Black holes in galactic nuclei

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Outline

- SMBHs: census and scaling relations
- Evolution of the SMBH population
  - ➡ accretion & feedback
  - ➡ mergers & galactic centers

SMBHs: census and scaling relations

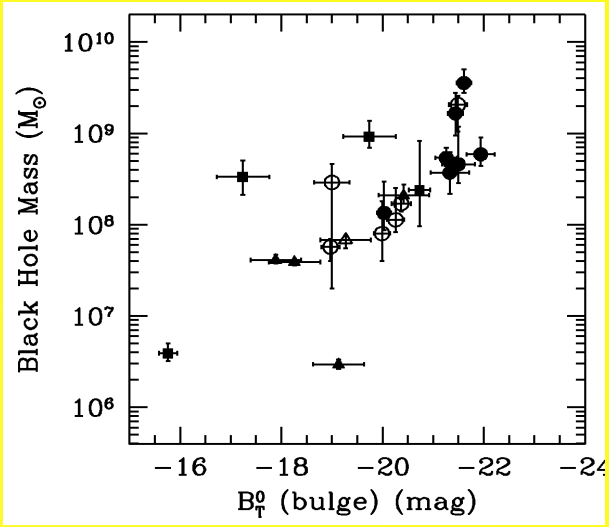
Quiescent SMBHs

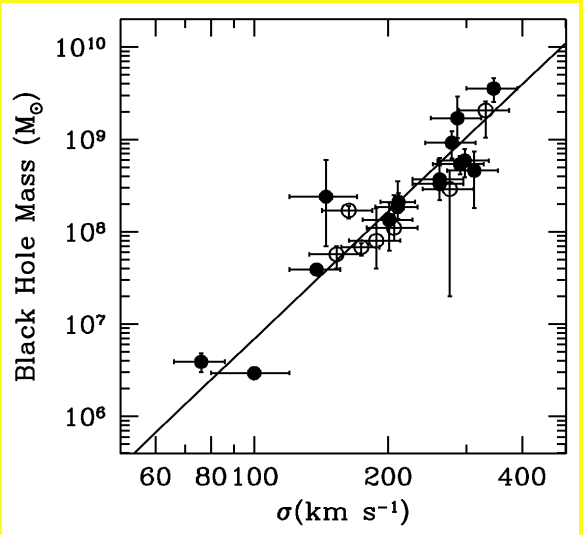
BH mass ➞

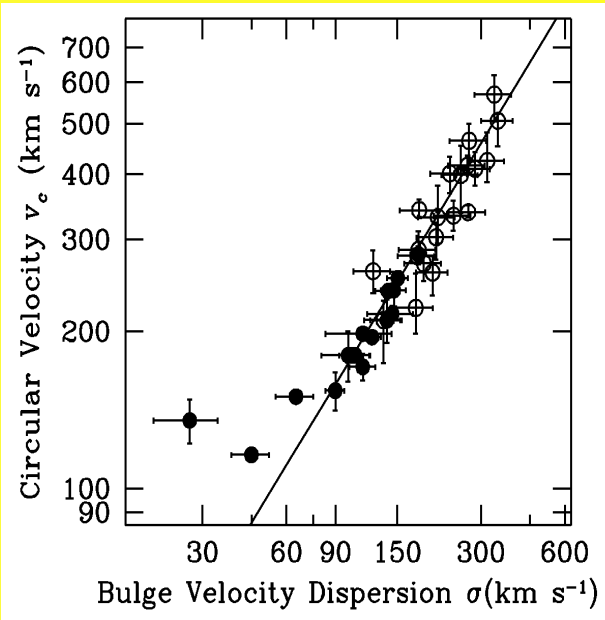
spheroid mass/
velocity dispersion ➞

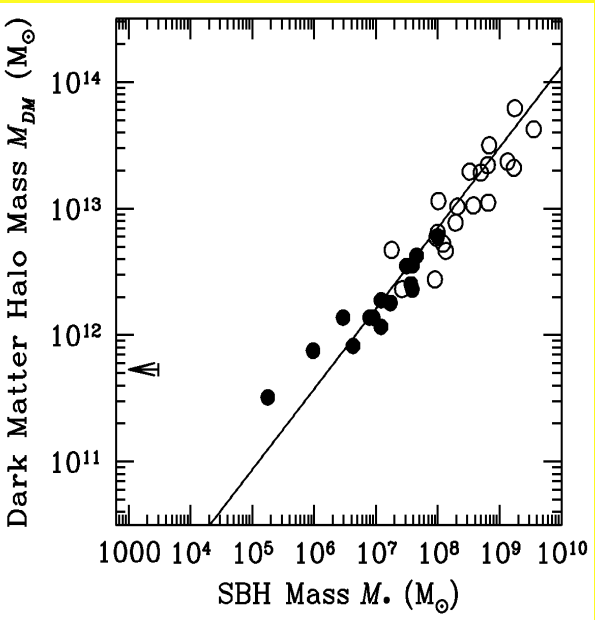
dark matter halo?

Wyithe & Loeb 2005: the tightness of the $M_{bh}-\sigma_{sph}$ relation suggests that the M_{bh}–M_{DM} correlation is incidental to the fundamental relation between the SMBH and its host spheroid.









from Ferrarese 2002

Why M_{bh}–σ_{sph}? ***FEEDBACK!!!***

- energy/momentum driven outflows?
  (e.g. Silk & Rees 1998, Fabian 1999, Murray et al. 2005, Di Matteo et al. 2005, ...)
- self-regulated SF, i.e. stars/BH competition
  (e.g. Burkert & Silk 2001, Haehnelt & Kauffmann 2000, ...)
- DM/stars accretion
  (e.g MacMillan & Henriksen 2002, Miralda-Escudé & Kollmeier 2005, Zhao et al. 2002, ...)

...Too many solutions?

Simulations...

- cosmological simulations: the global framework. Resolve galaxy size systems
- galactic mergers simulation. Gas/stellar average evolution. Resolve ~100 pc size
- sph simulations of accretion discs. From <20-50 $R_{sch,}$ ~pc scale down
- N-body simulations of star clusters around BHs, resolve individual stars, now?

...Can we link the large scale to the small scale simulations?

Accretion history of the SMBH population

