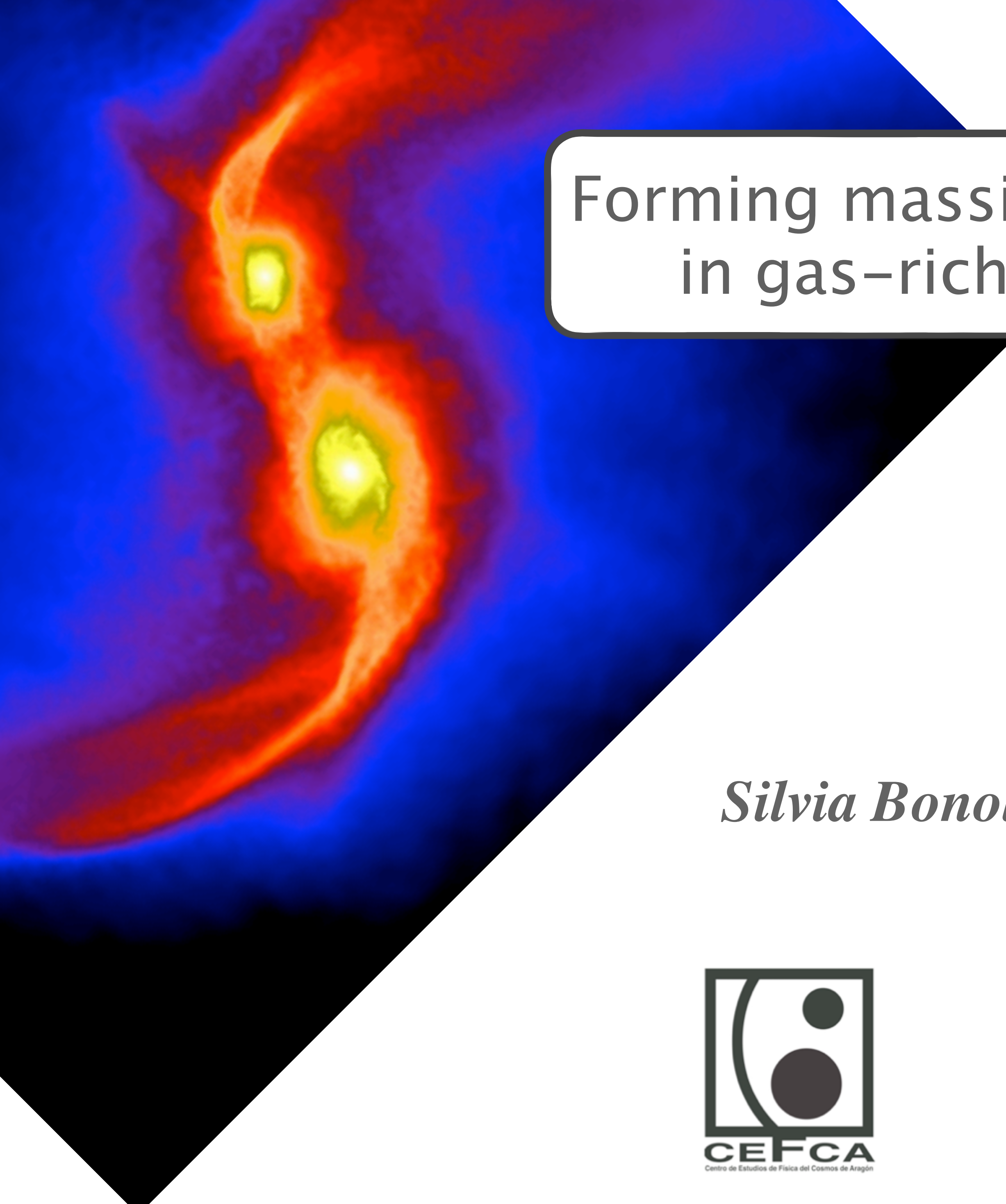

Forming massive black hole seeds in gas-rich galaxy mergers

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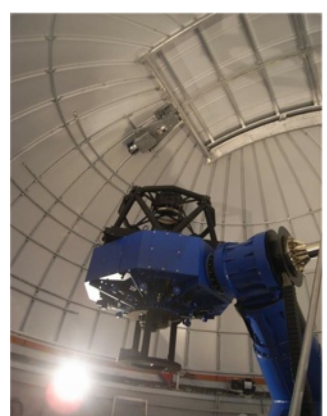
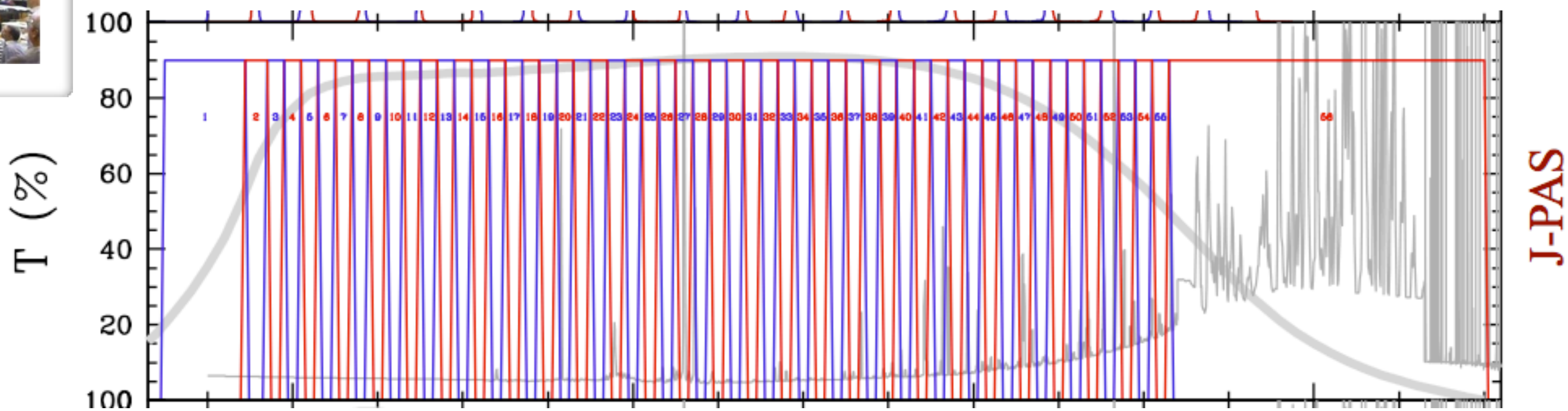
Observatorio Astrofísico de Javalambre



