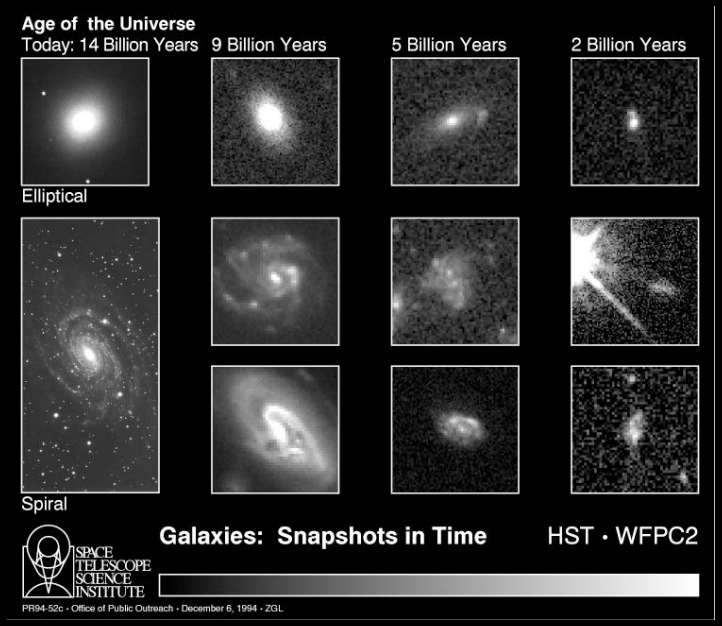
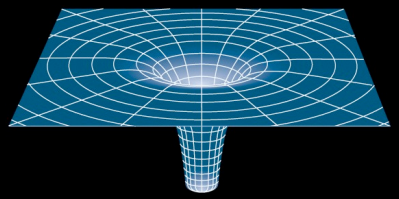
Supermassive black holes and their hosts

Marta Volonteri

University of Michigan





- SMBHs: census and scaling relations
- Evolution of the SMBH population*
  - ➡ MBH formation
  - ➡ accretion & feedback

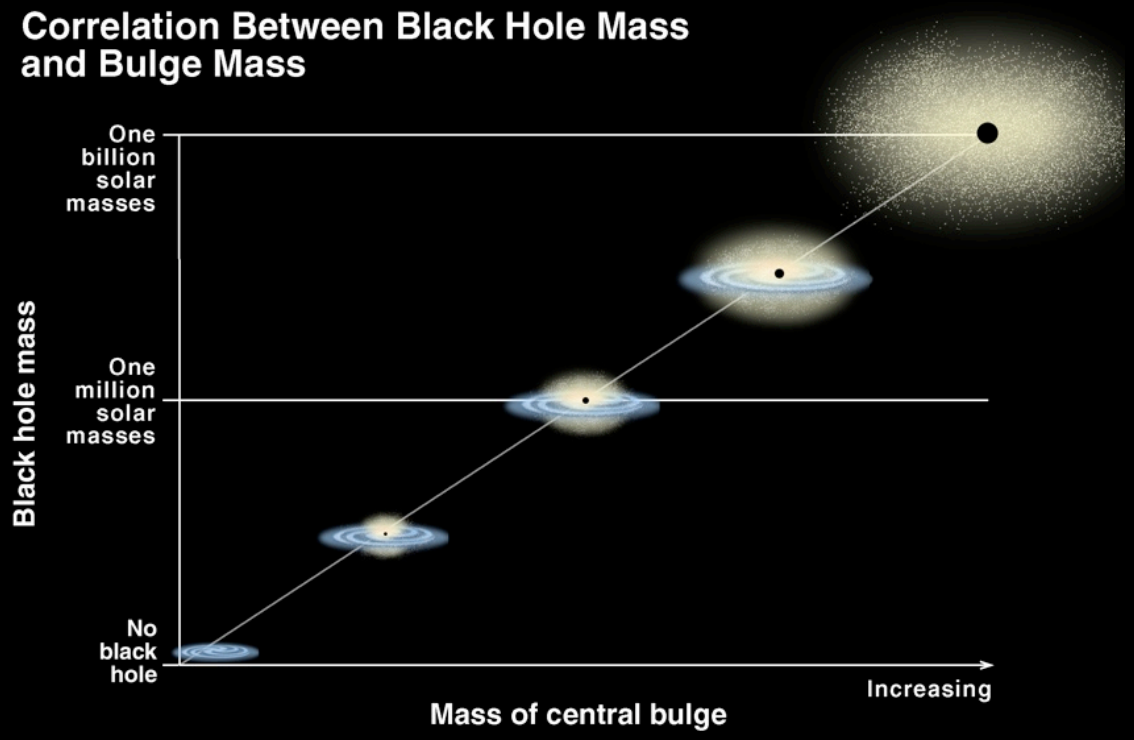
* with ≪ 20 free parameters!

M_{BH}- host relationships : co- evolution of SMBHs and galaxies

SMBHs

stellar bulges host

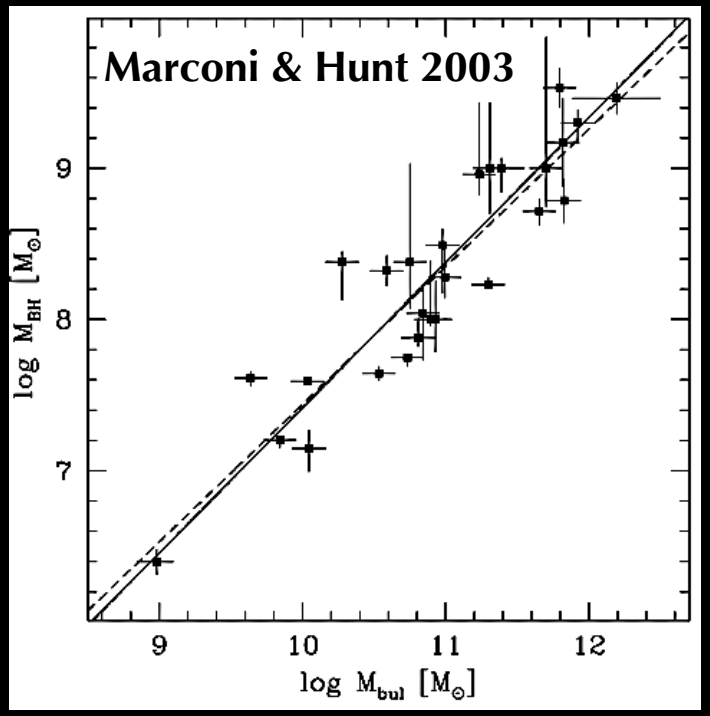
DM halos (???)



