Title: Growth of supermassive black holes and their relationships to their host galaxies

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Abstract: Black holes are the engines that power quasars and active galactic nuclei throughout cosmic time. The masses of black holes in nearby galaxies define clear correlations with the properties of their host galaxies. These results suggest that black holes, while a thousand times lighter than the galaxy, grow alongside their hosts during its cosmic evolution. I will discuss the growth of black holes, and the establishment of the connection between galaxies and black holes.

Massive Black Holes and their host galaxies

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Quasars and AGN

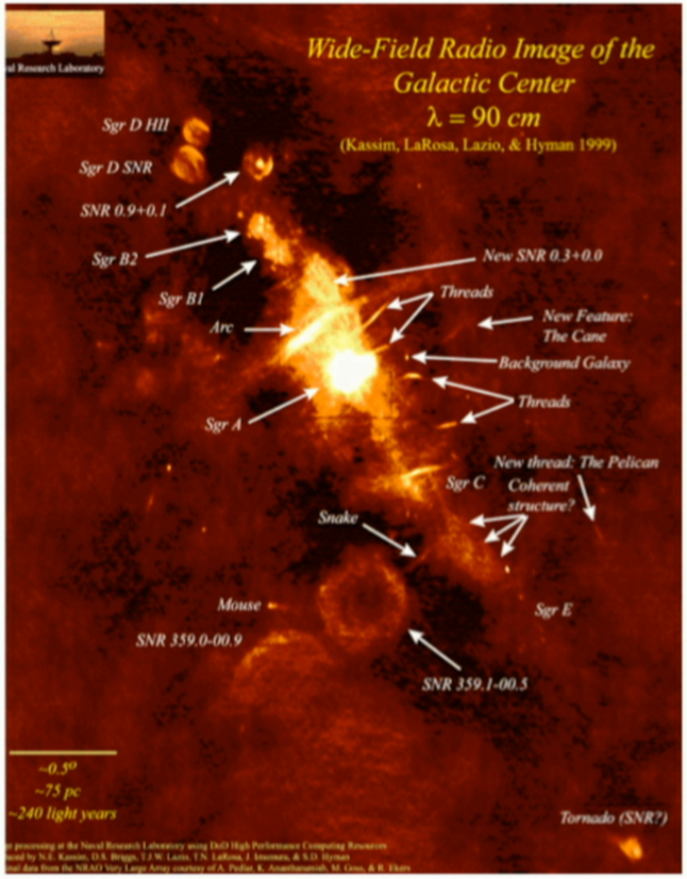
Point-like, or star-like, radio sources which varied rapidly:`quasi-stellar' radio sources or quasars.

The quasar 3C273 is 640 Mpc~2.6 billion light years away.

The luminosity of 3C273 is more than 100 times the luminosity of our entire galaxy.

Quiescent MBHs

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



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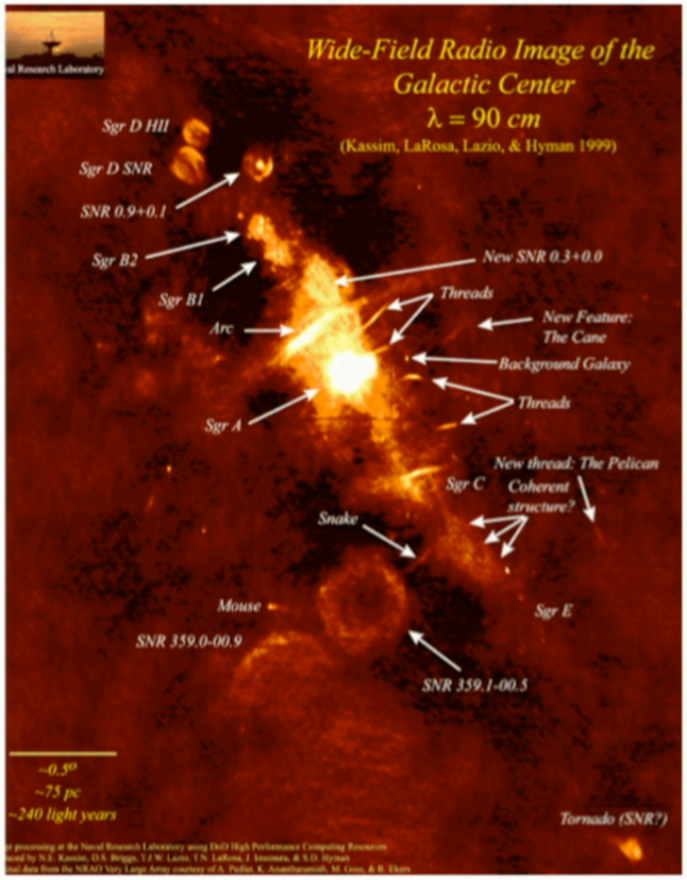
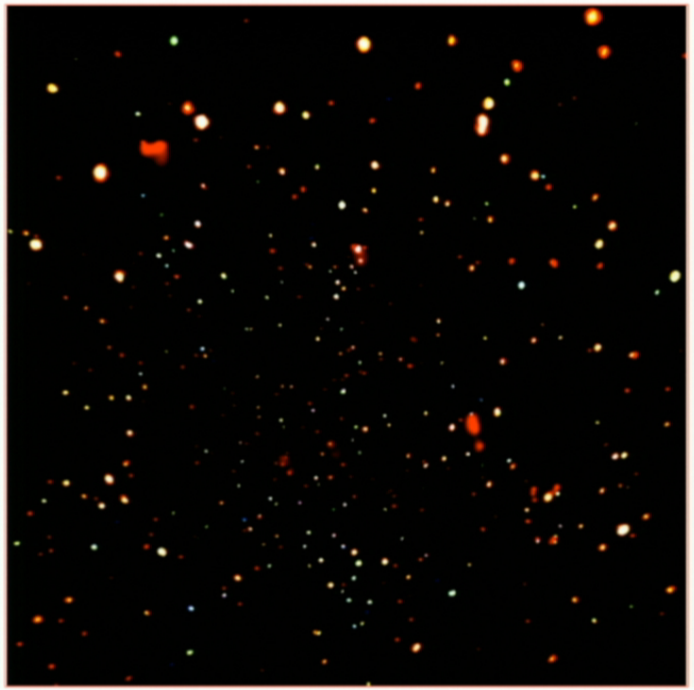
The typical luminosity coming from the very center, Sgr A*, is ~10^{34} erg/s.

