Hierarchical assembly of massive black holes

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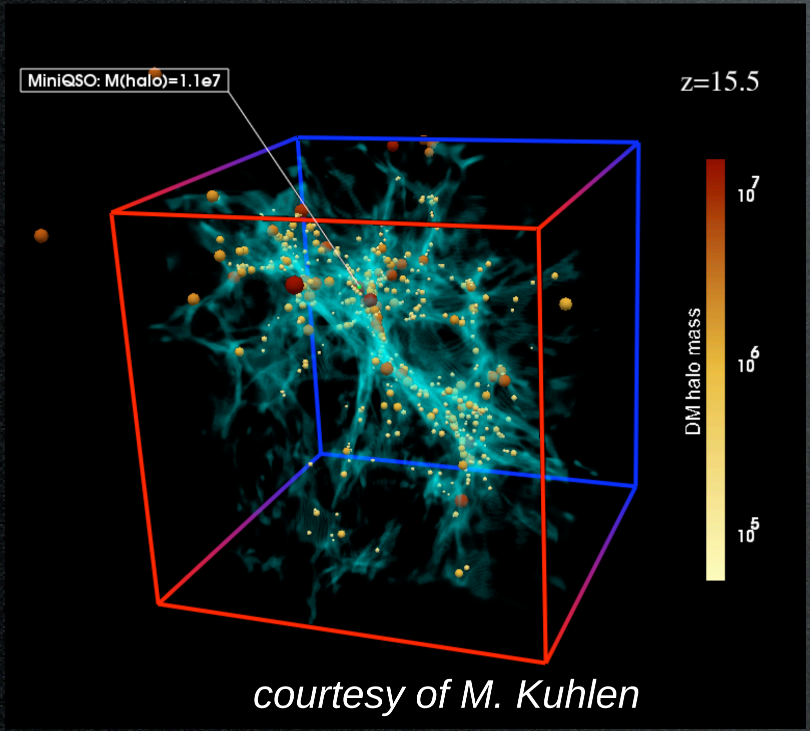
SDSS 1148+3251 at **z=6.4** **M_{BH}=2-6 x10^9 M_{sun}** (Willott et al 2003, Barth et al 2003)

As massive as the largest SMBHs today, but when the Universe was 1 Gyr old!



courtesy of M. Kuhlen

We have to look at even earlier times for the seeds...

Hierarchical Galaxy Formation:
only a small fraction of high-z halos allow efficient gas cooling

First black holes in pregalactic halos $z \approx 10\text{-}30$

$M_{BH} \sim 100\text{-}600\ M_{sun}$

PopIII stars remnants

(Madau & Rees 2001, Volonteri, Haardt & Madau 2003)

- ✓ Simulations suggest that the first stars are massive $M \sim 100\text{-}600\ M_{sun}$ (Abel et al., Bromm et al.)
- ✓ Metal free dying stars with $M > 260 M_{sun}$ leave remnant BHs with $M_{seed} \geq 100 M_{sun}$ (Fryer, Woosley & Heger)

$M_{BH} \sim 10^3\text{-}10^6\ M_{sun}$

Viscous transport + supermassive star

(e.g. Haehnelt & Rees 1993, Eisenstein & Loeb 1995, Bromm & Loeb 2003, Koushiappas et al. 2004)