$\rho^{B}_{qso(0)}=2\ x10^{5}[0.1(1-\varepsilon)/\varepsilon]M_{\odot}\ Mpc^{-3}$ OPTICAL

$\rho^{X}_{qso(0)}=2\div4\ x10^{5}[0.1(1-\varepsilon)/\varepsilon]M_{\odot}\ Mpc^{-3}$ X-RAY

$\rho_{SMBH}=2.5\div4.5\ x10^{5}M_{\odot}\ Mpc^{-3}$

Yu & Tremaine 2002, Elvis et al 2002, Merloni et al 2004, Barger et al 2005

- The final mass of the SMBHs is dominated by accretion, with mergers playing a secondary role
- Mergers can be important possibly at z>5 - the Soltan argument does not apply where the LF is not constrained!

MBH mergers and their consequences

The evolution of a SMBH binary roughly follows the following steps:

1. **dynamical friction** (Lacey & Cole 1993, Colpi et al. 2000)

- BHs approach each other, losing angular momentum by dynamical friction, acting on the BHs envelopes

- efficient only for major mergers against mass stripping

minor mergers: mass stripping lengthen the orbital decay

If only galactic major mergers are efficient in forming close MBHB, we might expect the mass ratio of MBHBs to peak ~0.1

... BHs become bound

2. **hardening of the binary** (Quinlan 1996, Merritt 1999, Miloslavljevic & Merritt 2001)

$$a < \frac{GM_2}{4\sigma^2} = 1\mathrm{pc}\left(\frac{M_2}{10^7 M_\odot}\right)\left(\frac{\sigma}{150\mathrm{km\,s^{-1}}}\right)^{-2}$$

the binding energy of the BHs is larger than the thermal energy of the stars

- 3 bodies scattering between the binary and the surrounding stars: the SMBHs create a stellar density core ejecting the background stars (Miloslavljevic & Merritt 2001) ➞ low-z / gas poor galaxies