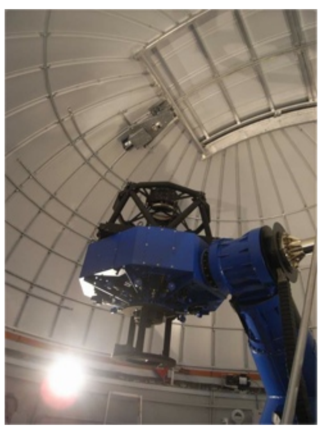
~8500 deg²

54 narrow, 2 broad band filters

width ~100A

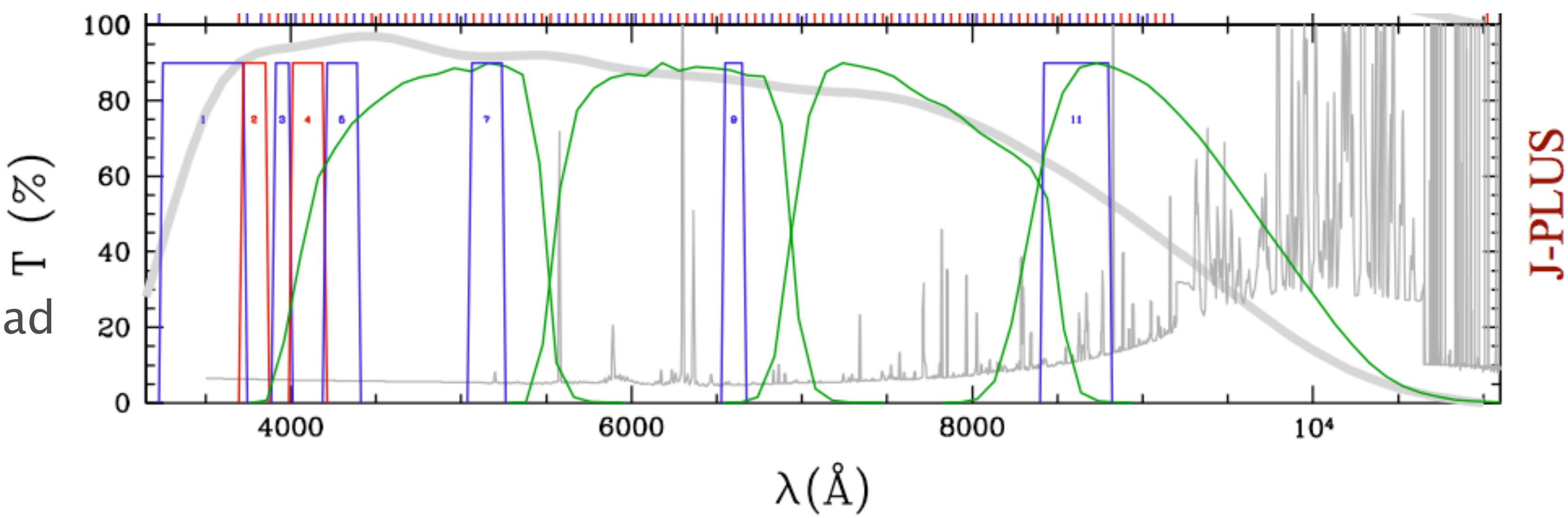


Javalambre Photometric Local Universe Survey

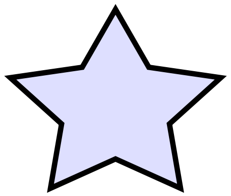


10 intermediate/broad band

2 narrow band



PopIII



~10^{1-2} M_{sun}

(Bond et al. 1984, Madau & Rees 2001, Volonteri et al. 2003, Volonteri & Rees 2006, Tanaka & Haiman 2009)

Uncertain the IMF starting mass might be low

Stacy et al, Clark et al. 2011, Greif et al. 2011, Wise et al.

Hard to constantly grow at the Eddington rate

(Alvarez et al. 2009, Johnson & Bromm 2007, Pelupessy et al. 2007, Milosavljević et al. 2009)

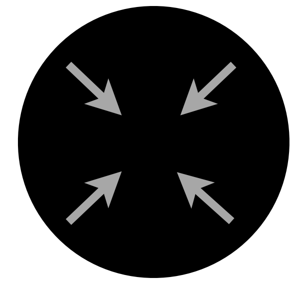
Direct collapse

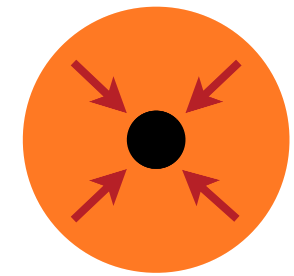
Nuclear star cluster

~10^{3} M_{sun}

(e.g., Rasio et al. 2004, Portegies Zwart 2002, Devecchi et al., Davies et al. 2011)

Supermassive Star





Quasi star

~10^{4-6} M_{sun}

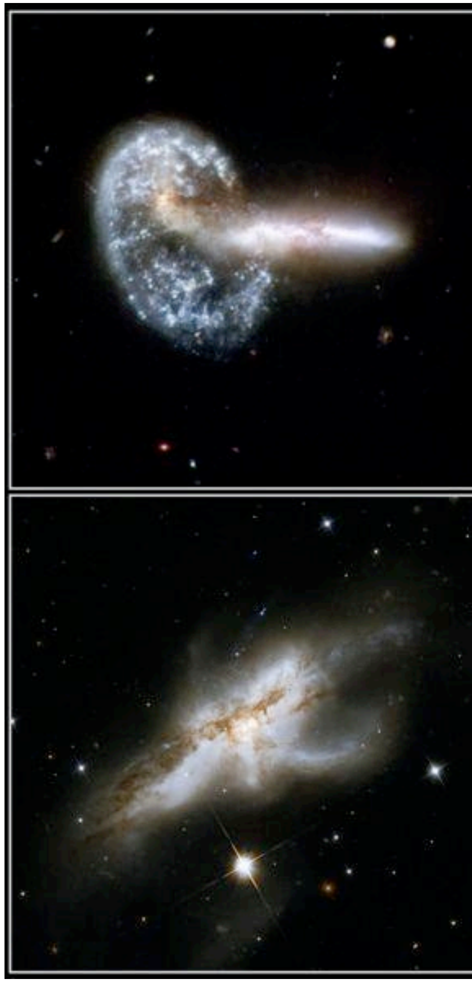
(e.g., Fowler & Hoyle 1966, Shibata & Shapiro 2002, Saijo & Hawke 2009)

(Begelman et al., Dotan et al)