- ✓ Efficient viscous angular momentum transport + efficient gas confinement

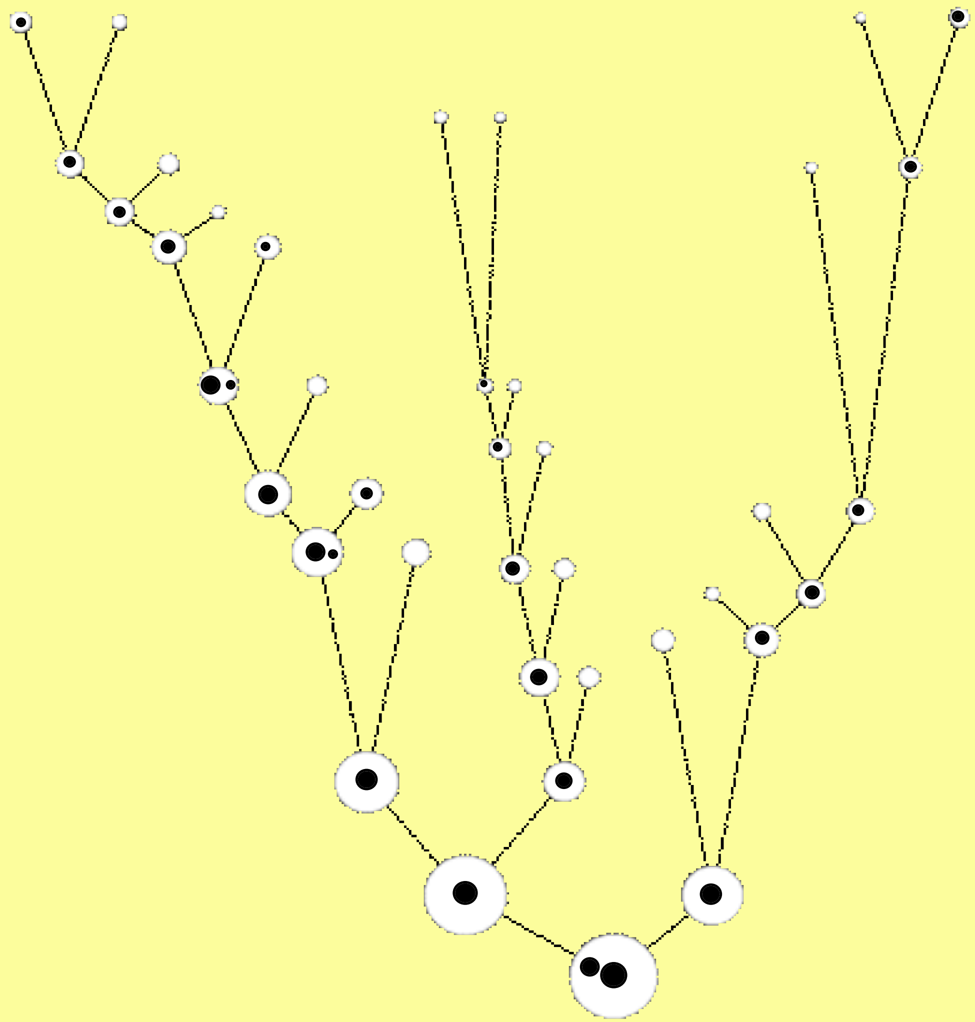
Bar-unstable self-gravitating gas + large "quasistar"

(Begelman, Volonteri & Rees 2006)

- ✓ Transport angular momentum on the dynamical timescale, process cascades
- ✓ Formation of a BH in the core of a low entropy quasistar $\sim 10^4\text{-}10^6$ Msun
- ✓ The BH can swallow the quasistar

SMBHS are grown from seed pregalactic BHs. These seeds are incorporated in larger and larger halos, accreting gas and dynamically interacting after mergers.

All models for first BHs predict a biased formation: in the HIGHEST PEAKS OF DENSITY FLUCTUATIONS at z~20-30



High-z MBHs: the survival of the fittest?

