Growing black holes in growing galaxies

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MBHG

SEVENTH FRAMEWORK PROGRAMME

Quasars and Active Galactic Nuclei (AGN)

Hubble Heritage Team

They are as luminous as galaxies: $L \sim 10^{11}$-10^{13} L_{sun}

Size of the emitting region is 10^6 times smaller than a galaxy ~ size of solar system

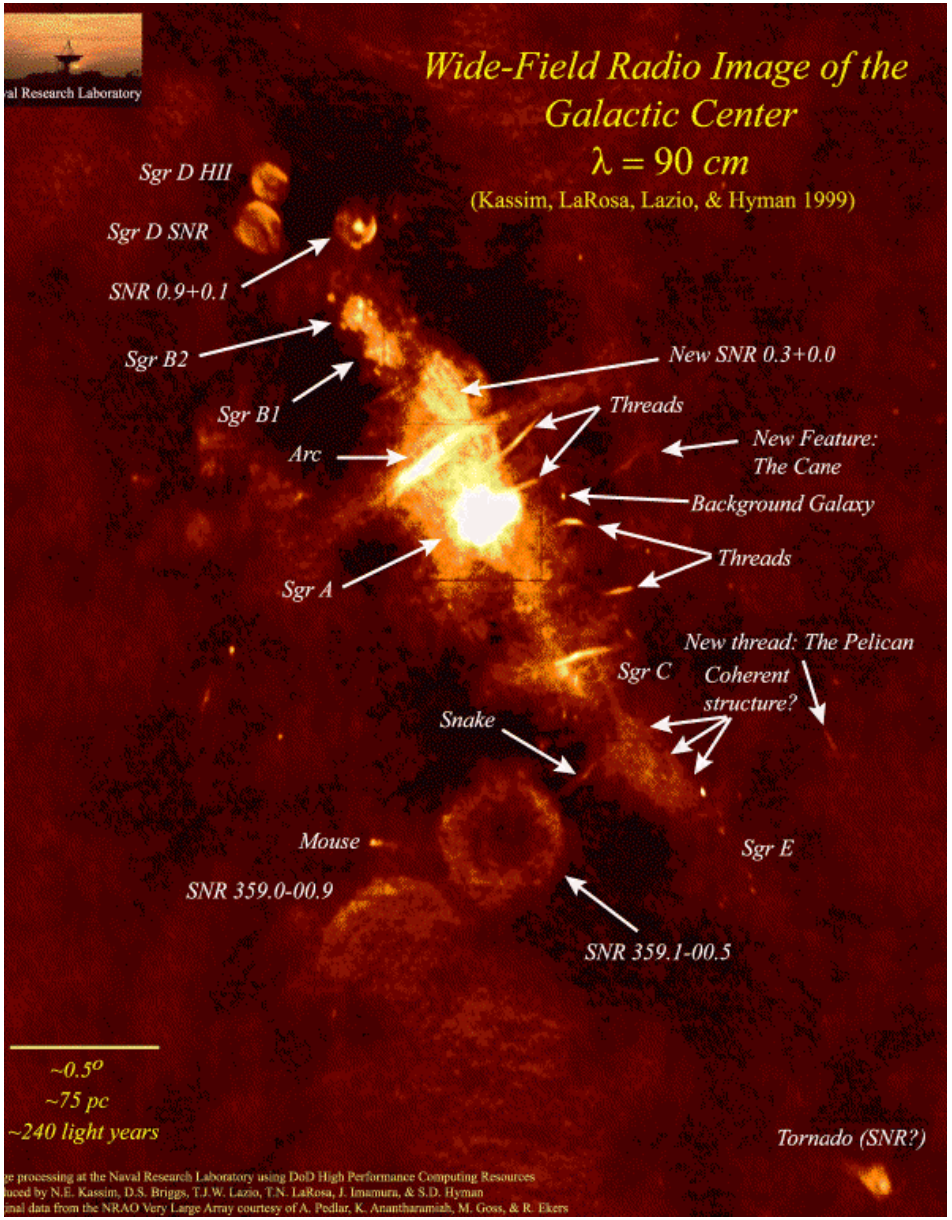
Powered by accreting black holes with masses of millions to billions of M_{sun}

Quiescent MBHs

Many MBHs are quiescent.
We have an example is in the center of the Milky Way.

The typical luminosity of Sgr A*, is ~10^{34} erg/s.

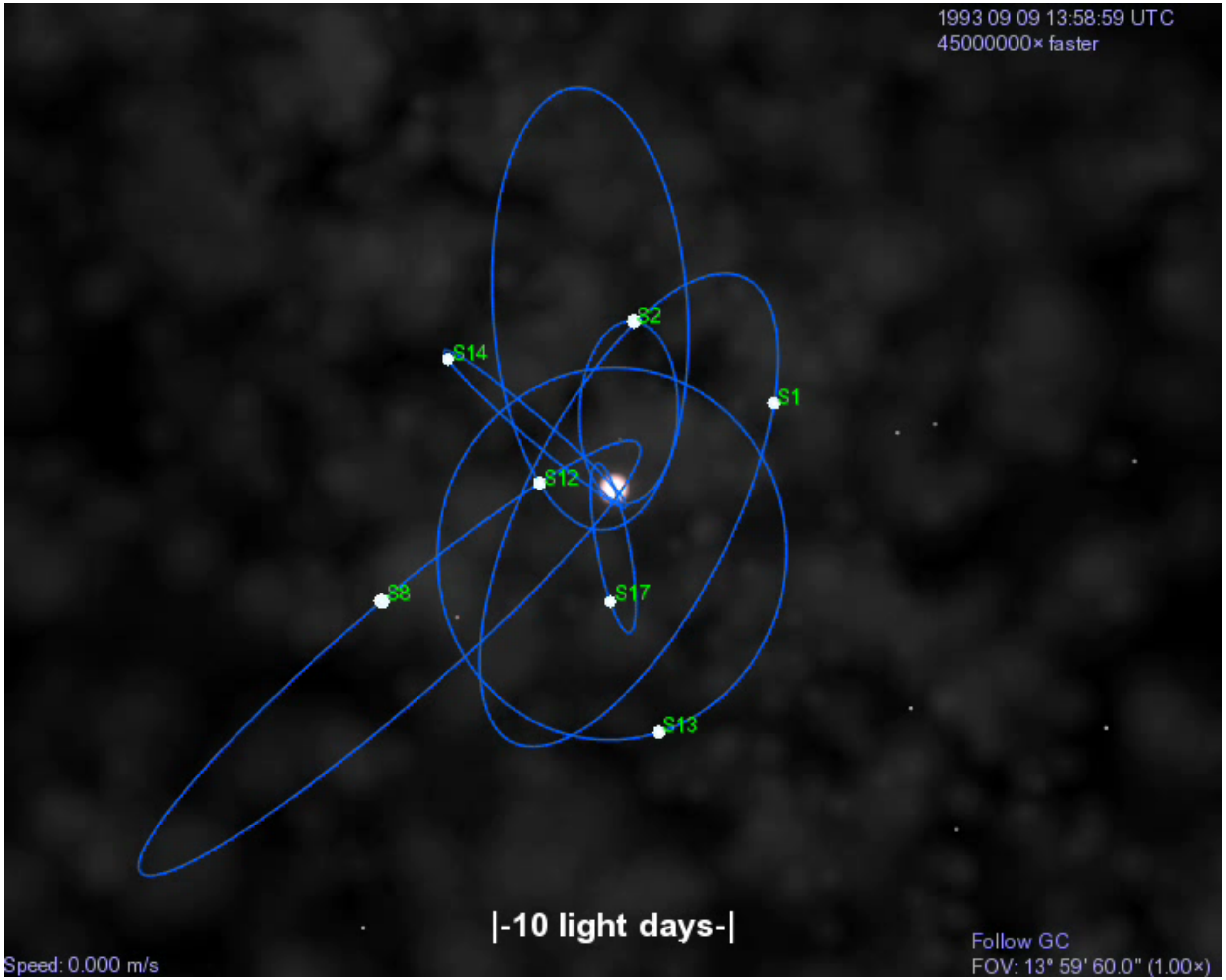
Not much more than the Sun ($4x10^{33}$ erg/s).



MBHs in local galaxies

The best example of search for a SMBH is the MILKY WAY: individual stars can be resolved

Keplerian motion – the central point mass is $\sim 4 \times 10^6 \, M_{sun}$

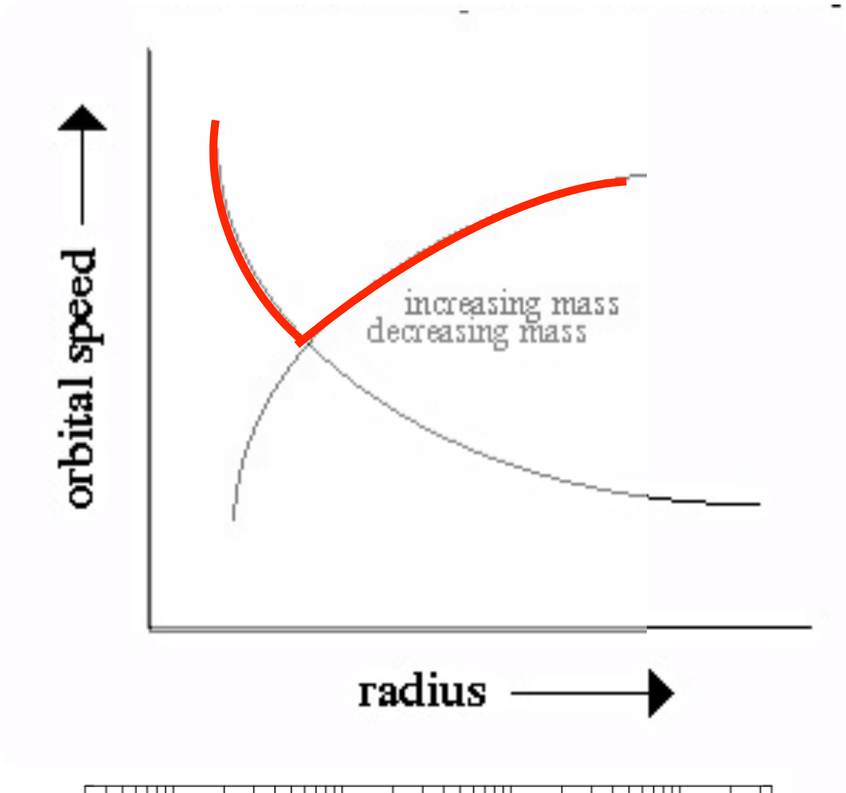


MBHs in local galaxies

In (almost) every other galaxy => velocity field from the integrated stellar light in galaxies with *quiescent* MBHs.

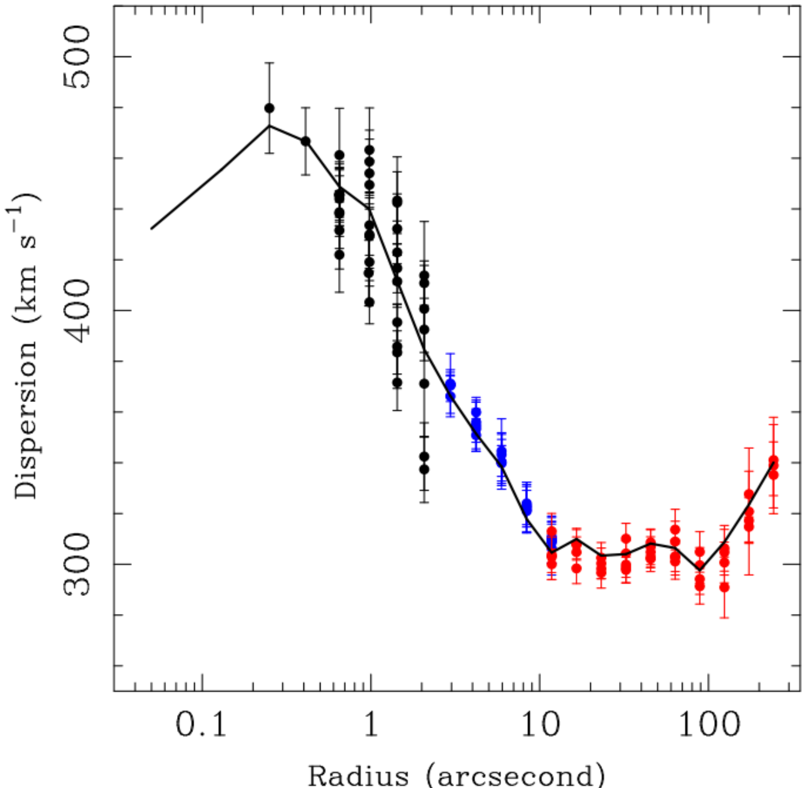
In the presence of a central MBH the velocity of stars is higher than expected from the galaxy potential only => peak in the velocity curve in the central ~pc