SMBHs: census and scaling relations

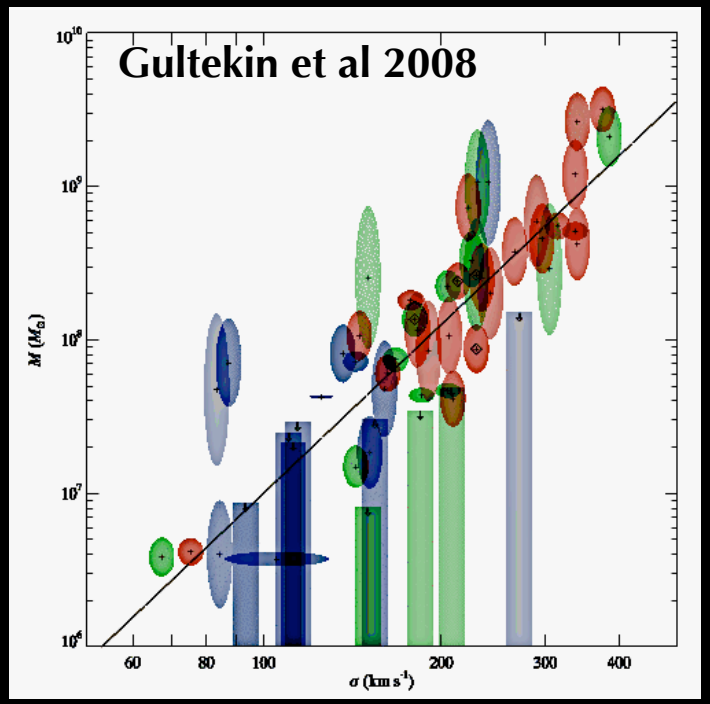
Quiescent SMBHs

BH mass → spheroid mass/
velocity dispersion



spheroid mass

BH mass



velocity dispersion

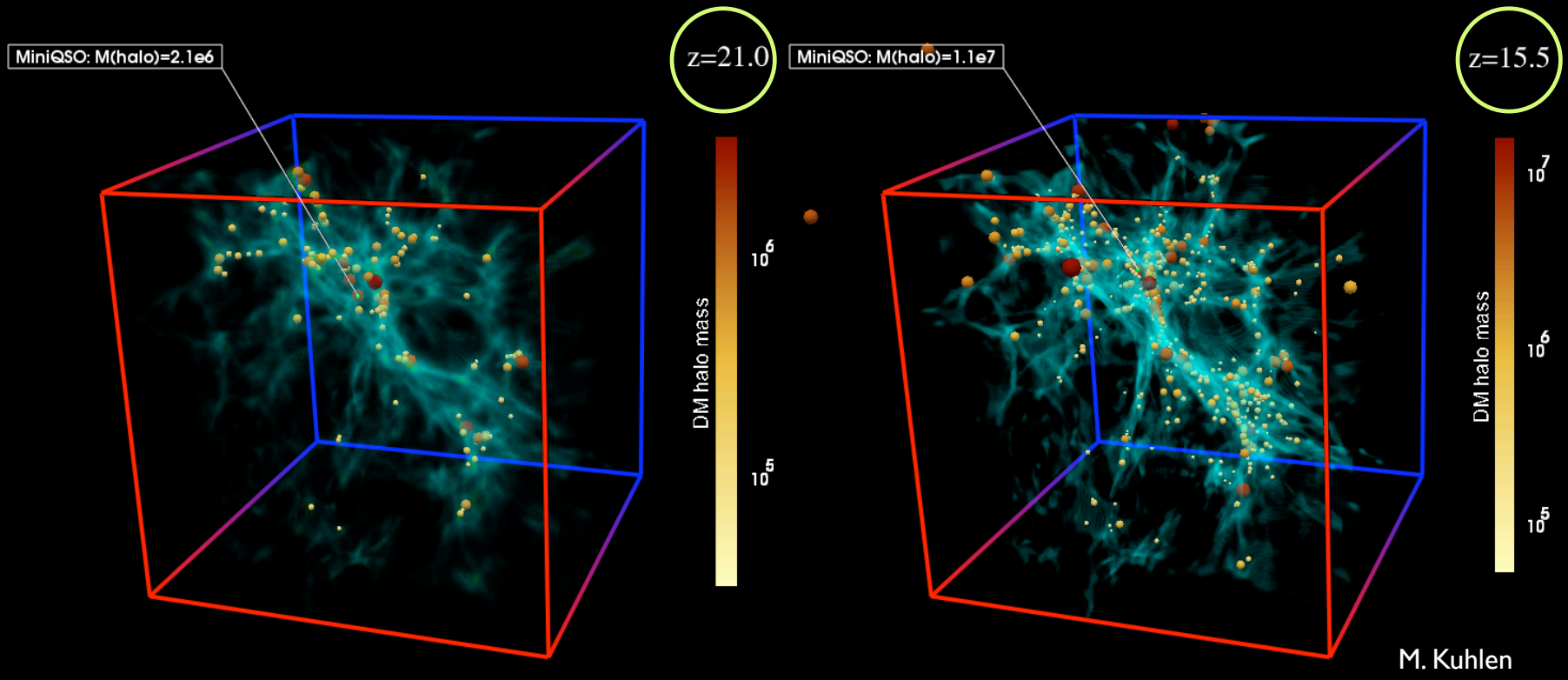
- SMBHs: census and scaling relations
- Evolution of the SMBH population
  - ➡ MBH formation
  - ➡ accretion & feedback

WHEN
do you make a (super)massive black hole?

The highest redshift quasar currently known
SDSS 1148+3251 at z=6.4
has estimates of the SMBH mass M_{BH}=2-6 x10^9 M_{sun}
(Willott et al 2003, Barth et al 2003)

AS LARGE AS THE LARGEST SMBHs SEEN TODAY, BUT WHEN THE UNIVERSE WAS 1 Gyr OLD

Stepping back in time: when did the MBH evolution start?



Hierarchical Galaxy Formation:
biased MBH formation

HOW can you make a massive black hole seed?

M_{BH}~100-600 M_{sun}

PopIII stars remnants

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

✓ Simulations suggest that the first stars are massive M~100-600 M_{sun}

(Abel et al., Bromm et al.)