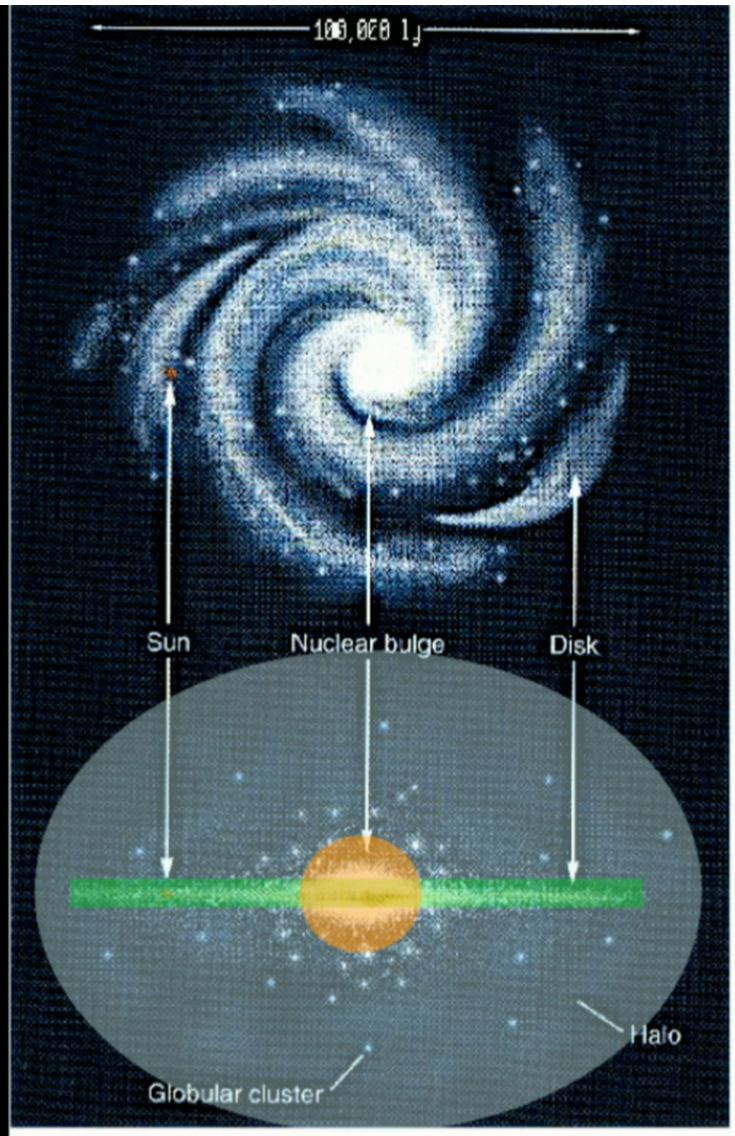


Massive black holes out there....

Hubble Deep Field
visible light – starlight
all galaxies
"black" black holes?



Chandra Deep Field
X-ray – high energy processes
quasars and active
galactic nuclei (AGN)