$$V = \sqrt{\frac{GM(<r)}{r}} = \sqrt{\frac{G(M_{BH} + M_{gal}(<r))}{r}}$$



Idealized case

~80 MBHs with measured mass in nearby galaxies to-date

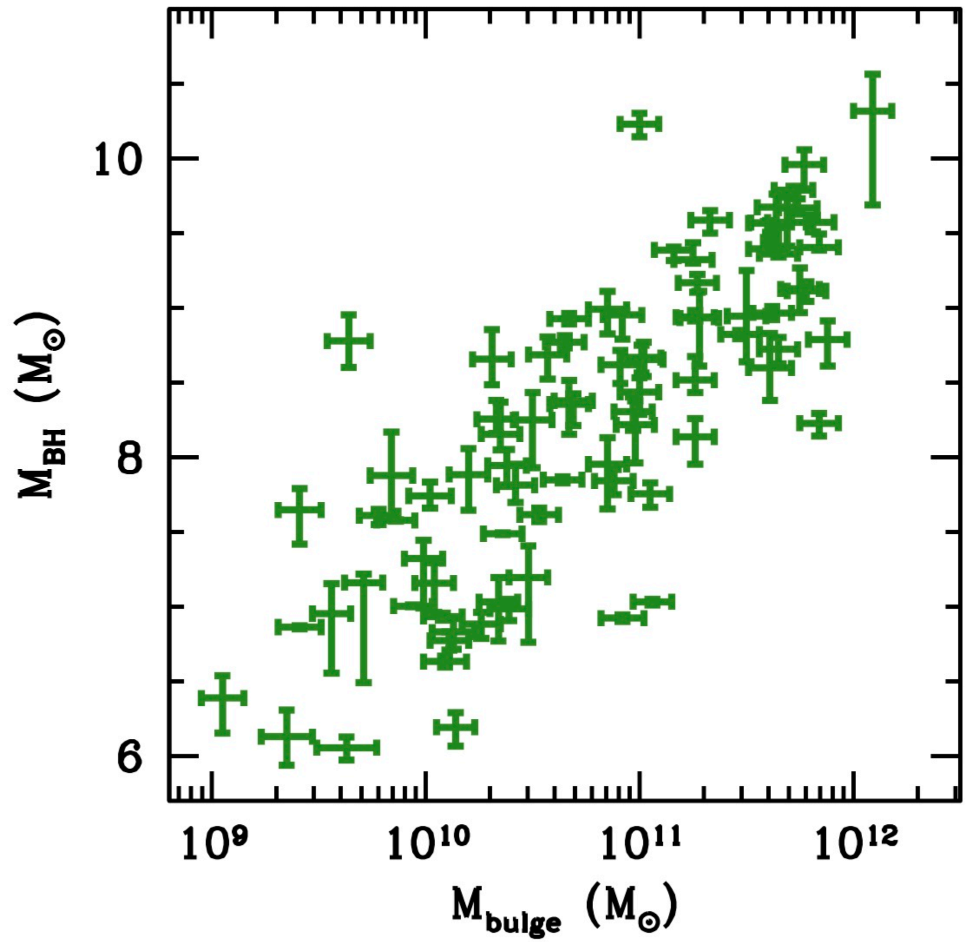


Real case

M87, Gebhardt et al. 2011

Black holes in local galaxies

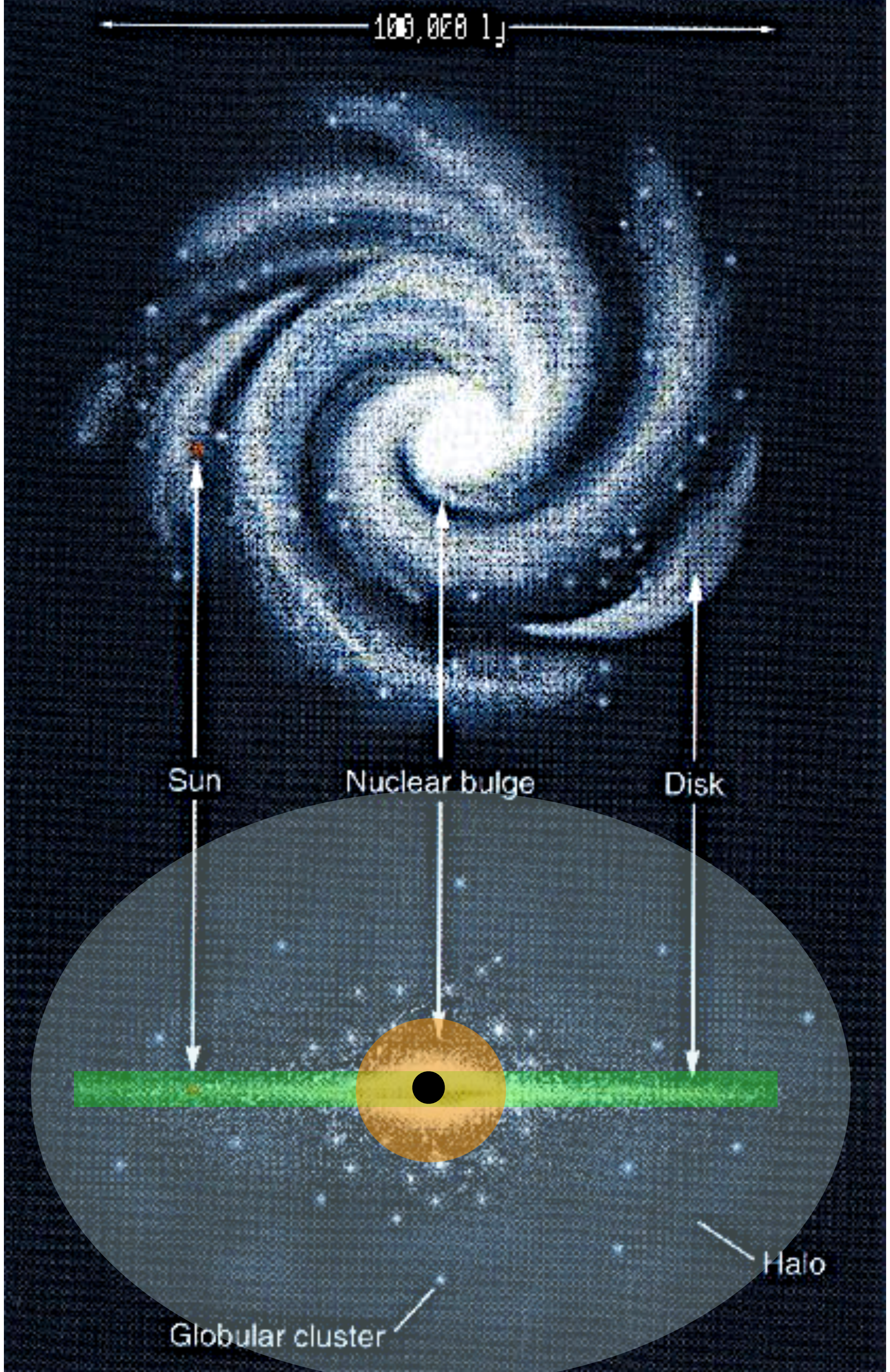
Black hole masses correlate with galaxy properties. This may mean their growth/evolution are intimately connected.



- $M_{BH} \sim 10^{-3} M_{bulge}$
- $M_{BH} \sim \sigma^4 - \sigma^5$

σ : velocity dispersion

- Through Faber-Jackson: $L \sim \sigma^4$
- IR light traces mass



Galaxies

mass: 10^9-10^{12} solar masses

$R_{halo} \sim GM_{halo}/\sigma^2$ MEGAPARSEC

$R_{bulge} \sim GM_{bulge}/\sigma^2$ KILOPARSEC

1 parsec=3.26 light years=3×10^{18} cm
$\sigma \sim$50-300 km/s for most galaxies

Massive Black Holes

mass: 10^5-10^9 solar masses

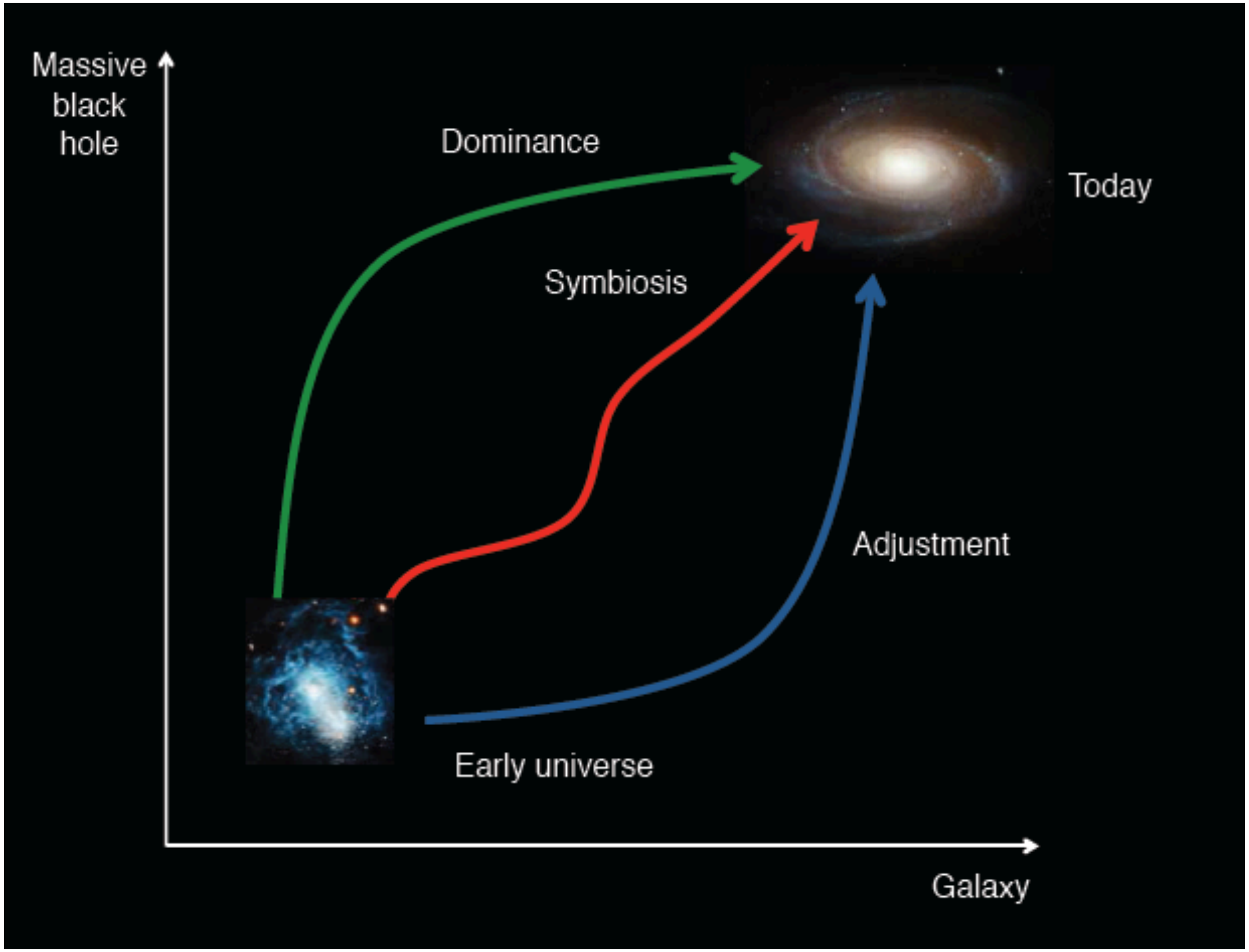
$R_{bondi} \sim GM_{BH}/c_s^2$ PARSEC

$R_{inf} \sim GM_{BH}/\sigma^2$ PARSEC

$R_{sch} = 2GM_{BH}/c^2$ MICROPARSEC

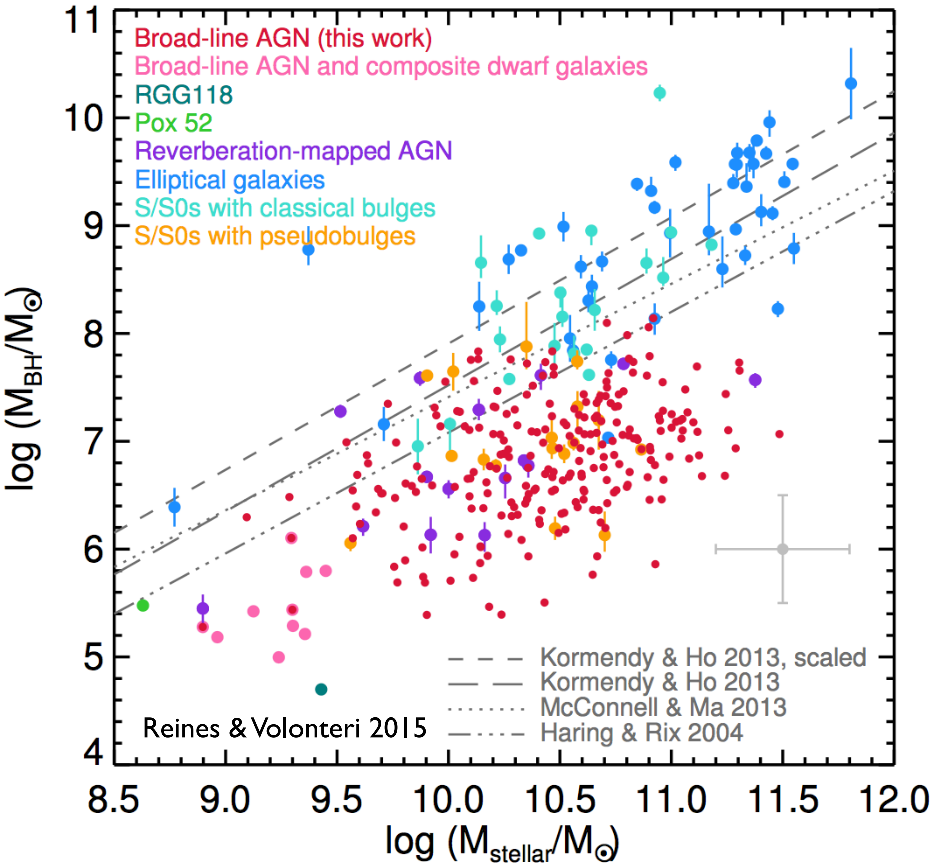
$c_s \sim$10-100 km/s for most galaxies
$c = 3 \times 10^5$ km/s

The growth of MBHs and galaxies



Black hole masses correlate with galaxy properties. This may mean their growth/evolution are intimately connected.

Growing BHs and galaxies



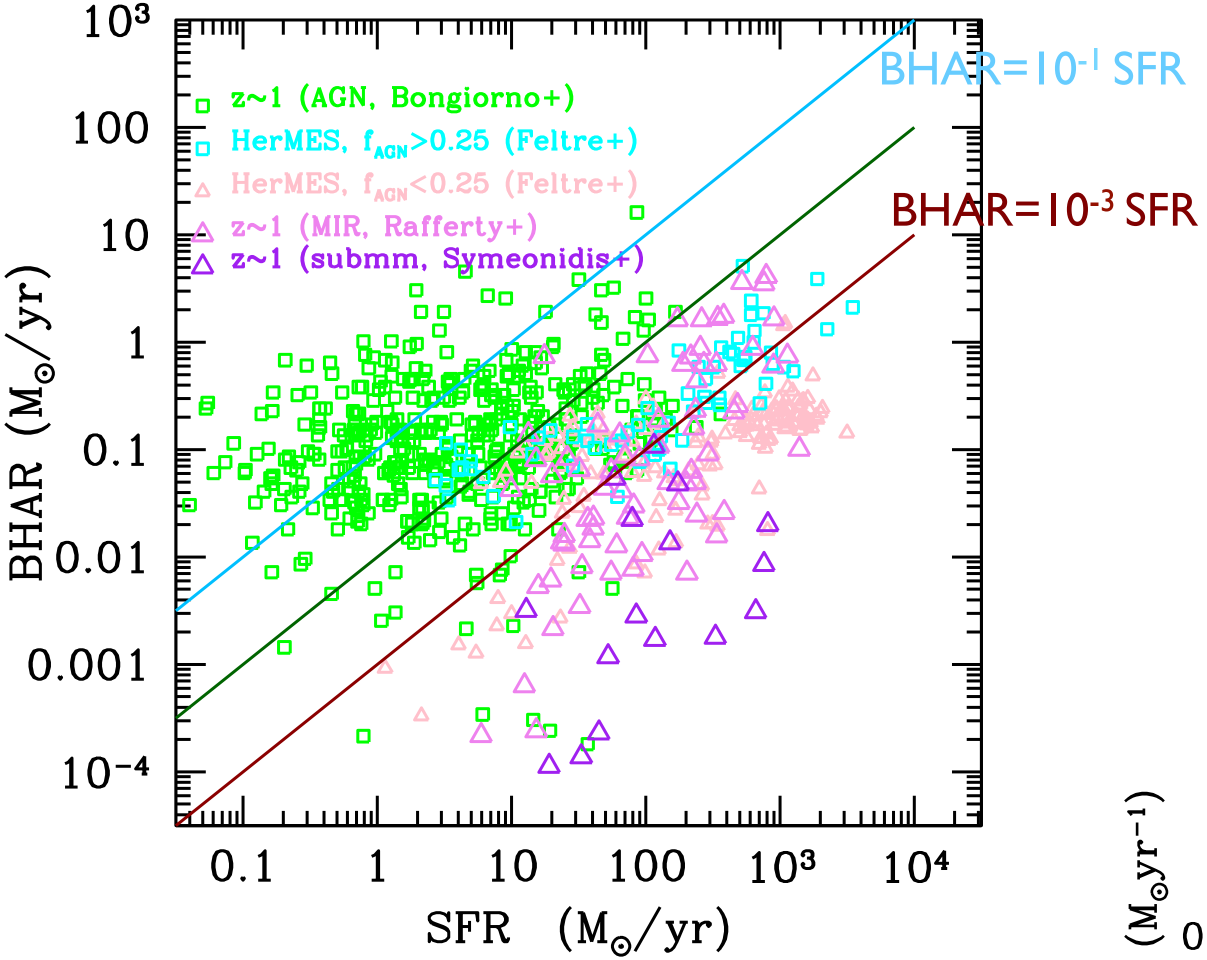
$M_{BH} \sim 10^{-3}\text{-}10^{-4}\ M_*$