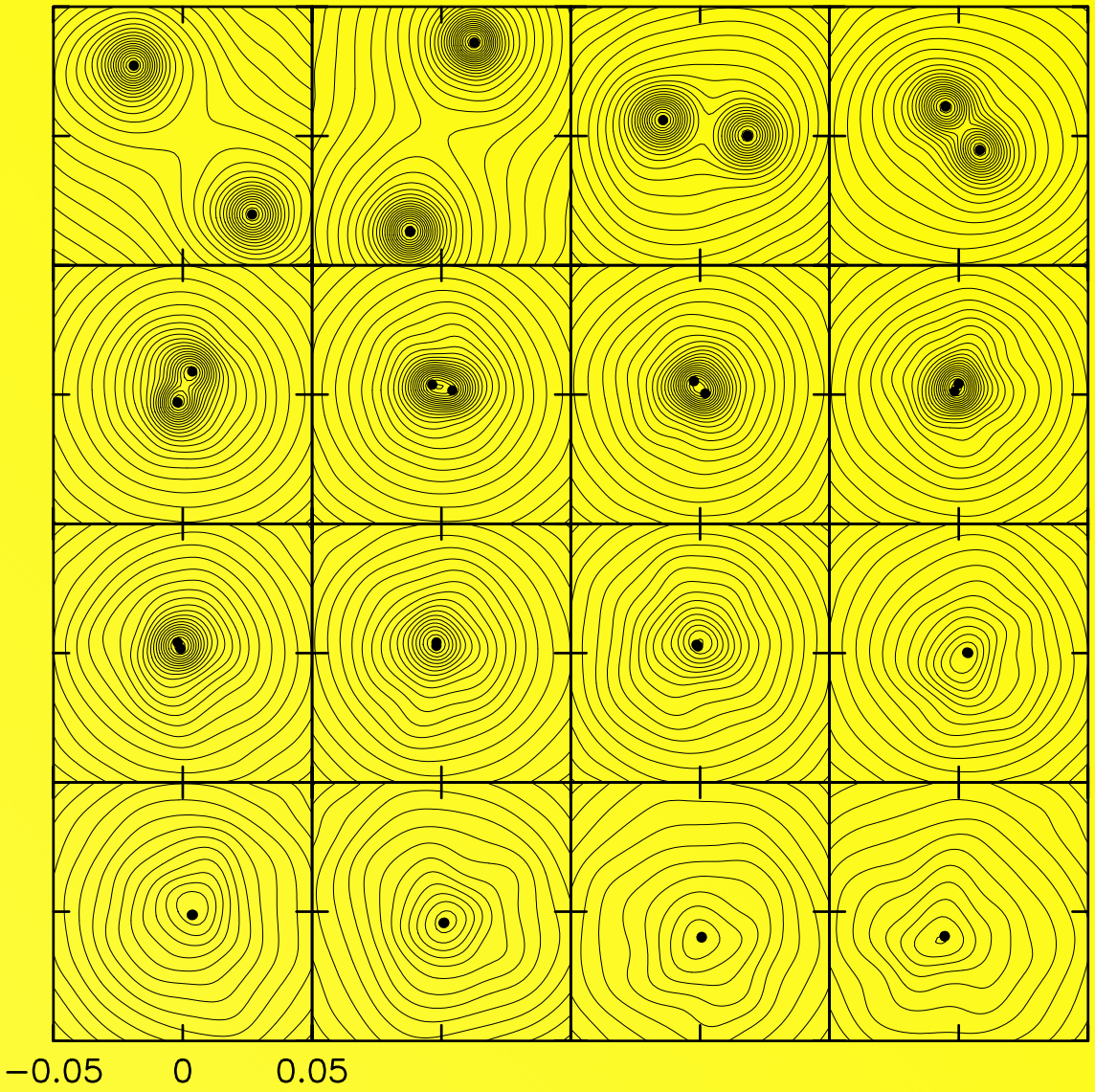
- interaction with gas/accretion disc: much more efficient than stellar scatterings (Armitage & Natarayan, Escala et al) ➞ high-z / gas rich galaxies

3. **emission of gravitational waves** (Peters 1964)
Takes over at (very) subparsec scales...