1. Dynamical issues: gravitational rocket

2. Accretion issues: spin and efficiency

1. Gravitational rocket

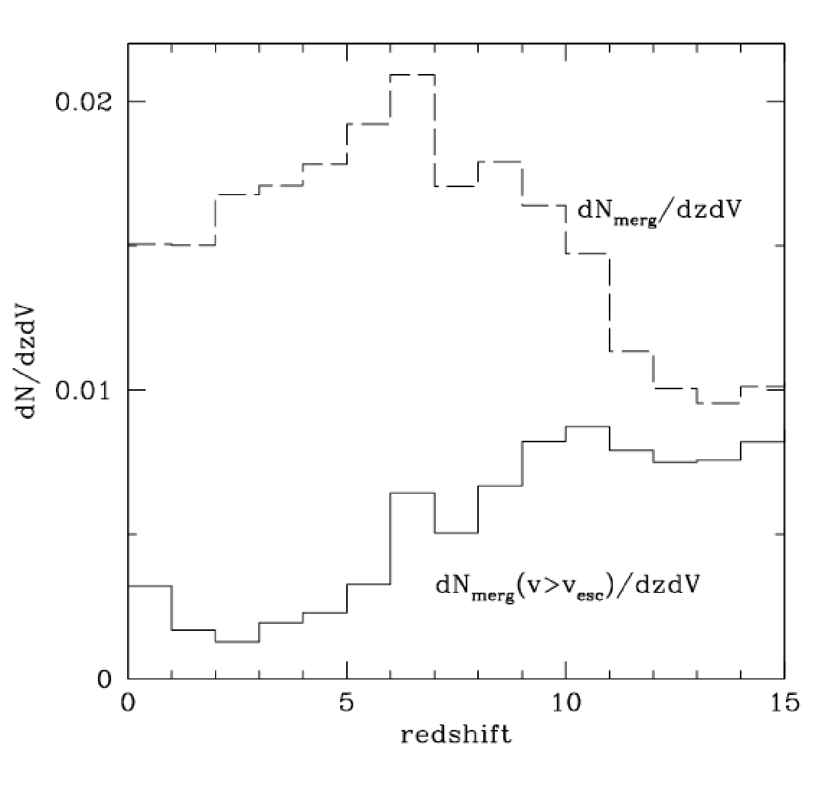
binary center of mass recoil during coalescence due to asymmetric emission of GW

(e.g. Fitchett 1983, Favata et al 2004, Blanchet et al 2005, Baker et al 2006)

$v_{rec} \leq 250$ km/s { $\ll v_{esc}$ from today galaxies; $\approx v_{esc}$ from high-z ones

GR SIMULATIONS:
see J. Centrella's talk

(Yoo & Miralda-Escude' 2004, Haiman 2004)



✓ *at z >10 more than 80% of merging MBHs can be kicked out of their halo (Volonteri & Rees 2006)*

the dynamical evolution CANNOT be ignored at these high redshifts!!!

✓ *at z < 6 no worries*

2. Accretion and efficiency

$$t_{acc} = 0.45 \frac{\epsilon}{1-\epsilon} \ln(\frac{M_{fin}}{M_{in}}) \mathrm{Gyr}$$

✓ *Small radiative efficiency* ε

M_{fin}/M_{in}~10^5, ε~0.1 ⇒ t_{acc}=0.6 Gyr

✓ *Large radiative efficiency* ε

M_{fin}/M_{in}~10^5, ε~0.4 ⇒ t_{acc}=3.5 Gyr

(Shapiro 2005)

Supercritical accretion onto pregalactic BHs: rapid growth in halos with Tvir>10^4 K