Galaxies

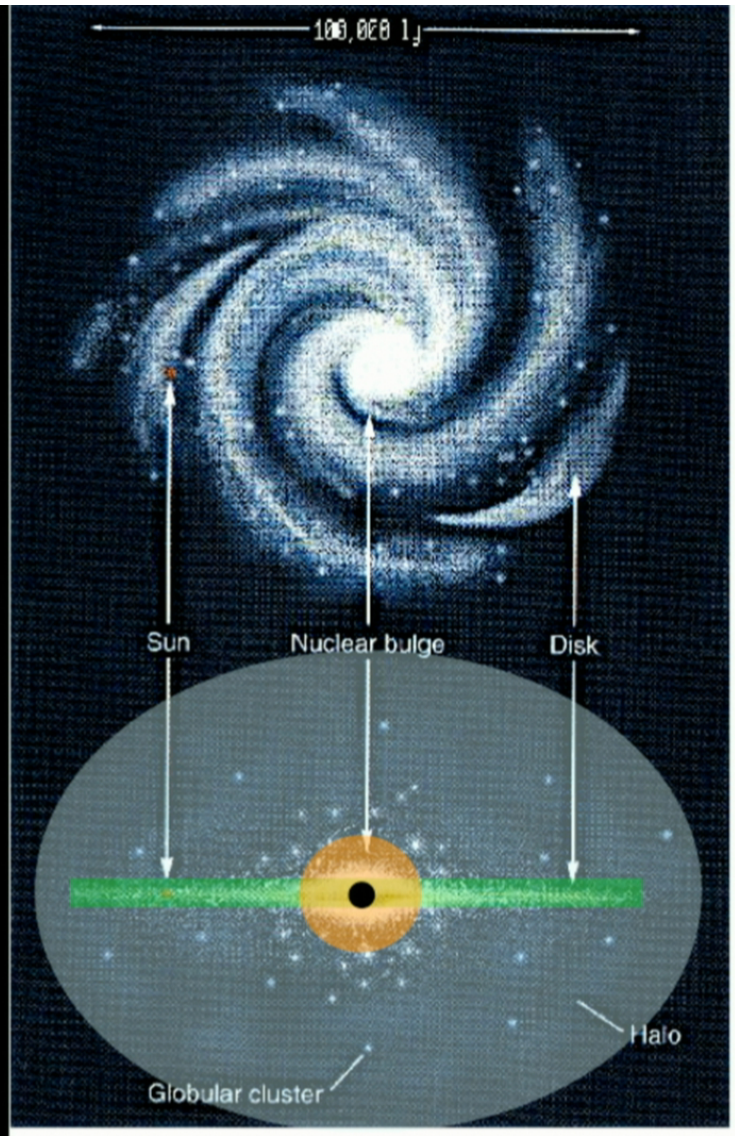
mass: 10^9-10^{12} solar masses

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

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

1 parsec=3.26 light years=3×10^{18} cm

σ ~50-300 km/s for most galaxies



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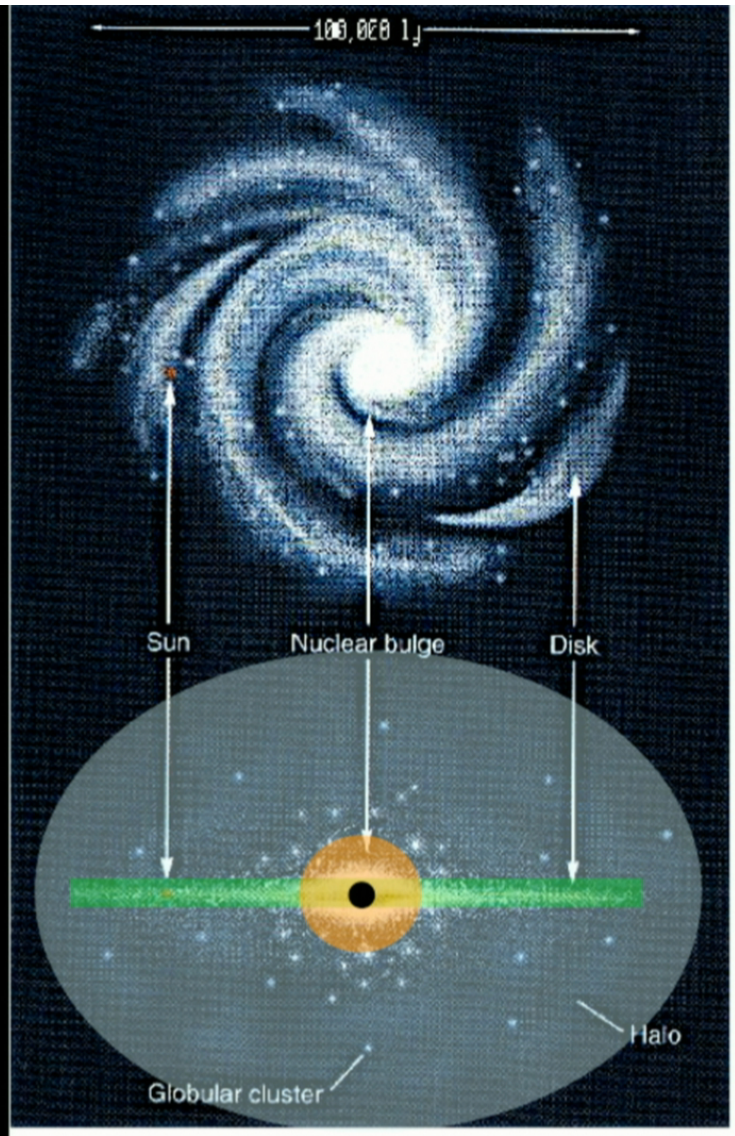
c_s~10-100 km/s for most galaxies

