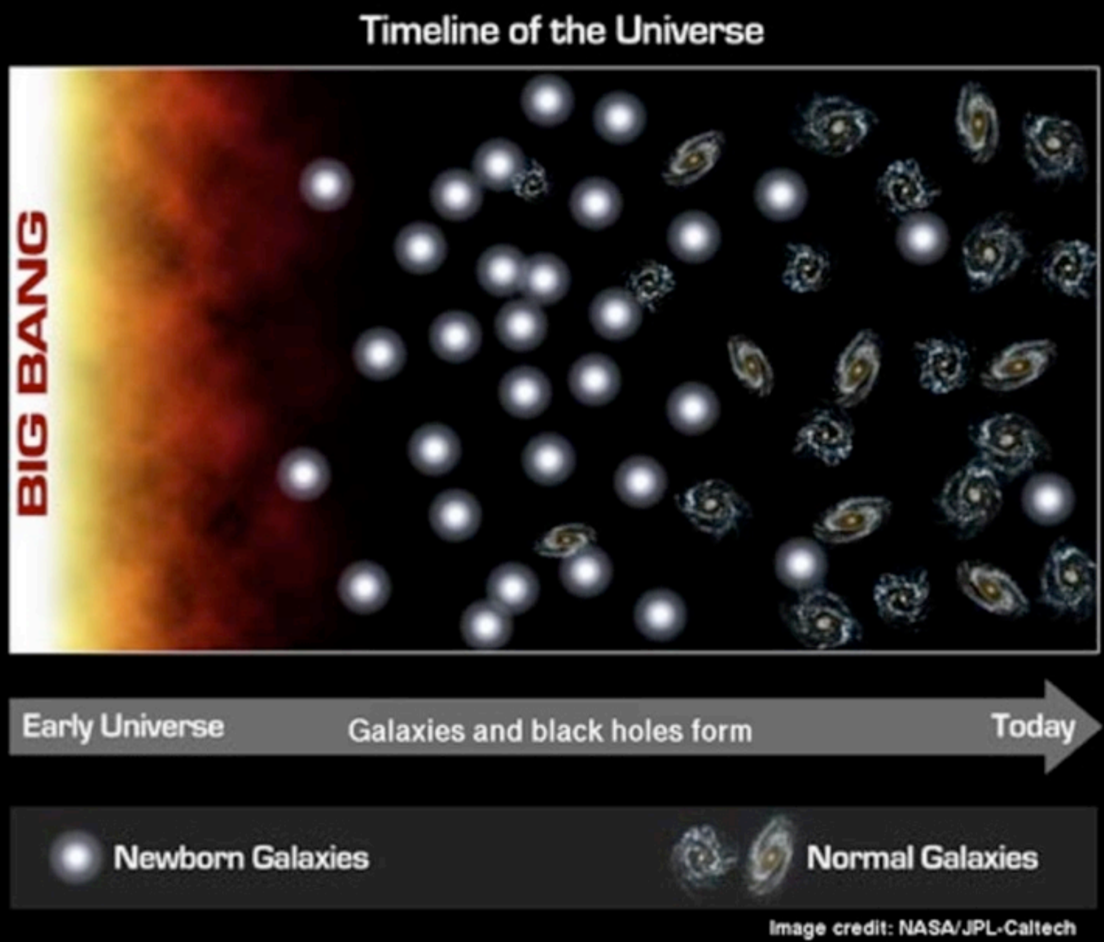
# Growing the first black holes

Marta Volonteri

University of Michigan

B. Devecchi, S. Van Wassenhove

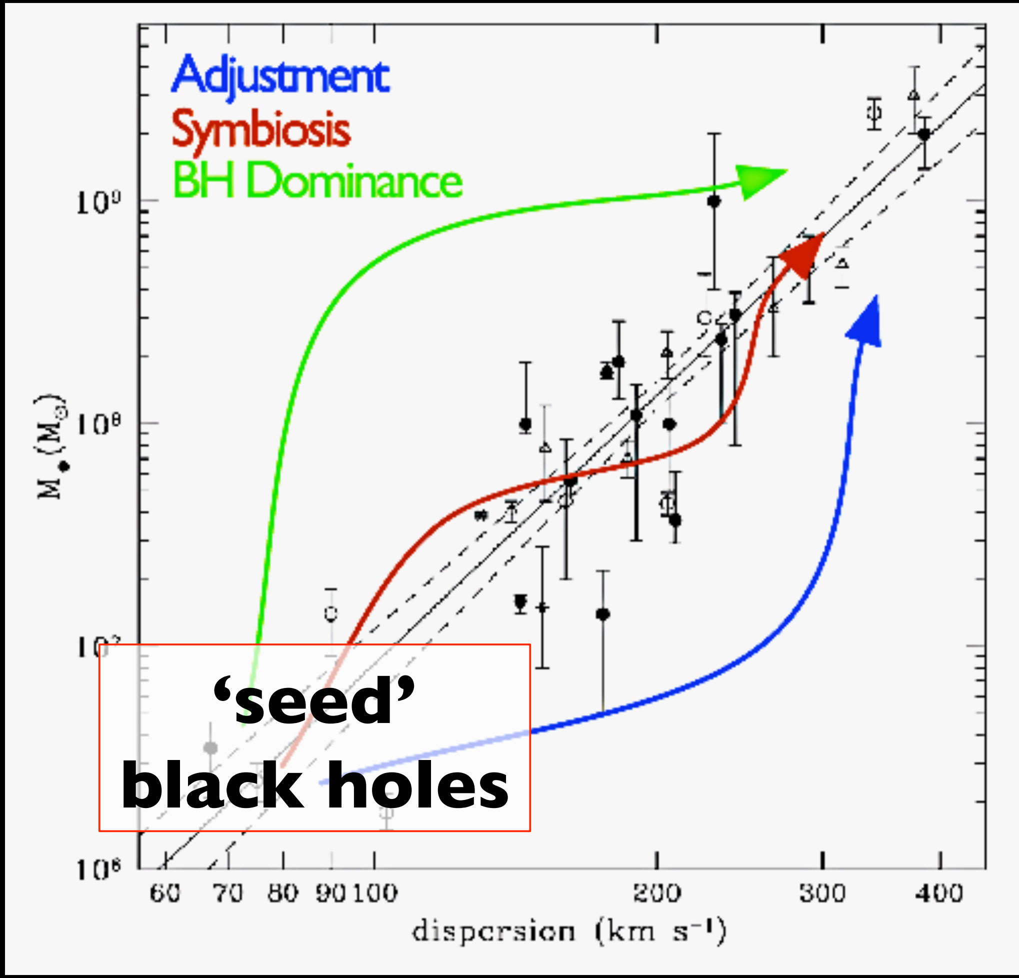
M. Begelman, P. Natarajan



# $M_{BH}$- host relationships : co- evolution of MBHs and galaxies

I.Forming MBHs

II. Growing MBHs




Colpi et al 2007

# HOW can you make the first massive black holes?

$M_{BH}$~100 $M_{sun}$

$M_{BH}$ ~$10^3$-$10^5$ $M_{sun}$

## PopIII stars remnants

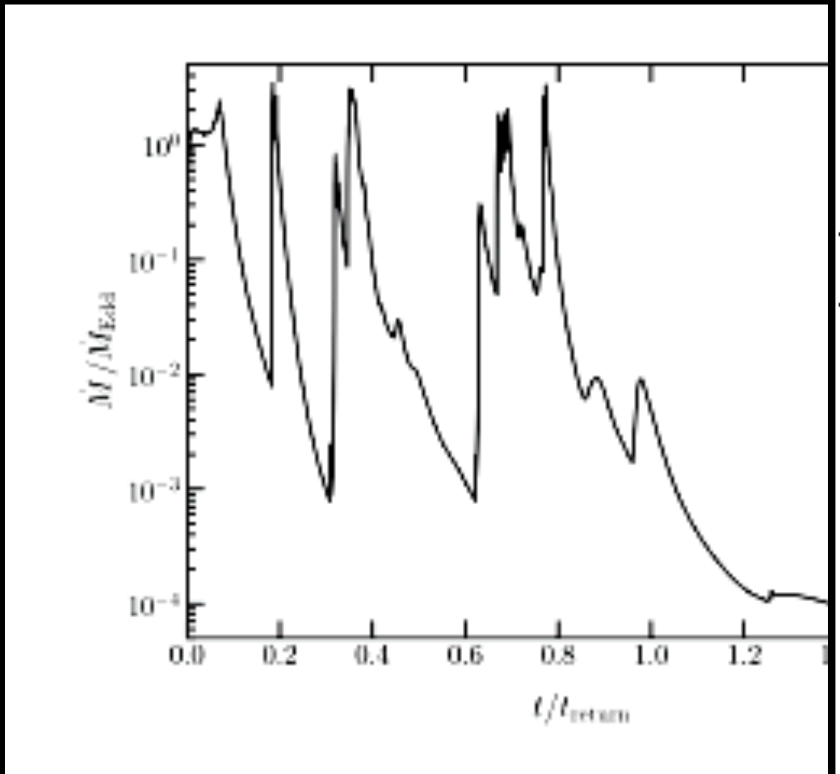
(Madau & Rees 2001, MV, Haardt & Madau 2003)

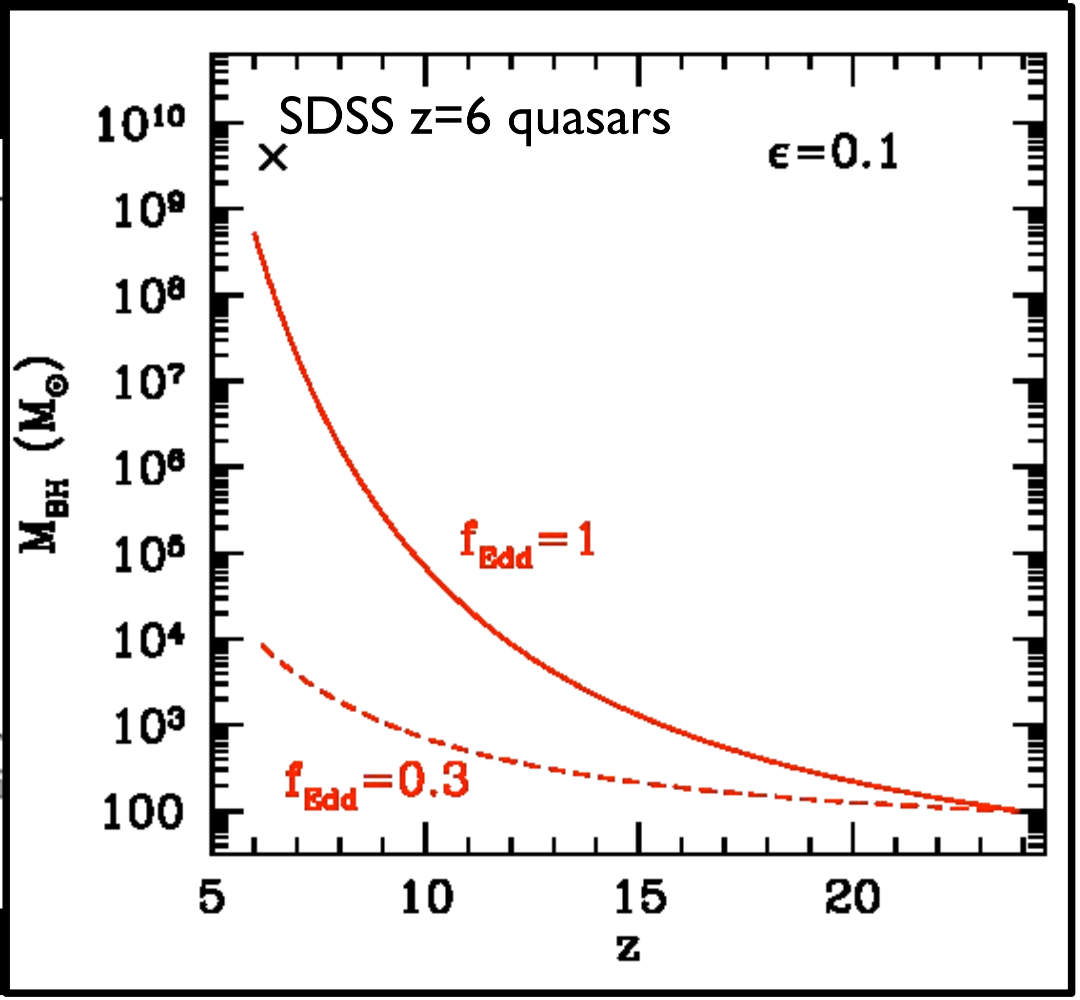
✔Simulations suggest that the first stars are massive M~100-600 $M_{sun}$
(e.g., Abel et al. Bromm et al.)