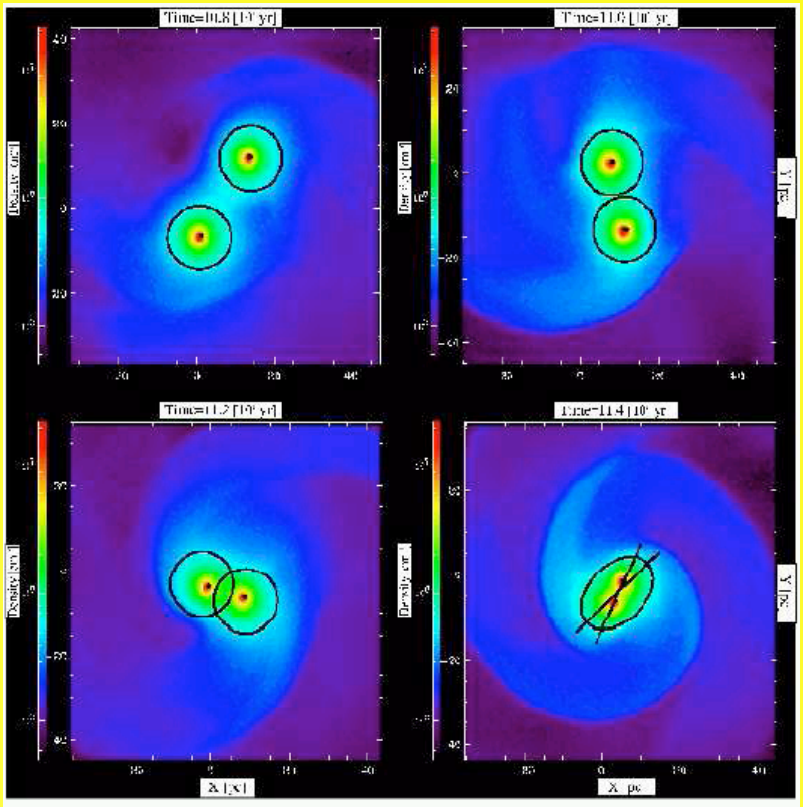
As the binary shrinks ejecting stars the central density drops.

Luminous elliptical galaxies show shallow density cores.
BH binaries to shape them?

Numerical simulations do not have the required resolution (relaxation, wandering...) yet?