✓ Metal free dying stars with $M>260M_{sun}$ leave remnant BHs with $M_{seed} \geq 100M_{sun}$

(Fryer, Woosley & Heger)

M_{BH}~10^3-10^6 M_{sun}

Viscous transport

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

✓ Efficient viscous angular momentum transport + efficient gas confinement

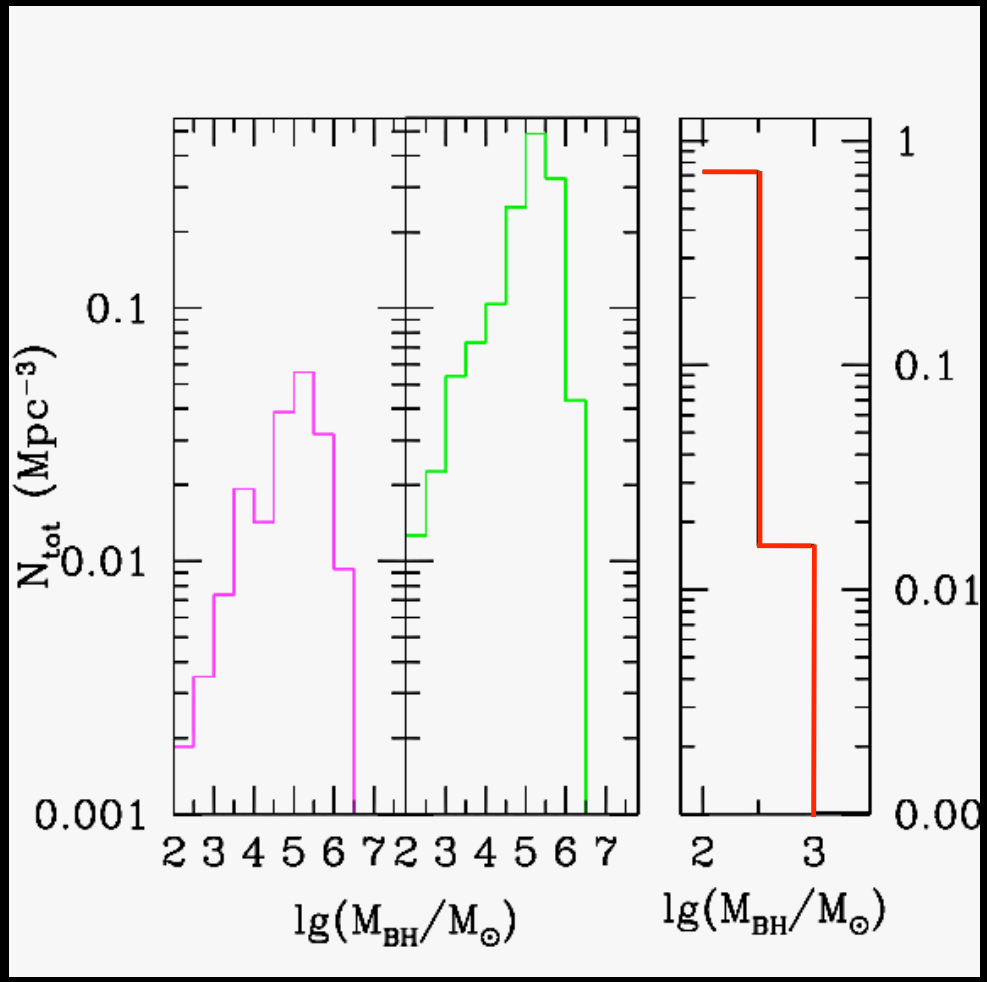
Bar-unstable self-gravitating gas

(Begelman, Volonteri & Rees 2006)

✓ Transport angular momentum on the dynamical timescale, process cascades

Mass function of seed MBHs

(Volonteri, Lodato & Natarajan 2007)