✔Metal free dying stars with $M>260M_{sun}$ leave remnant BHs with $M_{seed} \geq 100M_{sun}$ (Fryer, Woosley & Heger)

For a BH accreting at a rate $f_{Edd}$ the time required to reach a final mass scales as:

$$t_{growth} = 0.45 \text{ Gyr} \frac{\varepsilon}{1-\varepsilon} f_{Edd} \ln\left(\frac{M_{fin}}{M_{in}}\right)$$



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$M_{BH} \sim 100\ M_{sun}$

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$M_{BH} \sim 10^3$-$10^5\ M_{sun}$

## DIRECT COLLAPSE:

### Gas-dynamical processes

(e.g. Haehnelt & Rees 1993, Eisenstein & Loeb 1995, Bromm & Loeb 2003, Koushiappas et al. 2004, Begelman, MV & Rees 2006, Lodato & Natarajan 2006)

### Stellar dynamical processes

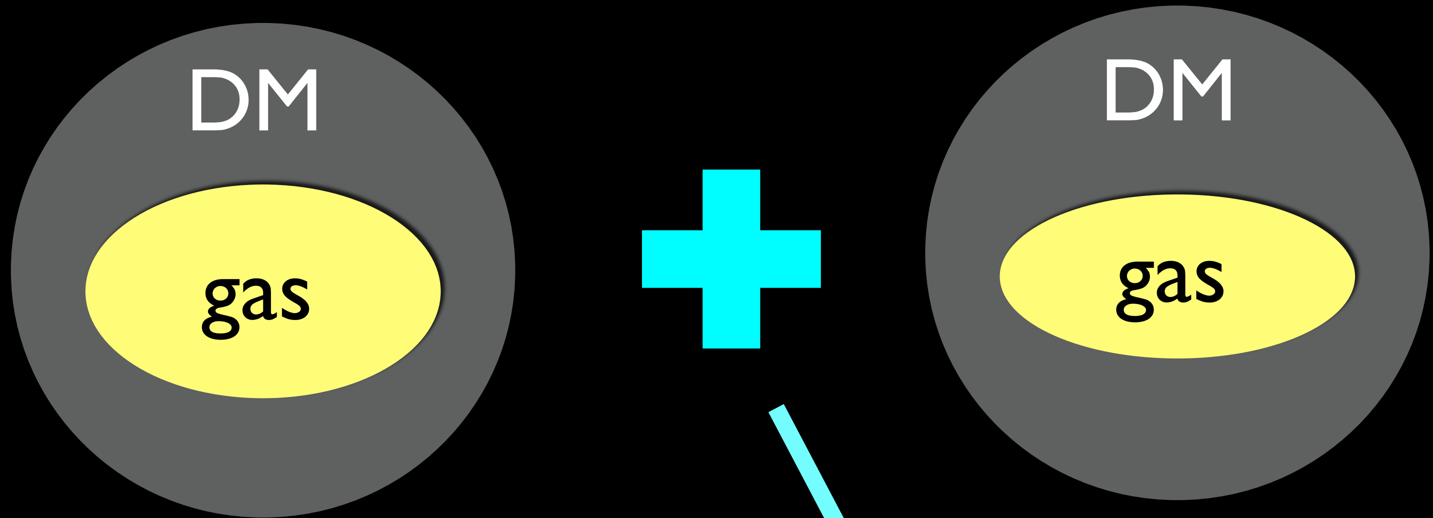
(Devecchi & MV 2009, Omukai et al. 2009)