$c=3\times10^5$ km/s



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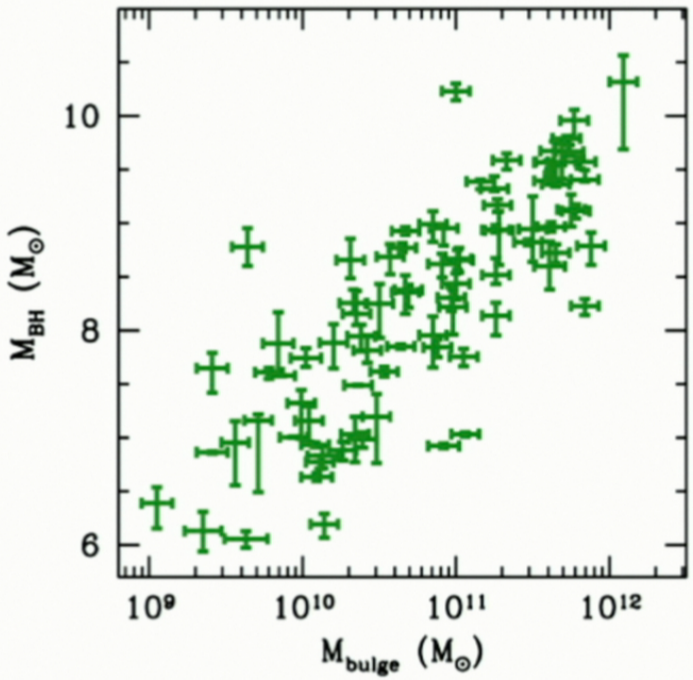
MBH- host relations

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



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MV using data from Kormendy & Ho 2013

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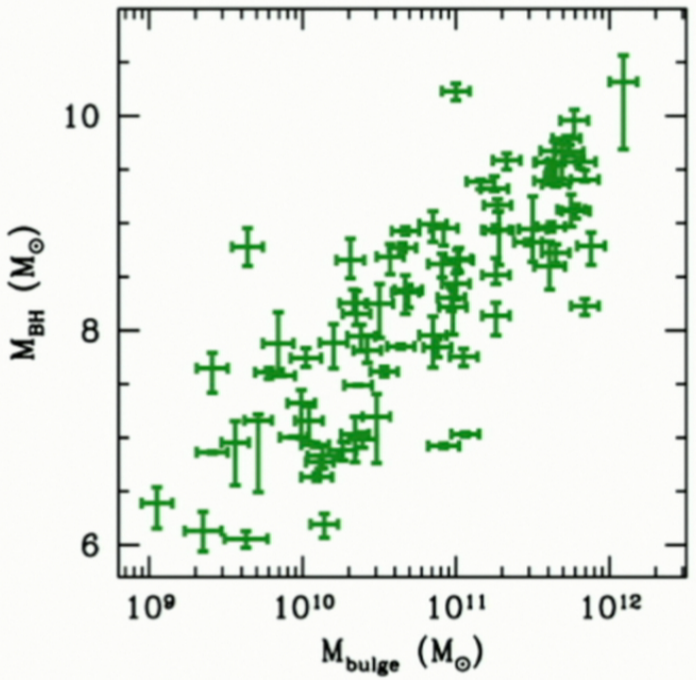

- $M_{BH} \sim 10^{-3} M_{bulge}$
- $M_{BH} \sim \sigma^4 - \sigma^5$

σ : velocity dispersion

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

MV using data from Kormendy & Ho 2013

M_{BH}- host relations: **how** are they established?

Is the correlation regulated by the galaxy or by the MBH?

Feeding: the galaxy sets the MBH mass by regulating the amount of gas that trickles to the MBH

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Casuality: a large number of mergers will average out the extreme values of M_{BH}/M_{bulge} towards the ensemble average

Feeding

Courtesy of
P. Capelo

Galaxy mergers trigger nuclear inflows of low angular momentum gas


Feeding
Streams of gas plunge into halos and feed the galaxy with large amounts of fresh material
Bellovary, MV et al. 2013

Feedback

The mass of the MBH is $\sim M_{BH} \sim 10^{-3} M_{gal}$.

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Fabian 2012

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$\Rightarrow E_{BH}/E_{gal} \sim 10^{-4}(c/\sigma)^2 > 80$

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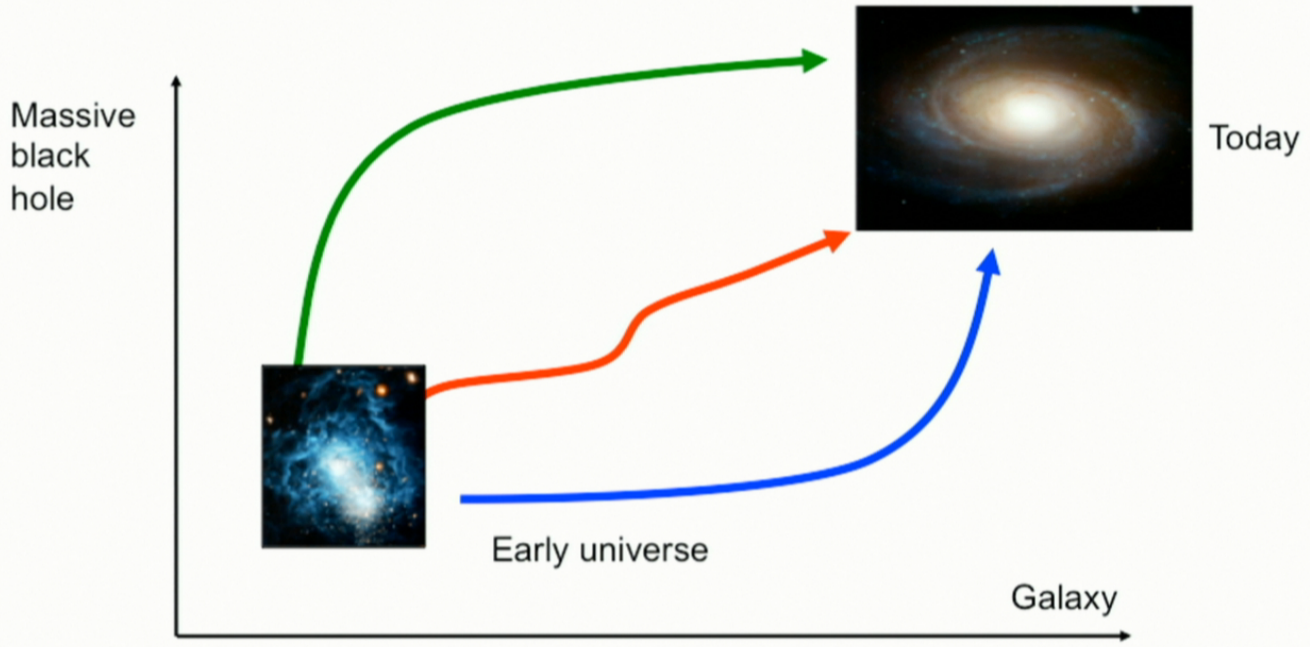
The binding energy of the galaxy is Egal ~ Mgal σ^2, with $\sigma <$ 400 kms^{-1}