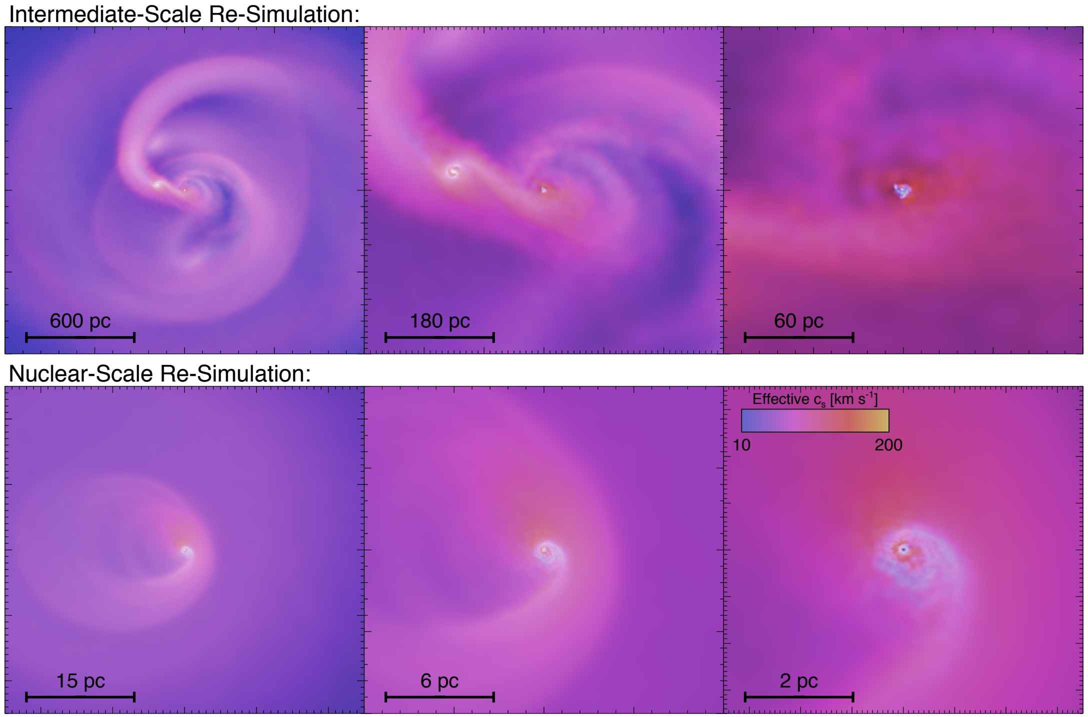
In isolated protogalaxies: shed angular momentum and avoid significant fragmentation

- Metal-free gas (Oh & Haiman 2002, Bromm & Loeb 2003, Lodato & Natarayan 2006, Omukai et al. 2008, Wise et al. 2008, Regan & Haehnelt 2009, Latif et al.)
- Prevent H_2-cooling (e.g., Lyman-Werner radiation - Haiman et al., Dijkstra et al. 2008, Agarwal et al. 2012)

What if we simply have a situation in which the inflow rate is higher than star formation rate?



Galaxy mergers are known to be able to trigger rapid global gas inflow from kpc to ~100pc scales
(e.g., Barnes & Hernquist 1996, Kazantzidis et al. 2004)



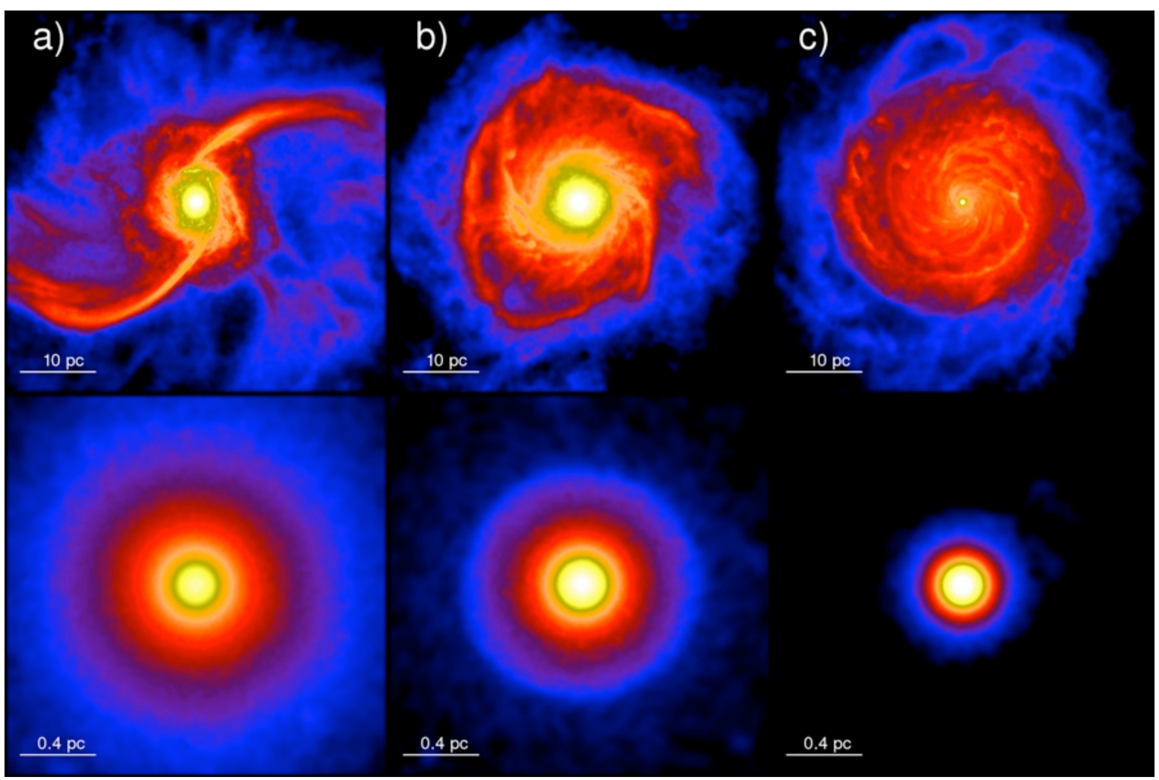
A substantial fraction of the gas can get to smaller scales, even during a nuclear starburst, in gas rich **mergers** or if other **dynamical instabilities** are present.

(Levine et al. 2008, Hopkins & Quataert 2010, Shlosman et al. 89, Begelman & Shlosman 2009 "Bars within bars", Angles-Alcazar 2013, **Mayer et al. 2010**)

Simulations of Mayer et al. 2010

- Gas-rich major merger of two massive disk galaxies in 10^{12} M_{Sun} DM halos
- NO PRE-EXISTING BH!!
- Resolution 0.1 pc in 10 kpc volume with EOS appropriate for nuclear starburst

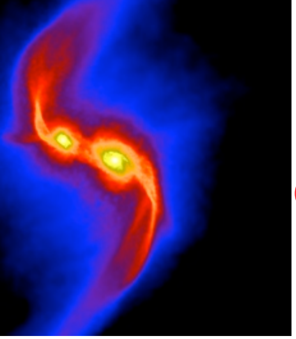
Nuclear disk ~2 billion Mo within r~80 pc



In first 10^5 yr after merger:

Mass inflow rate
~10^4-10^5 Mo/yr

Formation of supermassive cloud of 10^8 Mo.