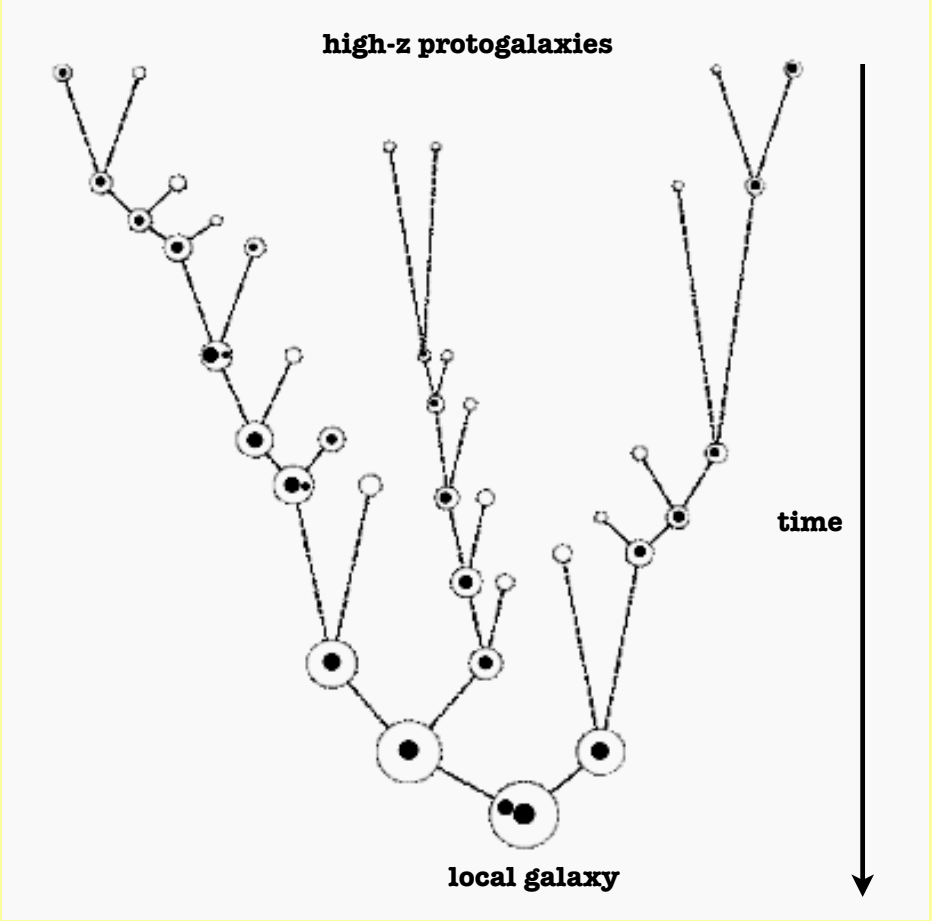


Direct collapse-low efficiency

Direct collapse-high efficiency

PopIII remnants

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

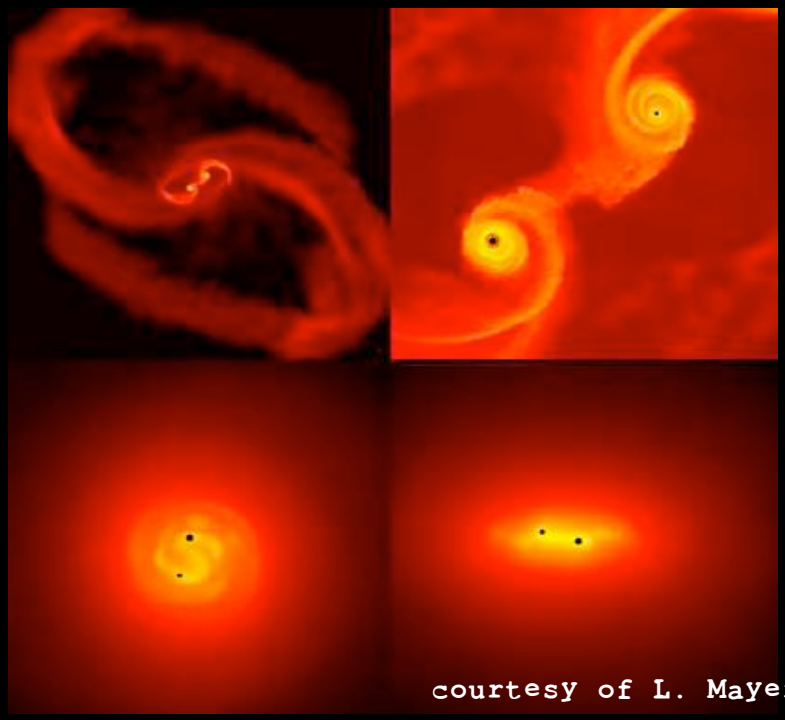


Volonteri, Haardt & Madau 2003

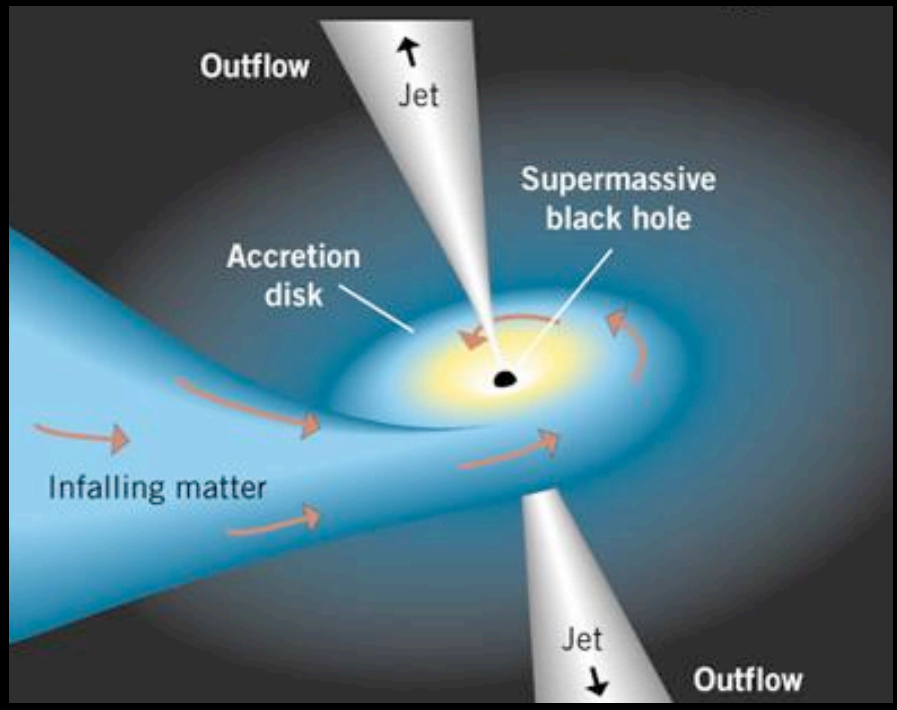
The seeds at z>20 are small, ~100-10^4 M_{sun}

How do MBH seeds grow to become supermassive?

BH-BH mergers vs gas accretion



Total mass density in MBHs is almost constant in time: just reshuffle the mass function



Total mass density in MBHs grows with time

Evolution of MBHs

Mass evolution:

- @ z<3-5 Soltan's argument ➔ accretion leads

$$\rho_{qso(0)} = 2 \div 4 \times 10^5 [0.1(1-\epsilon)/\epsilon] M_{sun}\ Mpc^{-3}$$

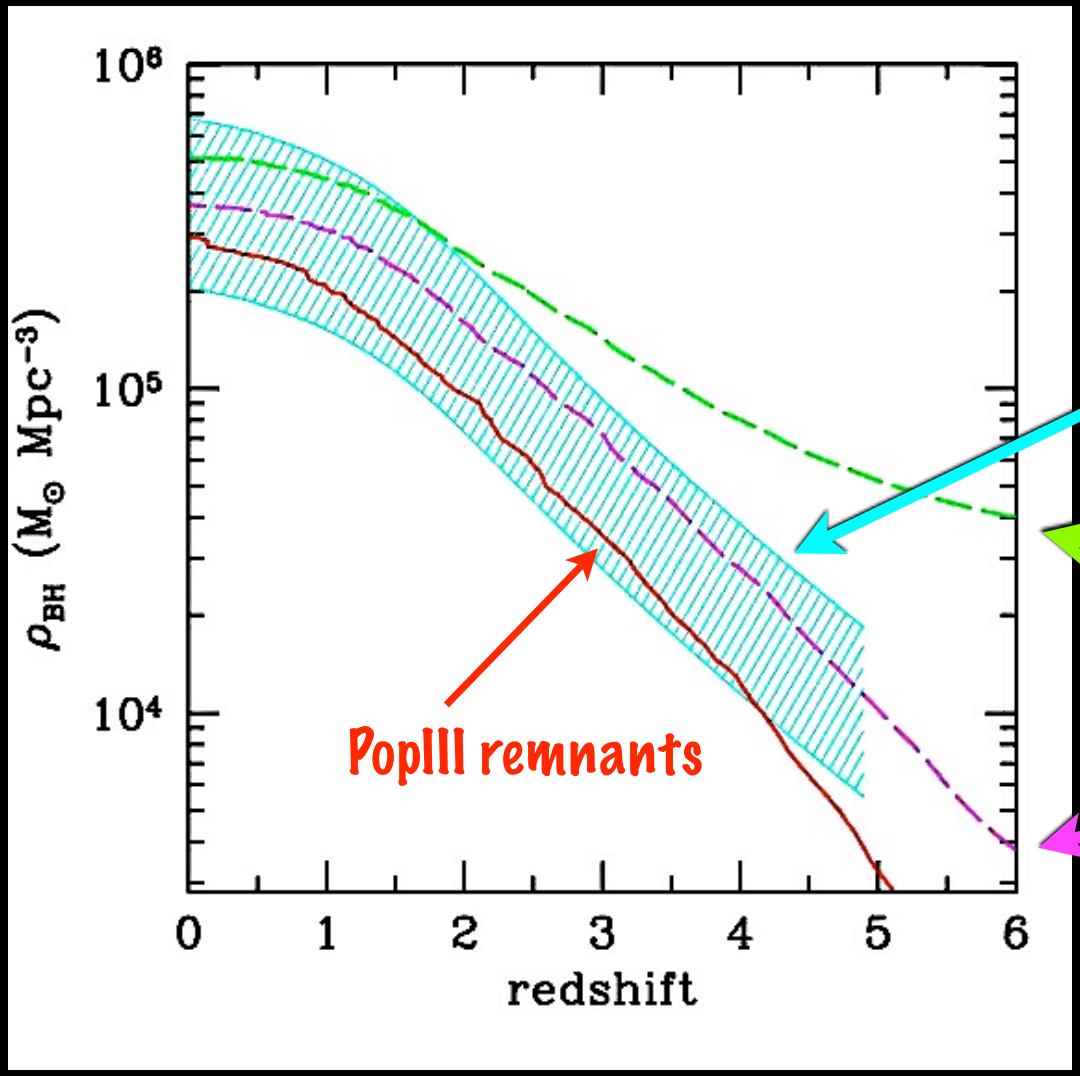
$$\rho_{SMBH} = 2.5 \div 4.5 \times 10^5 M_{sun}\ Mpc^{-3}$$

