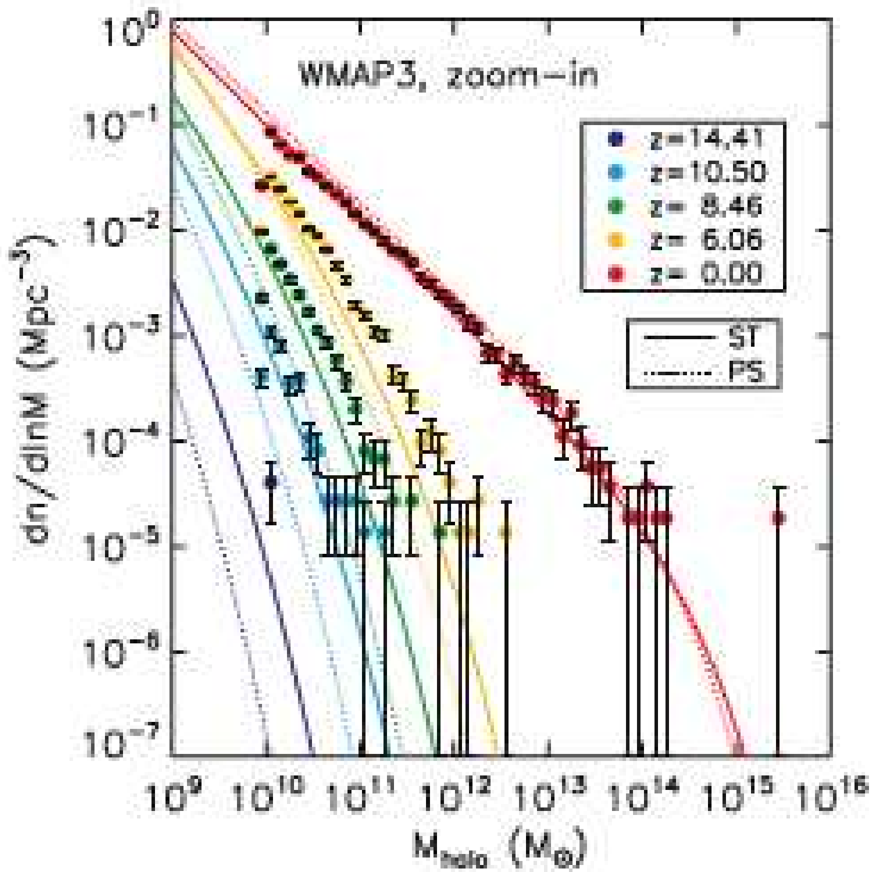
- Traces mergers throughout redshift
- The most massive progenitors at each redshift are traced by tags to identify earlier progenitors
- Groups that contribute >10% of the halo mass at each time step are progenitors
- This will give the history of our suspect quasar

Halo Mass functions from cosmological simulations.
Coarse Run.

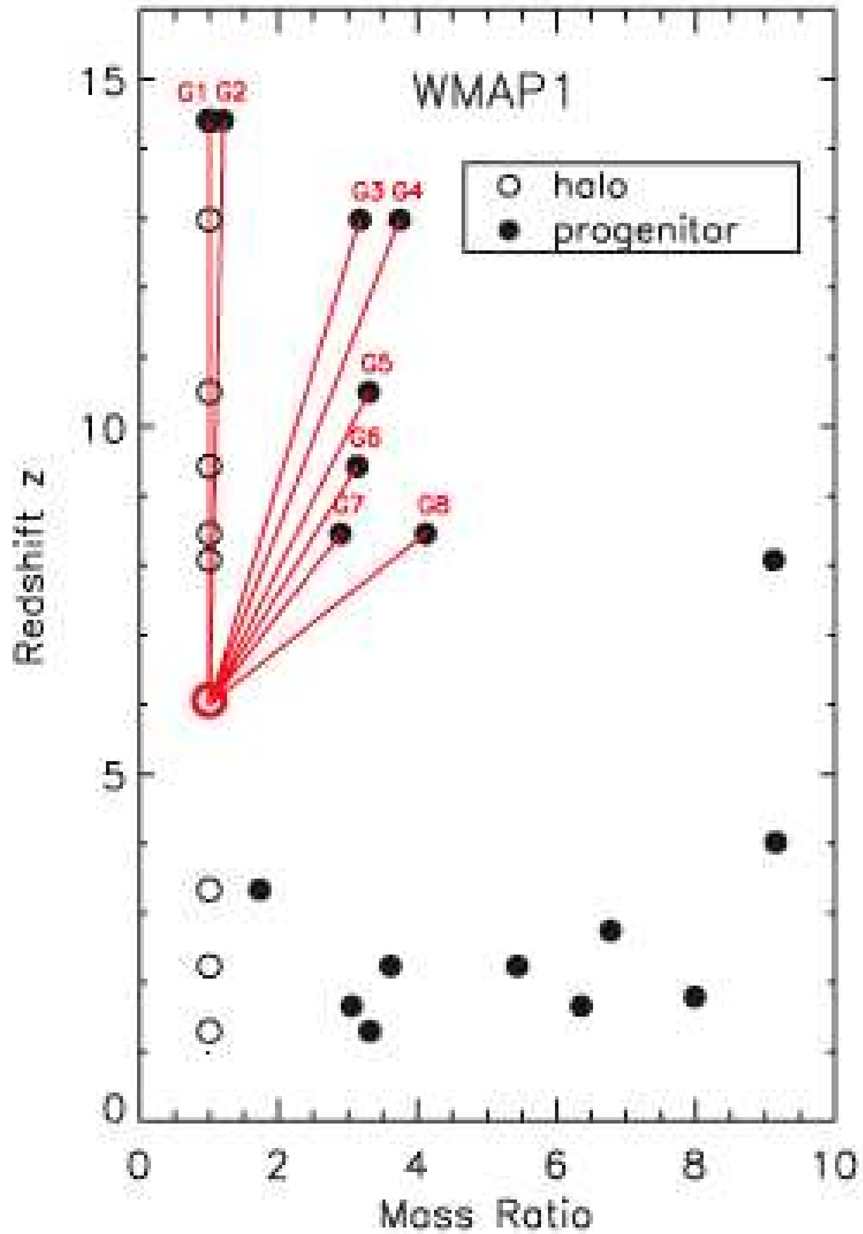


Halo Mass functions from cosmological simulations.
Zoom in Run.





Merging history of the largest halo.



Modeling Mergers major factors

- Major mergers = mass ratio of the merging galaxies are near unity.
- Only the major mergers play the most important role in the formation and evolution of massive galaxies
- Gas in a rotationally supported disk loses angular momentum through gravitational torques excited by tidal forces in a merger, driving the growth of SMBH. This is most effective in a major mergers.