# Gas-dynamical processes

## Need **high** inflow rates ~ 1 $M_{sun}$/yr (Begelman 2010)

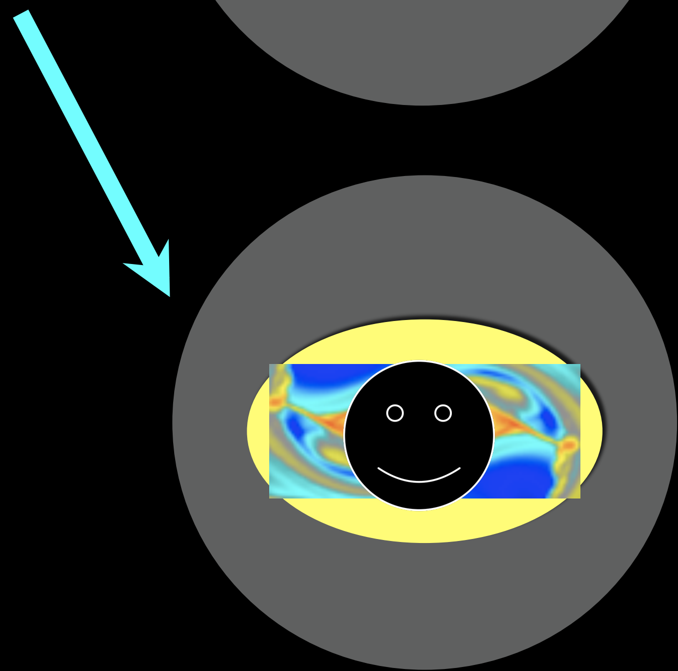
## ➔highly unstable systems, eg merger driven gas collapse

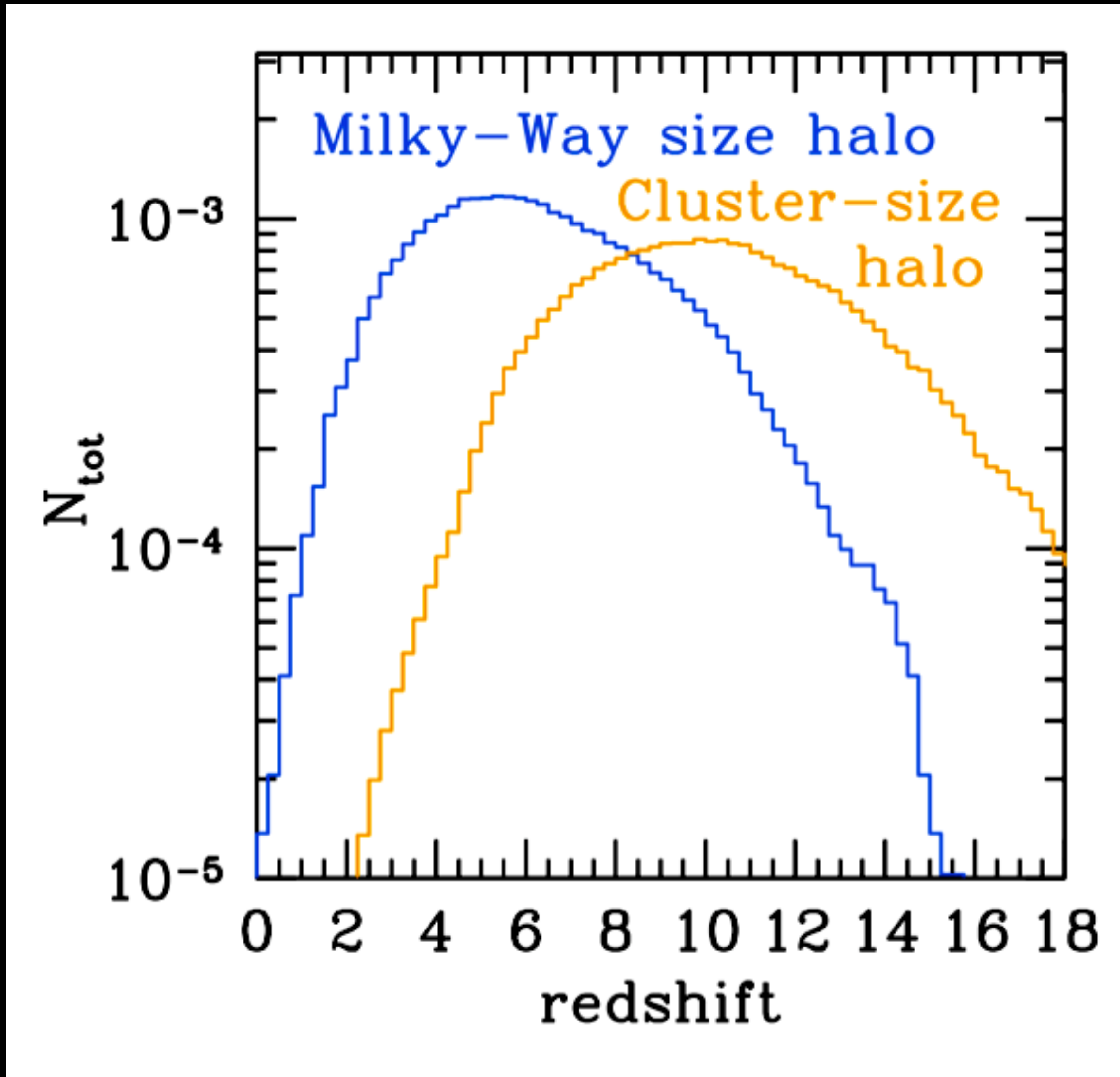
(Mayer et al 2010, Begelman & MV 2010)




The central regions fulfill the conditions for MBH formation: quasistars?