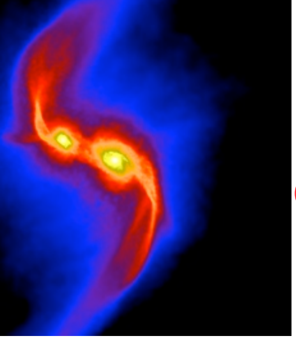


Gas-rich major mergers of disk galaxies in massive halos could set the condition for the formation of a supermassive star

↓

10^5 seed black hole (likely via a quasi-star)

ALSO IN A METAL-POLLUTED ENVIRONMENT



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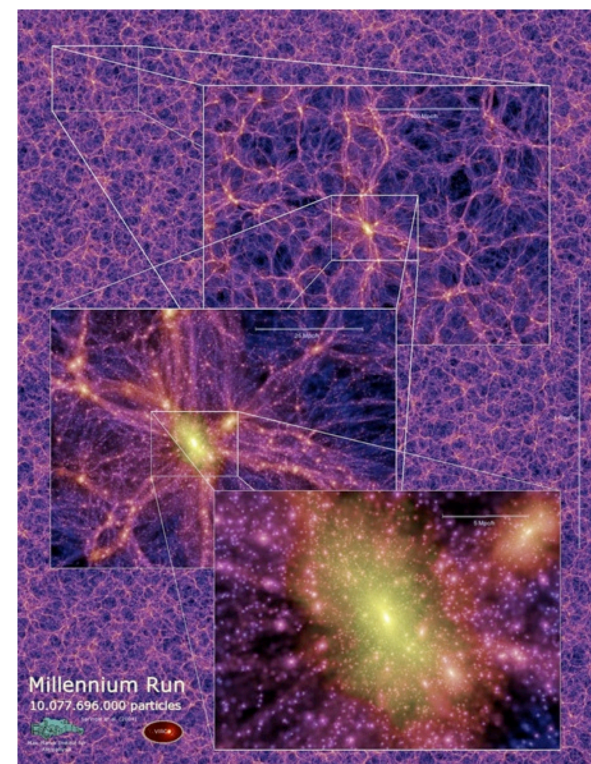
ALSO IN A METAL-POLLUTED ENVIRONMENT

How often does this happen in a LCDM universe?

first study of quasi-stars from mergers:
Volonteri & Begelman 2010

Here: Munich model of galaxy formation
(e.g., Croton et al 2006, DeLucia&Blaizot 2007, Bonoli et al. 2009...)

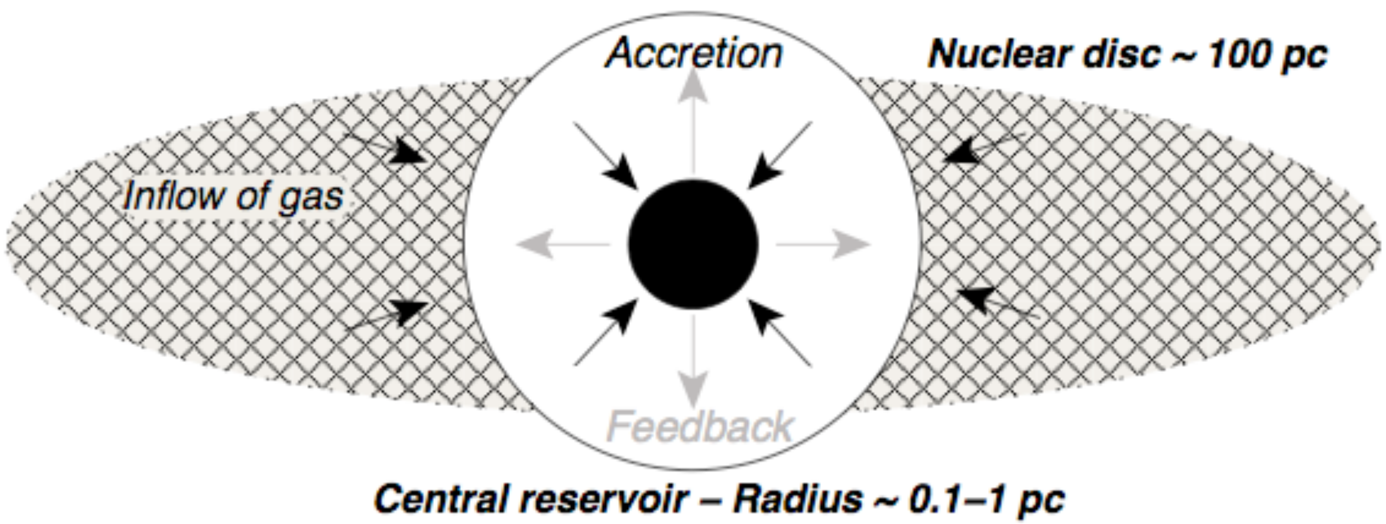
We have a full population of galaxies evolving in a cosmological framework



Conditions for the formation of massive seed black holes

- ✓ 1. Major merger (1:3) of gas-rich late-type galaxies ($B/T < 0.2$)
- ✓ 2. Host halo $M_h > 10^{11} M_{Sun}$
- ✓ 3. No a pre-existing black hole of $M_{BH} > 10^5\ M_{Sun}$

Seed black hole of $10^5\ M_{sun}$, which starts accreting from a large reservoir of gas