Table of Mergers

TABLE 1

PROGENITOR PROPERTIES AND NUMERICAL PARAMETERS

Galaxy[a]	z[b]	M_{vir}[c] ($10^{10}\ h^{-1}\ M_{\odot}$)	V_{vir}[d] (km s^{-1})	f_{gas}[e]	M_{BH}[f] ($10^{5}\ h^{-1}\ M_{\odot}$)	R_p[g] (h^{-1} kpc)	R_0[h] (h^{-1} kpc)
G1	14.4	6.3	234.1	1.0	0.15	...	...
G2	14.4	5.3	220.3	1.0	0.15	0.2	7.1
G3	13.0	15.0	297.8	1.0	0.51	0.2	8.5
G4	13.0	17.7	314.6	1.0	0.51	0.3	10.7
G5	10.5	49.1	401.0	1.0	6.56	0.4	11.3
G6	9.4	79.6	448.6	0.9	23.3	0.5	18.2
G7	8.5	160.0	540.4	0.9	89.2	0.7	25.2
G8	8.5	207.7	589.5	0.9	89.2	1.0	34.5

[a] Name of galaxy progenitor. G1 is the halo at $z = 14.4$.
[b] Redshift at which the progenitor enters the merger tree.
[c] Virial mass, assuming overdensity $\Delta = 200$.
[d] Virial velocity, assuming overdensity $\Delta = 200$.
[e] Gas fraction of the progenitor baryonic mass.
[f] Progenitor BH mass at the merger redshift.
[g] Pericentric distance of the incoming progenitor to the center of mass of the existing system.
[h] Initial distance of the incoming progenitor to the existing system.

Black Hole seeds

- Need to grow a BH up to 10^9 M_{sun} in less than 800 million years.
- **1. Pair instability PopIII - BH ~10^2 M_{sun}**
- 2. Hot, dense clumps of gas collapse to form ~10^6 M_{sun}
- 3. ~20 M_{sun} BHs from direct collapse of self-gravitating gas due to global instabilities.
- In simulation - it is necessary for galaxy progenitors to have massive BH seeds (~10^5 M_{sun})

Escaping BHs ?

- When galaxies merge, the BH's may merge or be ejected by gravitational recoil.
- Depends on: $V_{esc}=\sqrt{(2|\Phi[r]|)}$.

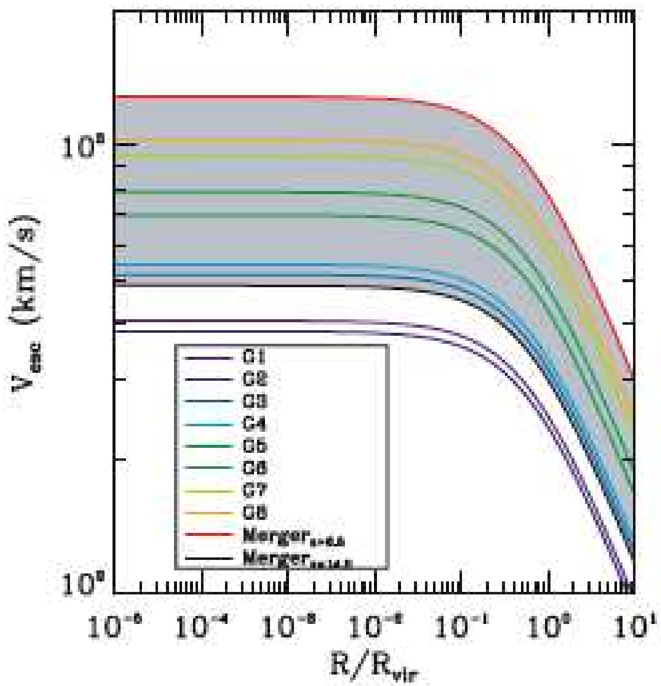


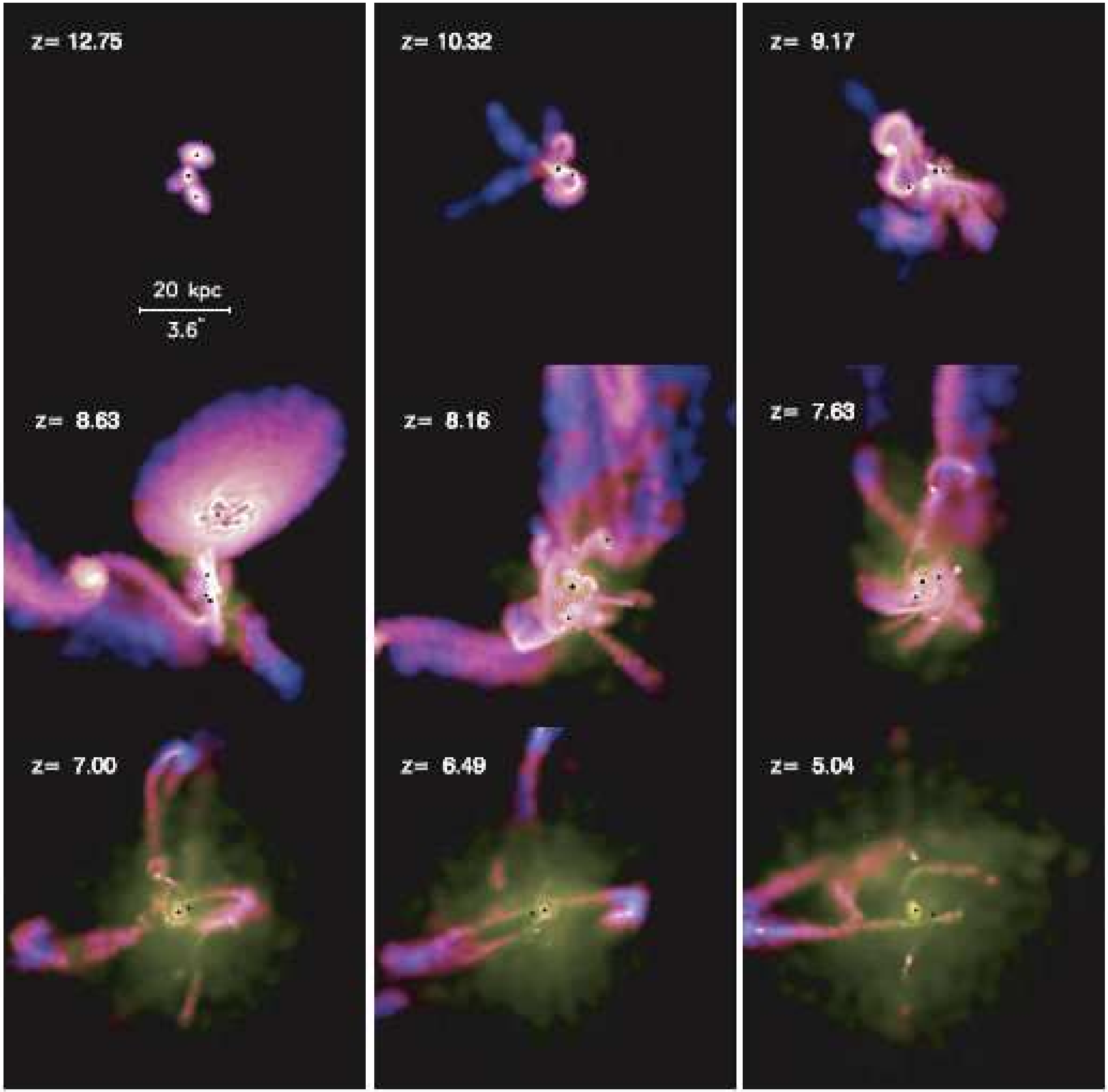
FIG. 4.— Halo escape velocity V_{esc} as a function of distance R/R_{vir} (R_{vir} is the virial radius) to the halo center for various models in our merger simulations. This plot includes the isolated halo progenitors G1 – G8 in Table 1, as well as the first merger remnant at $z \simeq 14$ and the last one at $z \simeq 6.5$, as labeled in the legend. The shaded region indicates the range of the escape velocities of the mergers in our simulations, with the values in the central regions being 486 km $s^{-1} \lesssim V_{esc} \lesssim 1284$ km s^{-1}.