'for every ~1000 units of star formation (SF) there is ~1–2 units of BH accretion' (Alexander & Hickox 2012)

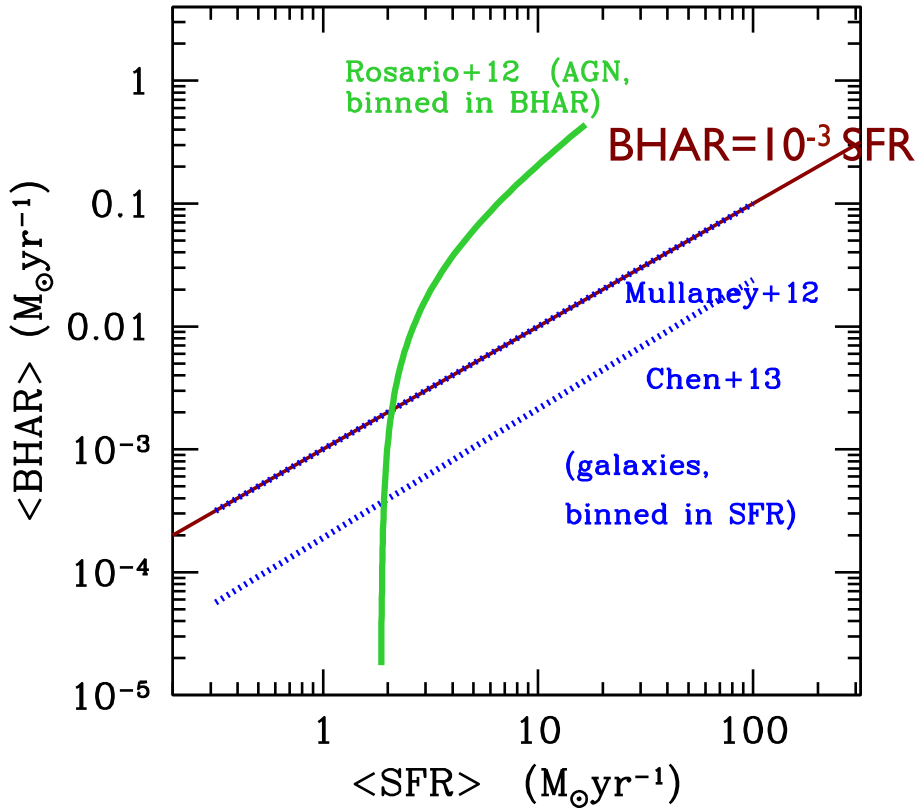
$M_{BH}=\langle BHAR \rangle \times t$

$M_*=\langle SFR \rangle \times t$

$\Rightarrow \langle BHAR \rangle = 10^{-3} \langle SFR \rangle$



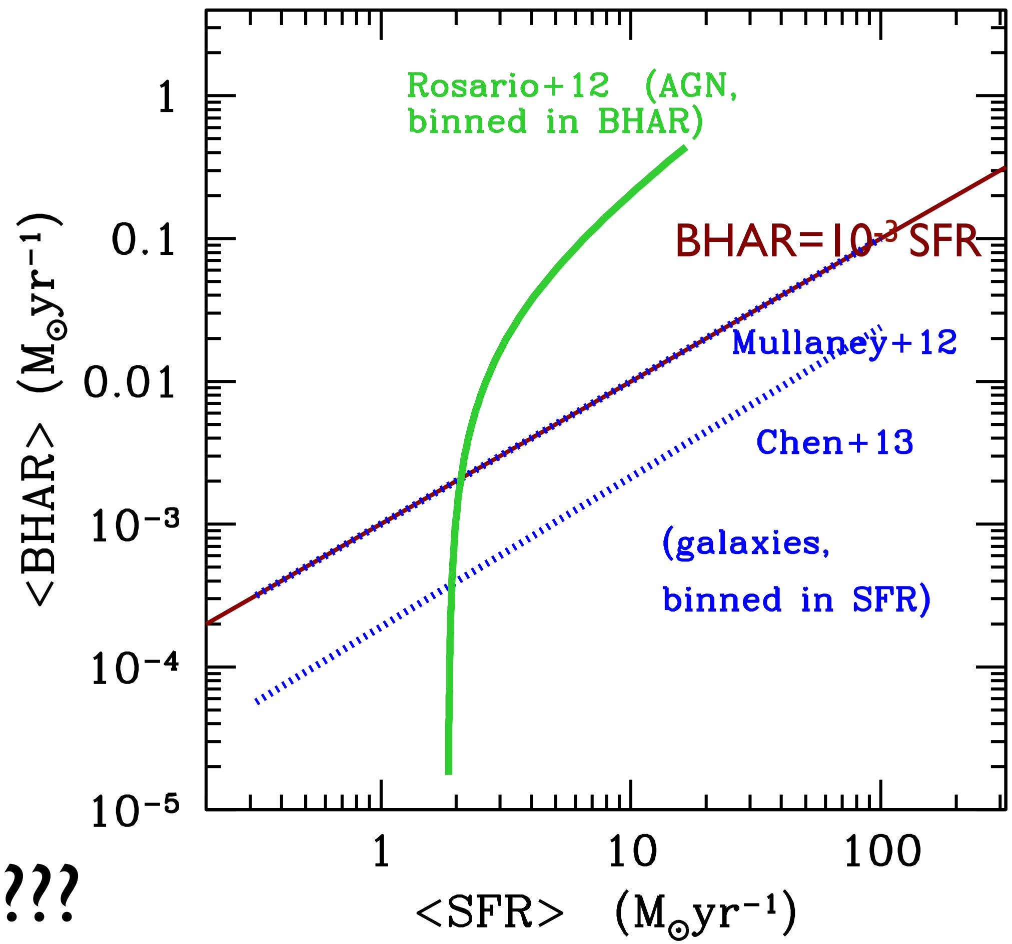
BHAR≠10^{-3} SFR



$\langle$BHAR$\rangle$=10^{-3} $\langle$SFR$\rangle$???

BHAR variability higher than SFR variability (~100 Myr)

Long-term average BHAR is perfectly correlated with the SFR (Hickox+14)



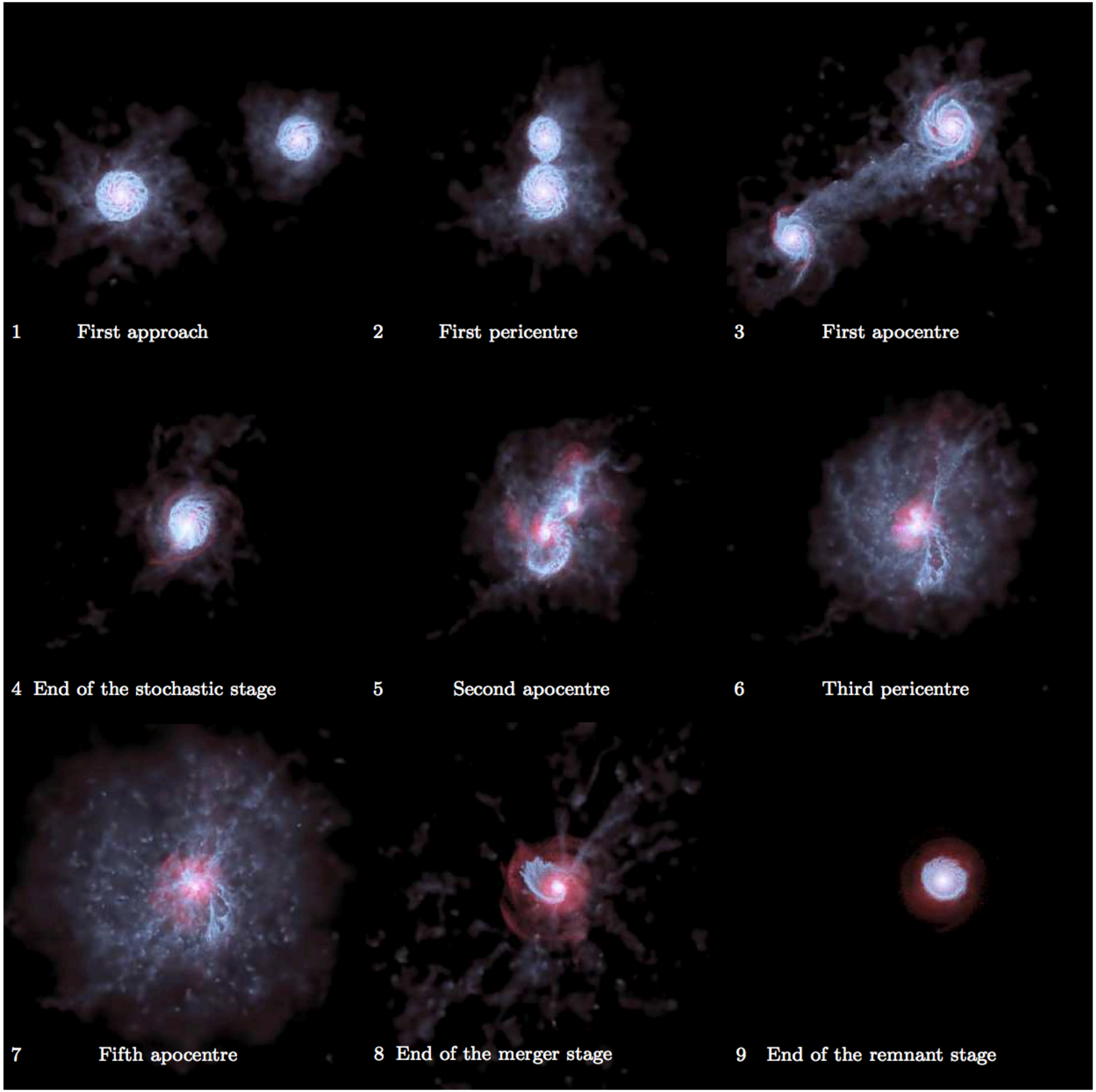
$\langle BHAR \rangle = 10^{-3} \langle SFR \rangle$???

Growing MBHs and galaxies

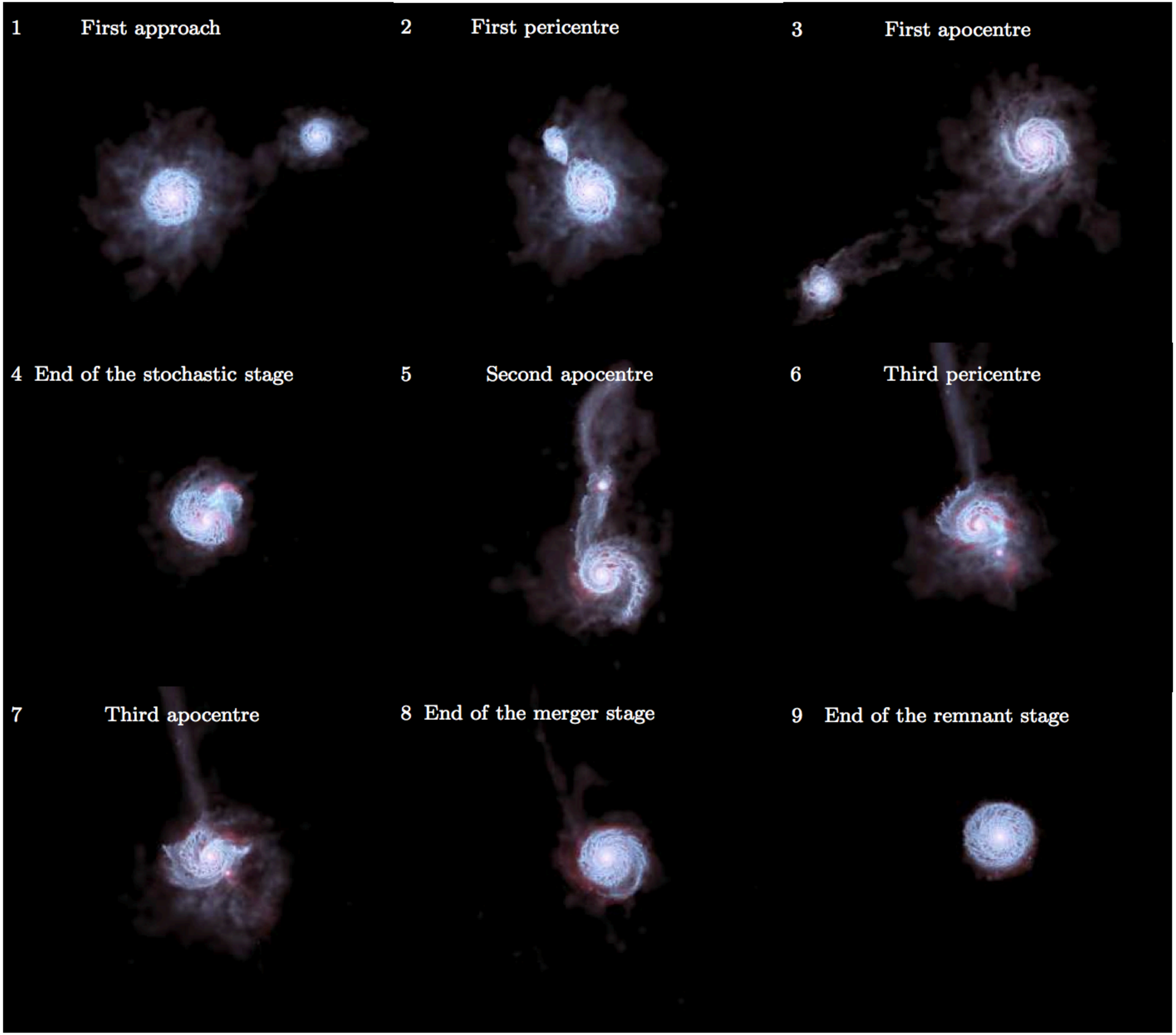
- High spatial (~10 pc) and temporal (0.1-1 Myr) resolution
- Wide range of mass ratios and orbital configurations

Name	Mass ratio (q)	θ_1	θ_2	gas fraction
m1.gf0.3.pro	1:1	0	0	0.3
m2.gf0.3.pro	1:2	0	0	0.3
m2.gf0.3.incl	1:2	$\pi/4$	0	0.3
m2.gf0.3.retprim	1:2	π	0	0.3
m2.gf0.3.retsec	1:2	0	π	0.3
m2.gf0.6.pro	1:2	0	0	0.6
m4.gf0.3.pro	1:4	0	0	0.3
m4.gf0.3.incl	1:4	$\pi/4$	0	0.3
m6.gf0.3.pro	1:6	0	0	0.3
m10.gf0.3.pro	1:10	0	0	0.3

Table 1. Parameters for our simulations. θ_1 and θ_2 are the angles between the spin axis and the total orbital angular momentum axis for each galaxy. q is the initial mass ratio between the merging galaxies.