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

- no clues at higher z

Evolution of MBHs*

(Volonteri, Lodato & Natarajan 2007)



Soltan's argument
LF from Ueda et al 2004

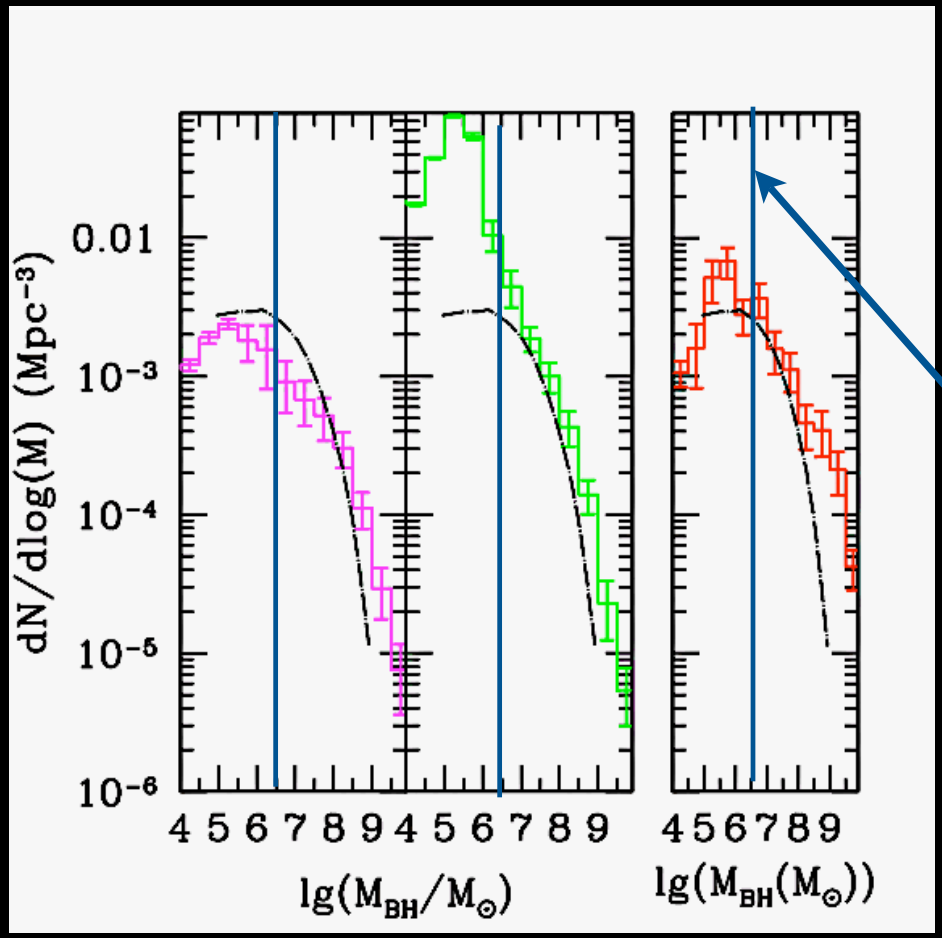
Direct collapse-
high efficiency

Direct collapse-
low efficiency

*** with 5 free parameters**

Mass function of MBHs @ z=0

(Volonteri, Lodato & Natarajan 2007)



Observations (Greene & Ho 2007)

Note: the INACTIVE BHs mass function is an extrapolation at $M<3\times10^6\ M_{sun}$