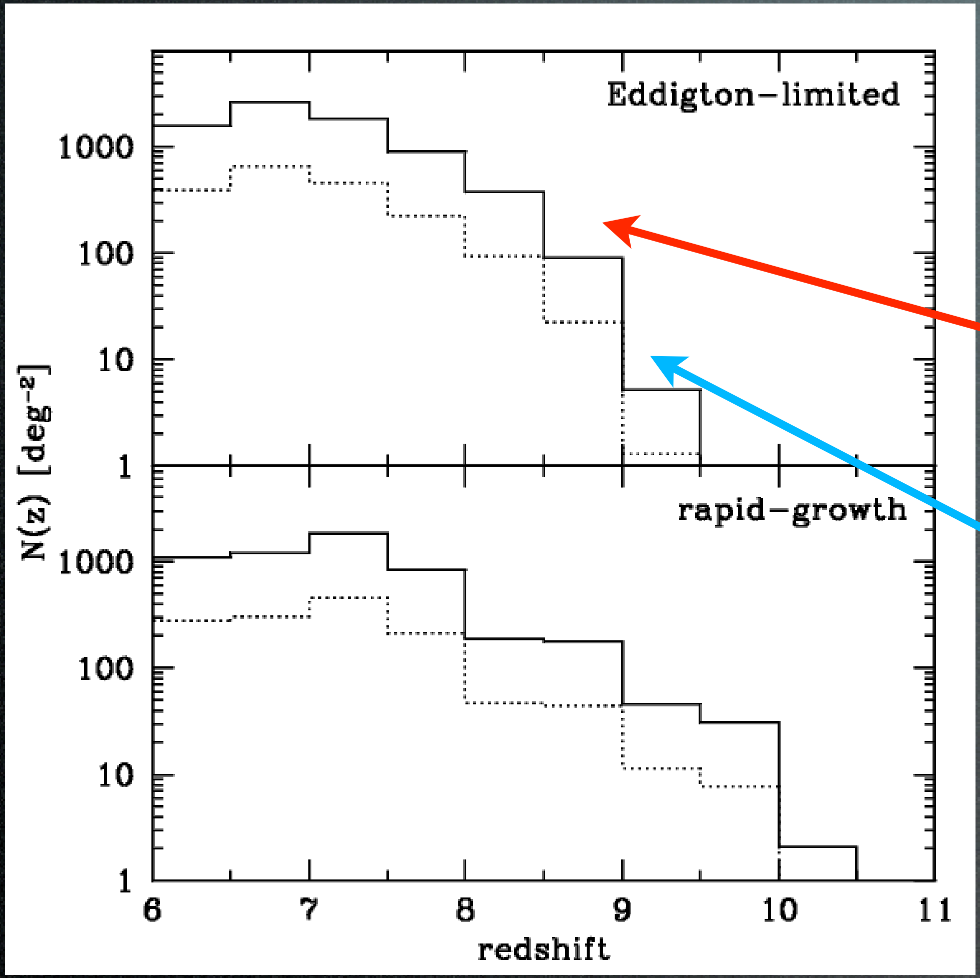
✓ small rotation: tiny accretion discs where radiation is trapped

(Volonteri & Rees 2005)

✓ unstable discs + bars cascade: formation of a seed within a supermassive "quasistar": the seed BH can grow at the Eddington rate of the star >> Eddington rate of the BH

(Begelman, Volonteri & Rees 2006)

EM bands: X-ray and NIR



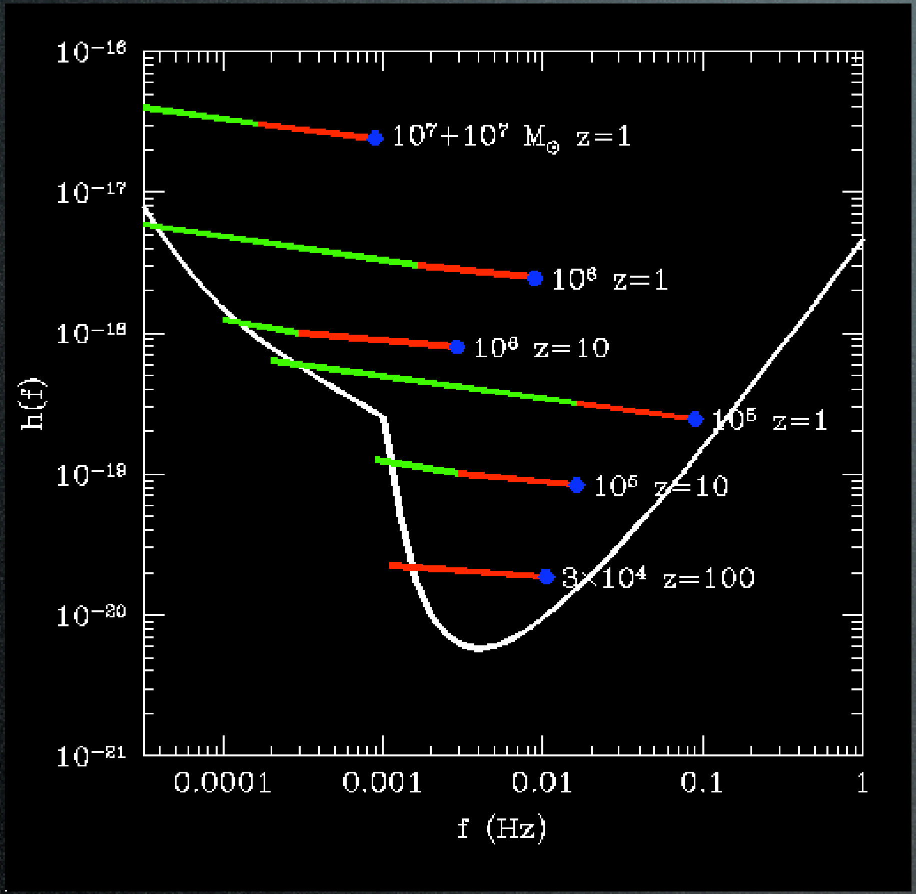
soft X-ray band [0.5-2 keV]
> 10^{-17} erg s^{-1} cm^{-2}