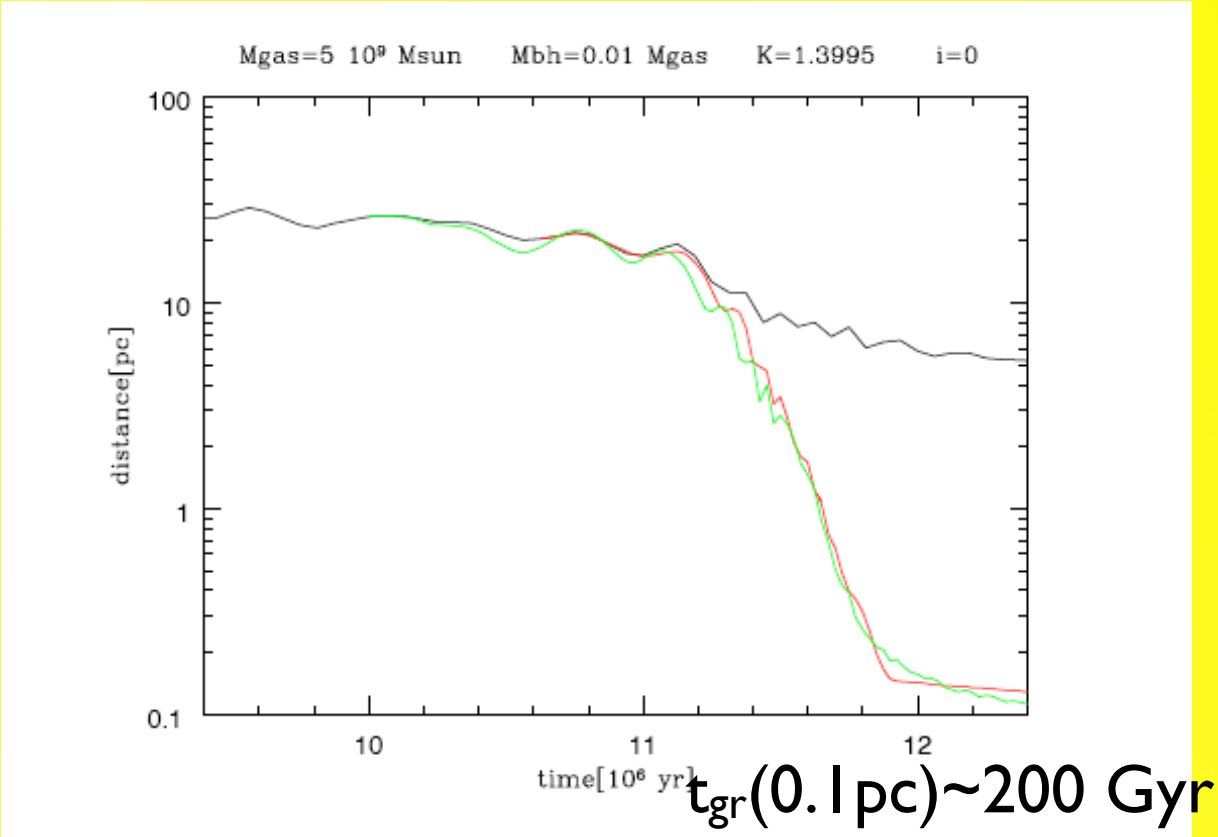


The BH sphere of influence is typically smaller than the core radii: additional processes to enlarge the core (e.g. hierarchical evolution, heating by reprocessed BHs orbital decay)



Gas is much more efficient than stellar scattering (Escala et al. 2004)

High-z galaxies: plenty of gas, few stars



Also, if an accretion disc is present, the satellite BH is dragged in by viscosity on short-ish timescales
(e.g. Armitage & Narayan, Ivanov et al.)