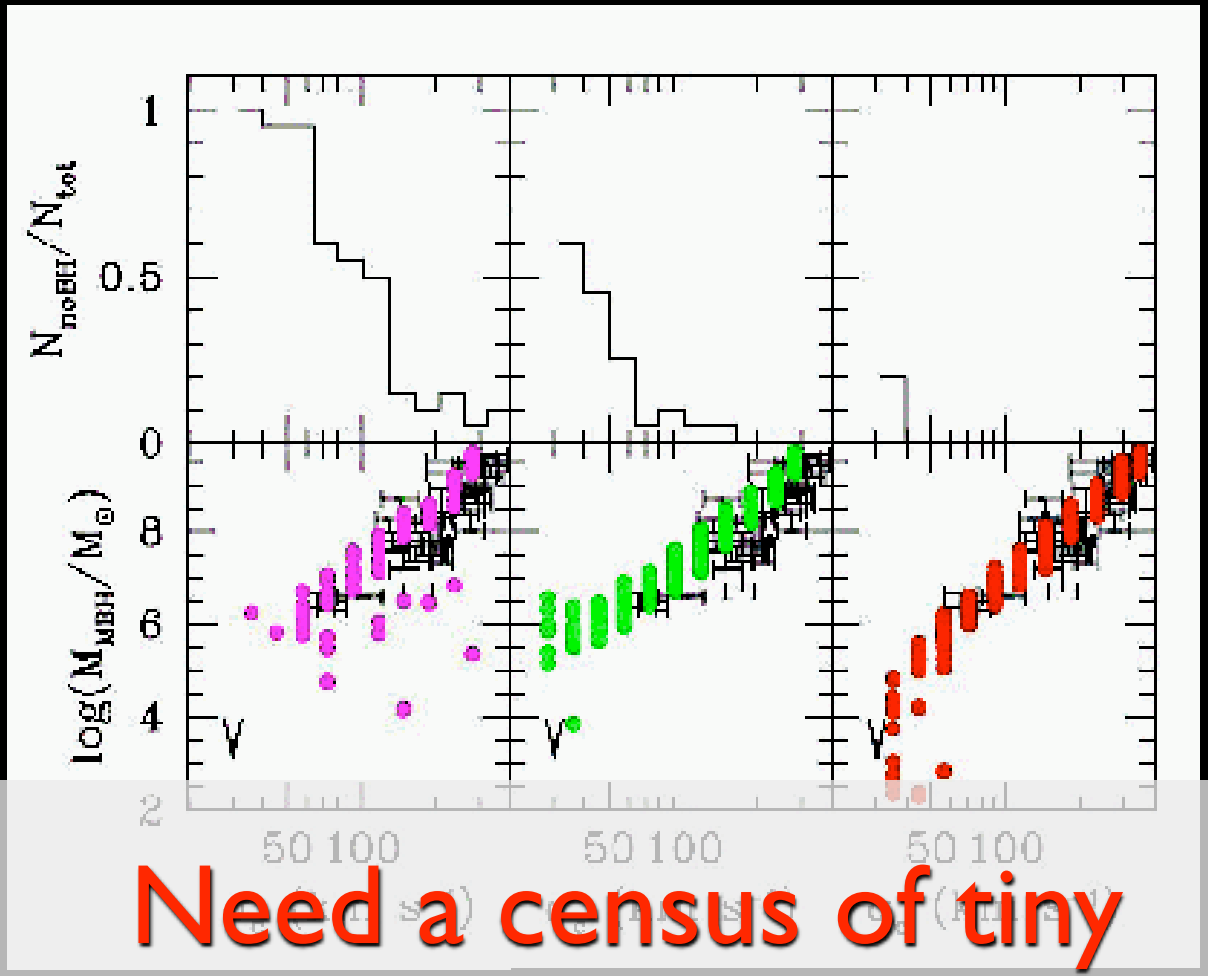
Direct collapse- low efficiency

Direct collapse- high efficiency

PopIII remnants

Occupation fraction and M_{BH}-σ @ z=0

(Volonteri, Lodato & Natarajan 2007)



Need a census of tiny black holes!!!

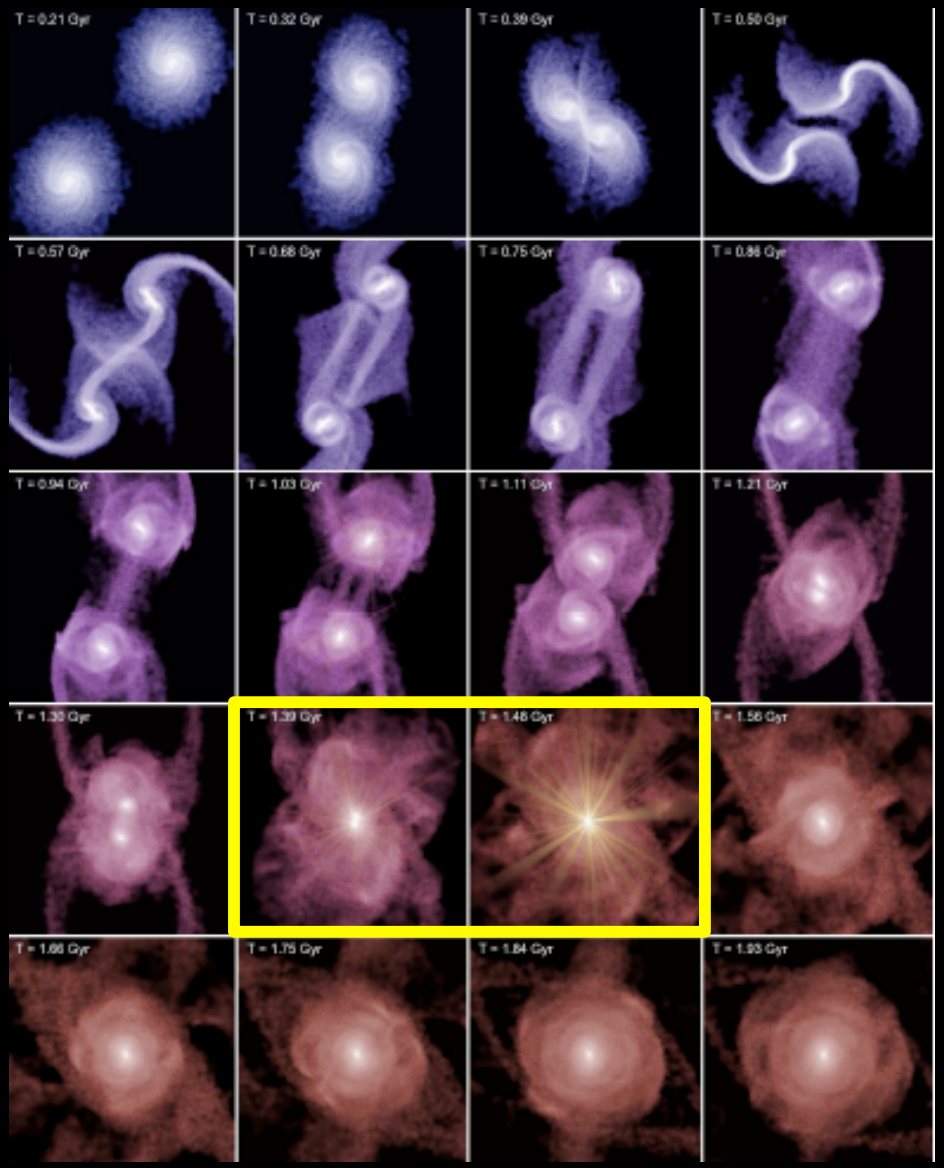
Direct collapse
low efficiency

Direct collapse
high efficiency

PopIII remnants

- SMBHs: census and scaling relations
- Evolution of the SMBH population
  - ➡ MBH formation
  - ➡ accretion & feedback