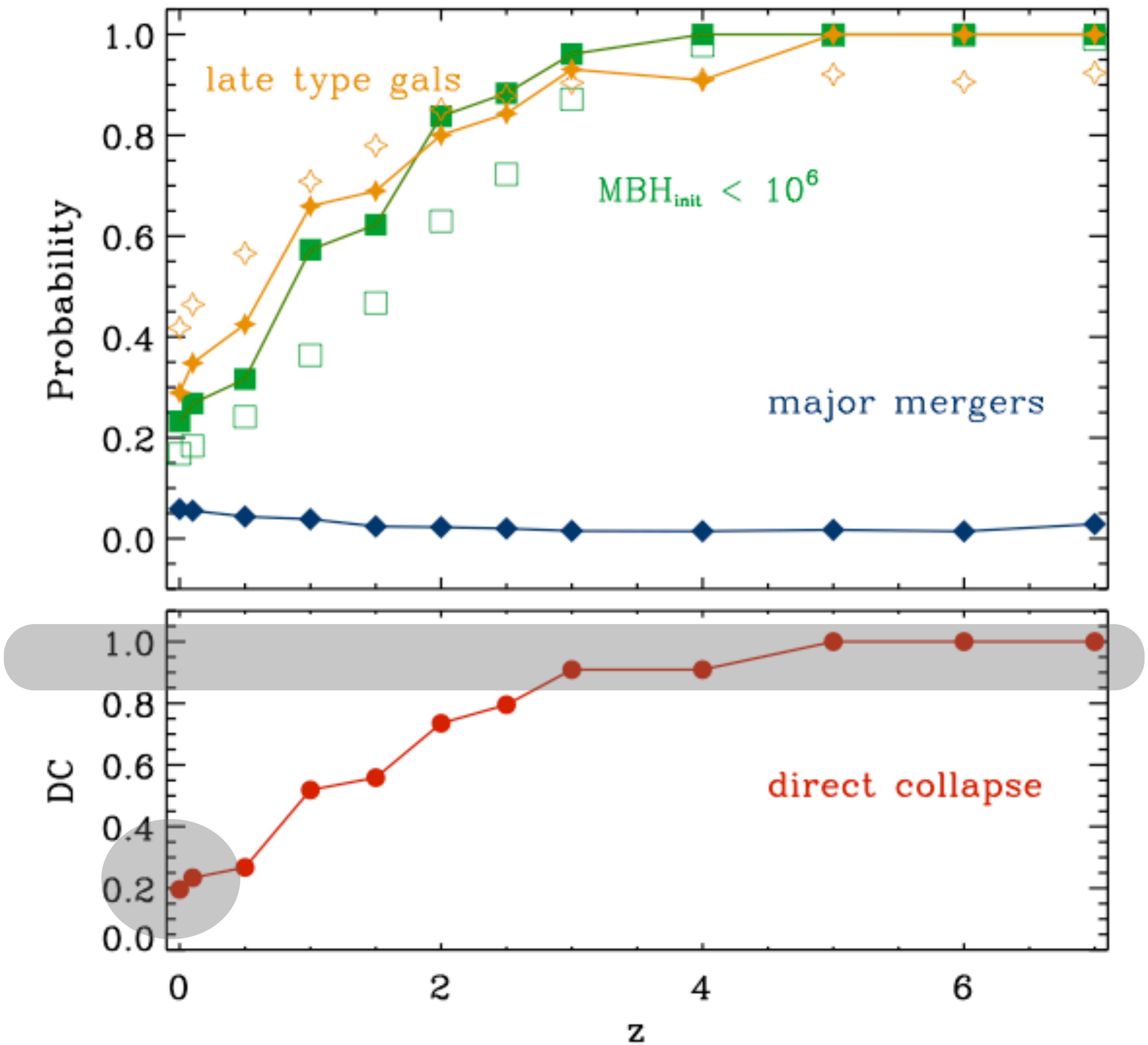


Self regulation: accretion stops once the feedback energy released by the black hole unbinds the reservoir (assumed isotropic thermal feedback)

Radius of the reservoir is a free parameter (0.1–1pc)

Statistics

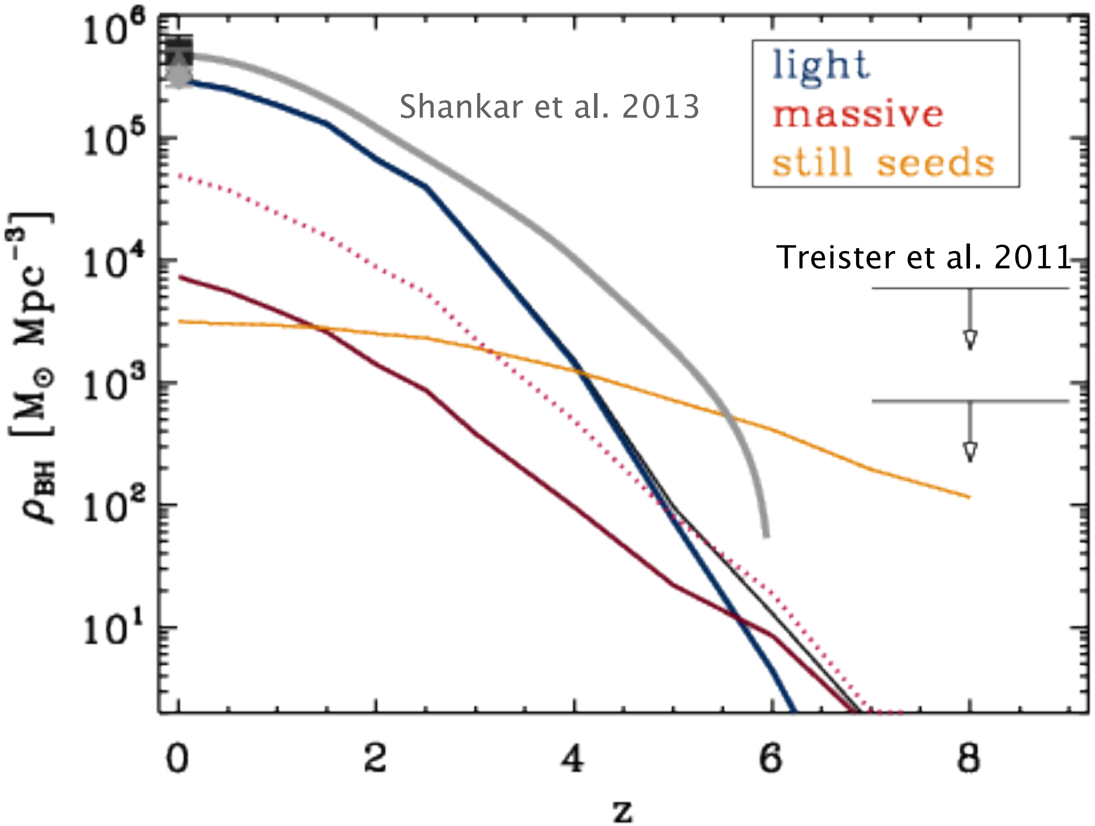
For all mergers in halos > 10^{11} M_{sun}



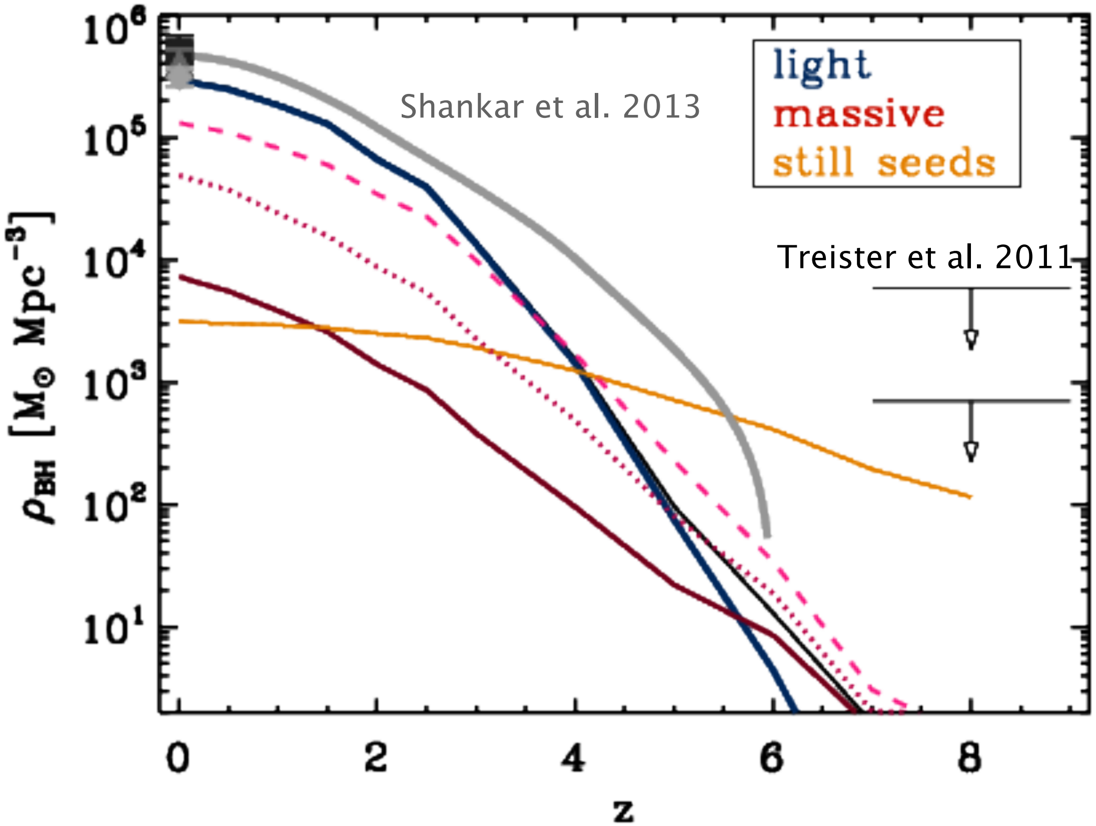
•Above z~4 almost all major mergers could lead to a massive seed

•Possible formation still in the local universe!