$t_{gr}(0.1\,pc) \sim 200$ Gyr

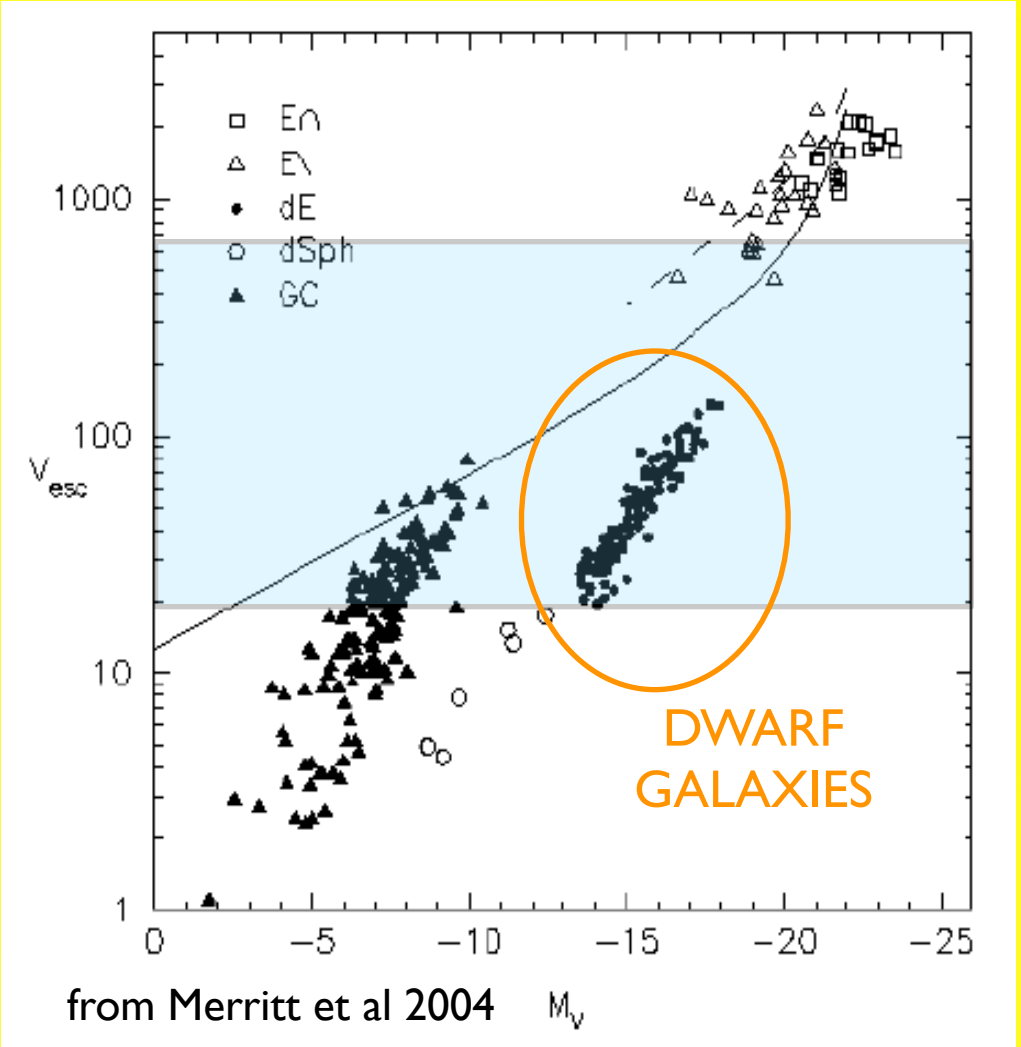
Gravitational rocket

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)

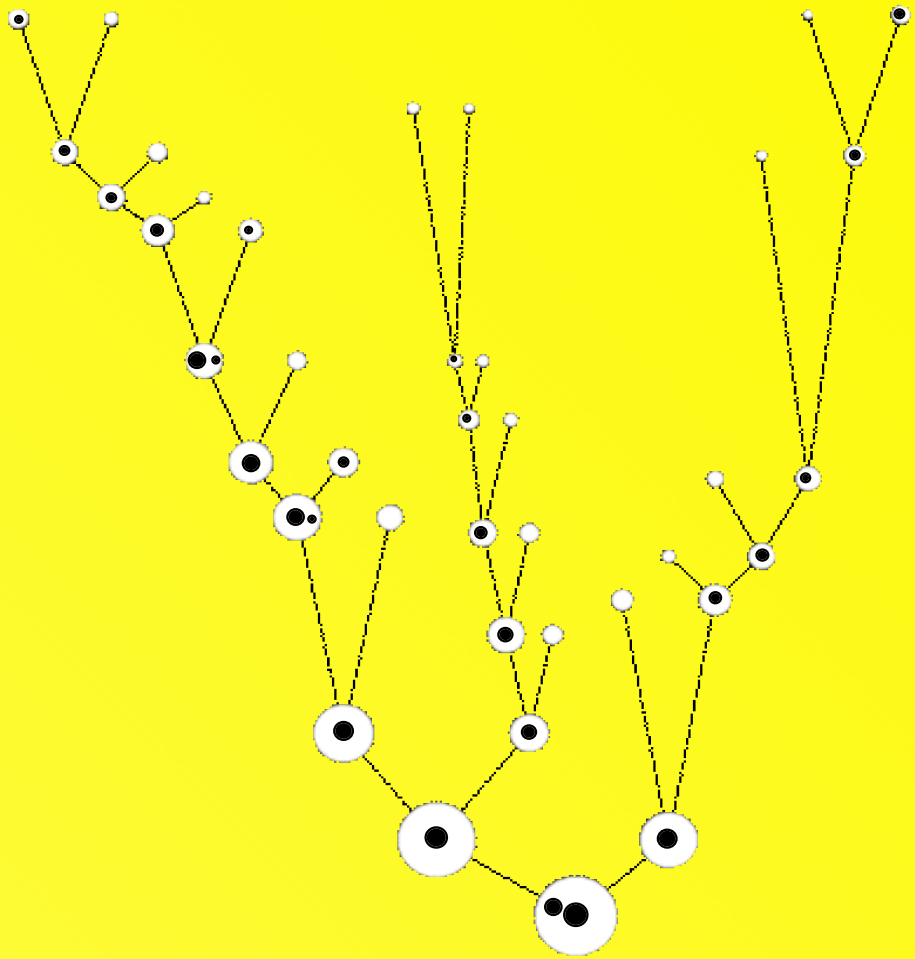
Are merging BHs ejected from galaxies?