Begelman, MV & Rees 2006





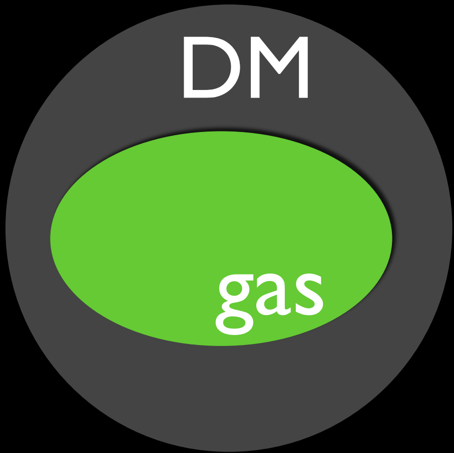

Biased MBH formation: from the HIGHEST PEAKS OF DENSITY FLUCTUATIONS down

MV & Begelman 2010

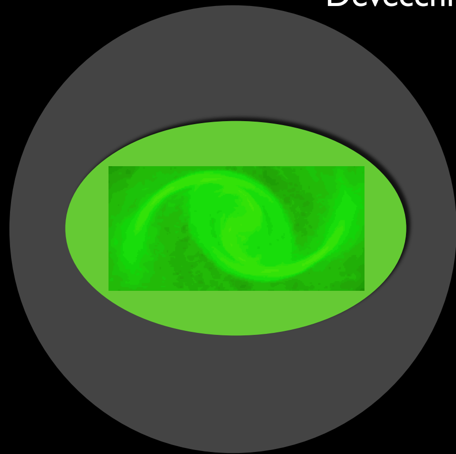
# Weaker inflow rates → only mildly unstable systems