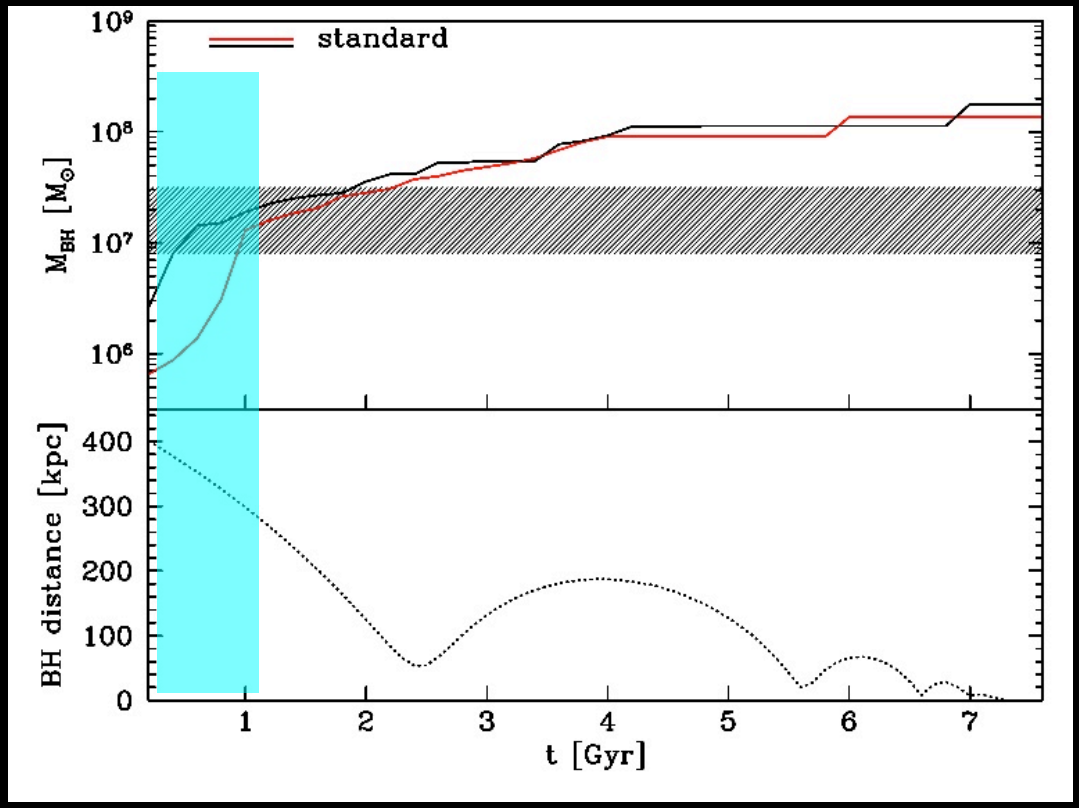
Merger driven accretion



di Matteo, Hopkins

Merger driven accretion

courtesy of
S. Callegari

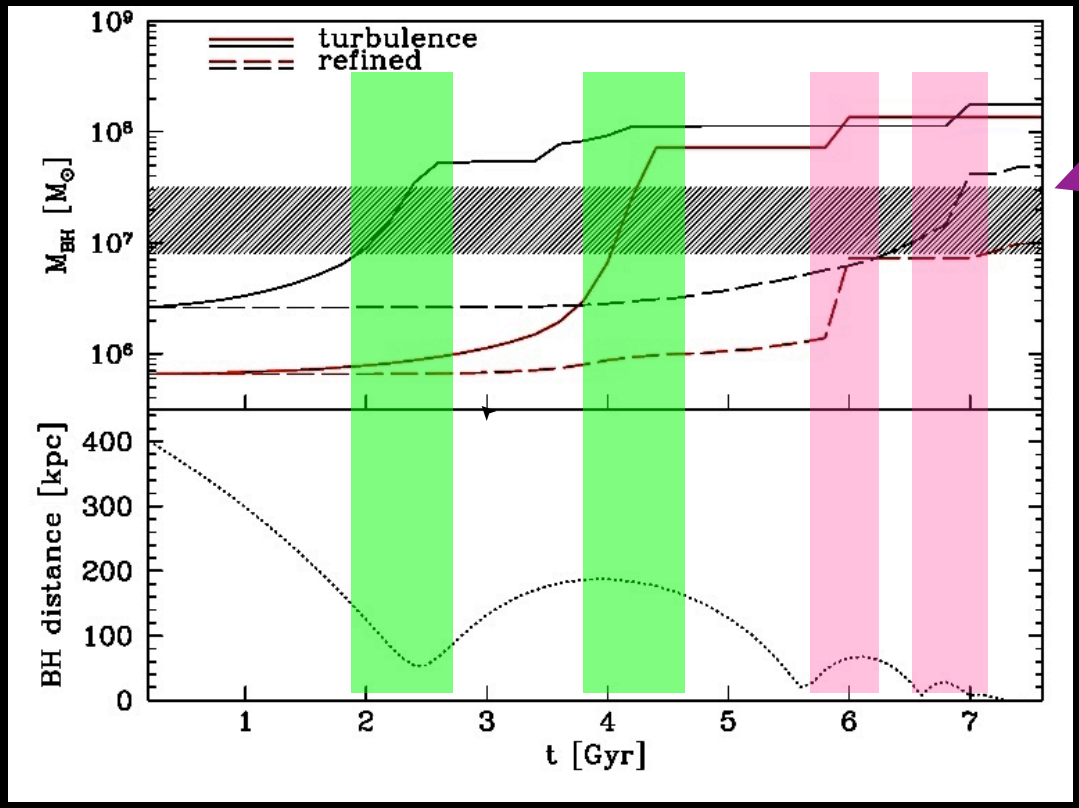


-"Standard" numerical Bondi-Hoyle accretion

-No feedback

Merger driven accretion

courtesy of
S. Callegari



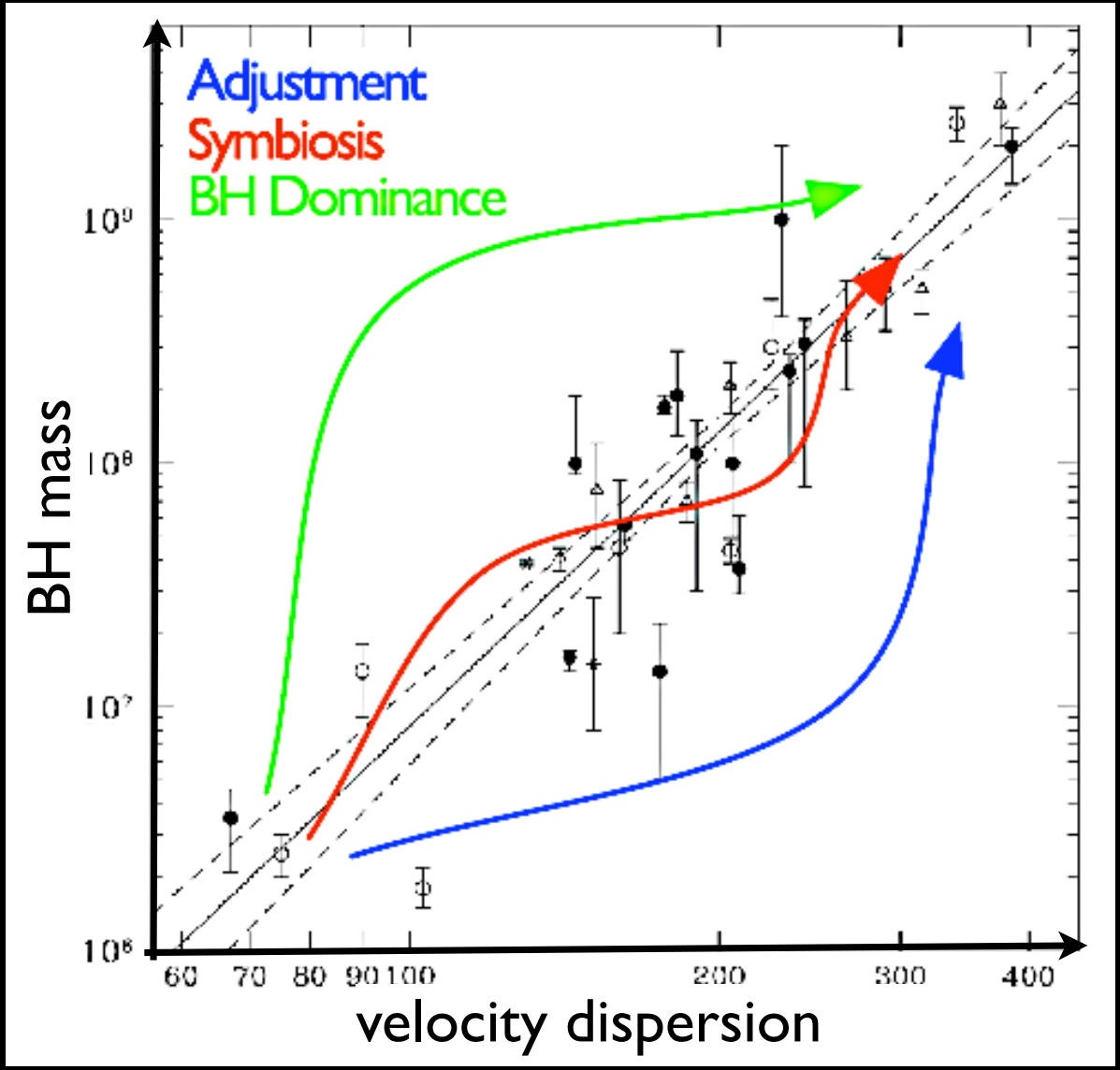
High resolution simulations: M-σ without feedback

- **turbulent motions**

- **extrapolation from the refined simulation**

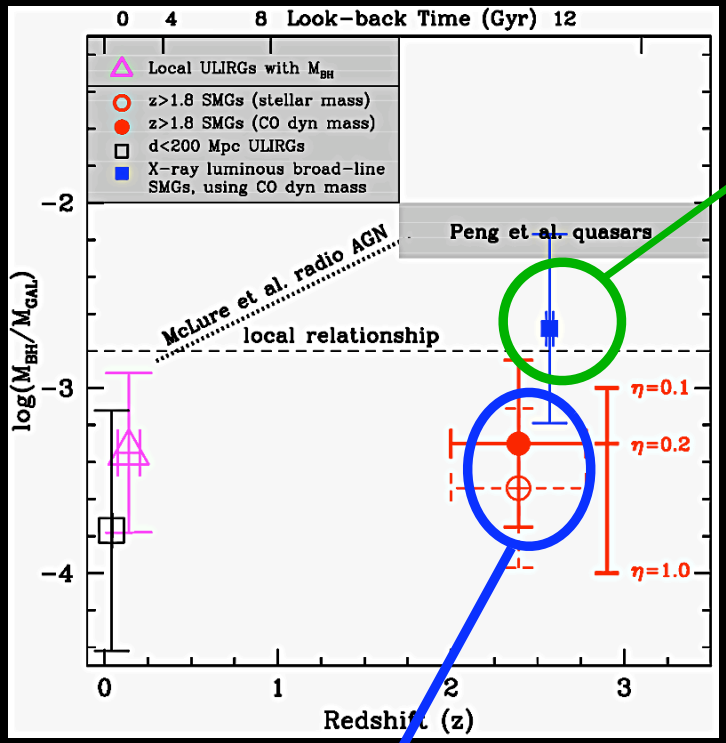