=> E_{BH}/Egal~$10^{-4}(c/\sigma)^2$> 80

If even a small fraction of the energy can be transferred to the gas, then an AGN can have a profound effect on the evolution of its host galaxy

Fabian 2012

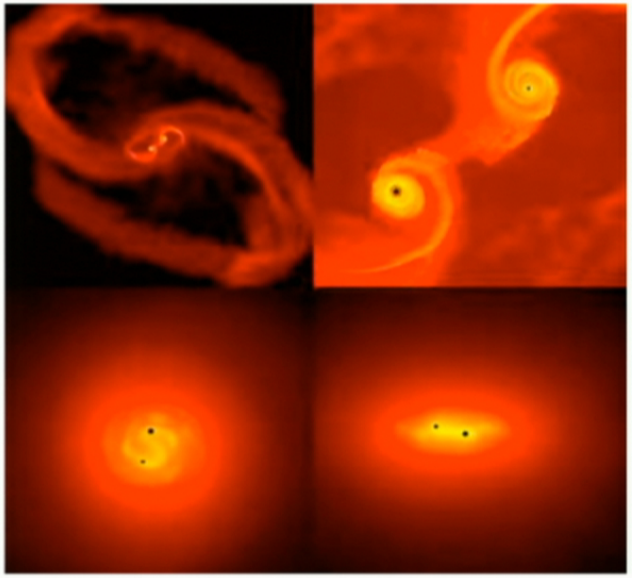
The growth of MBHs in galaxies



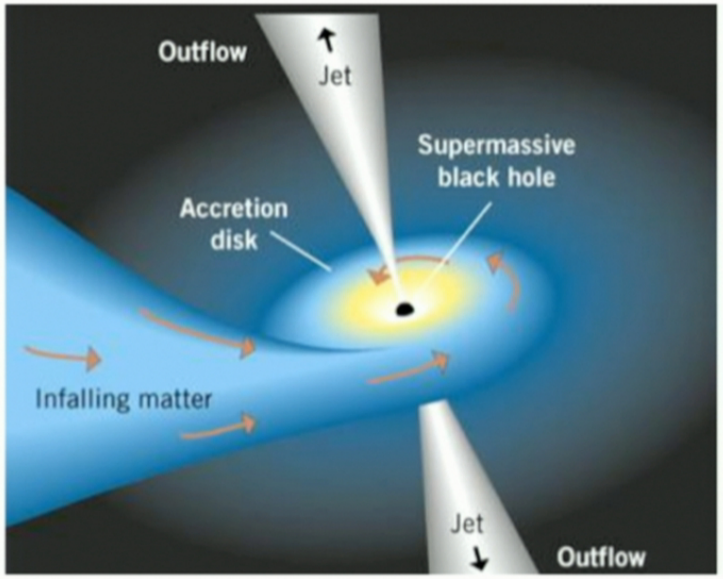
How do MBHs grow to become supermassive?

How do MBH seeds grow to become supermassive?

MBH-MBH mergers vs gas accretion



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



Accretion: Total mass density in MBHs grows with time

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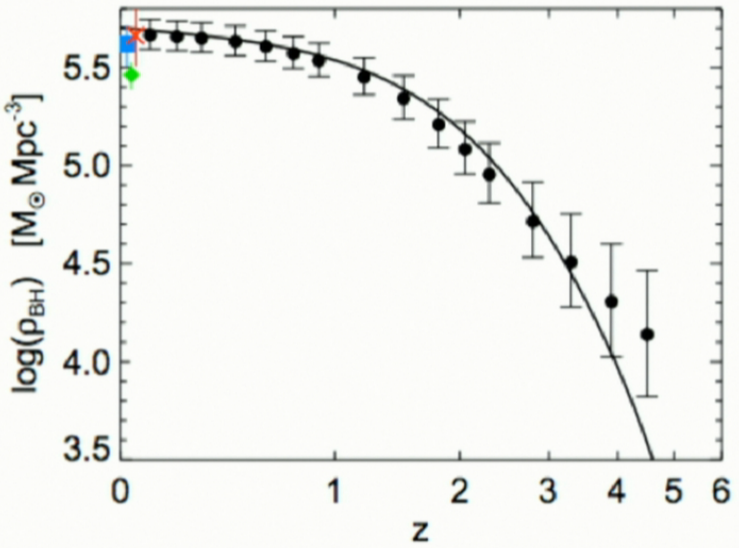