## Stellar-dynamical processes

Devecchi & MV 2008

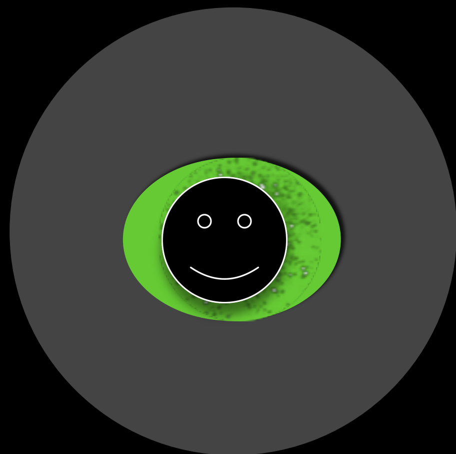



Mildly unstable



very low Z

Fragmentation if n> $n_{crit}$ : inner region only



dense star cluster formation

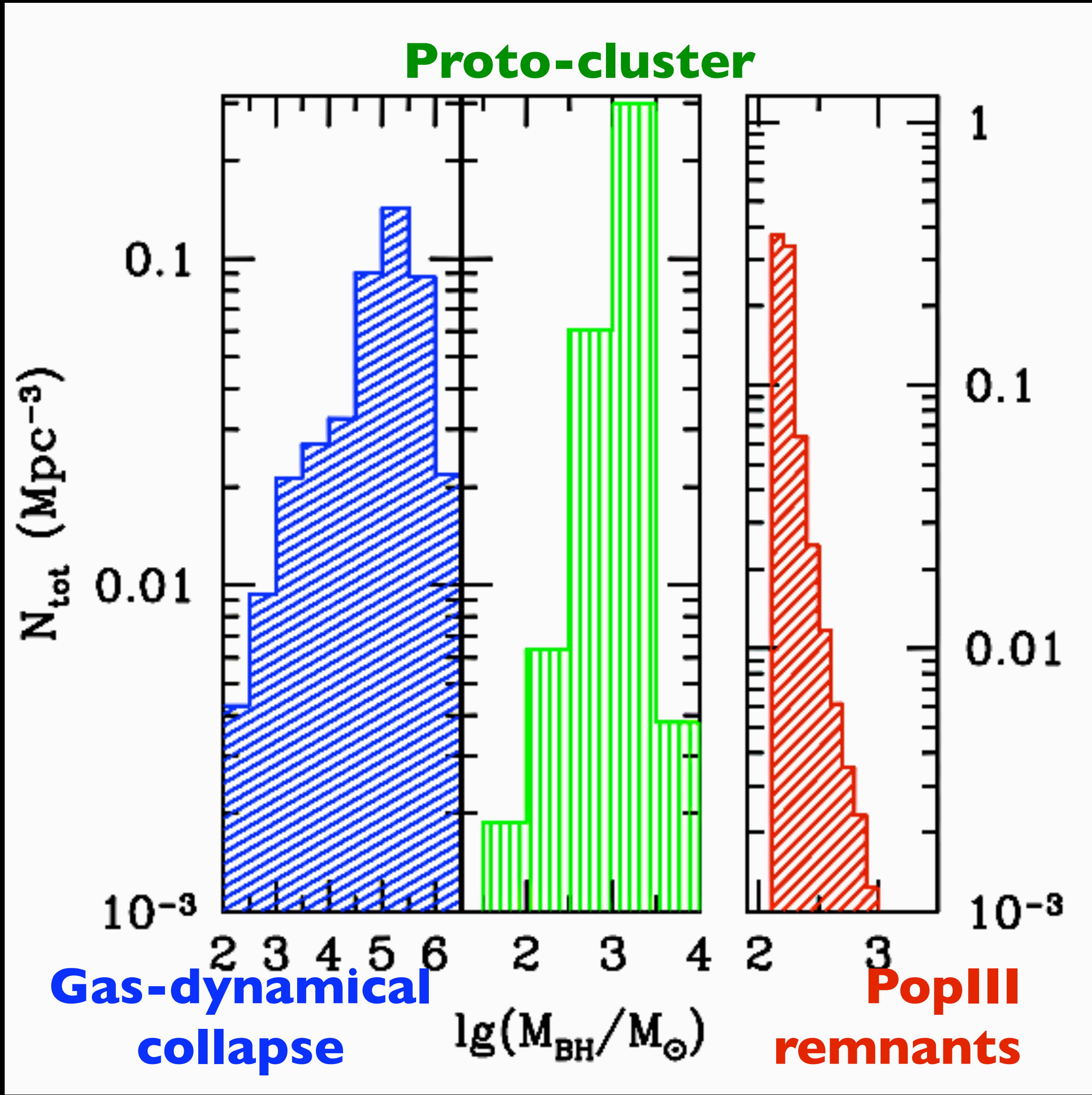
Collisions

Runaway growth

BH

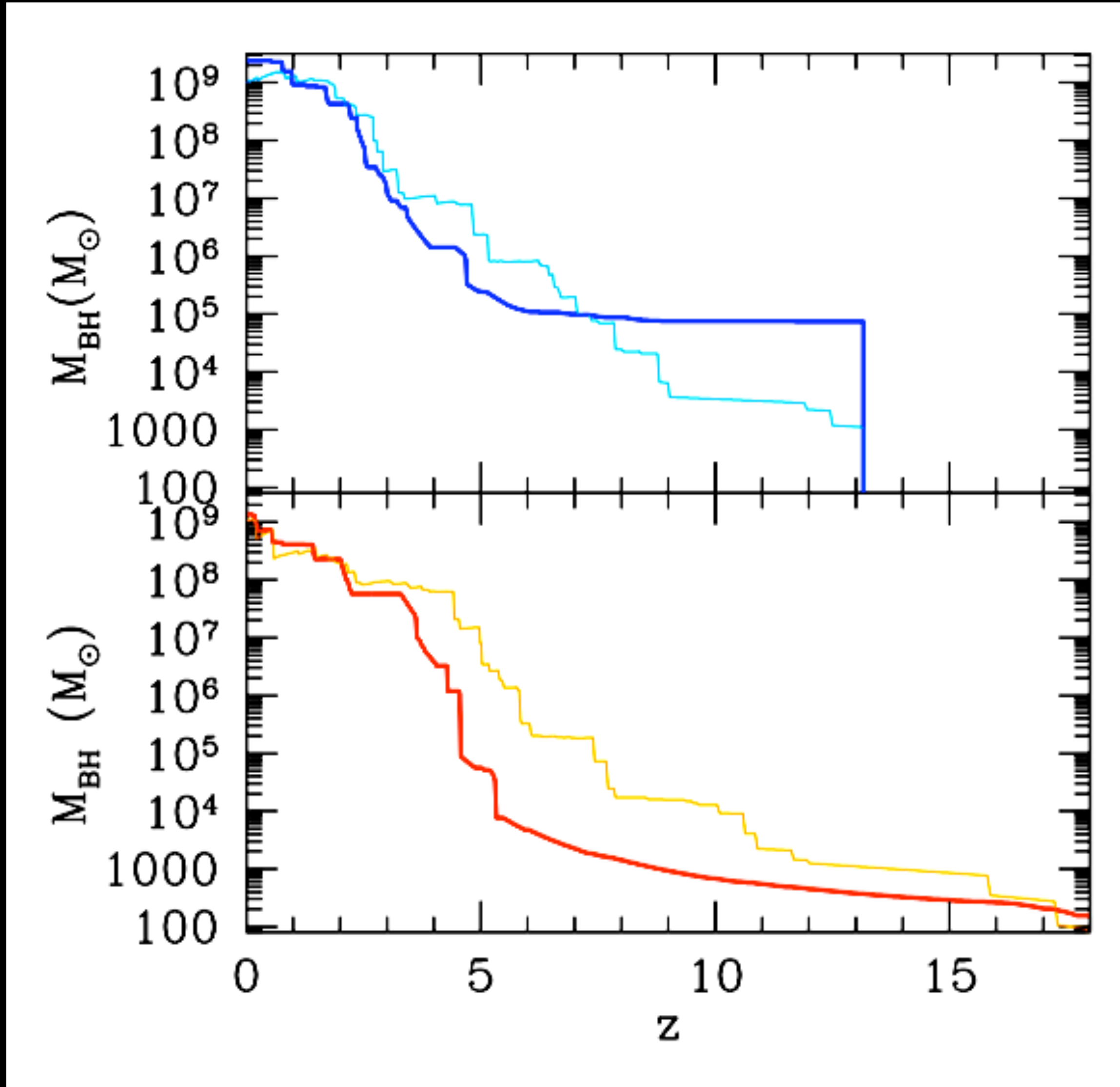
# Mass function of seed MBHs

(MV, Lodato & Natarajan 2008; Devecchi & MV 2009)

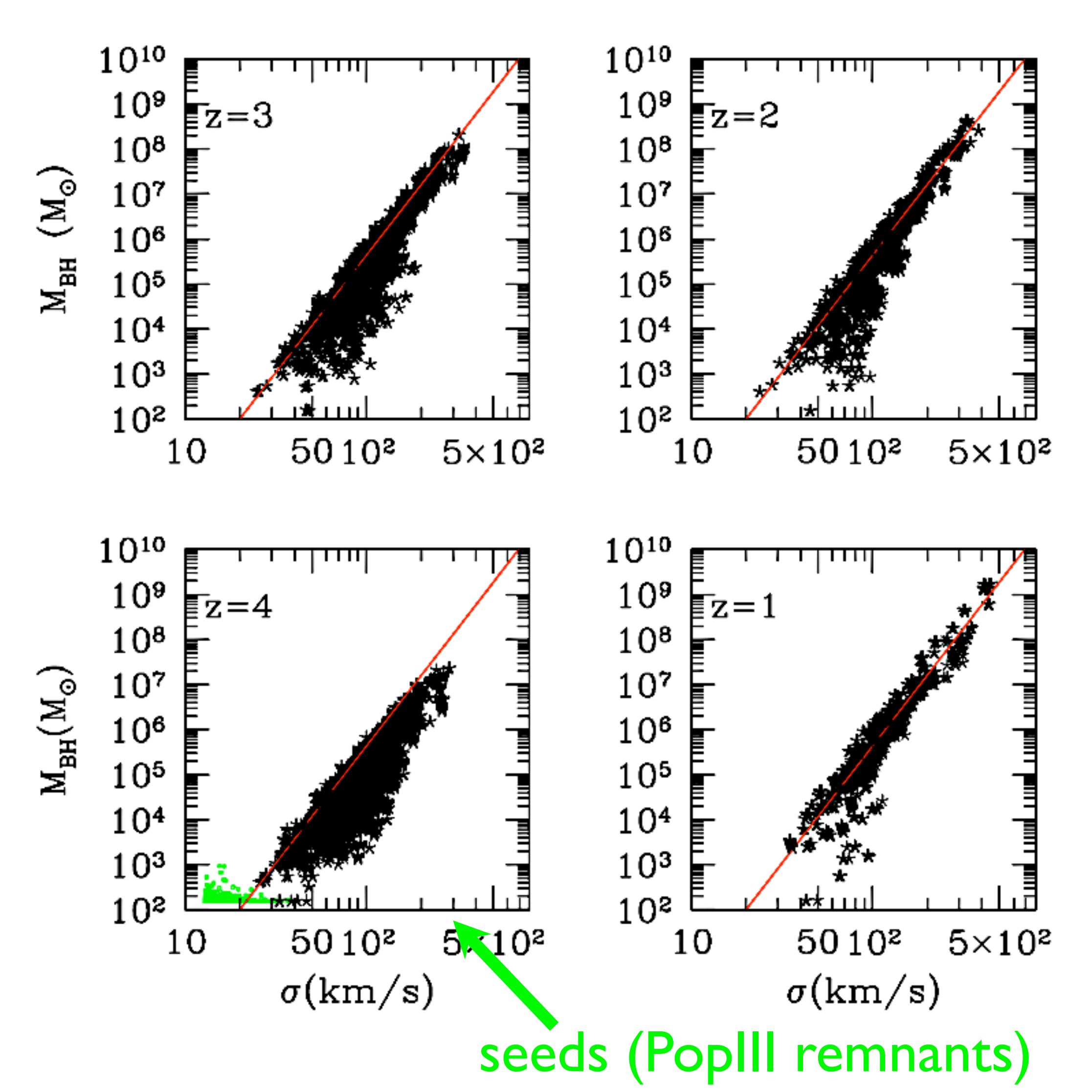


Since the "average" MBH grows by several orders of magnitude by accretion at z≤3-5 the initial conditions are washed out:

**looking for uncontaminated clues**



# Journey to the M-sigma relation

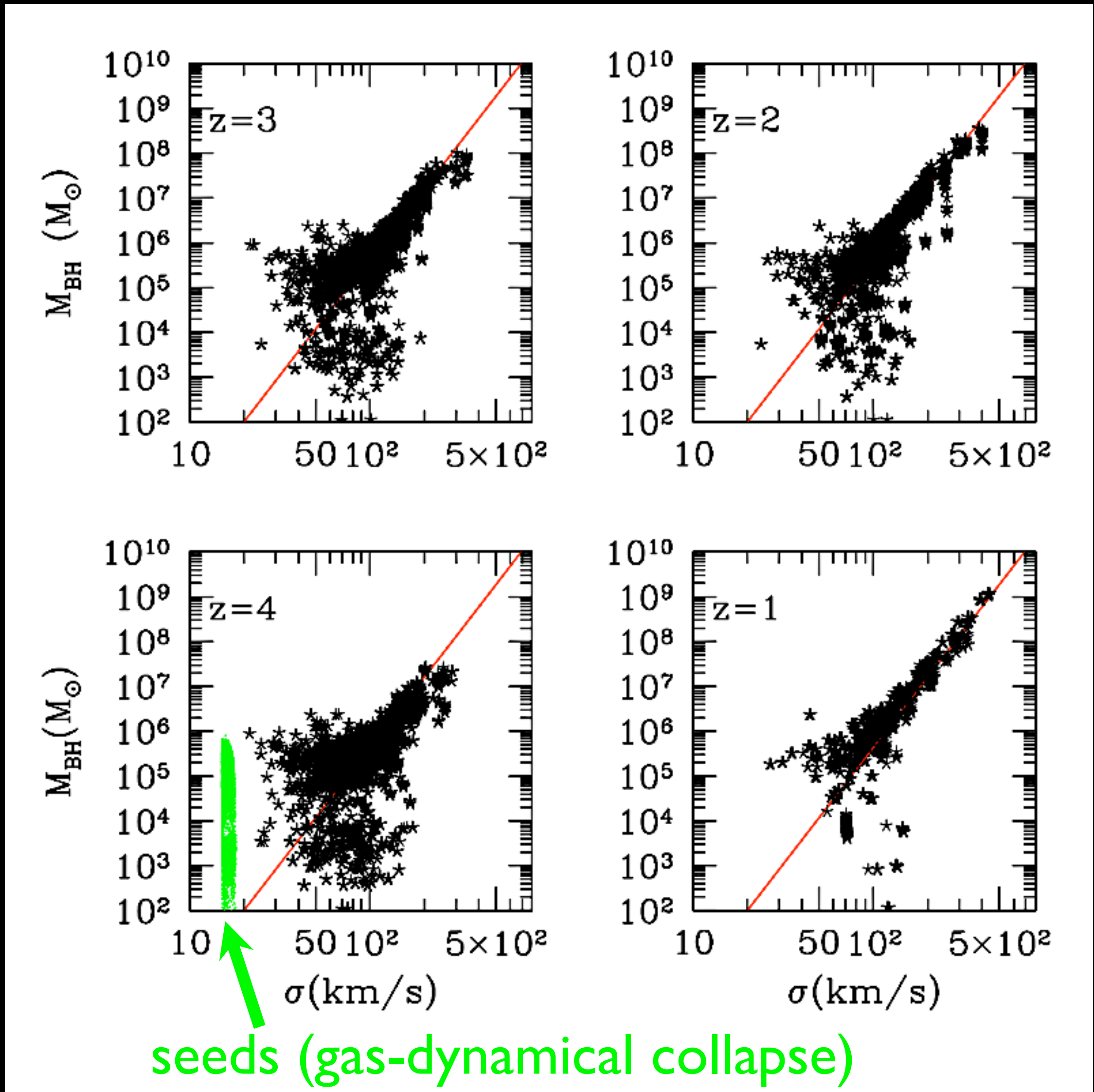



'Standard' merger-driven accretion =>each episode grows a MBH onto the M-sigma relation

MBHs move onto the M-sigma from below

# Journey to the M-sigma relation

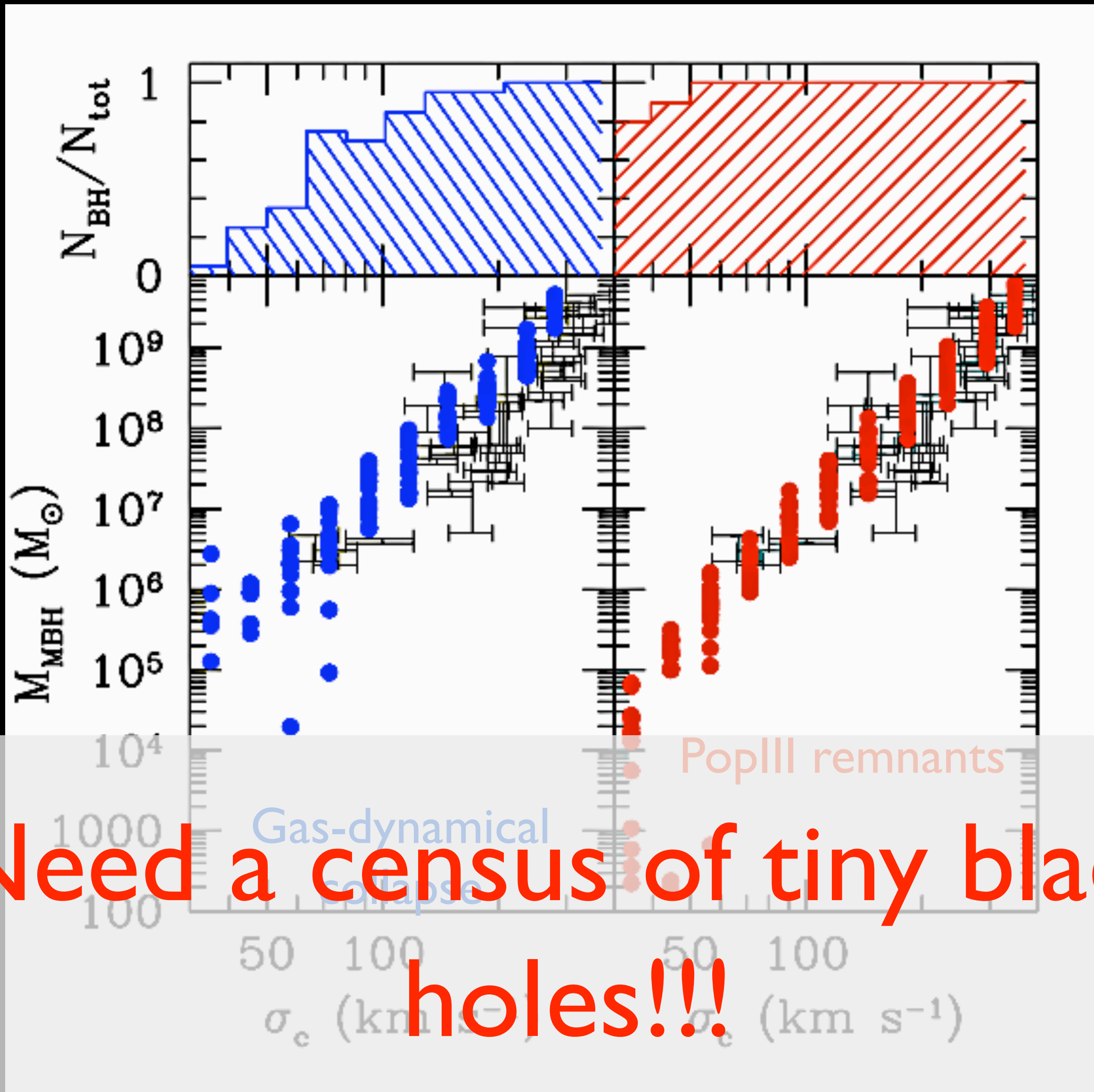
(MV & Natarajan 2009)




The smallest galaxies retain memory of the initial conditions: quiet life.... no major mergers, no accretion