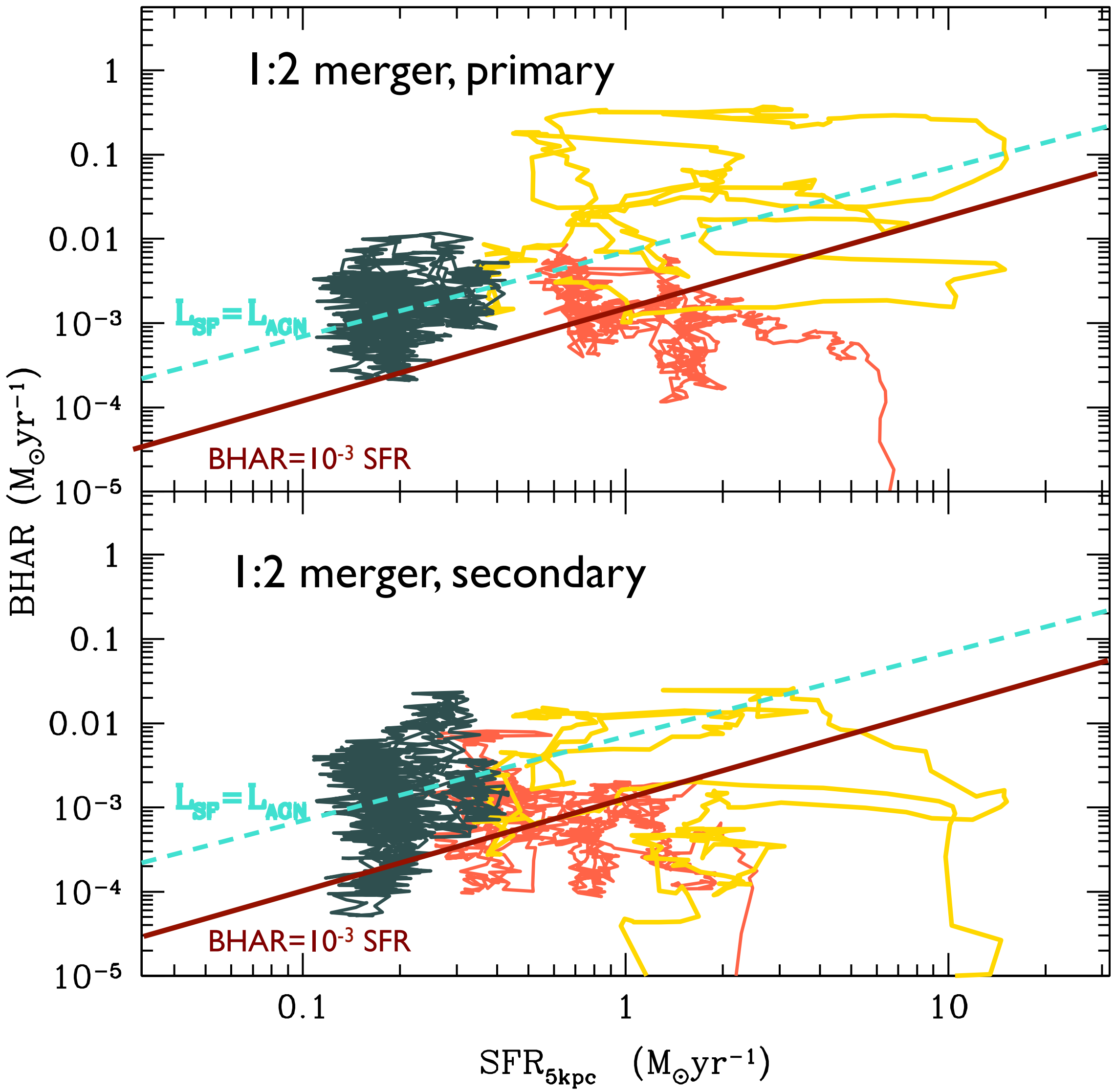


mass ratio
1:2



mass ratio
1:6

Tracking BHAR vs SFR



Before the merger:

- BHAR~10^{-3} SFR
- galaxies are SF dominated

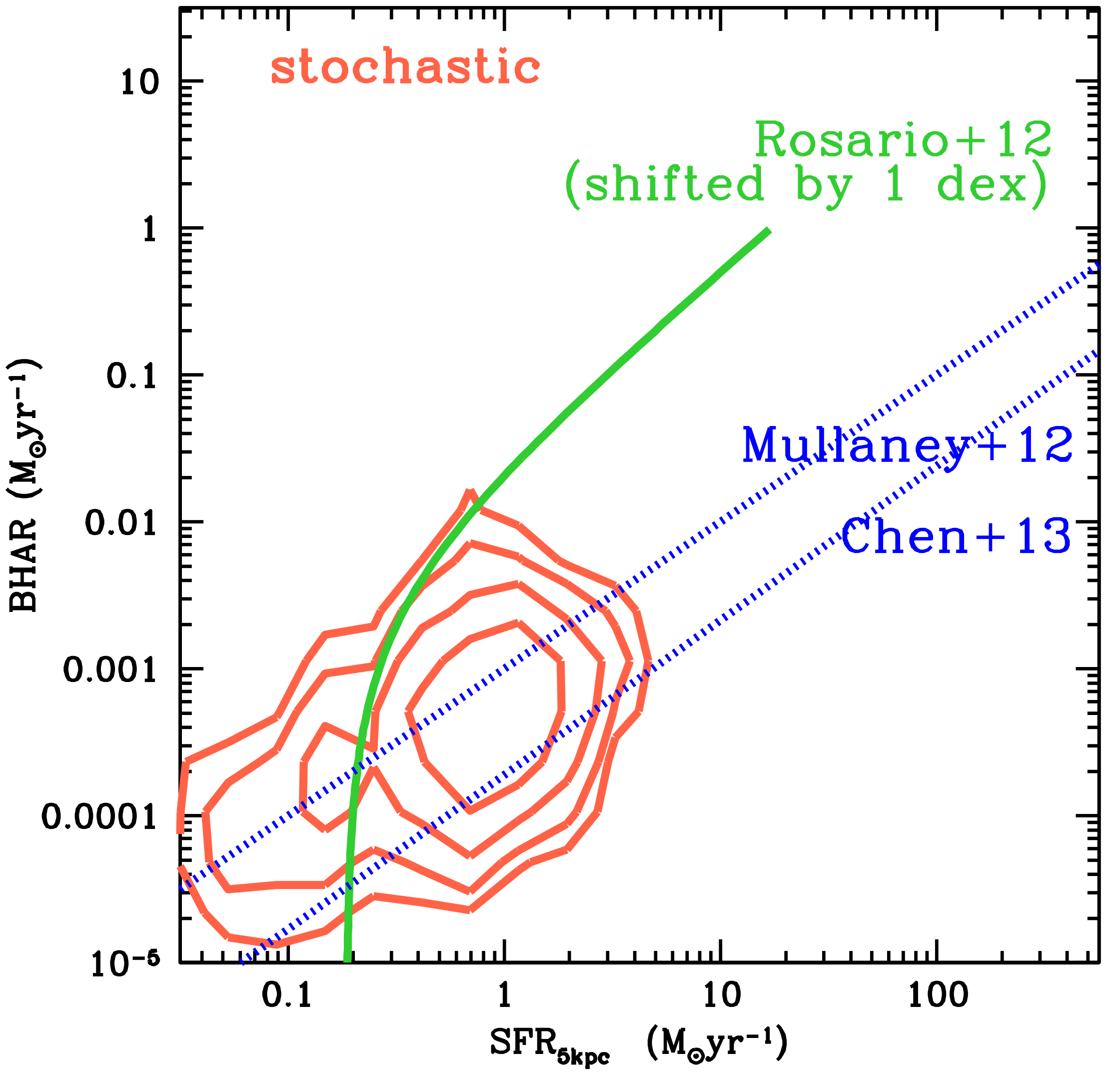
During the merger:

- complex and chaotic behaviour

After the merger:

- initially BHAR>10^{-3} SFR
- between the AGN and the SF dominated regions

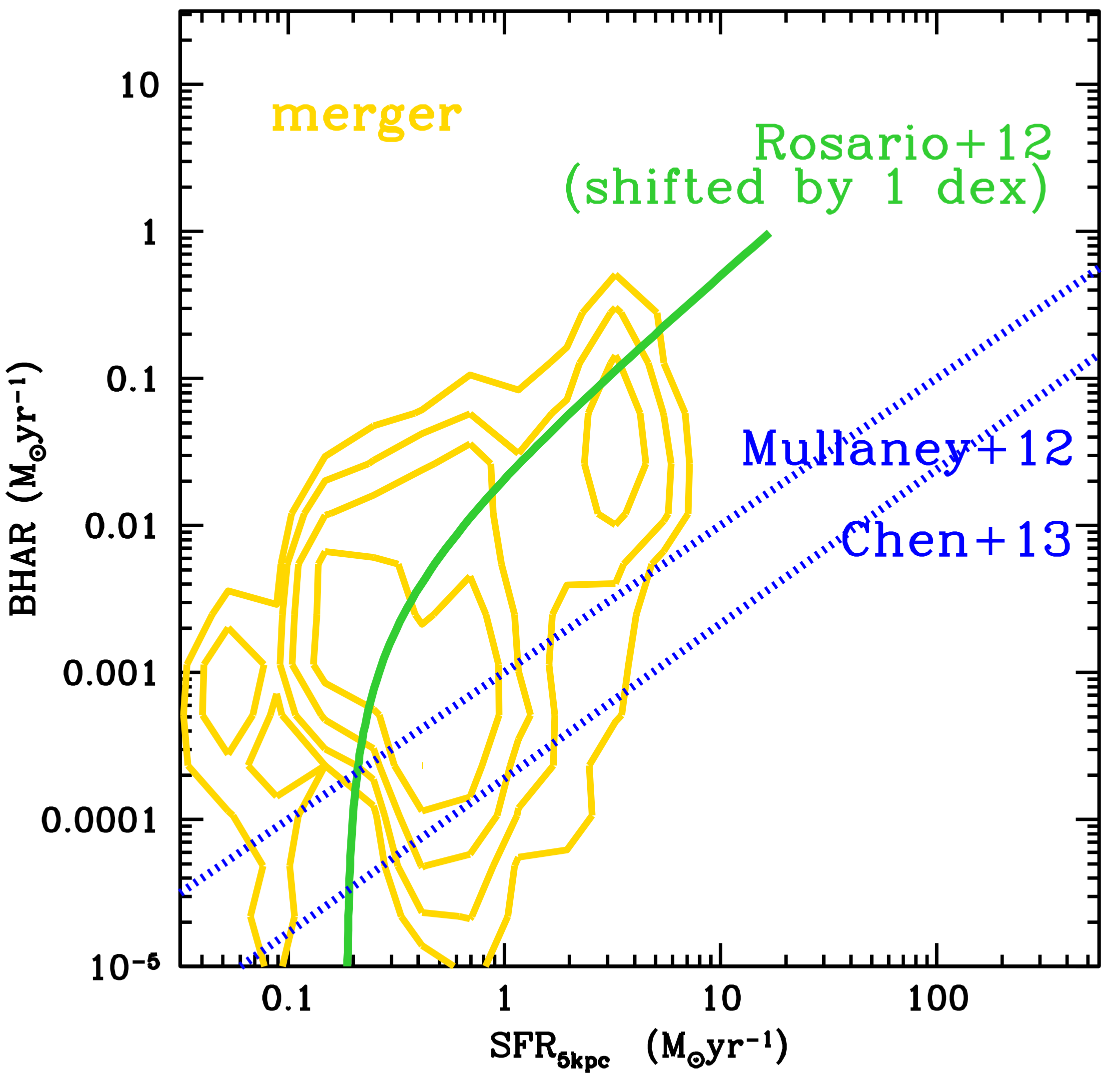
Growing MBHs and galaxies



Before the merger: region between the relations found for star-forming galaxies

Volonteri+15

Growing MBHs and galaxies

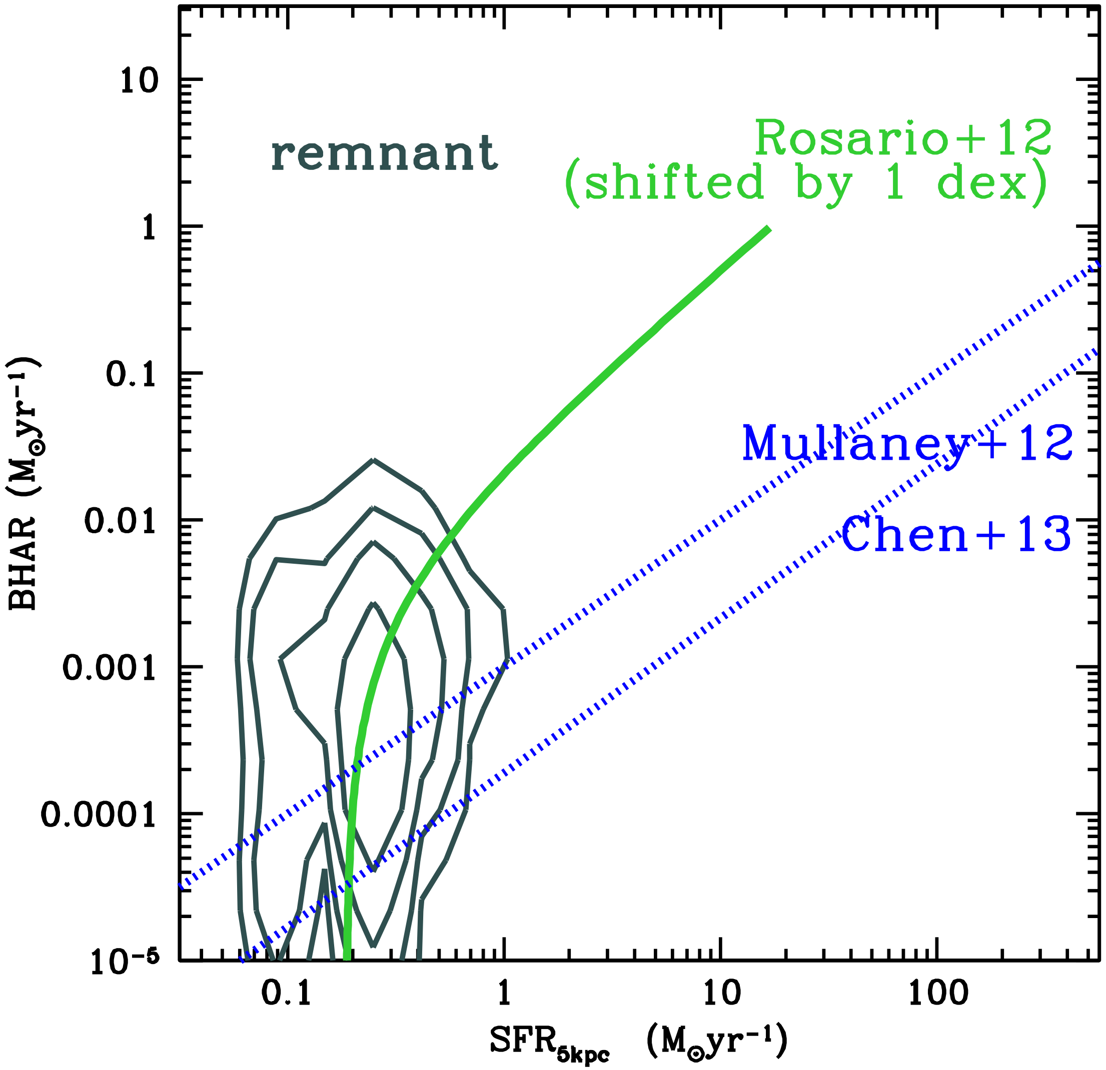


During the merger (200-300 Myr):