Hierarchical Assembly of the Quasar

- Progenitors are very compact and gas rich.
- Strong gravitational interactions between the merging galaxies lead to tidal tails, strong shocks and efficient gas inflow that triggers large-scale starbursts.
- Highly concentrated gas fuels rapid accretion onto the SMBH
- Z ~14-9, merging systems are small (tens of kiloparsecs). By Z~ 9-7, scale and strength are much greater.

Part 2

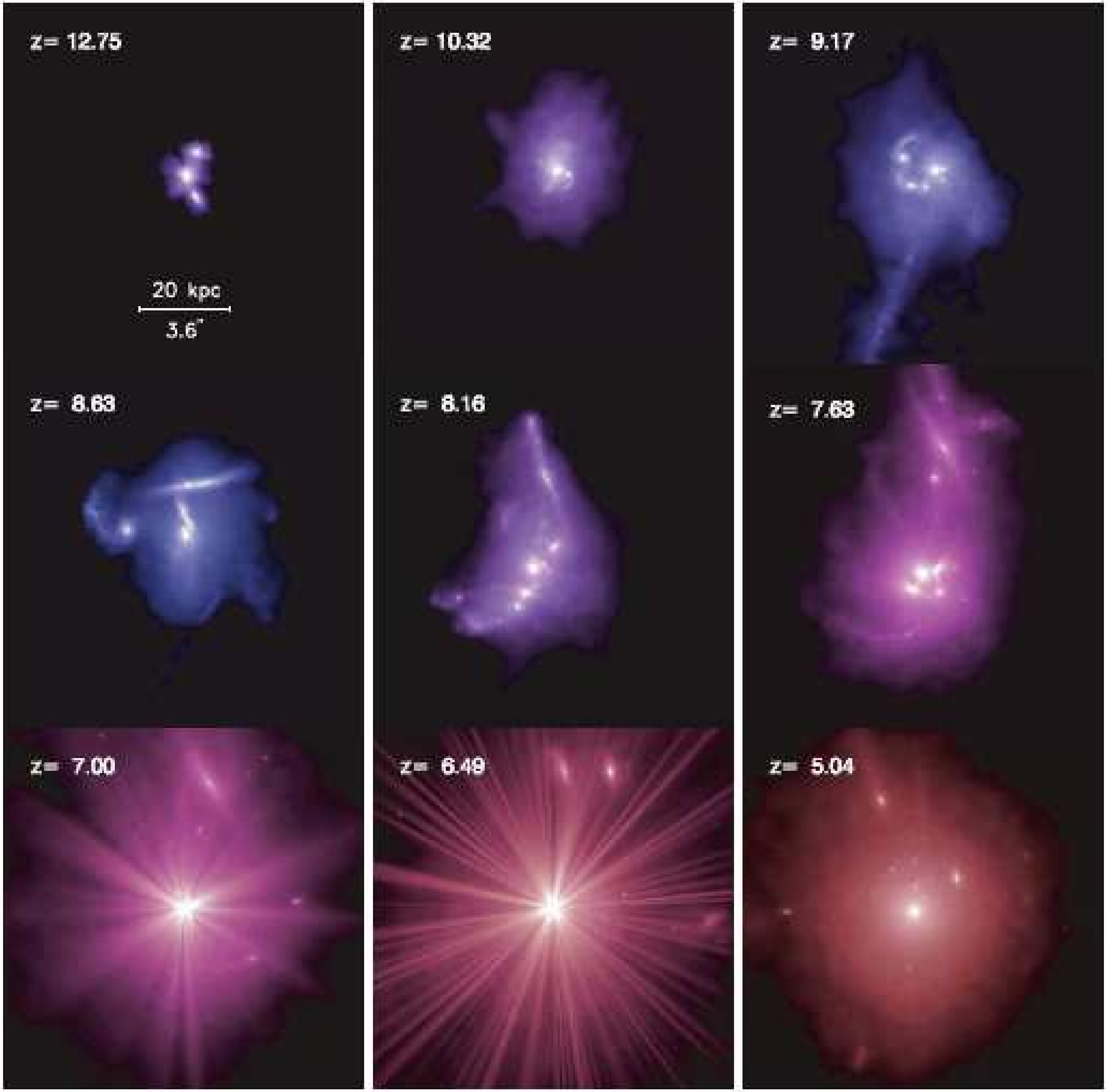
- At Z ~6.5, progenitors galaxies coalesce SMBH accretion and feedback to a climax.
- This feedback introduces a powerful wind that clears the material around the quasar.
- The largest SMBH appears as a optically bright quasar. After this, the quasar feedback quenches star formation and quasar activity dies down.