NIR fluxes above the planned JWST sensitivity

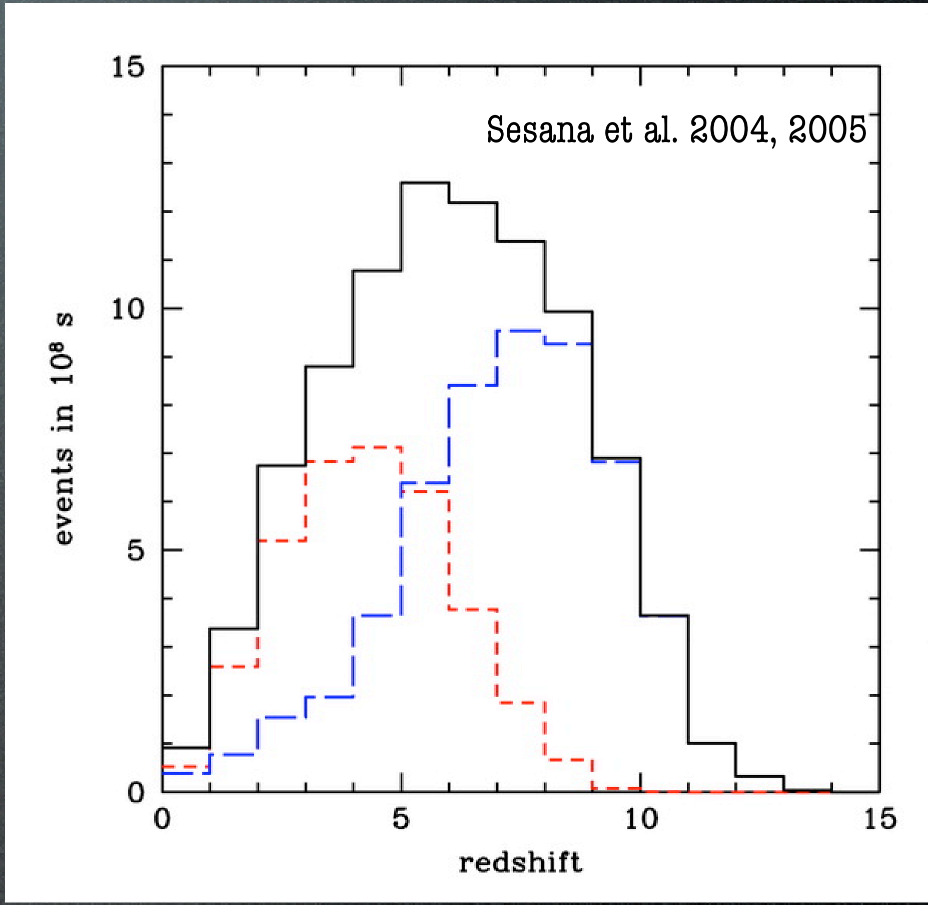
Salvaterra, Haardt & Volonteri 2006

Future space missions can easily detect the early stages of MBH evolution

Gravitational waves: LISA



MBHs $M<10^5$ Msun can be detected up to z=15-20



Resolvable events in 3 years

Inspirals: longlasting wide binaries, small frequency change

Bursts: binaries coalescing during the observation period

Summary

SMBHs can be built up from seeds dating back to the end of the cosmological dark ages

- ✔ *seed BHs are born in the highest density fluctuations at high z*
- ✔ *mass accretion dominates the mass and spin evolution*
- ✔ *mergers unimportant for the mass build-up*
- ✔ *dynamical and gravitational interactions can displace BHs … BUT they don't hinder the assembly of SMBHs*
- ✔ *supercritical accretion to explain z=6 quasars*