Can SMBHs be formed from mergers of small BHs?



from Merritt et al 2004

Hierarchical evolution of massive black holes

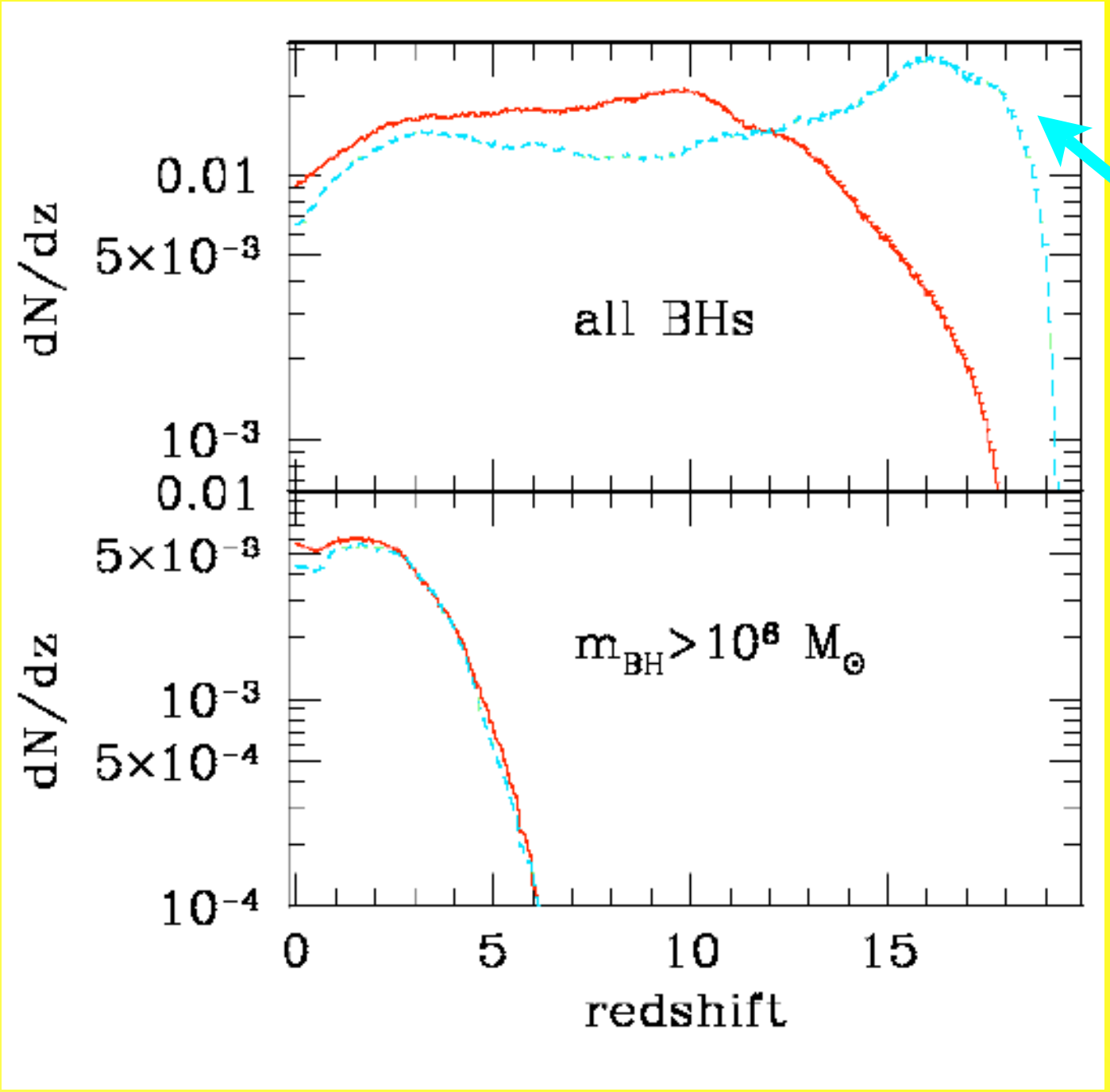


The seeds of SMBHs appear at very high redshift and follow the hierarchical evolution of their host halos.