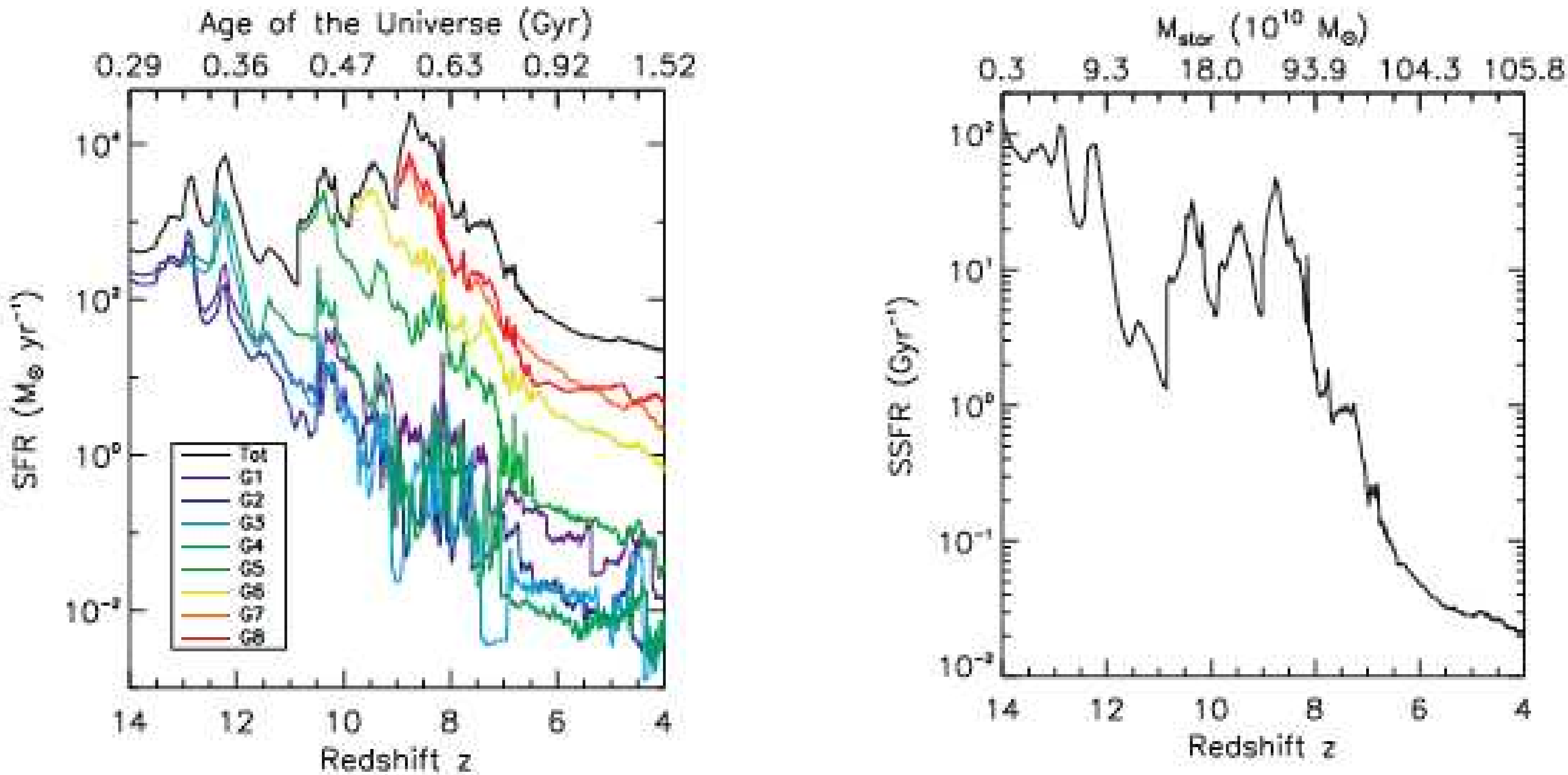


z= 12.75
20 kpc
3.6"
z= 10.32
z= 9.17
z= 8.63
z= 8.16
z= 7.63
z= 7.00
z= 6.49
z= 5.04

Star formation

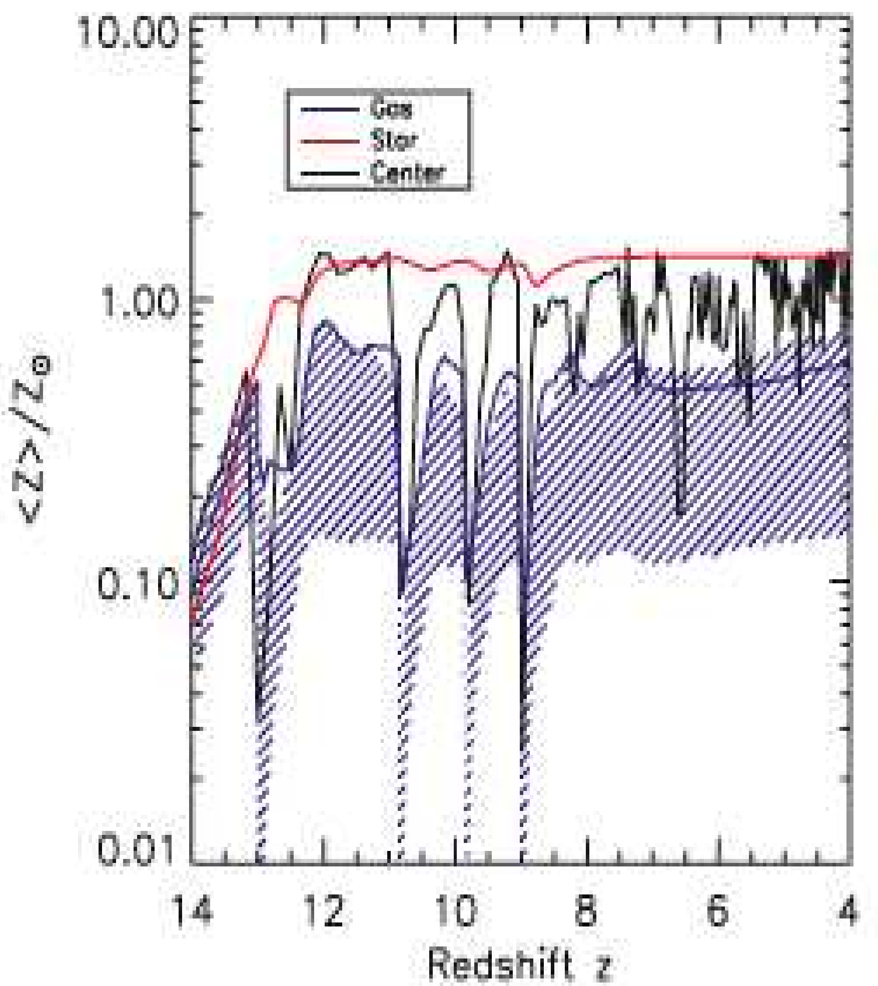
- As progenitors undergo strong interactions, stars form rapidly.
- Total SFR : 100 to > 10^4 M_{sun}/year
- By Z < 7, SFR decreases gradually due to depletion of gas supply and strong feedback
- By Z ~ 6.5 SFR: ~ 100 M_{sun} / year (order of mag lower than J1148+5251)


z= 12.75
20 kpc
3.6"
z= 10.32
z= 9.17
z= 8.63
z= 8.16
z= 7.63
z= 7.00
z= 6.49
z= 5.04