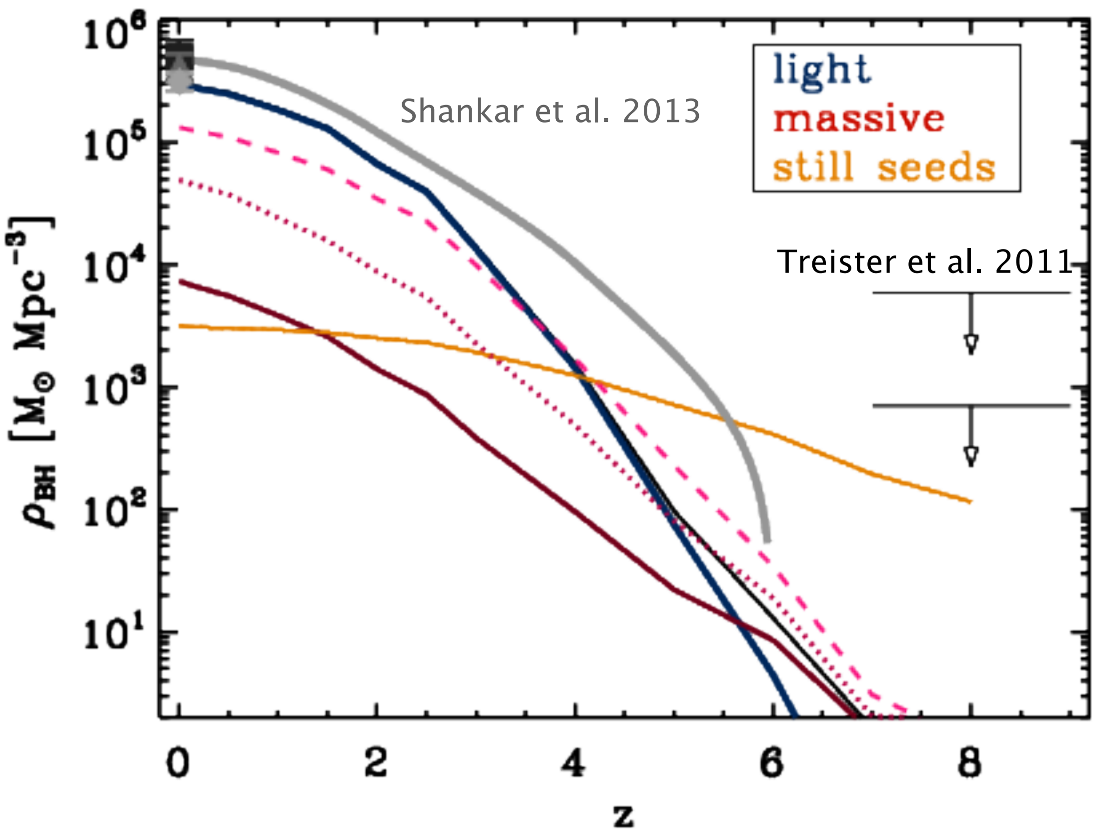
BH mass density

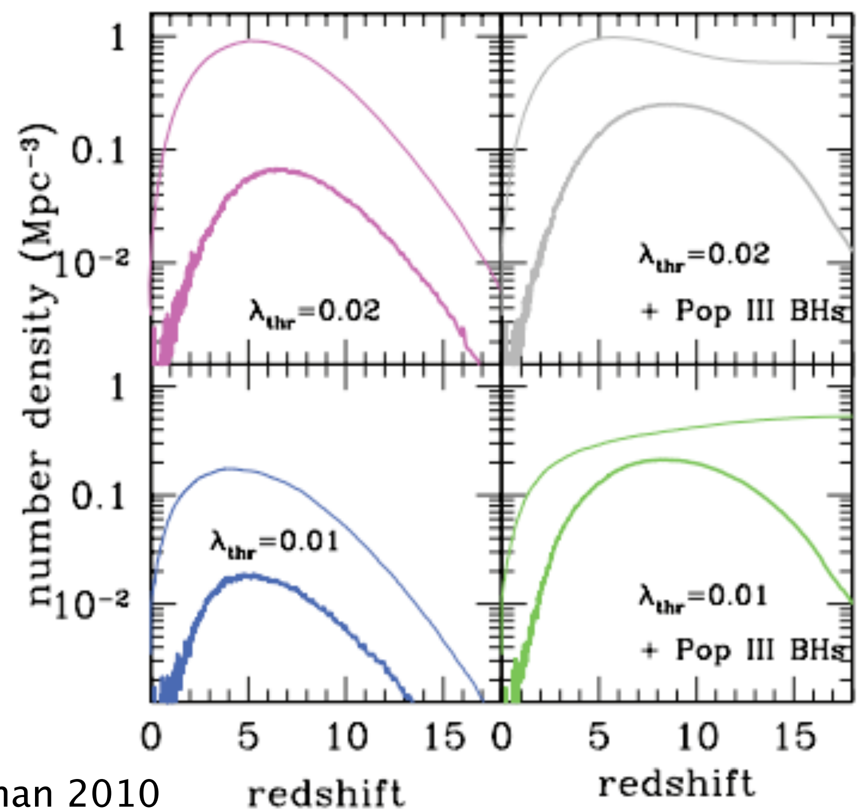


BH mass density



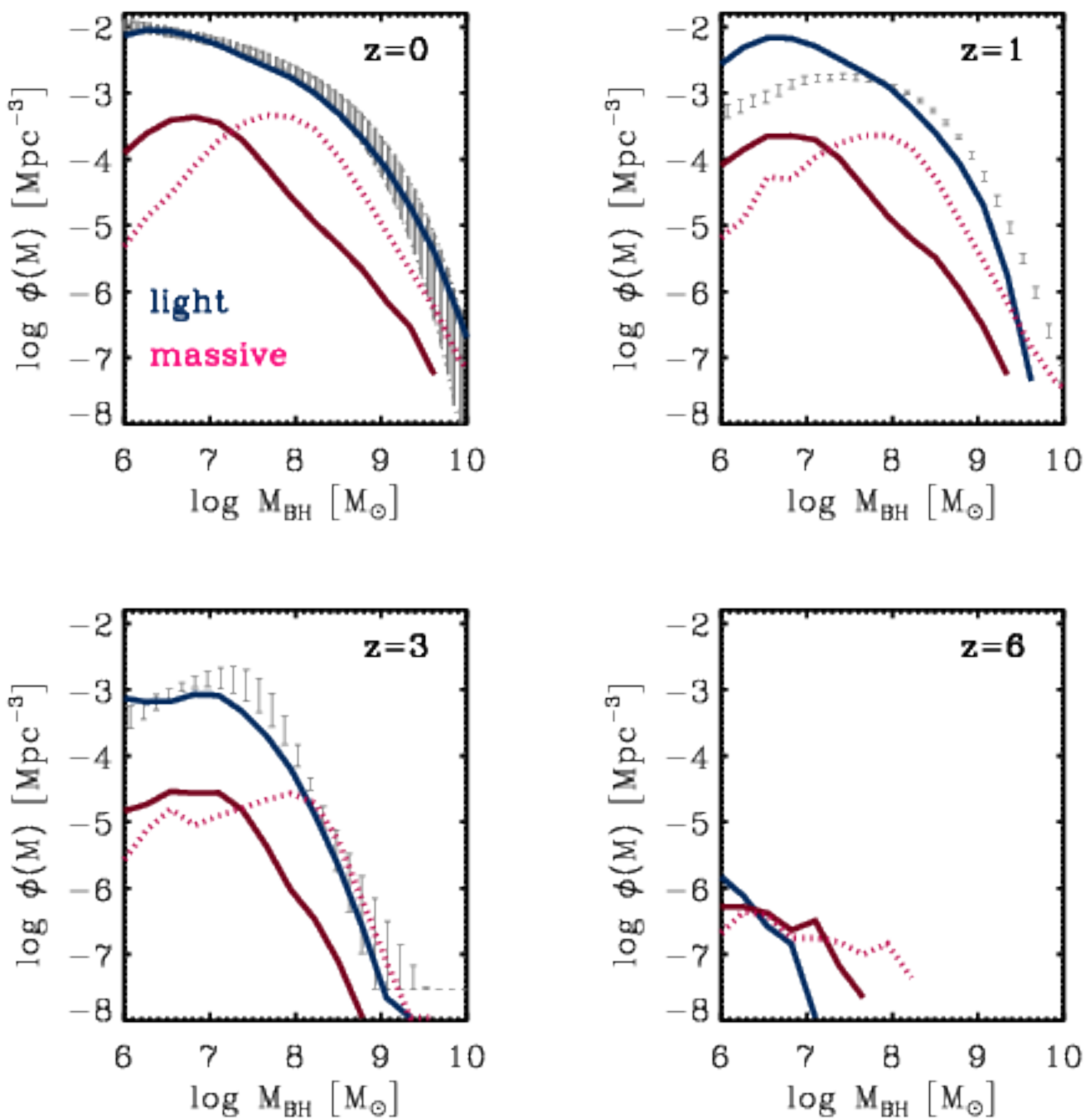
BH mass density





Volonteri & Begelman 2010

BH mass function



@z=0 Shankar et al. 2004

@z>0 Merloni & Heinz 2008

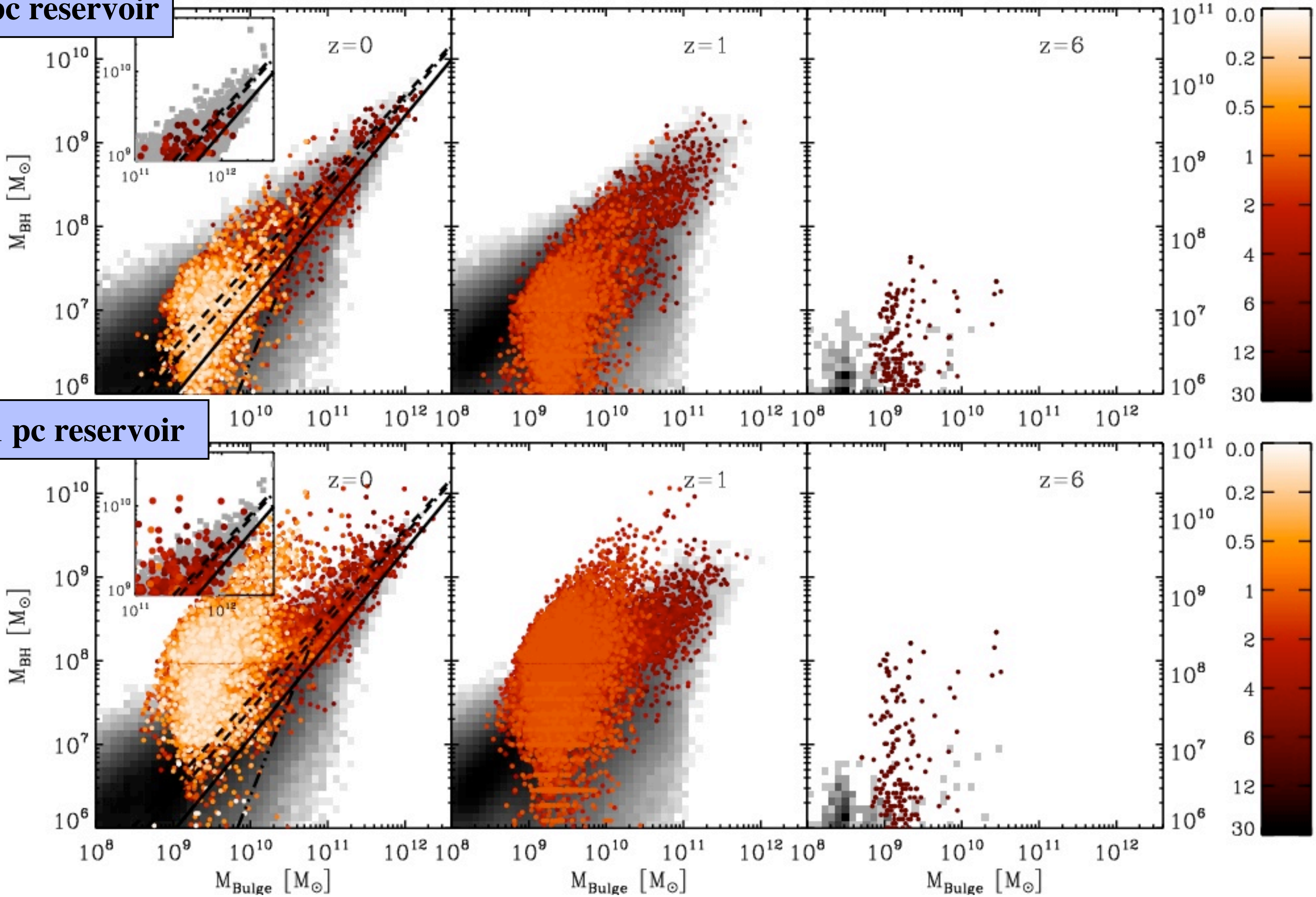
1 pc reservoir

0.1 pc reservoir

MBH-MBulge

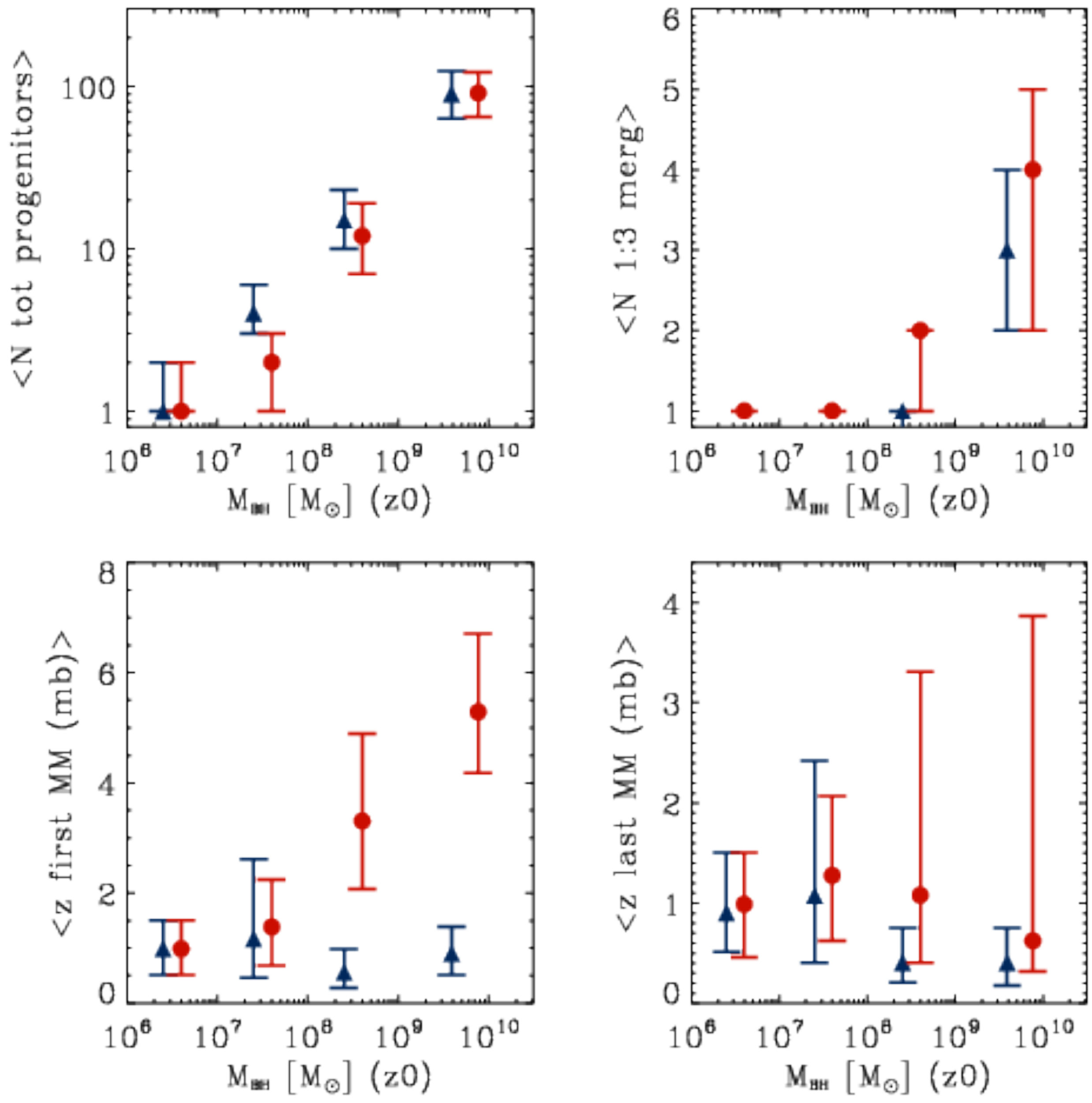
1 pc reservoir

0.1 pc reservoir