→ M. Dotti's talk

Merger driven accretion



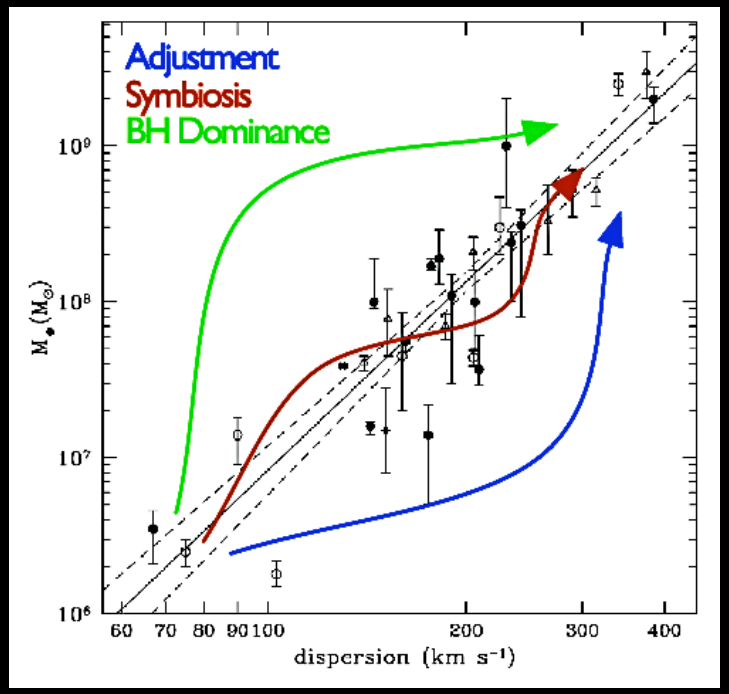
Colpi et al. 2007

M_{BH}- hosts at high-z



QSOs: galaxy growth lags the MBH growth: dominance

SCUBA galaxies: MBH growth lags the stellar growth: adjustment



Alexander et al.2007

- MBH formation: determines ***where*** MBHs are now

- accretion & feedback: determine ***how*** *big* MBHs are now

- scaling relations: help to ***disentangle*** the effects of accretion vs feedback vs galaxy growth