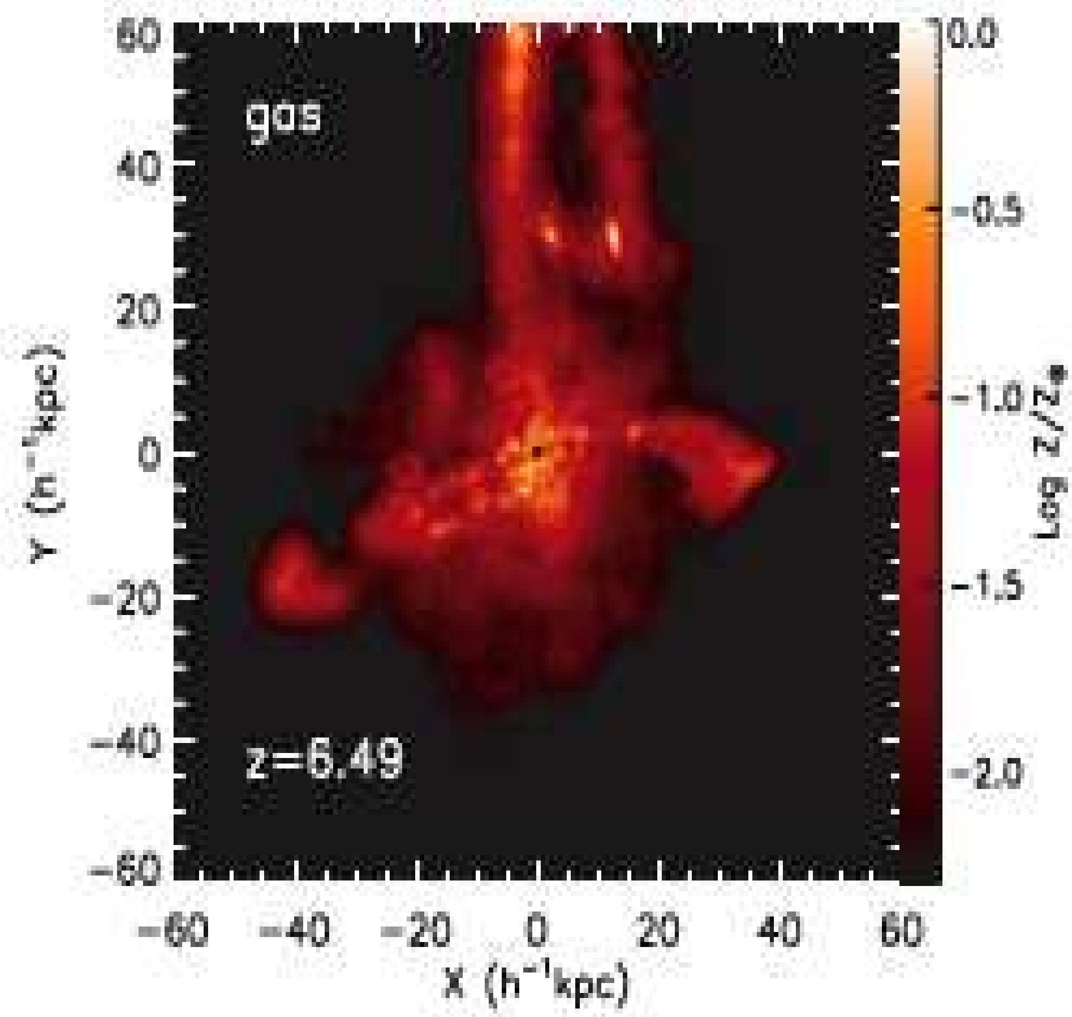


Age of the Universe (Gyr)
0.29
0.36
0.47
0.63
0.92
1.52
SFR ($M_\odot$ yr^{-1})
Tot
G1
G2
G3
G4
G5
G6
G7
G8
14
12
10
8
6
4
Redshift z
M_{star} (10^{10} $M_\odot$)
0.3
9.3
18.0
93.9
104.3
105.8
SSFR (Gyr^{-1})
Redshift z

Metallicities



- Rapid star formation produces an abundant mass of heavy elements.
- Dips and jumps are due to new material mergers.
- Metals are widespread due to outflows.



Some regions are supersolar metallicity.

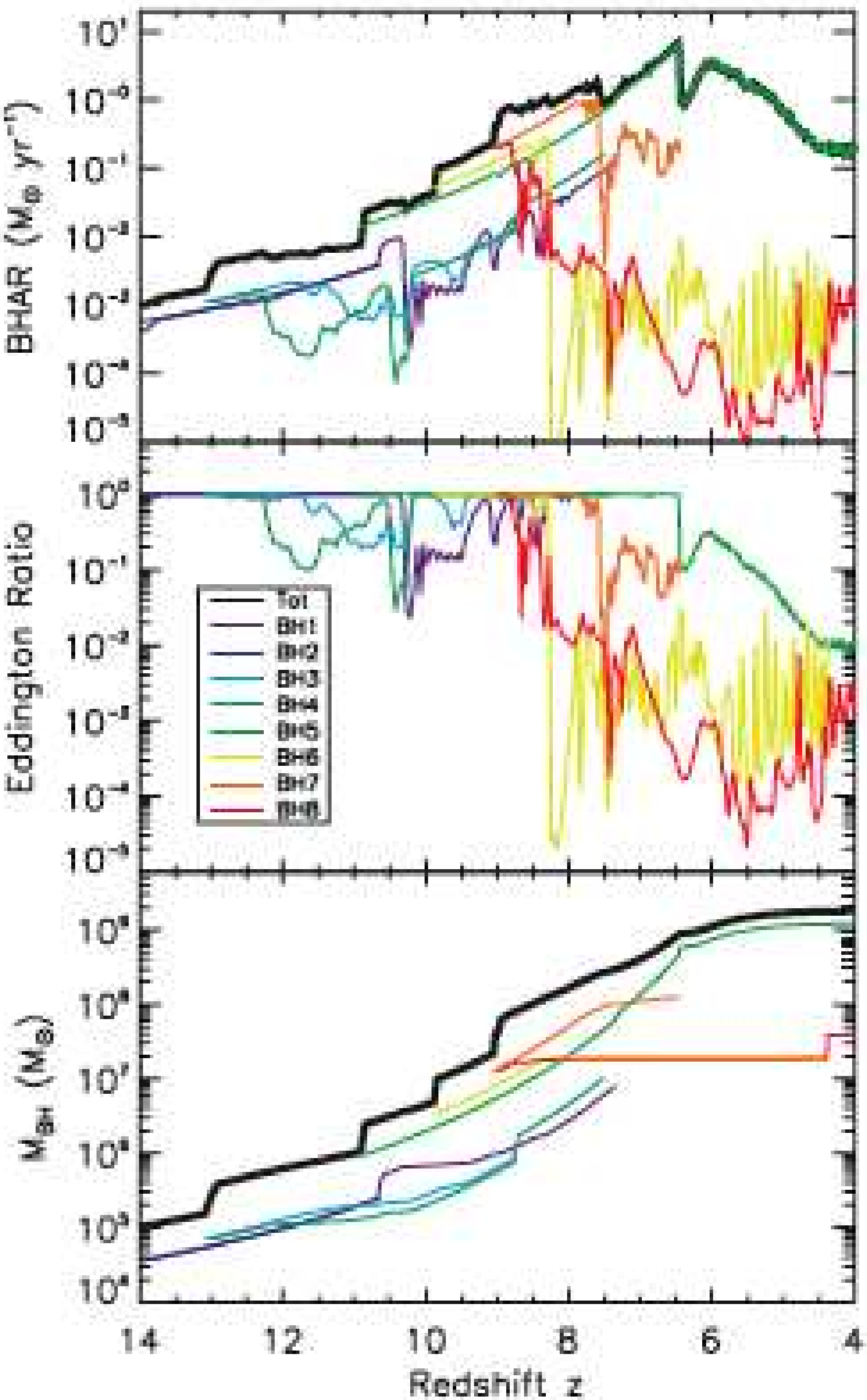
Due to infalling material triggering small scale star formation.