Mergers: total mass density in MBHs is constant in time: just reshuffle the distribution of masses

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

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

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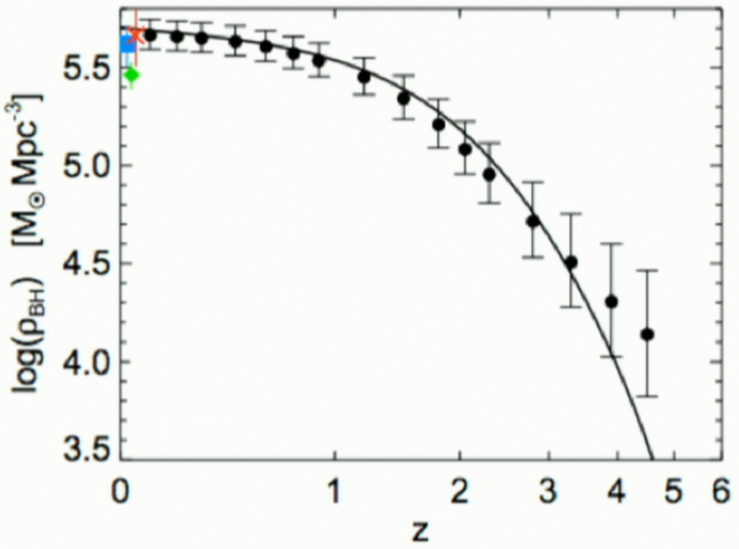

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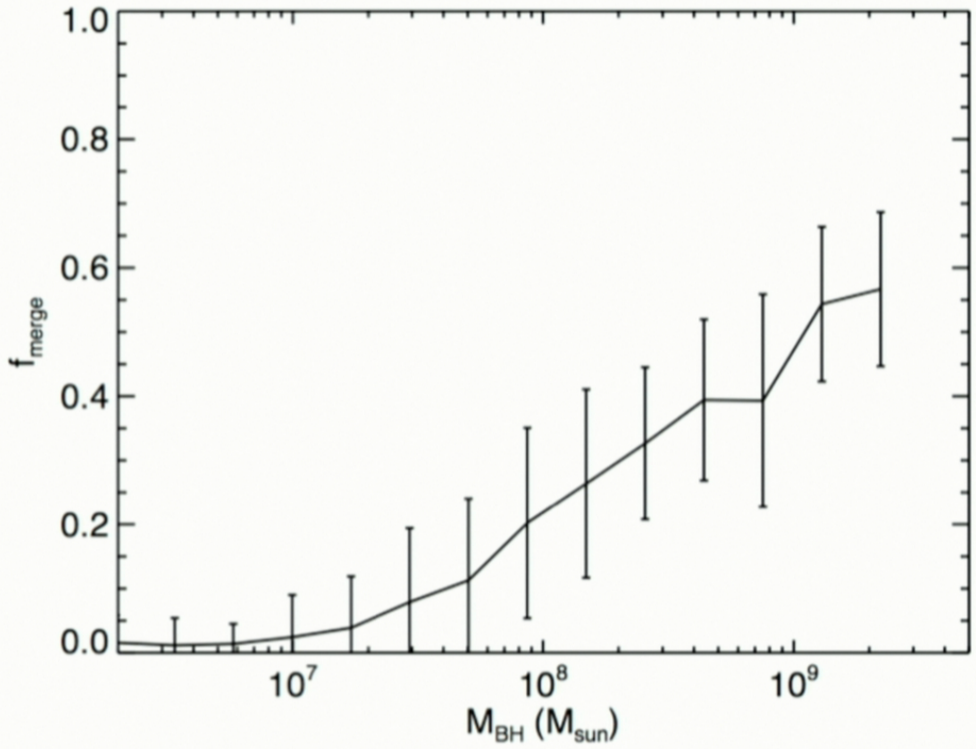
Do MBH-MBH mergers ever count?



Fraction of mass gained through MBH-MBH mergers:

$f_{merge}=\triangle M_{merge}/M_{BH}$

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

Dubois, Volonteri & Silk 2013

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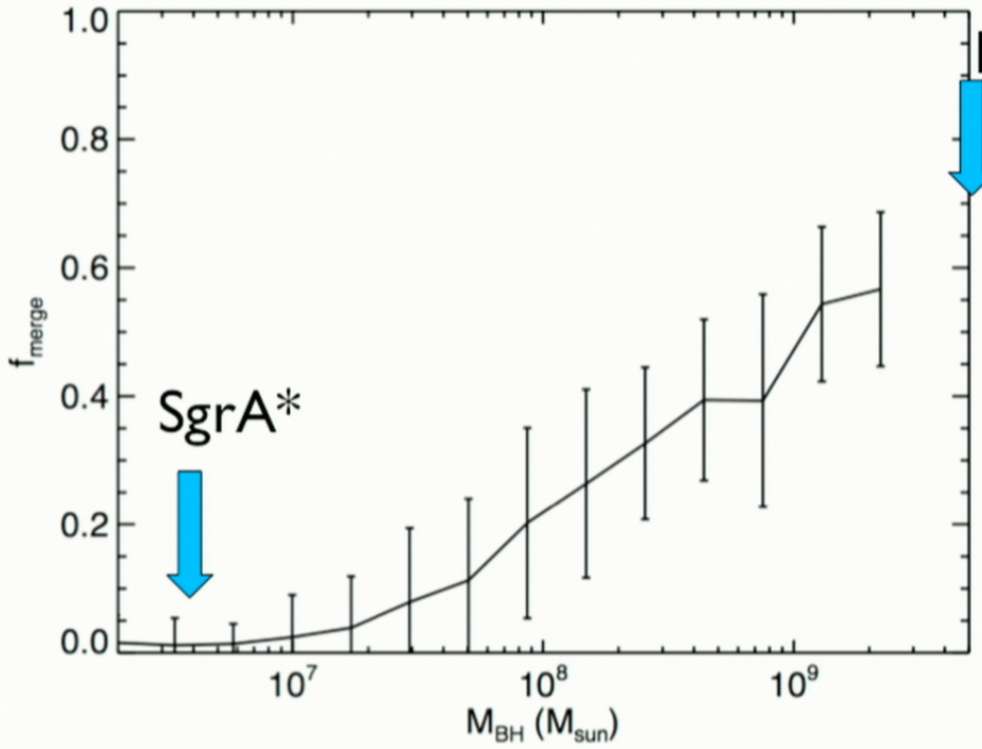

High-mass MBHs!

SgrA* and M87 had very different growth histories

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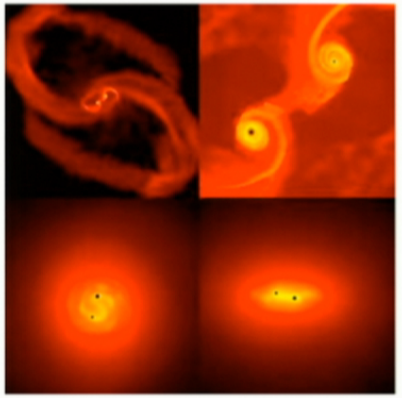
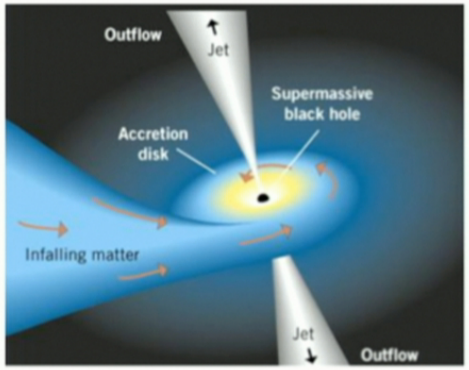
What is the typical MBH spin?

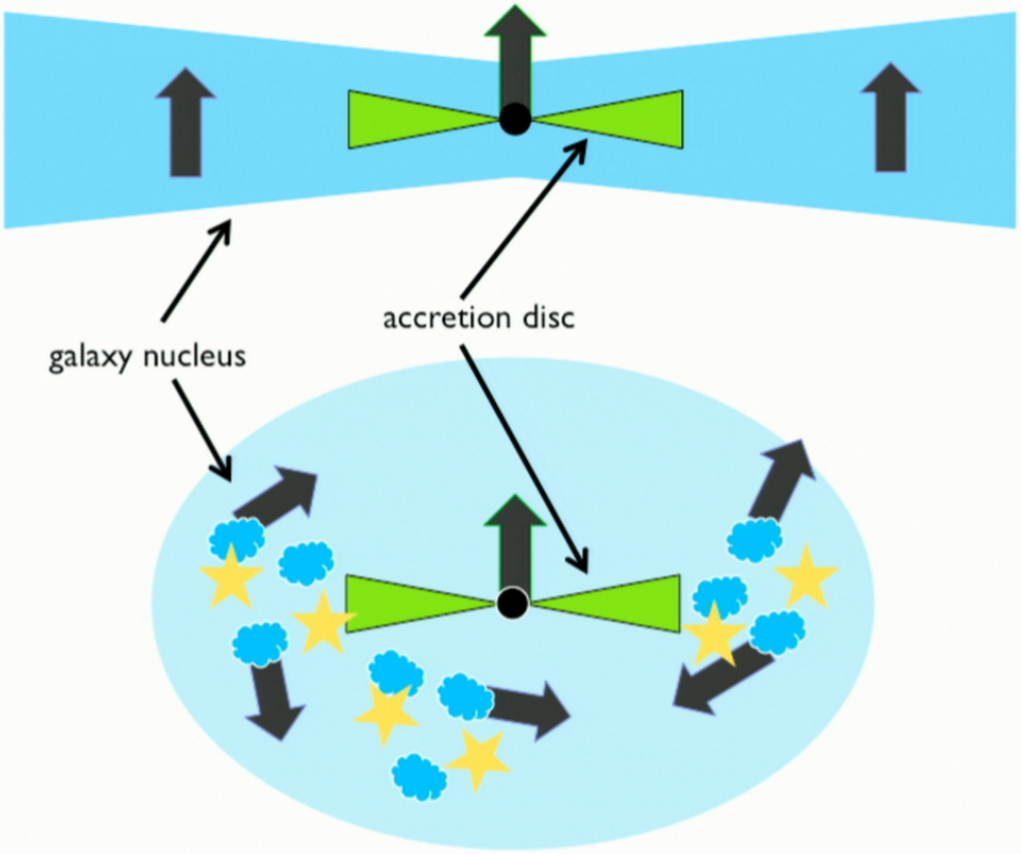
✔ mergers can spin MBHs either up or down, but typical mergers yield spin ~ 0.7