These seeds are incorporated in larger and larger halos, accreting gas and dynamically interacting after mergers.

Volonteri, Haardt & Madau 2003

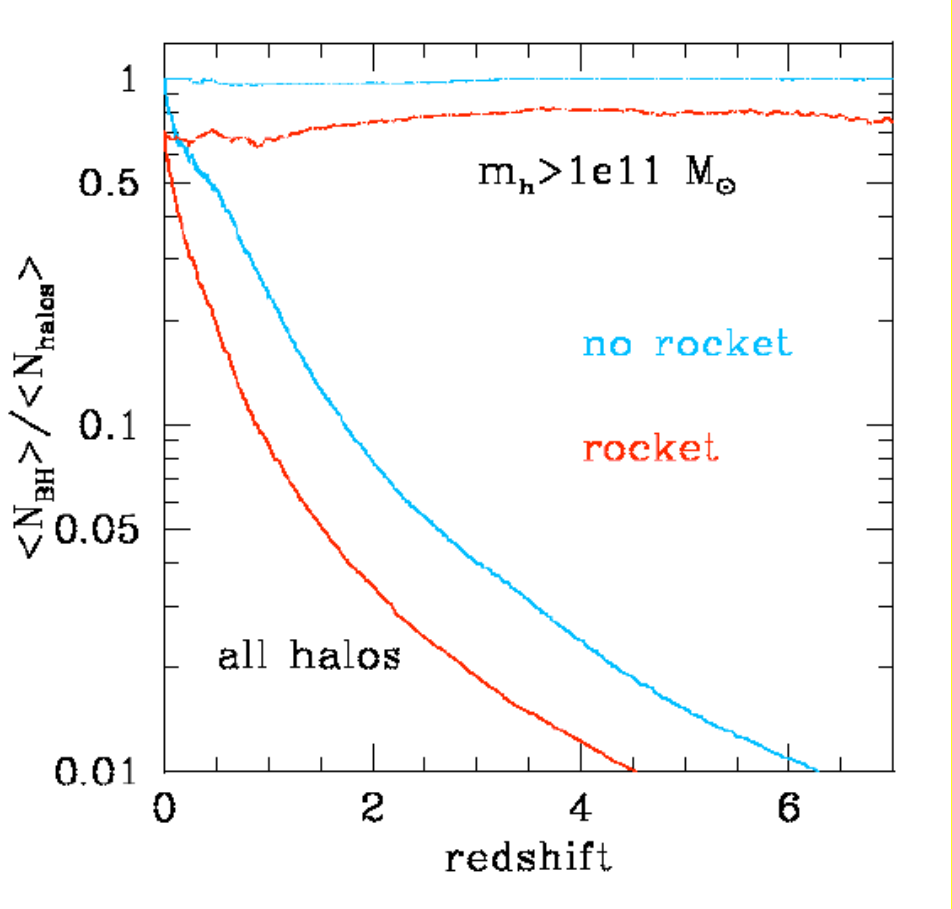
Binary BHs Merger Rate



$t_{merger}=t_{df}$

MBH occupation fraction

- for halos with mass larger than 3e12 $M_\odot$, the occupation fraction is unity, though
- Blanchet et al. 2005 suggest recoil velocities ~1/2 of those considered here
- not ALL BHs experience a merger in their lifetime, only ~40-50%, about 50% are then ejected
- SMBHs gain their mass primarily by accretion at "low-ish" redshift (z<5)



Summary

- BHs inhabit the centers of most massive (and less massive) galaxies today
- BH feedback as a panacea to solve galaxy formation puzzles: red galaxies, LF, cooling flows...
- The observable population of SMBHs grows by accretion of gas mainly @ z<5
- MBH mergers important at high-z? Caveat: gravitational rocket
- MBHs can shape their environment, either by dynamical interactions or radiative/thermal feedback