Growth of SMBH

- Total BH accretion rate grows steadily during assembly.
- Eddington ratio: L_{bol}/L_{edd} ($3.3\ 10^4\ (M/M_{sun})\ {*}L_{sun}$)
- Although each BH may not accrete at Eddingtion rate, so growth of quasar is a collective contribution of each BH.

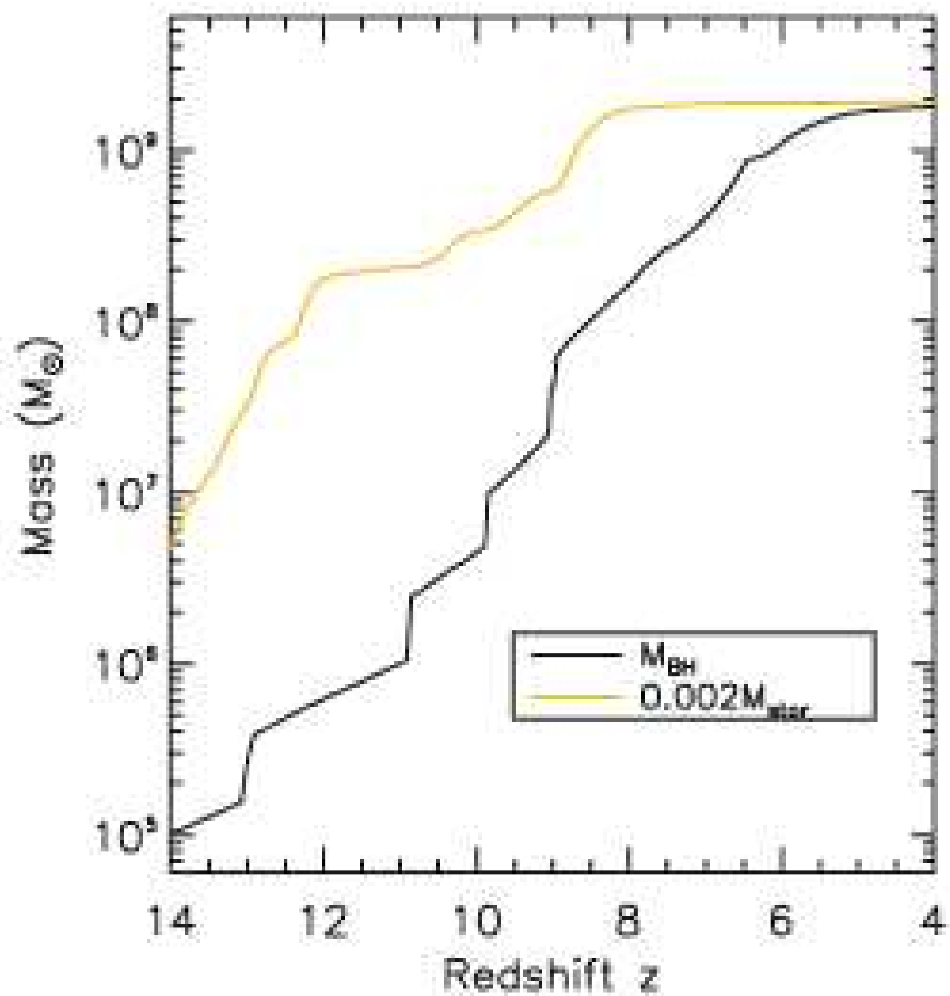
Escaping BHs?

- Emission of gravitational waves carries away linear momentum, could cause BH to recoil.
- If recoil velocity is greater than escape velocity, BH escape.
- But, simulation shows that recoil/kick velocity is much smaller than escape velocities

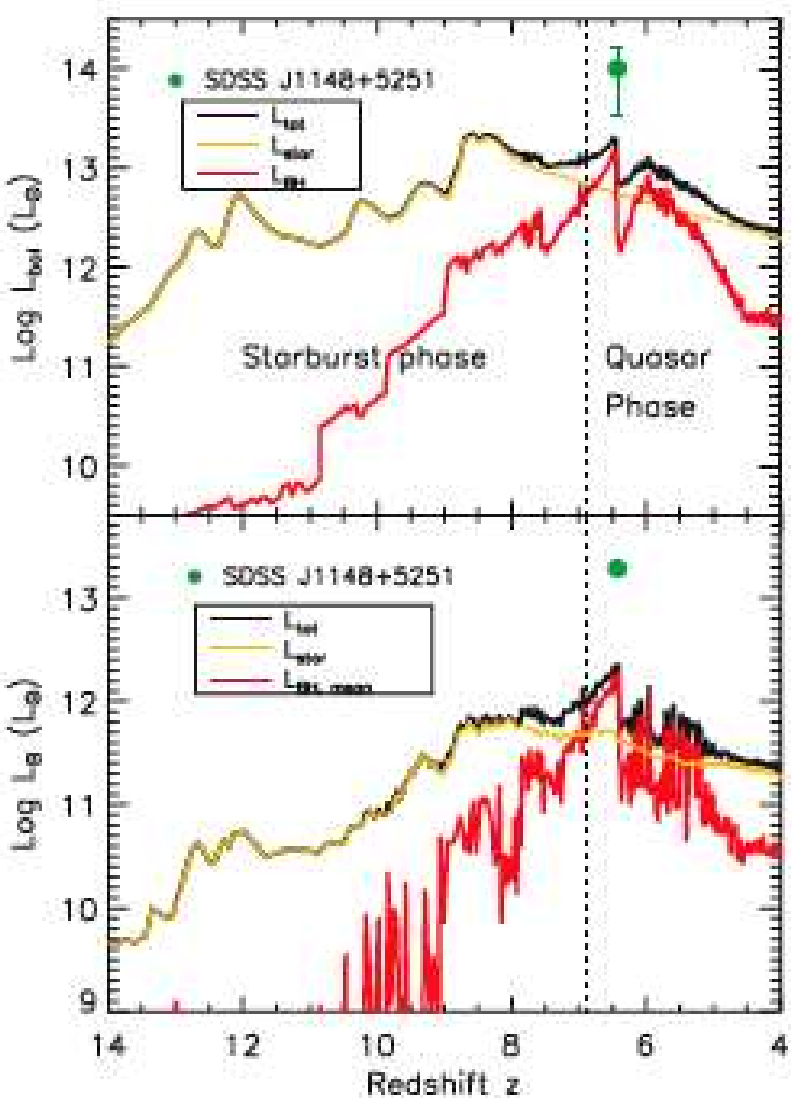


BHAR ($M_\odot$ yr^{-1})
Eddington Ratio
M_{BH} ($M_\odot$)
Tot
BH1
BH2
BH3
BH4
BH5
BH6
BH7
BH8
Redshift z

Evolution of total BH and stellar mass.