- approach the upper part of the curves for AGN
- BHAR and SFR driven by same global dynamics

Volonteri+15

Growing MBHs and galaxies



After the merger:

- lower part of the AGN curve
- a wide range of BHAR can be associated to a given SFR

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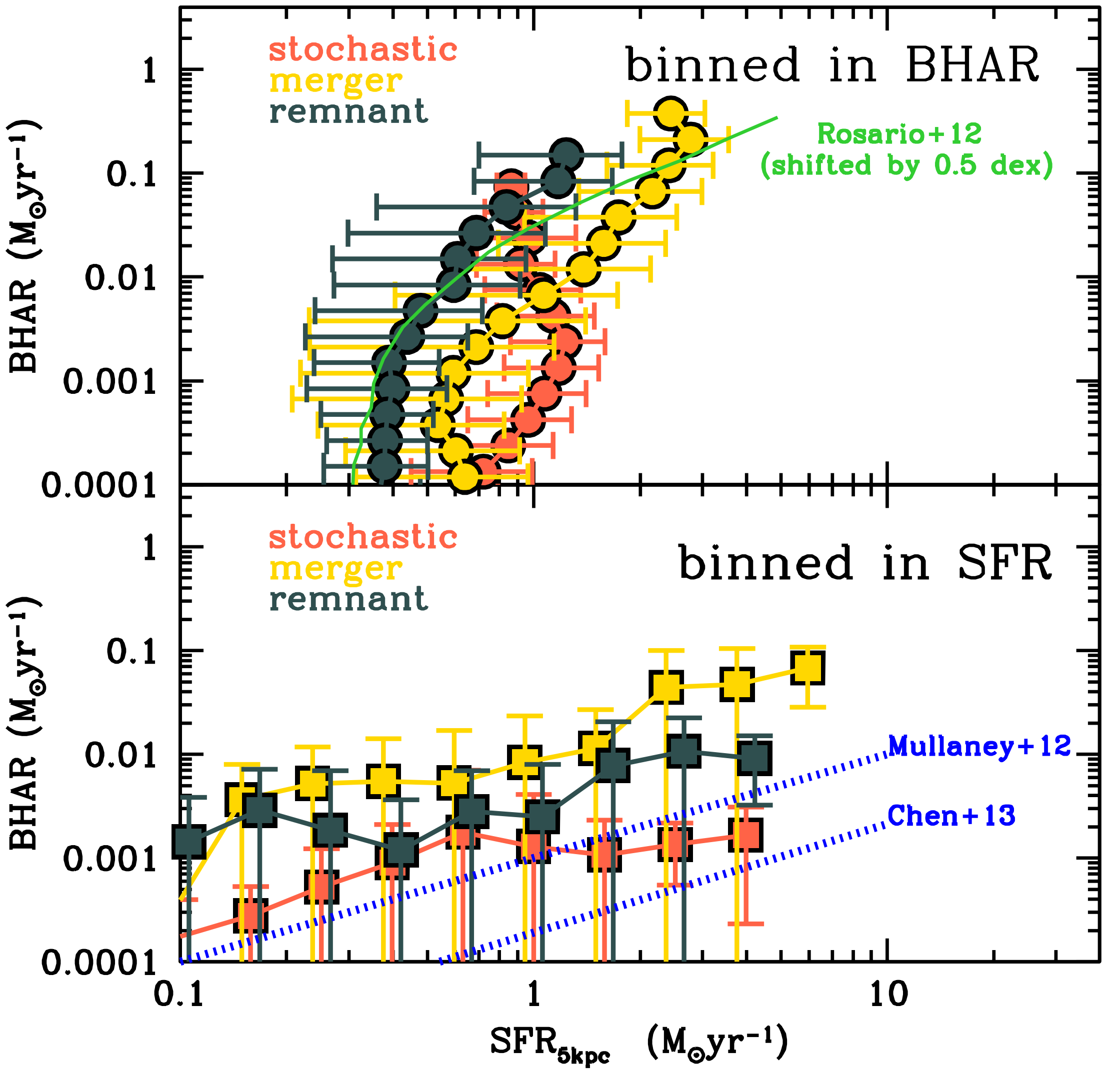
BHAR versus SFR using binned data



Mean SFR in bins of BHAR (Rosario, AGN)

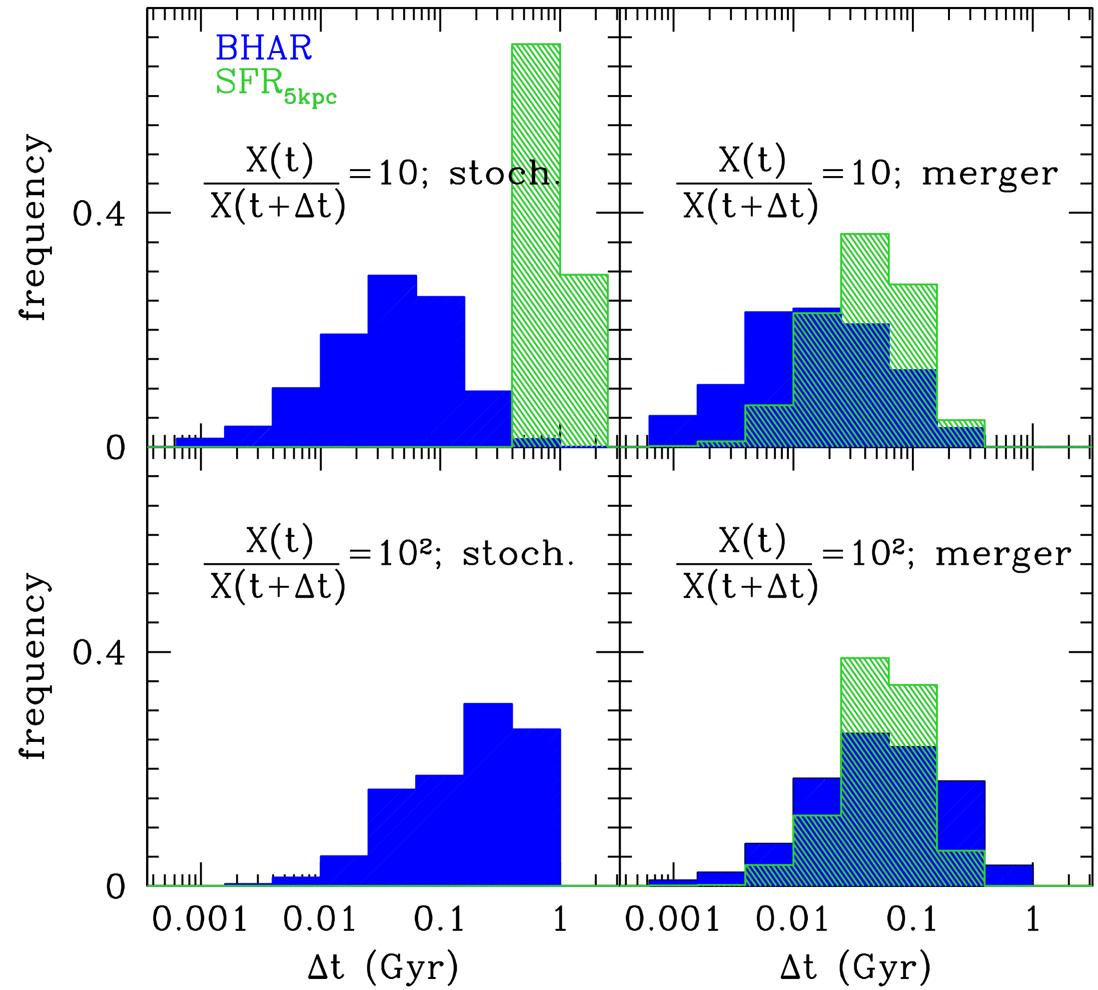
Mean BHAR in bins of SFR (Chen, Mullaney, galaxies)

The different trends found for AGN and SF galaxies are *partly* caused by the different projections of the full bivariate distribution

Volonteri+15

BHAR variability higher than SFR variability (~100 Myr)

Long-term average BHAR is perfectly correlated with the SFR (Hickox+14)



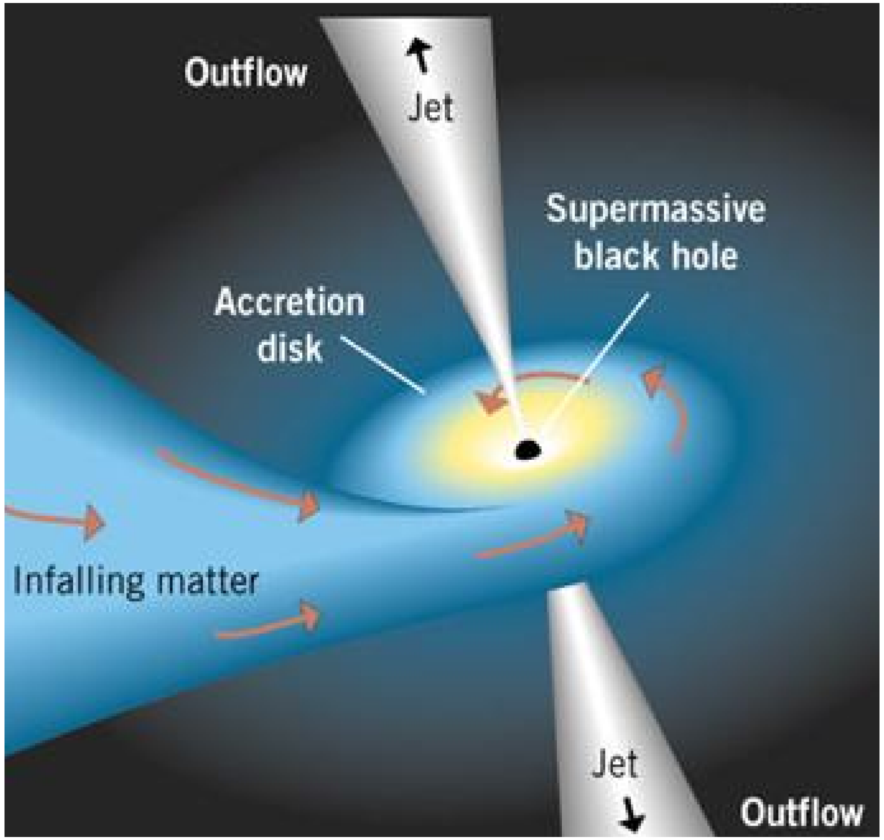
Growing MBHs and galaxies

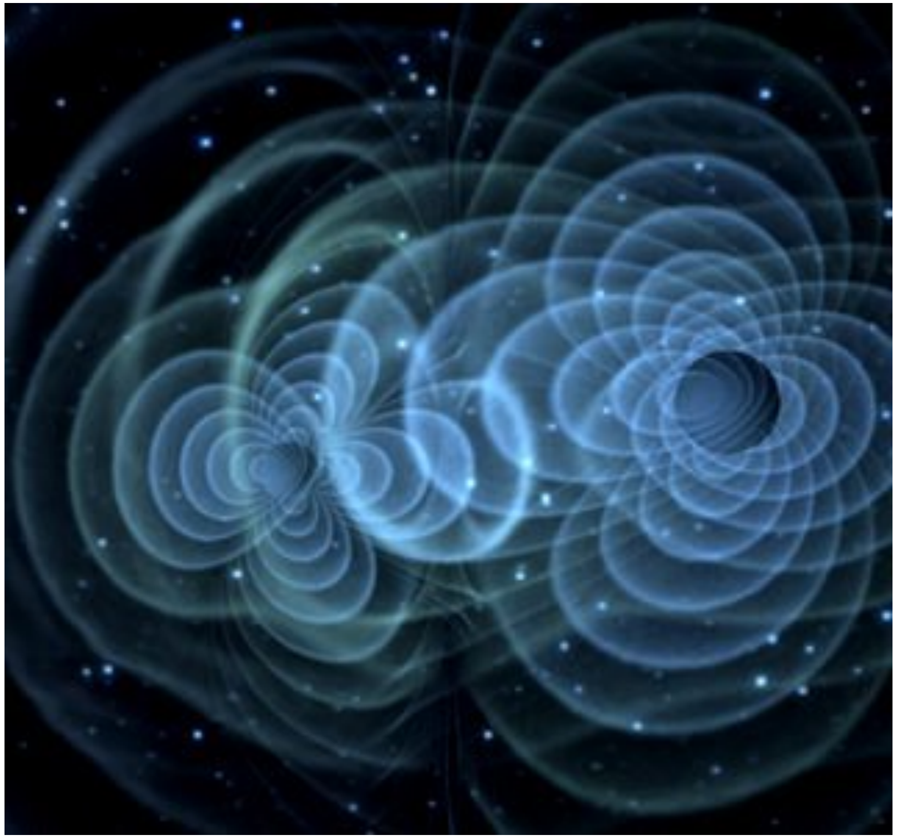
Starting from an *AGN parent sample* one studies the direct link between BHAR and SFR for galaxies in an active phase

Starting from a *galaxy parent sample* one studies MBH-galaxy co-evolution over cosmic time and the whole population

How do MBHs grow ?