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

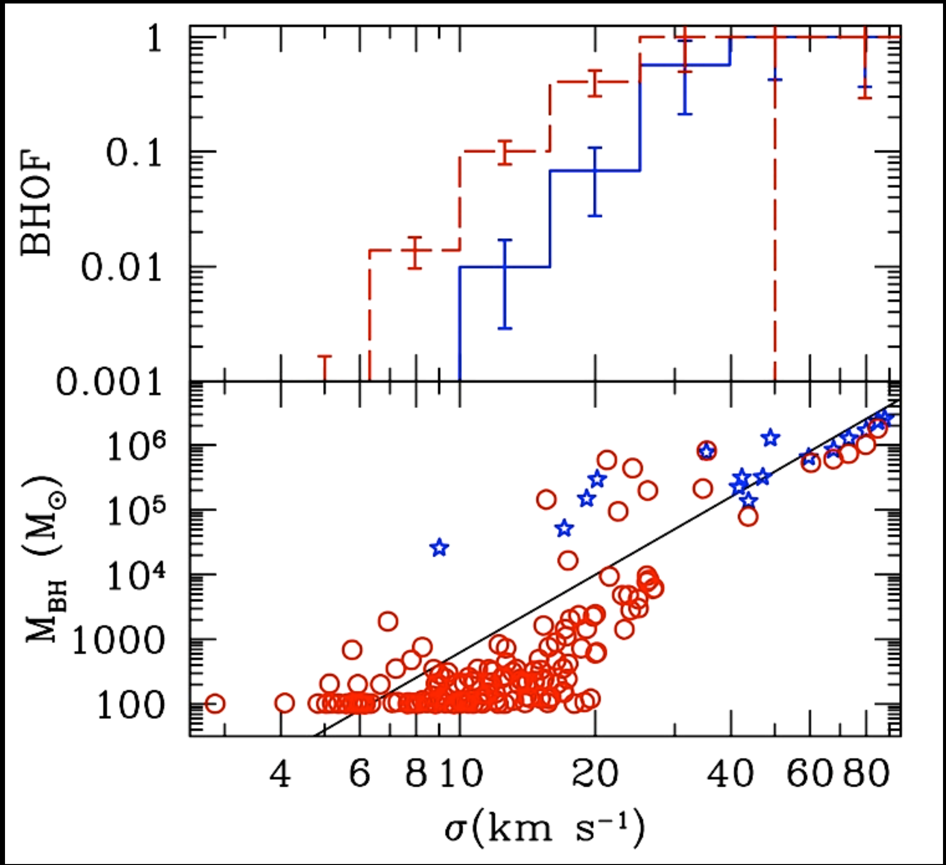
(MV, Lodato & Natarajan 2008)

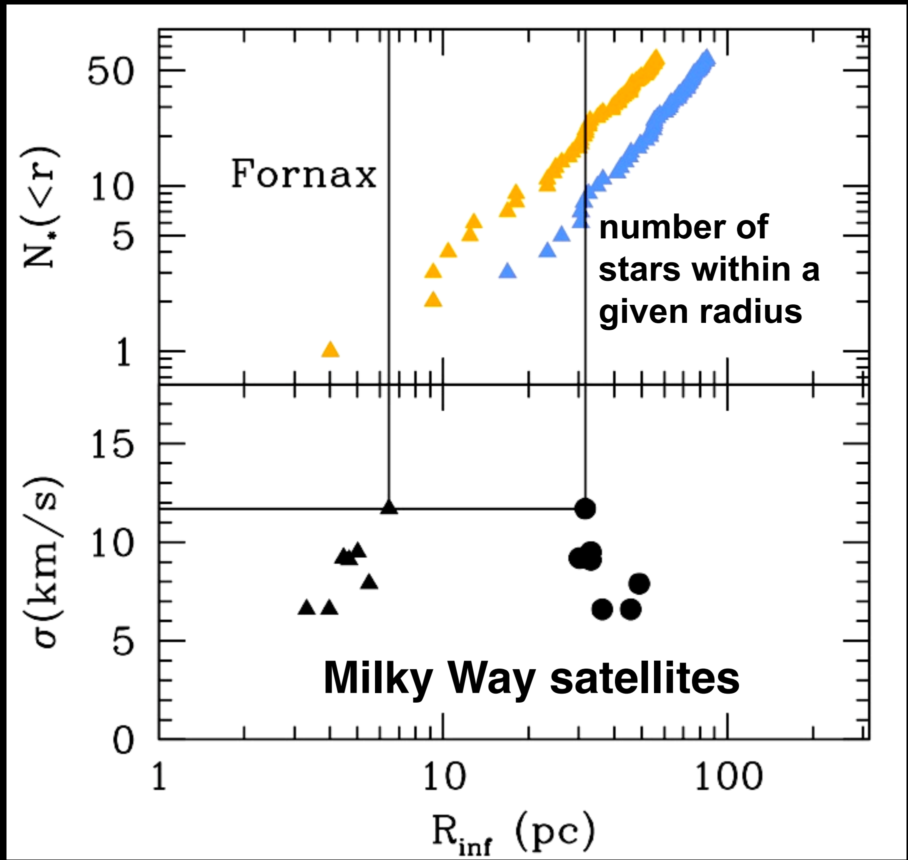



Need a census of tiny black holes!!!

# MBHs in Milky Way Satellites

(Van Wassenhove,MV,Walker & Gair 2010)