✔ angular momentum is transferred from disk to hole, spin up or down depends on disk/hole mass ratio and alignment



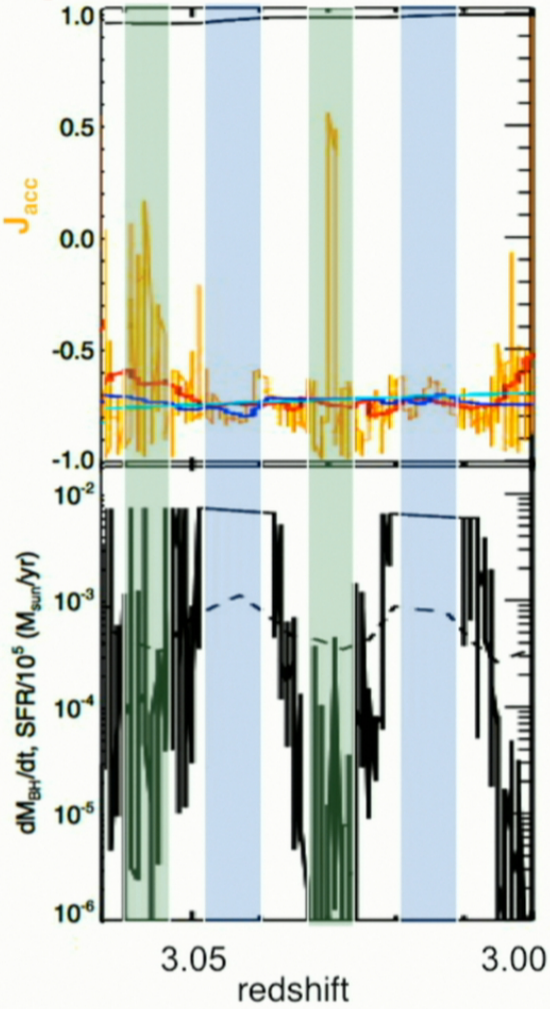
Spins from accretion



Coherent: material has ~ constant direction of angular momentum vector ⇒ high spin

Chaotic: droplets of material with random direction of the angular momentum vector⇒ low spin

Spins from accretion: local environment



Dubois, MV, Silk et al. 2014

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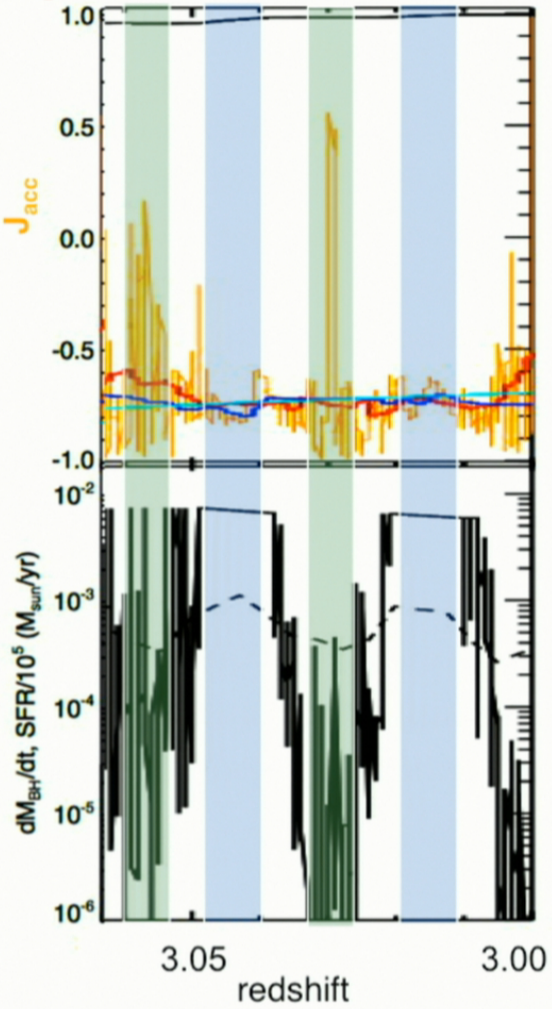

Cold, dense gas tends to reside in a rotationally supported disc => Eddington-limited accretion episodes are synchronous with **coherent** accretion (J_{acc}~const) that dominates the mass budget

In phases characterized by low accretion rate the gas is hot and diffuse => **chaotic** accretion (J_{acc} fluctuates) dominates, but neither mass nor spin change much

Dubois, MV, Silk et al. 2014

Sgr A* & M87 in context

Mass: they're somewhat at the two extremes of the mass range known today

Accretion rate: both very sub-Eddington => must have grown in the past

M87: have MBH-MBH mergers played a role?

Milky Way: when has the MBH grown last?

Sgr A* & M87 in context

Spin: conjectures

M87: if MBH-MBH mergers, expect spin~0.7 (statistically!) cf Doeleman+2012: a>0.2

SgrA*: if most of the growth driven by rapid accretion: initially high-spin, but spinning down because of slow accretion of hot gas
cf Broderick, a~0 (<0.7); Moscibrodzka, Drappeau, a>0.5
Orientation? Psaltis+2014