Gas accretion vs MBH-MBH mergers





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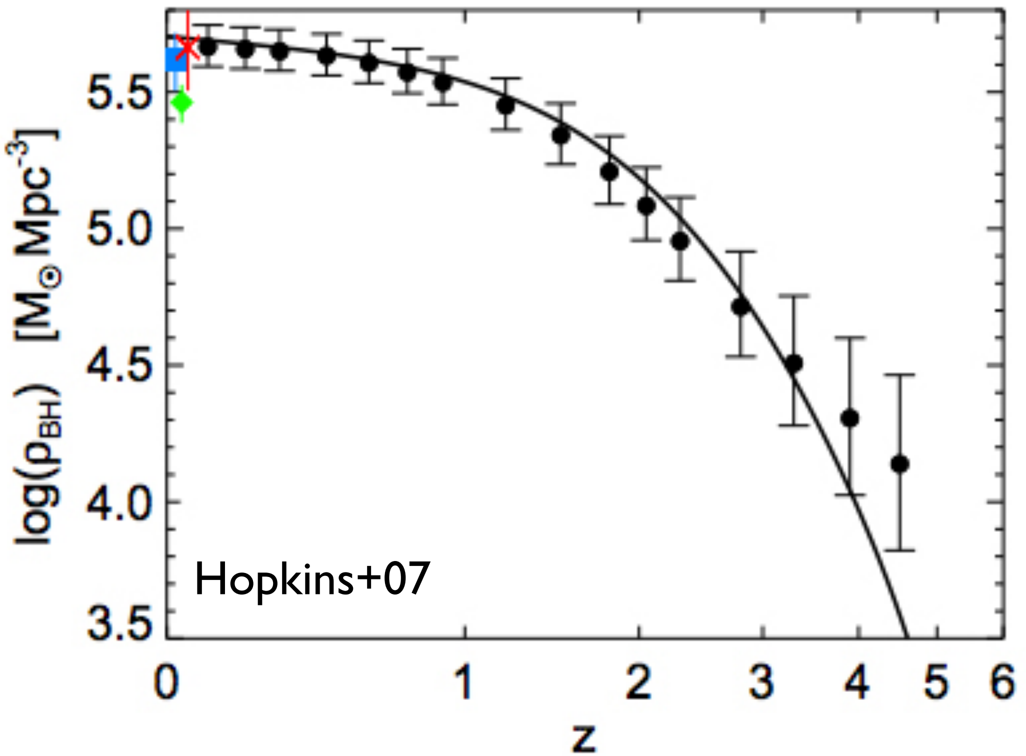


Mergers: total mass density in MBHs is constant in time: just reshuffle the distribution of masses

Accretion: adds external matter => total mass density in MBHs grows with time

Soltan's argument:
BH mass density increases by > one order of magnitude in the last ~10 Gyr: **accretion** leads

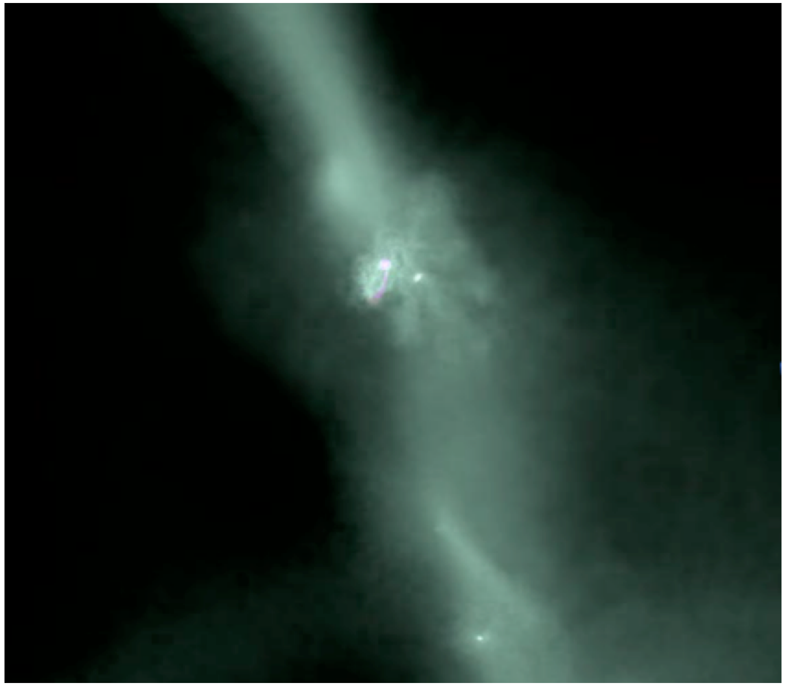
Yu & Tremaine 2002

How do *galaxies* get their gas?

Streams of gas from filaments feed the galaxy with large amounts of fresh material

Low-mass galaxies simply accrete cold diffuse gas

In massive galaxies, when gas enters the virial radius, shocks, and then falls in to the disk.
Cold collimated filaments can sometimes penetrate the shock



Bellovary, Brooks, MV et al 2013

How do *galaxies* get their gas?

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Of course, mergers deliver gas as well (clumpy)

Bellovary, Brooks, MV et al 2013

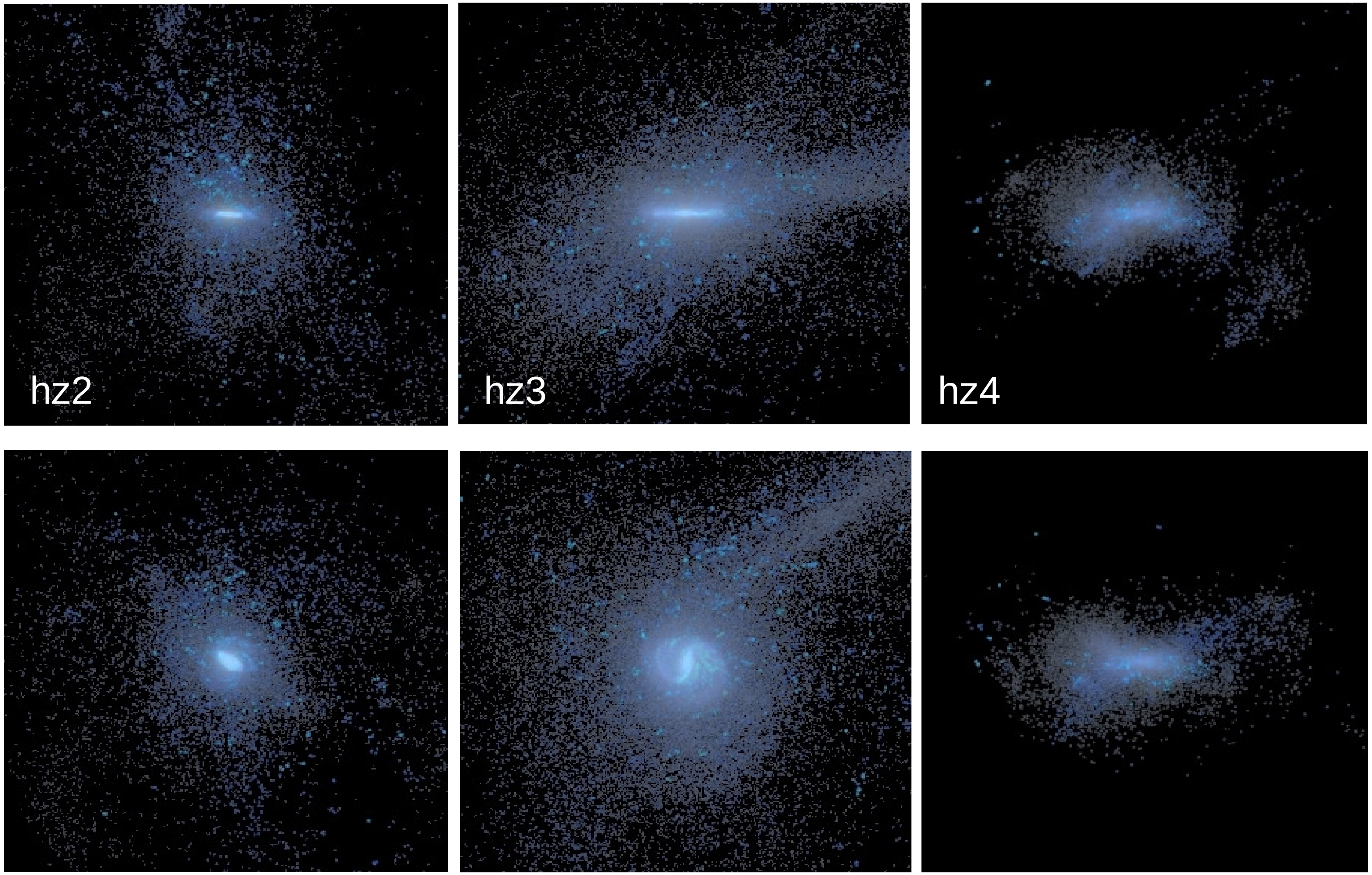
How do *galaxies* get their gas?

- Cold accretion
  - low mass, filaments
- Shocked accretion
  - high mass
- Clumpy accretion
  - mergers