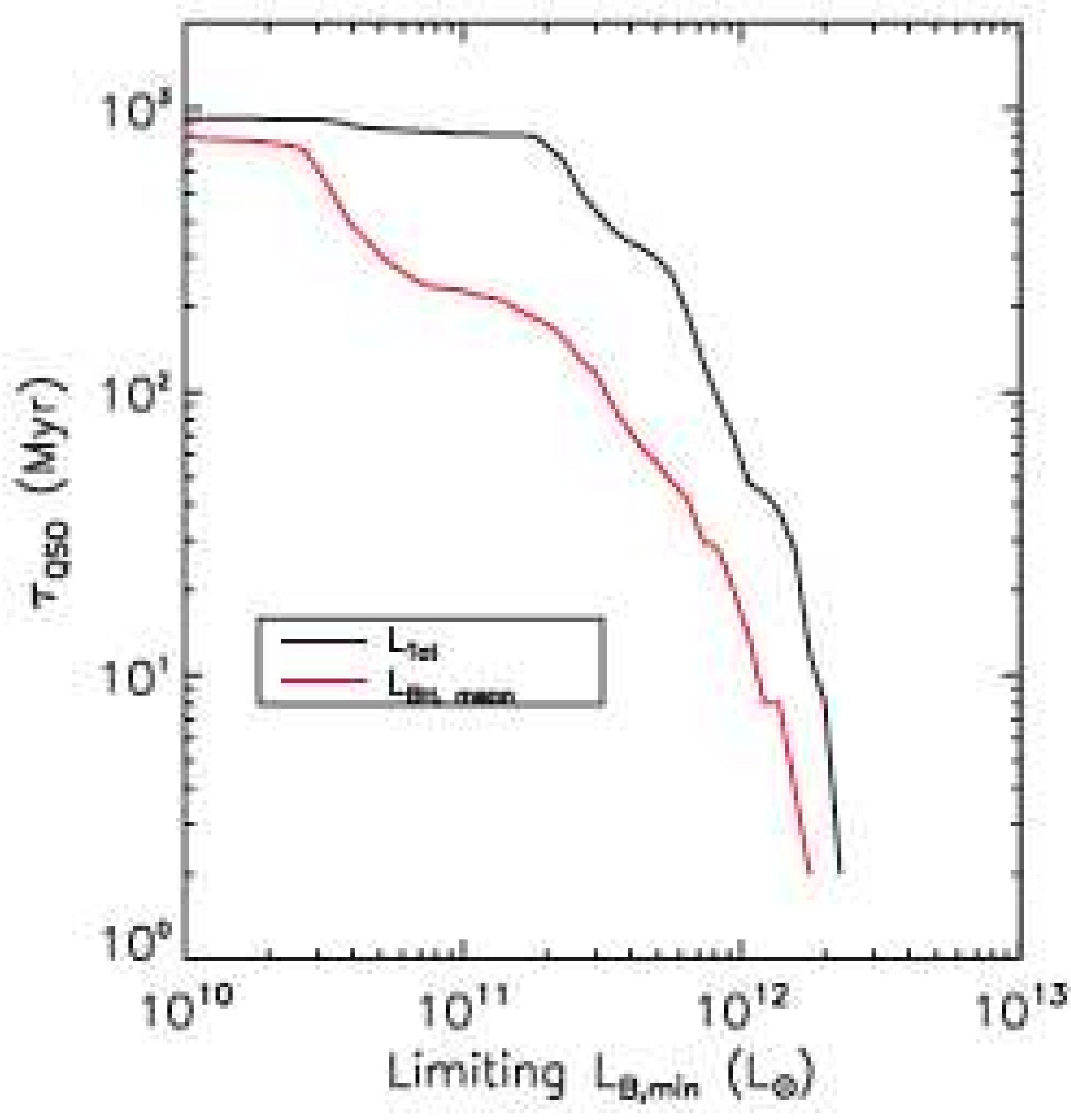


Quasar Luminosities

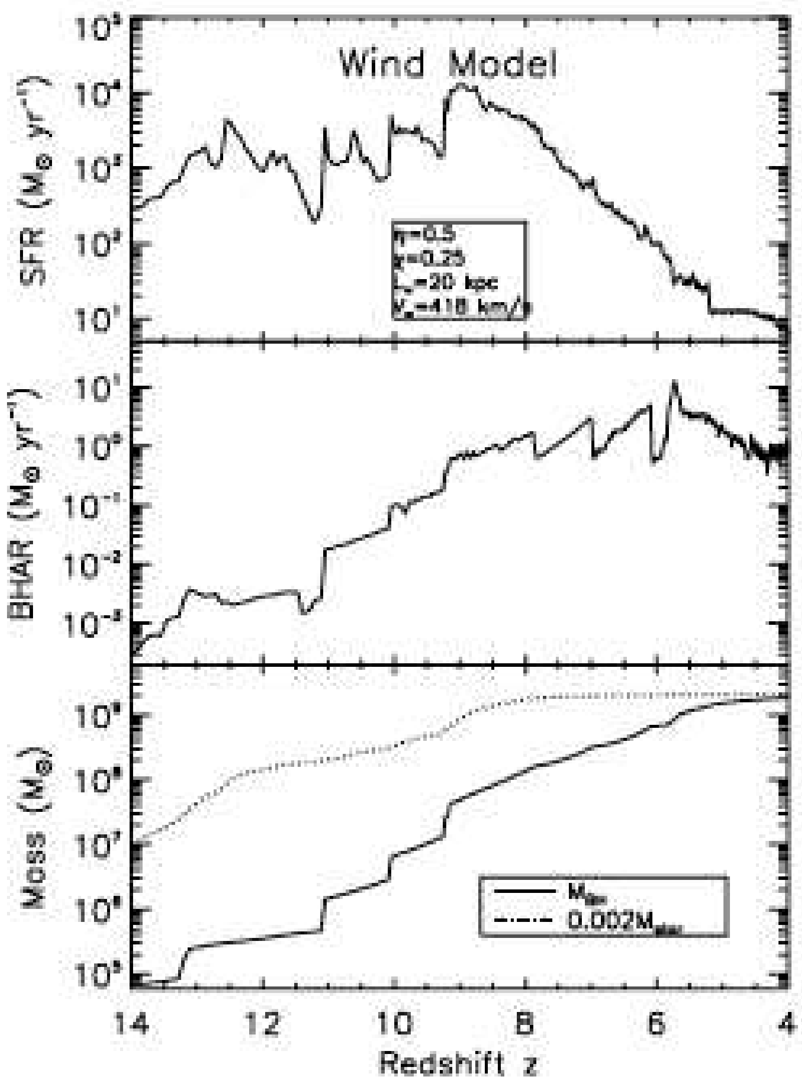


- $L_{bol}=\varepsilon_r Mc^2$, $\varepsilon_r=0.1$
- If BHs are spinning, L is increased by a factor of 4.
- Host appears as an ultraluminous infrared galaxy (ULIRG) $L_{bol} > 10^{12} L_{sun}$