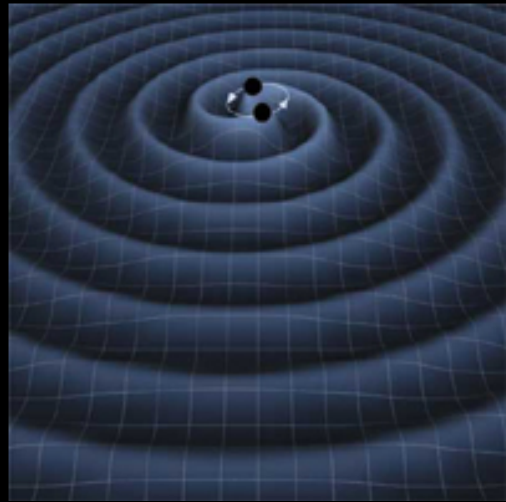

Gas-dynamical collapse

PopIII remnants

Triangles: the MBH sits on the M-σ relationship

Dots: fixed MBH mass, $10^5$ $M_\odot$

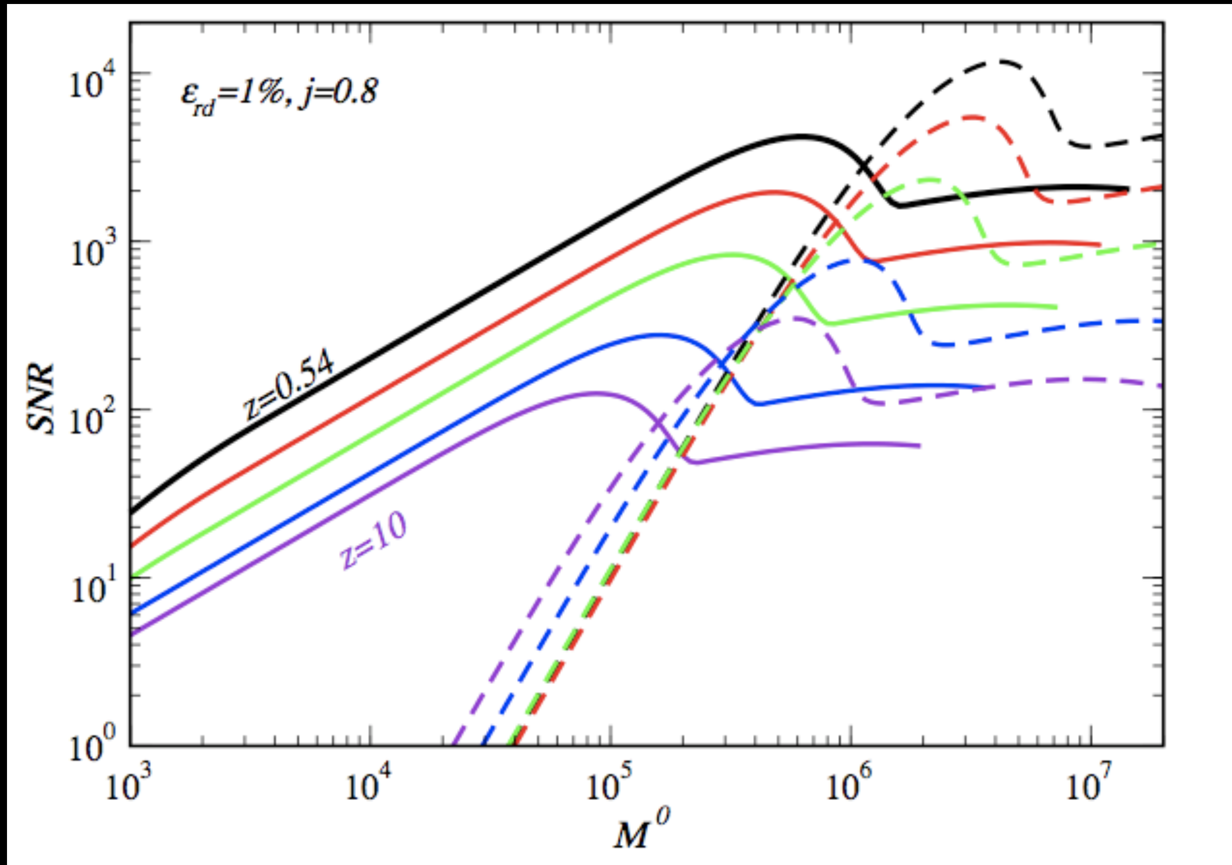
# GWs from MBH binaries



space based interferometer: LISA

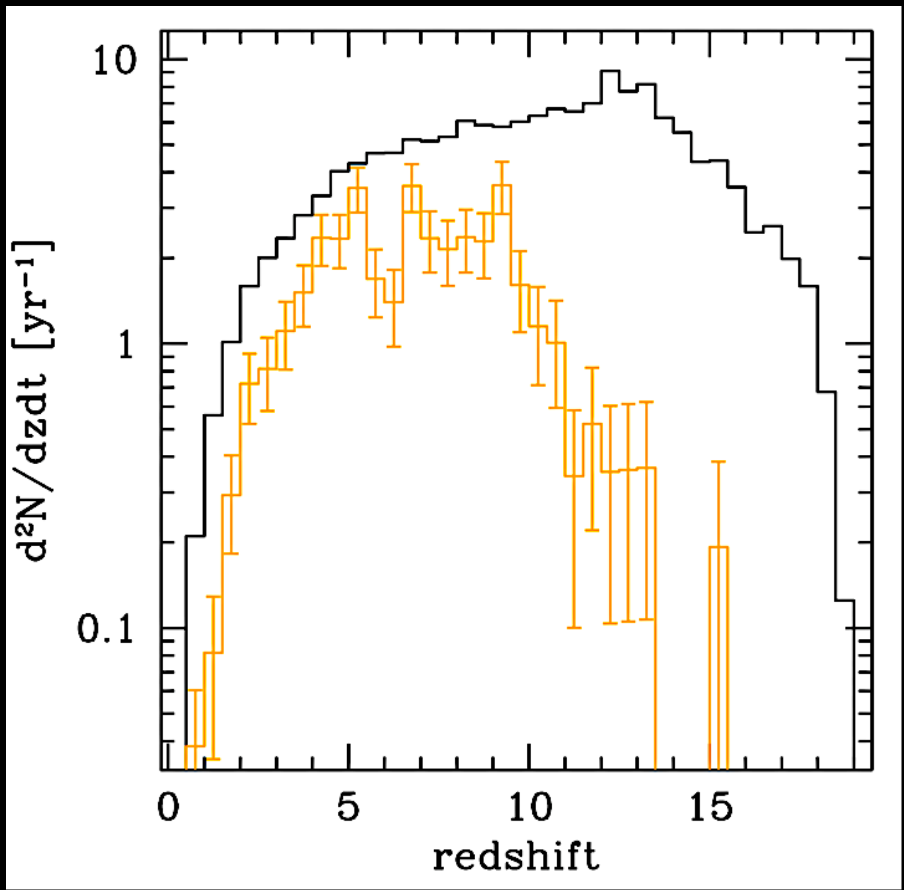
Joint NASA/ESA mission

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

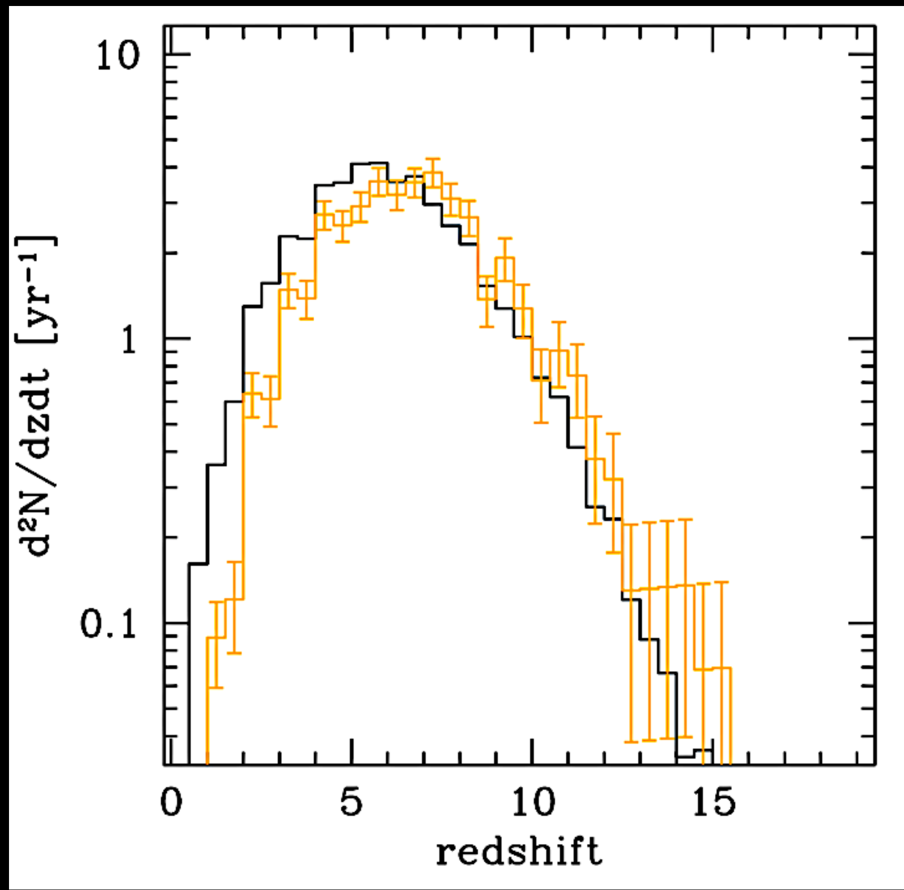


# GWs from MBH binaries

with Cutler, Berti & the LISAPE taskforce




PopIII remnants




Direct collapse

| Model | $N$ | $f_{\rm yr^{-1}}$ | $f_{10\%{\rm D_L}}$ | $f_{10\,{\rm deg}^2}$ | $f_{10\,{\rm deg}^2,\,10\%{\rm D_L}}$ | $f_{1\,{\rm deg}^2}$ | $f_{1\,{\rm deg}^2,\,1\%{\rm D_L}}$ |
|---|---|---|---|---|---|---|---|
| SE | 80 | 0.41 (0.32) | 0.62 (0.32) | 0.25 (0.060) | 0.24 (0.044) | 0.068 | **0.051** |
| SC | 75 | 0.45 (0.35) | 0.51 (0.17) | 0.18 (0.014) | 0.16 (0.014) | 0.039 | **0.037** |
| LE | 24 | 0.97 (0.92) | 0.89 (0.35) | 0.43 (0.035) | 0.42 (0.030) | 0.096 | **0.054** |
| LC | 22 | 0.95 (0.86) | 0.69 (0.23) | 0.31 (0.028) | 0.26 (0.025) | 0.085 | **0.047** |

# Summary

✔seed MBHs in biased proto-galaxies

✔Big or small?

✔look back at the earliest times – before accretion erases initial conditions

✔today MBHs @ low masses tell the story