Bellovary, Brooks, MV et al 2013

High-z MBHs and galaxies

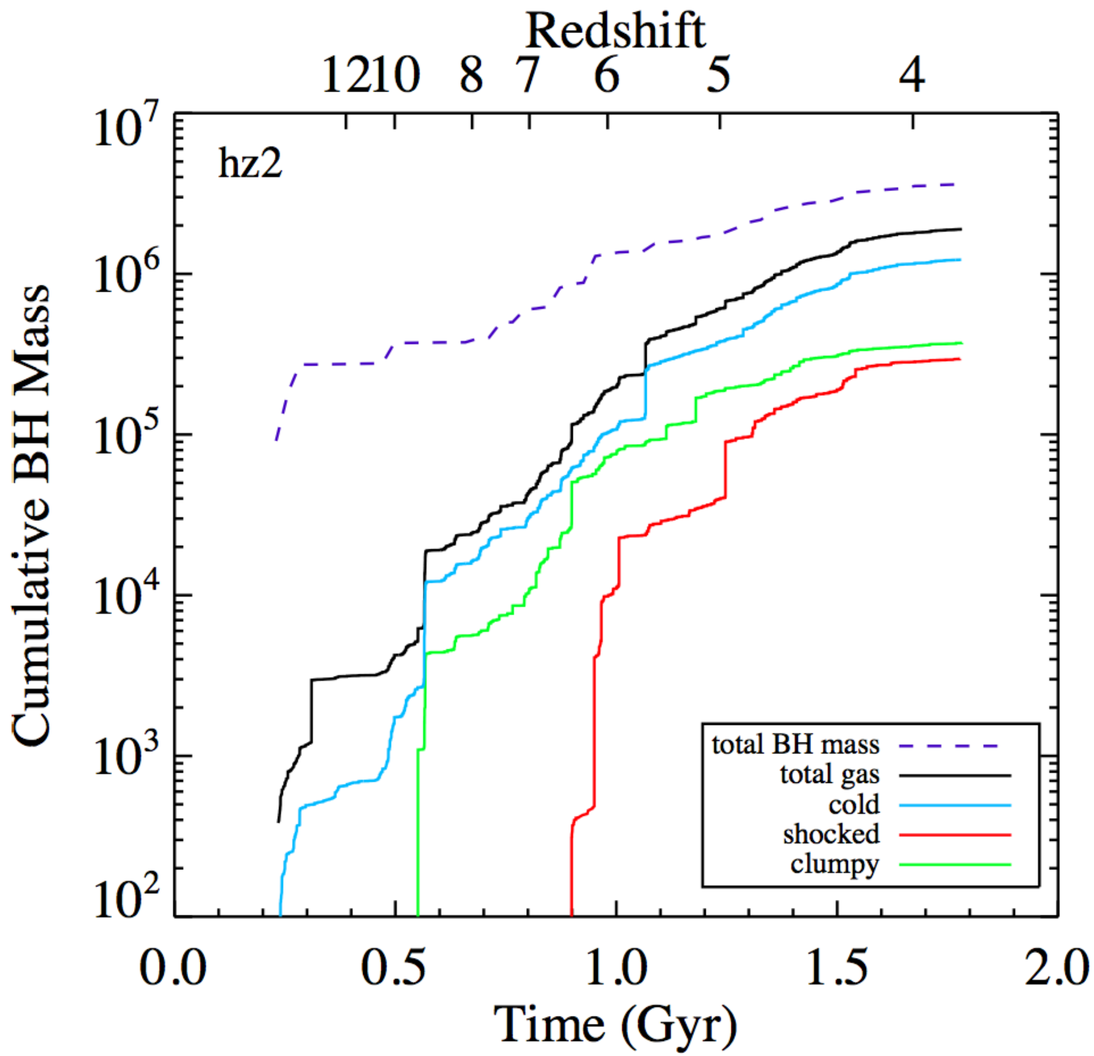
z = 4



z = 4 Stellar mass (M_{sun})	1.63×10^{10}	2.06×10^{10}	9.64×10^{8}

Bellovary, Brooks, MV et al 2013

High-z MBHs and galaxies



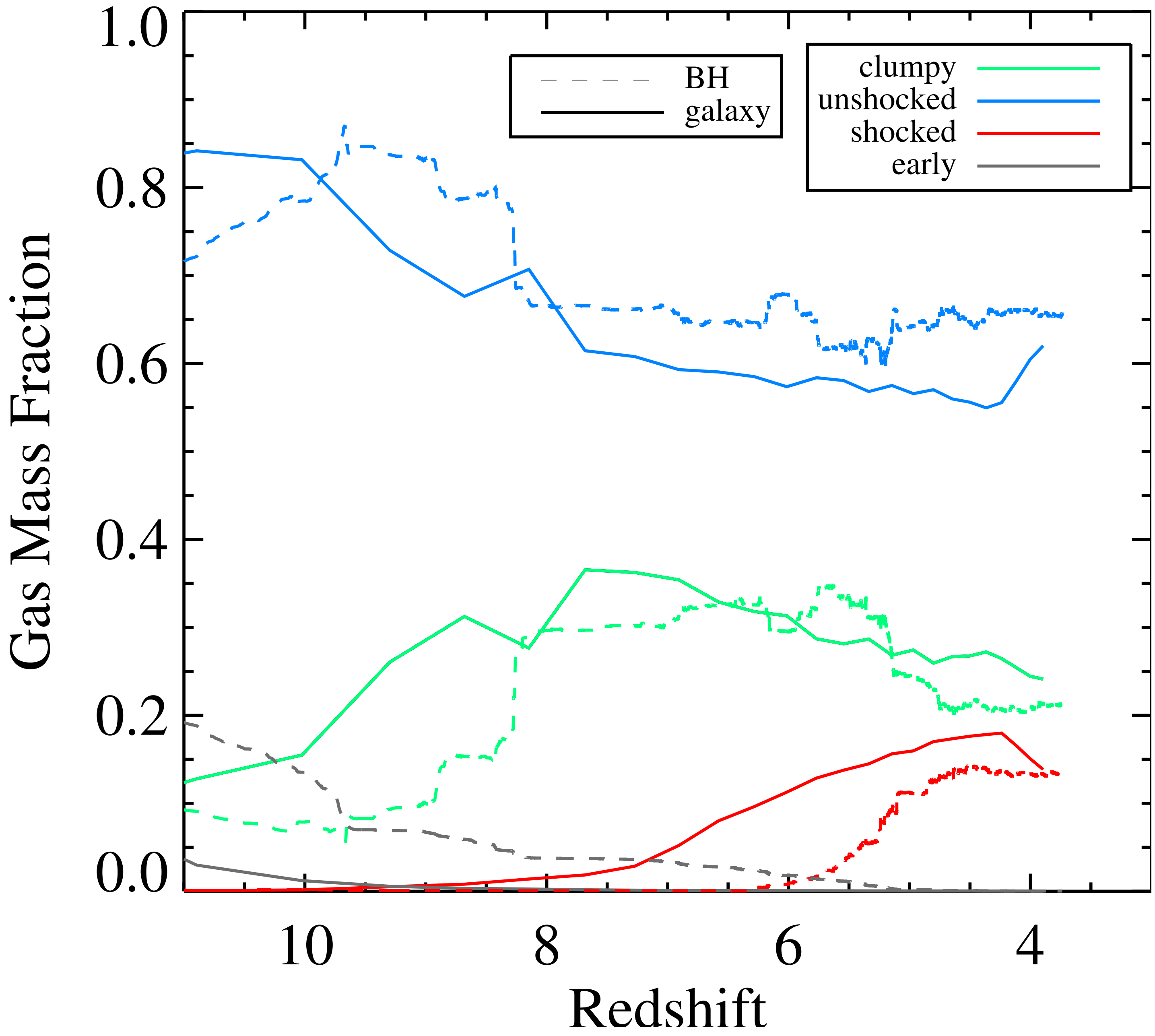
- cold streams of gas plunge into halos

- in massive halos gas gets shock heated before it reaches the central regions

- galaxy mergers trigger nuclear inflows of low angular momentum gas

Bellovary, Brooks, MV et al 2013

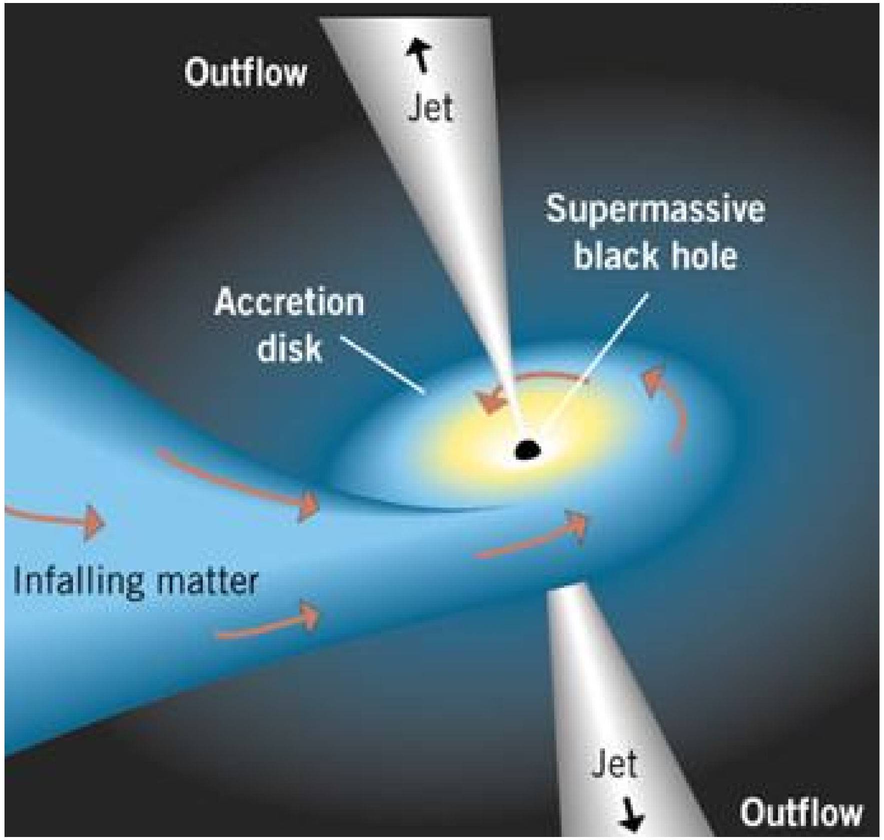
High-z MBHs and galaxies

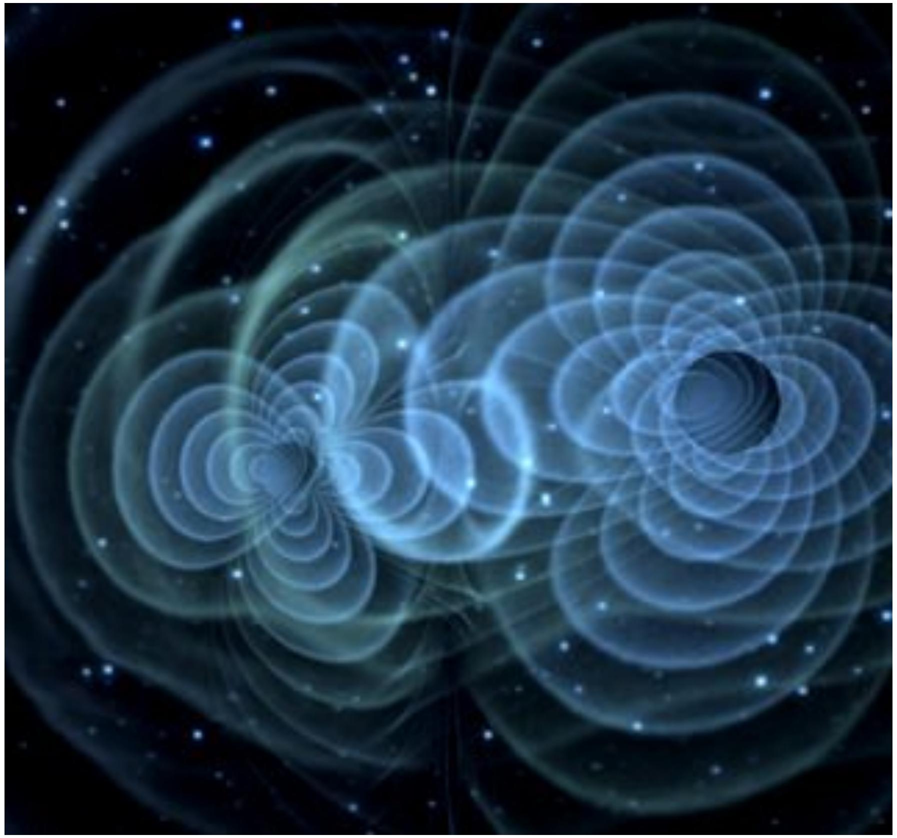


Composition of galaxy = composition of MBH

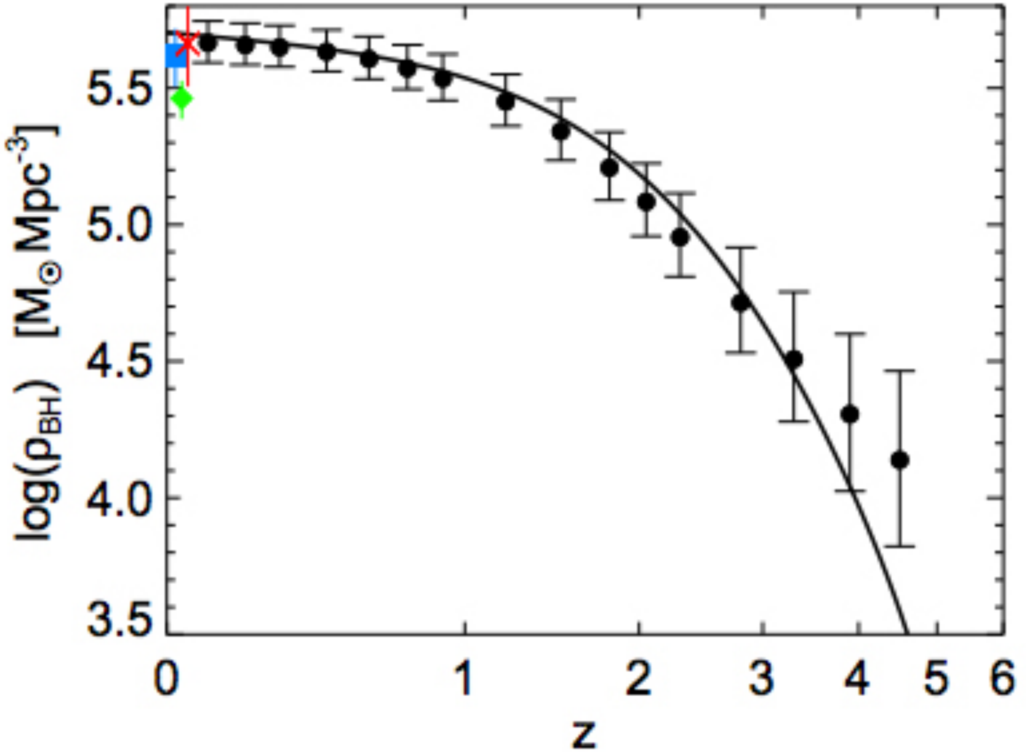
Bellovary, Brooks, MV et al 2013

How do MBHs grow ?
Gas accretion vs MBH-MBH mergers





How do MBHs grow ?
Gas accretion vs MBH-MBH mergers



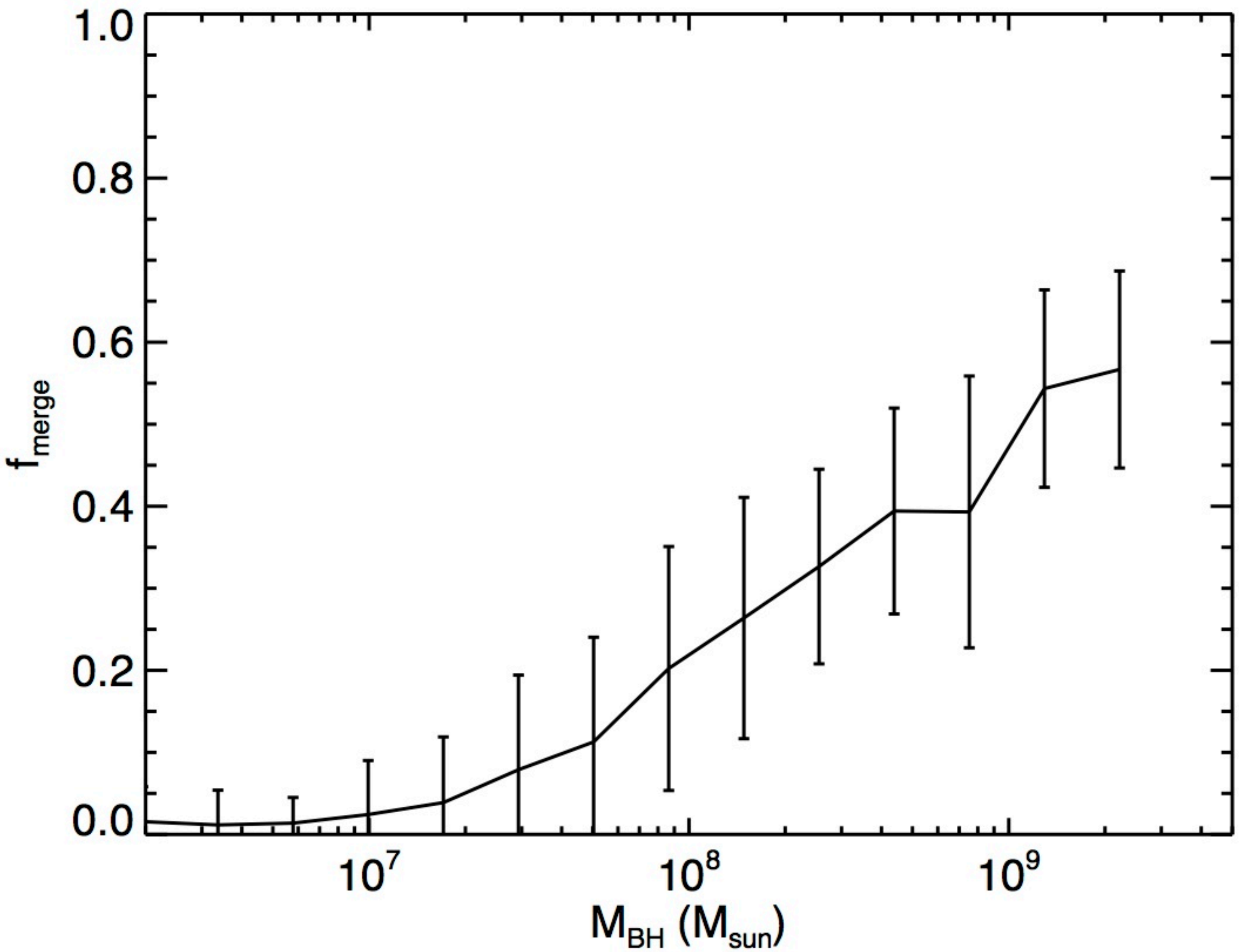
Mergers: total mass density in MBHs is constant in time: just reshuffle the distribution of masses

Accretion: adds external matter => total mass density in MBHs grows with time

Soltan's argument: $$\rho_{acc,tot,QSO}(z) = \frac{1-\epsilon}{\epsilon c^2}\int_z^\infty \left|\frac{dt}{dz}\right| dz \int_0^\infty \Phi(L,z) L dL$$

mass density increases by > one order of magnitude in the last ~10 Gyr: **accretion** leads

Are MBH-MBH mergers ever important?