Quasar lifetimes

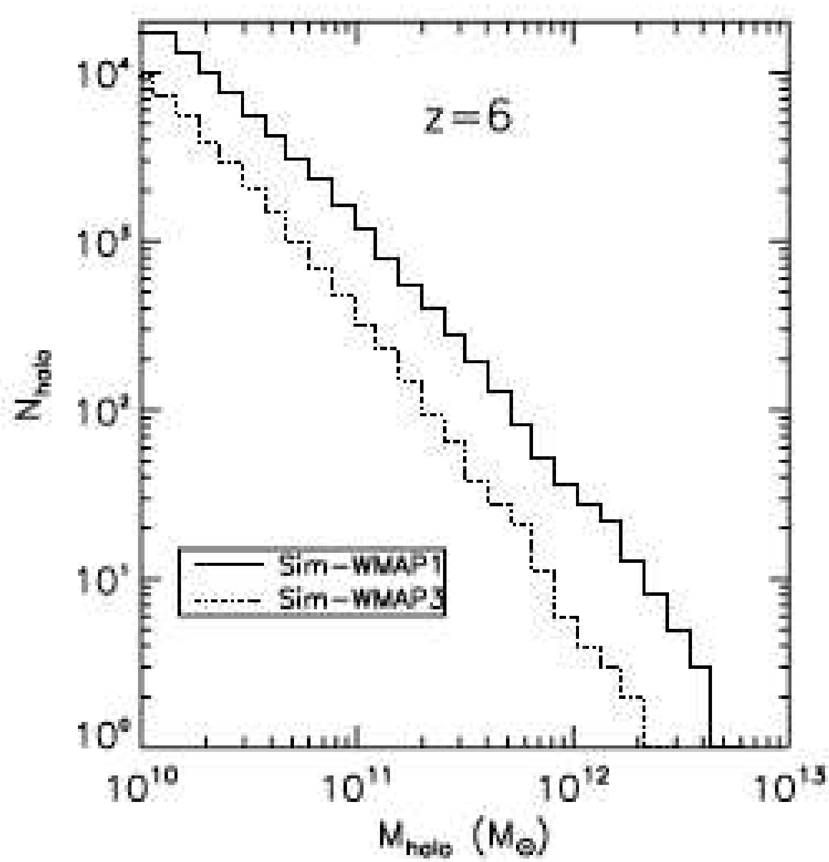


Feedback from Starburst Driven wind



- Same simulation run, but at lower resolution and wind model.
- Effect of wind on quasar evolution is minor

Number of such Quasars



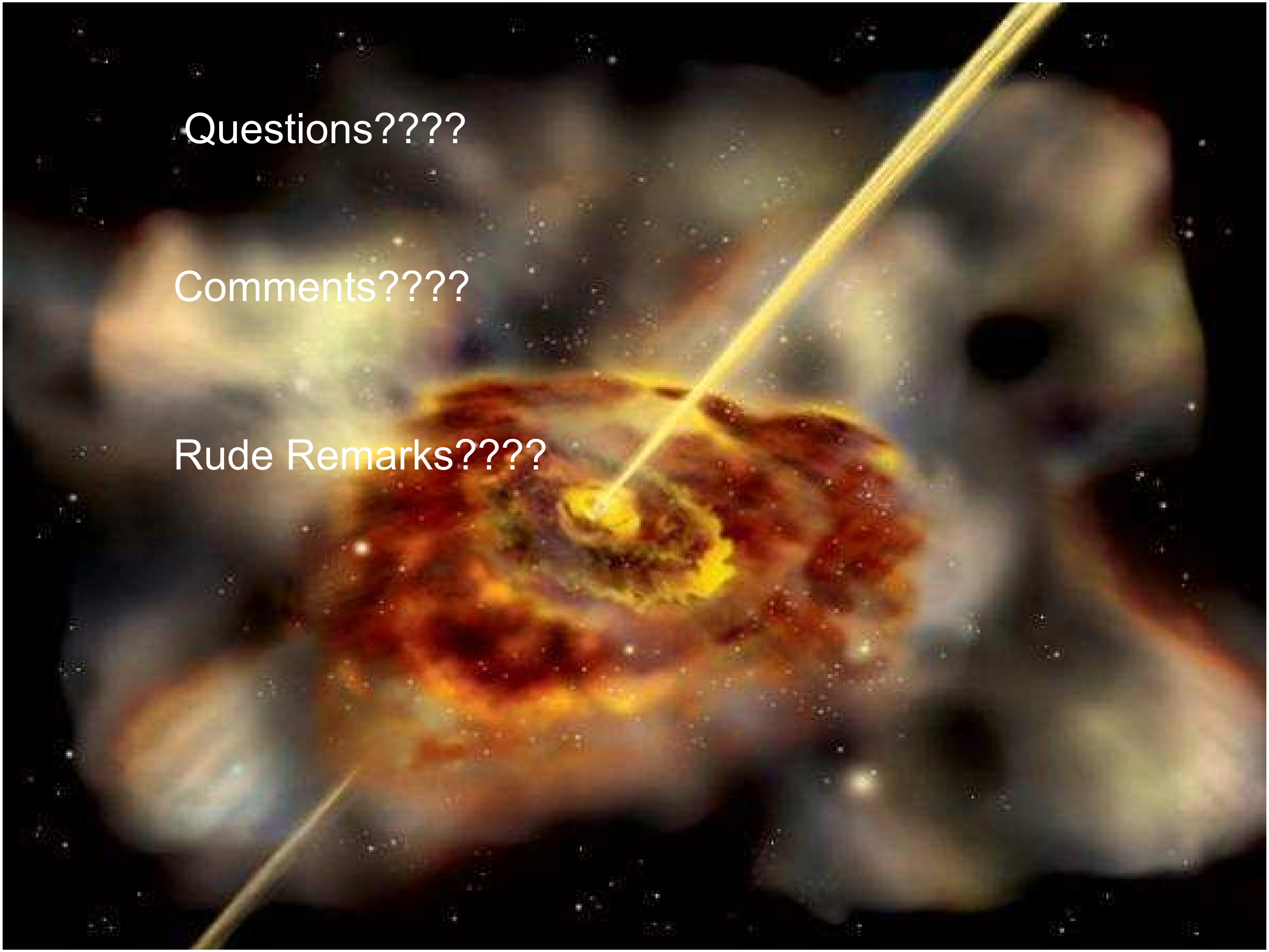
- Depends on cosmological constants used.
- WMAP1 ~ 36
- WMAP3 ~ handful
- WMAP3 will produce fewer luminous quasars

Era of Reionization

- WMAP3 results - universe was 50% ionized at Z ~9.3

Summary

- Find target halo by performing a N-body simulation in large volume.
- Largest halo reaches M ~ $5.4 \times 10^{12}\ h^{-1}\ Gpc^3$ through 7 major mergers between Z ~14.4 and Z~6.5
- Quasar host galaxy build rapidly through gas rich mergers.
- SFR up to $10^4\ M_{sun}$ /year
- Reaching stellar mass of $10^{12} M_{sun}$ at Z~6.5
- BH accretion reaches 20 M_{sun}/year and M = $2 * 10^9\ M_{sun}$
- At peak, this is consistent with J1148-5251


Questions????
Comments????
Rude Remarks????