Merger history

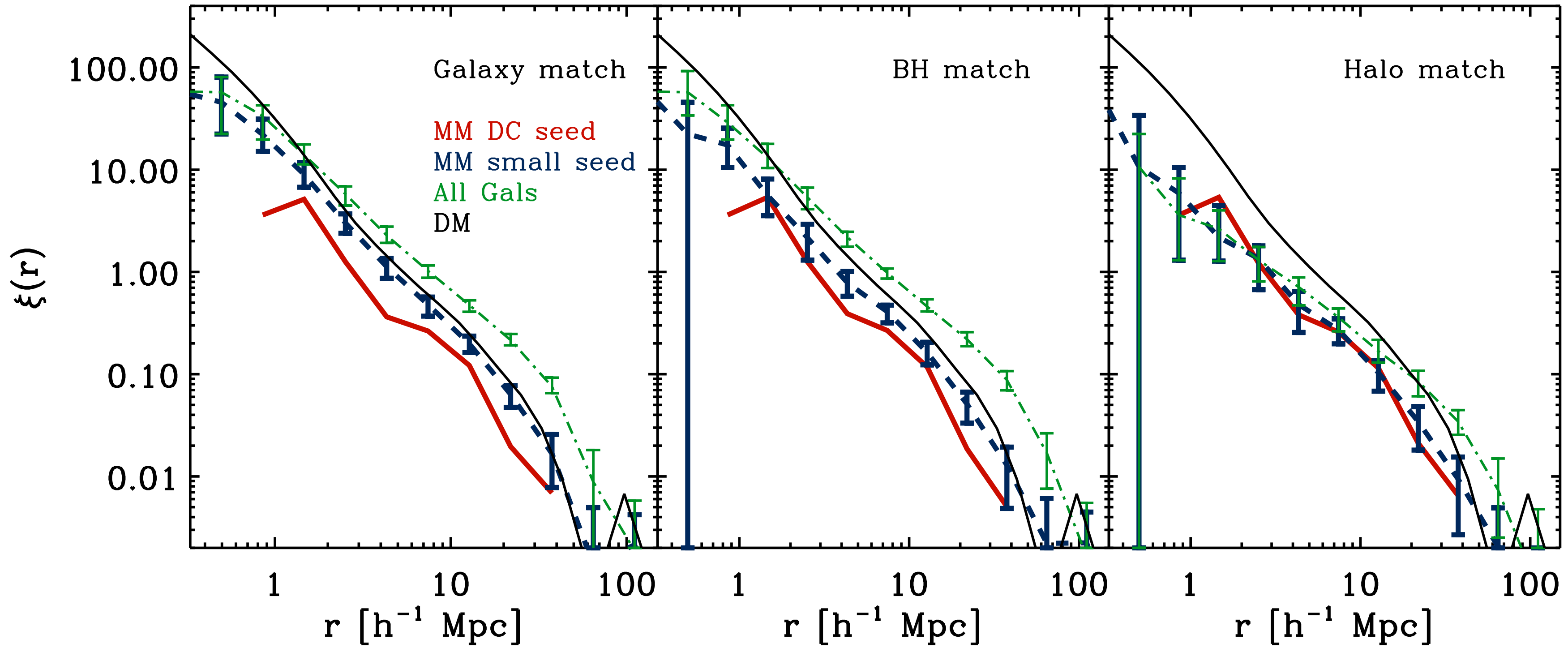
Light seeds
Massive seeds



Clustering

Two-point correlation function: the excess probability (with respect to a random distribution) of finding a pair of objects at a distance r

$$dP = n^2[1+\xi(r)]dV_1 dV_2$$



Summary

- Hydro simulations have shown that **fast and strong inflows of gas are possible in gas-rich major mergers** in massive halos (more realistic simulations are in progress!!)

- **Most major mergers at very high-z** could satisfy the conditions for direct collapse black hole formation and BHs from direct collapse could power the bright quasars above z~2-3

- A **small fraction** of major mergers **in the local universe** could still satisfy the conditions for direct collapse

- **Differences in the large scale environment and scaling relations** might help distinguish the two populations

- Any **direct observation**?!