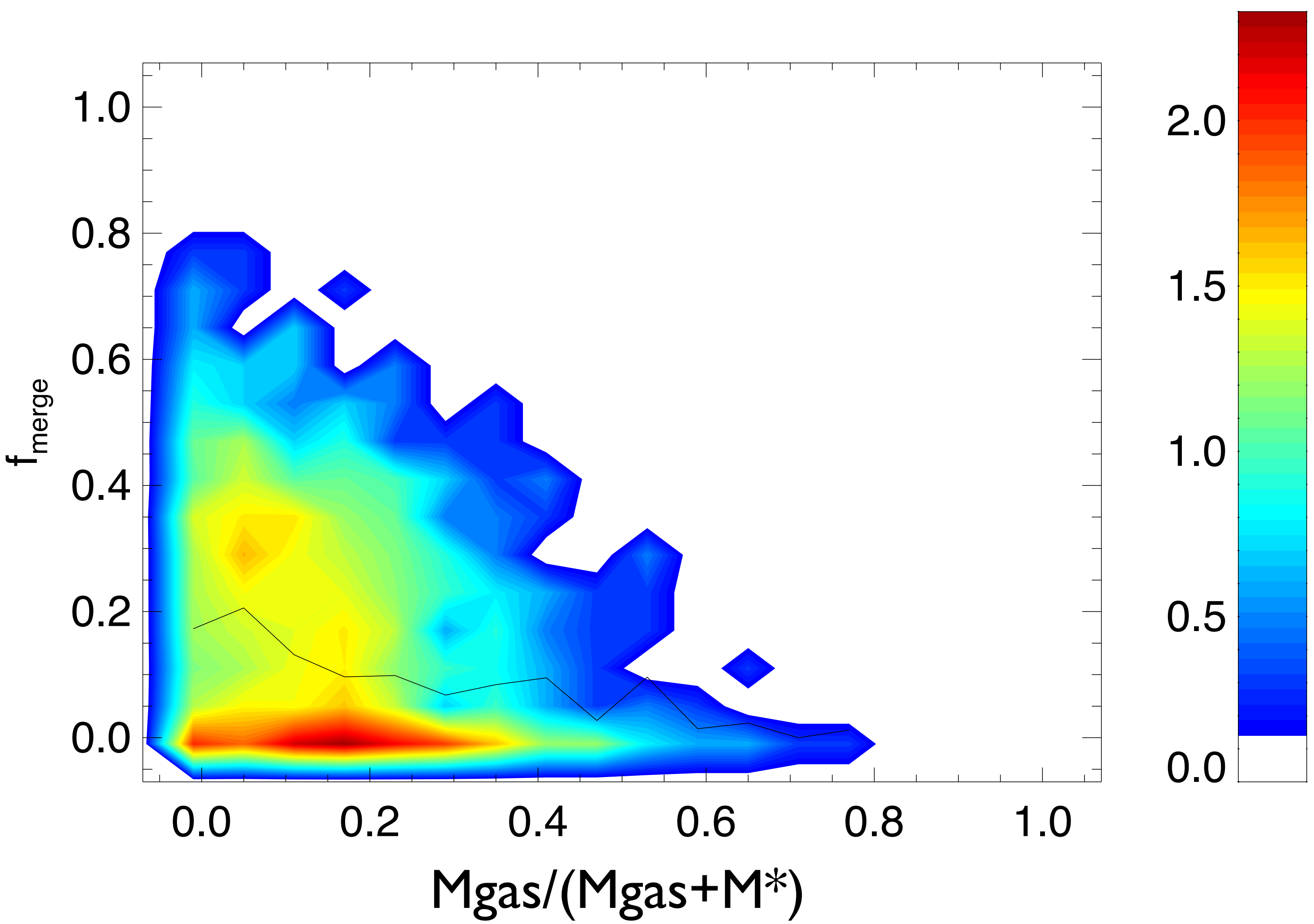
High-mass MBHs!

Fraction of mass gained through MBH-MBH mergers: $f_{merge}=\Delta M_{merge}/M_{BH}$

ΔMmerge is the sum of the masses of all merged MBHs and does not account for gas accretion on these MBHs

Dubois, Volonteri & Silk 2013

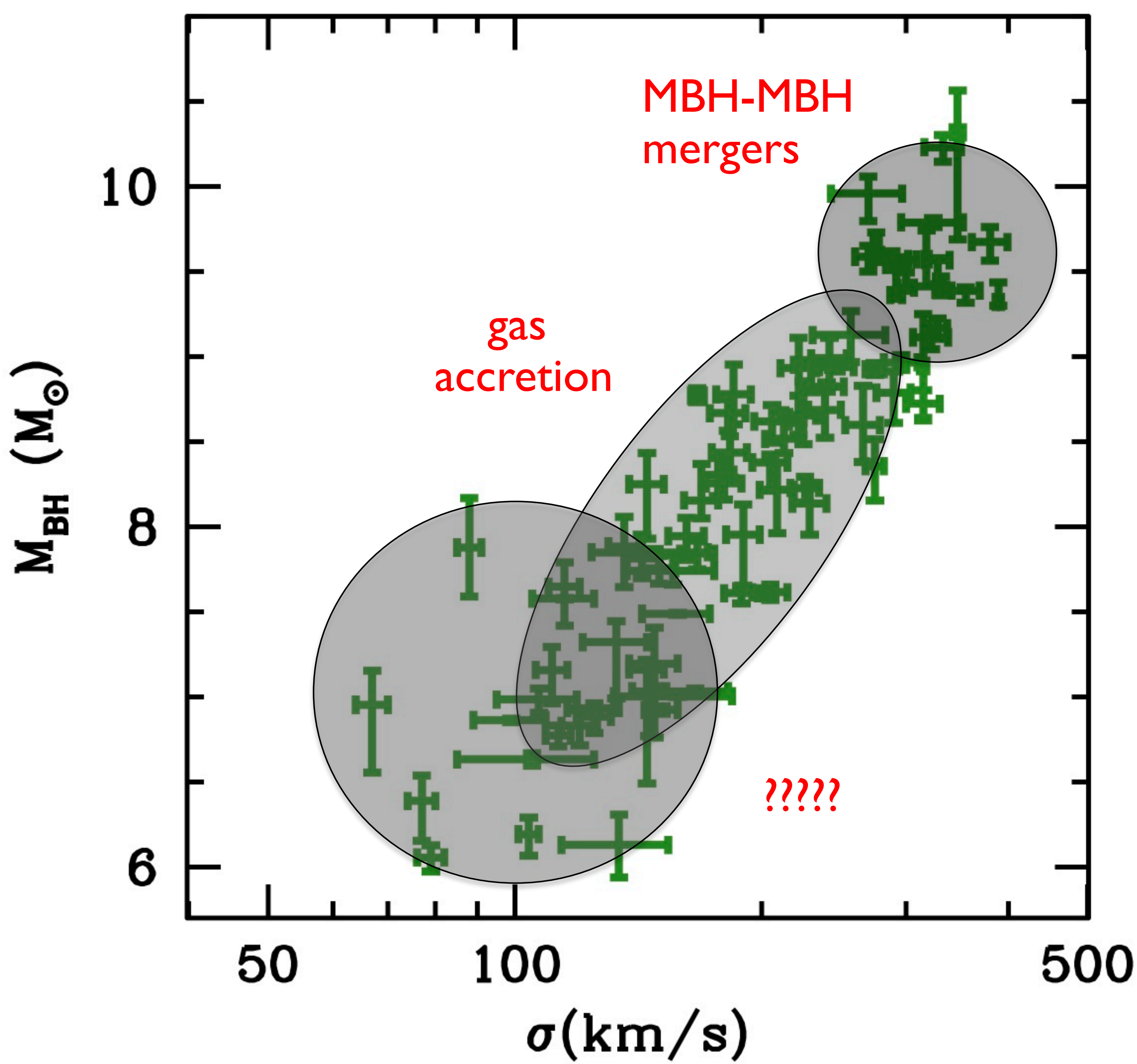
Are MBH-MBH mergers ever important?



Gas-poor galaxies!

Fraction of mass gained through MBH-MBH mergers $f_{merge} = \Delta Mmerge/M_{BH}$

Dubois, Volonteri & Silk 2013



MBH-MBH
mergers
gas
accretion
?????
10
8
6
M_{BH} ($M_\odot$)
50
100
500
σ(km/s)

Dwarf galaxies

Composition of galaxy = composition of MBH

Dwarf galaxies do not grow much in mass (doh!)

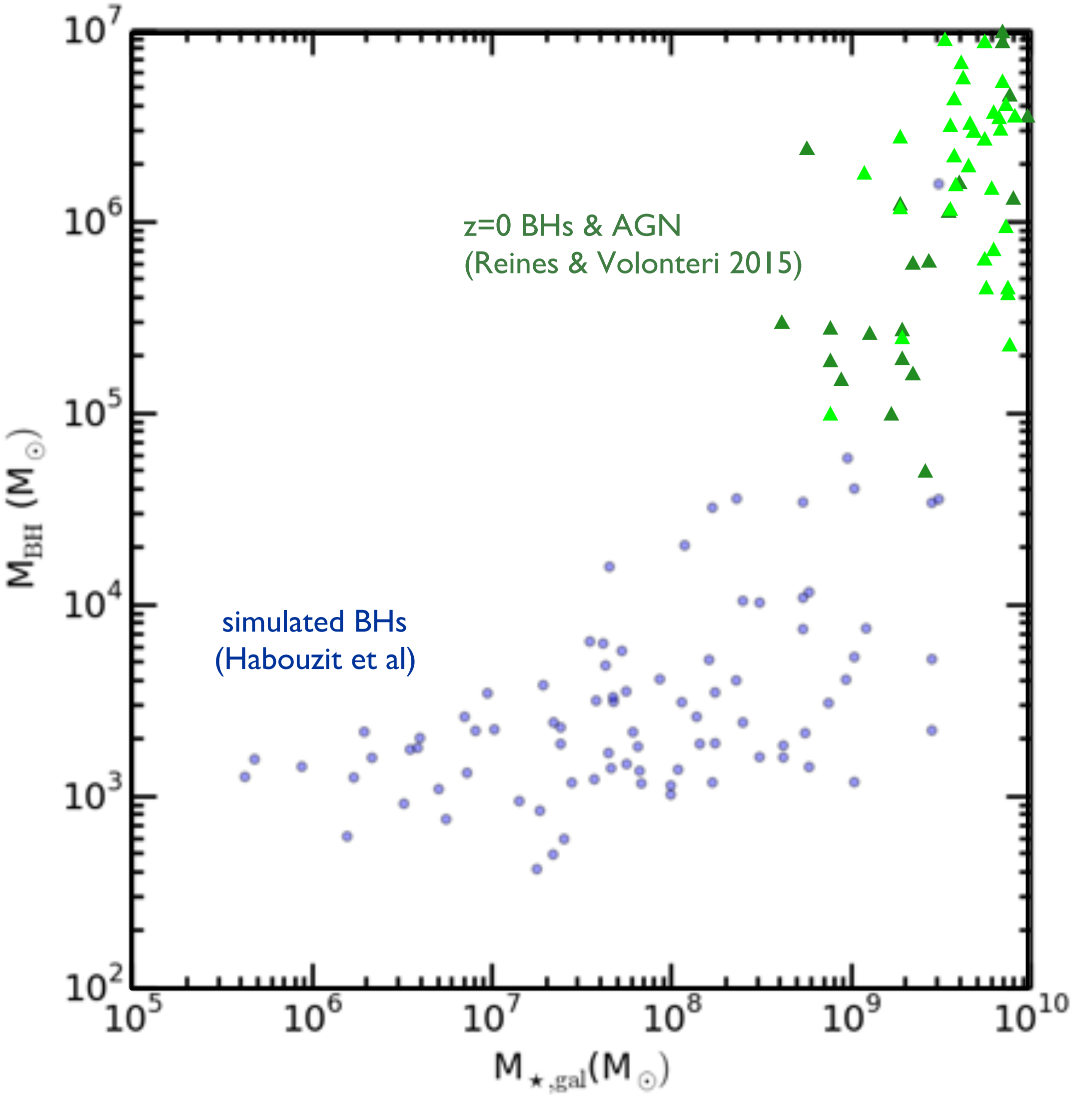
Not many mergers

The MBH (if any) has not grown much either

Trace the mass of the initial “seed”

M_{BH}-M_{gal} @ low mass

(MV+08, Van Wassenhove, MV et al. 2010, Habouzit, MV+ in prep)

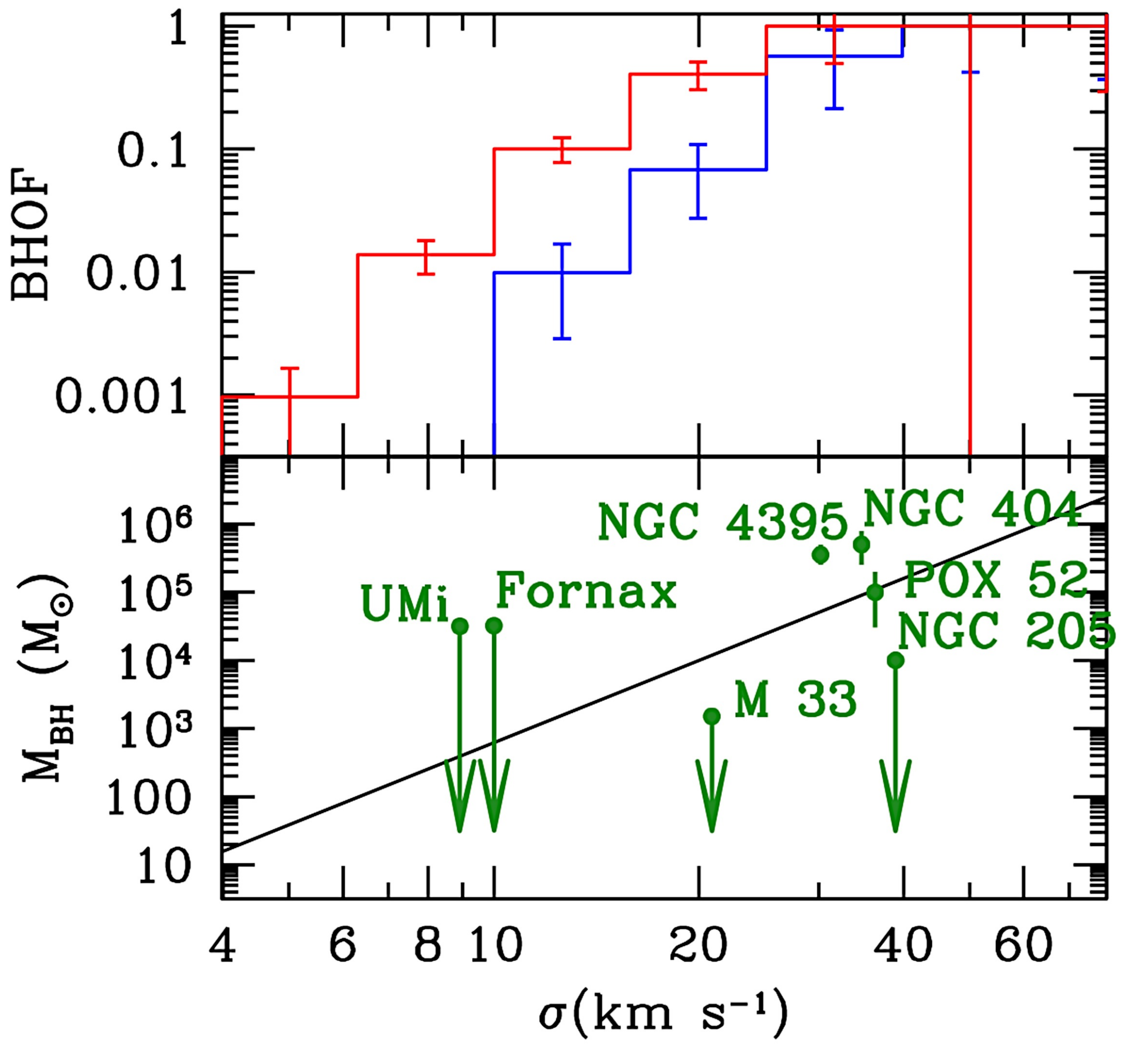


MBHs in the smallest galaxies “stuck” at mass close to initial one

AMR RAMSES simulation, 10 Mpc box, Δx=75 pc

Low-mass galaxies

(MV+08, Van Wassenhove, MV et al. 2010)



Note: MBH formation models predict that many low-mass galaxies do **NOT** host MBHs

Gas-dynamical collapse

PopIII remnants

MBH-galaxy connection

- MBHs feed on what their host is able to provide them
- MBHs and galaxies not always grow in tandem
- At the high-mass where gas is unavailable MBH mergers become important
- At the low-mass end relationship may break down and trace MBH formation properties rather than co-evolution with galaxy host