

Supermassive black holes and synergies with X-ray missions

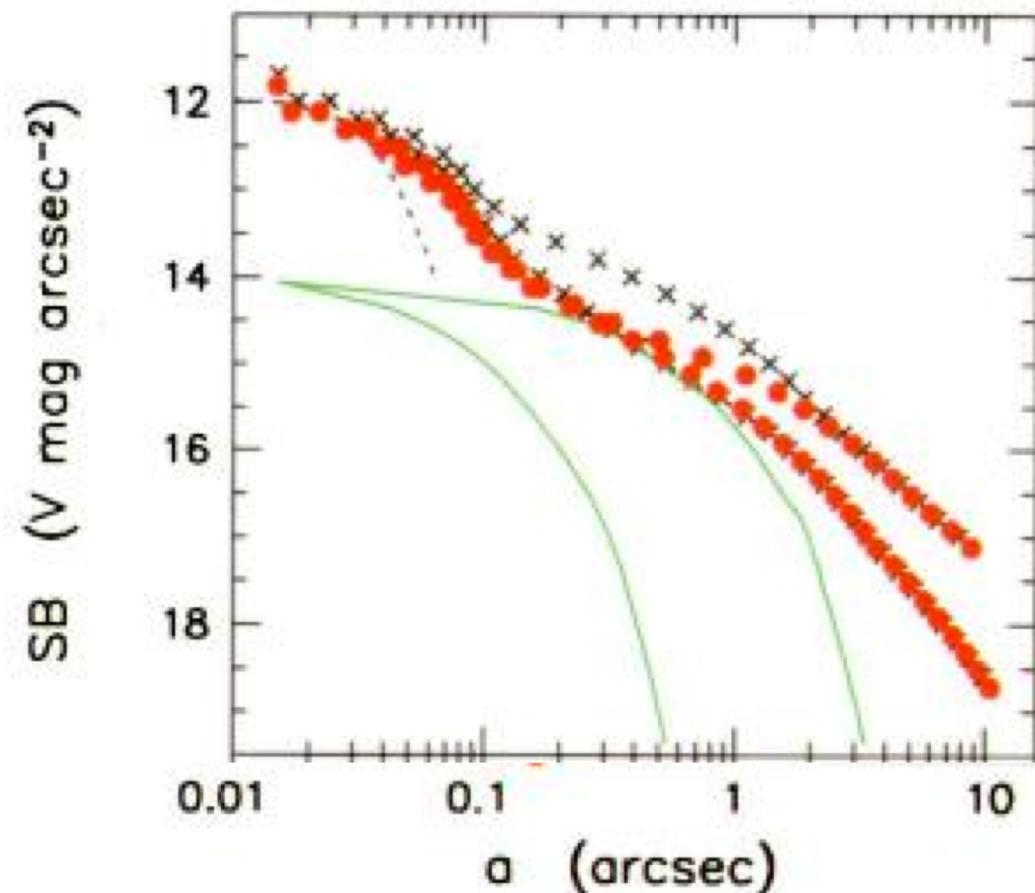
Sean McGee
University of Birmingham



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Supermassive black holes Evidence for existence

High resolution imaging of elliptical/spheroid galaxies taken with the Hubble Space telescope

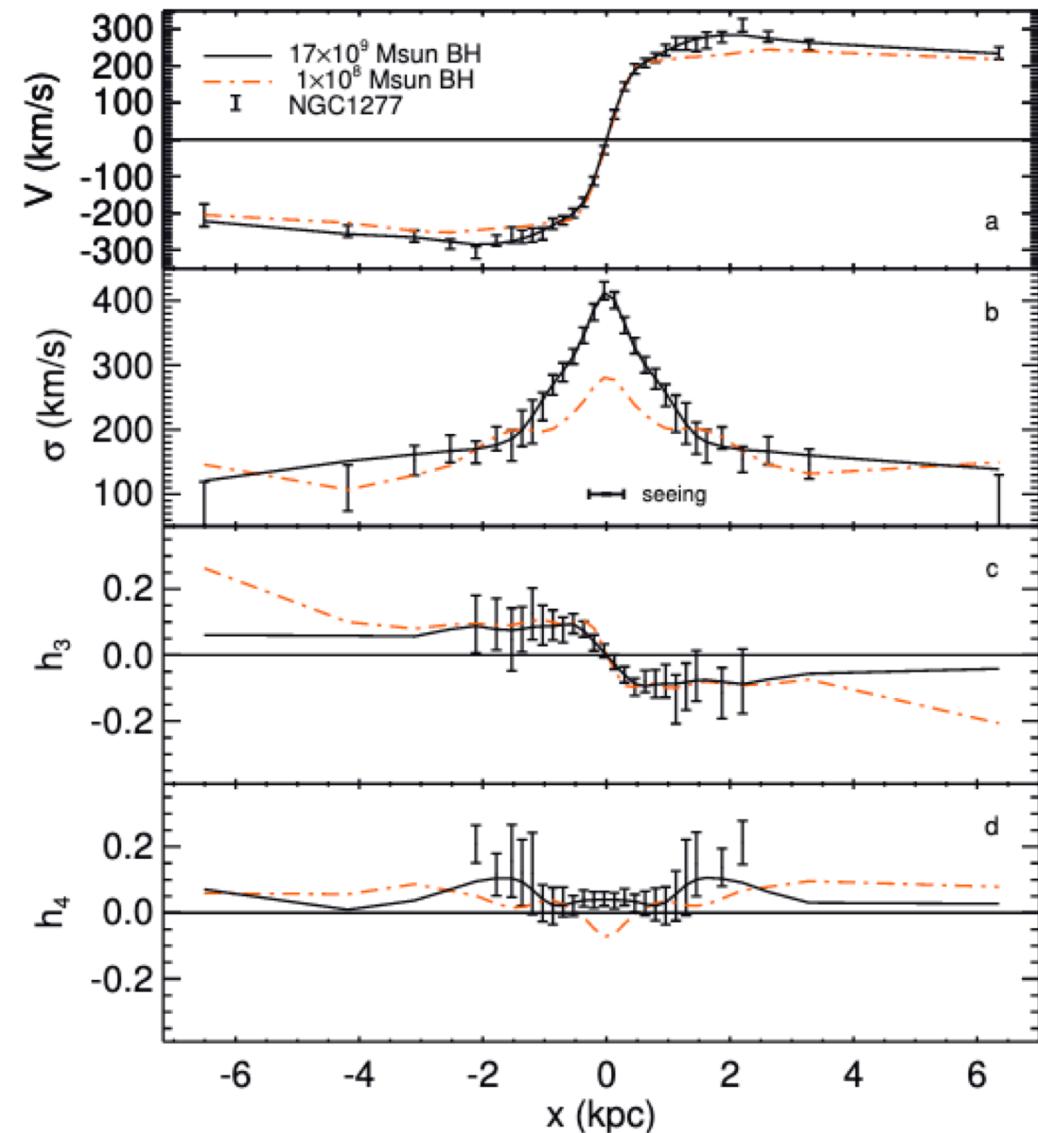
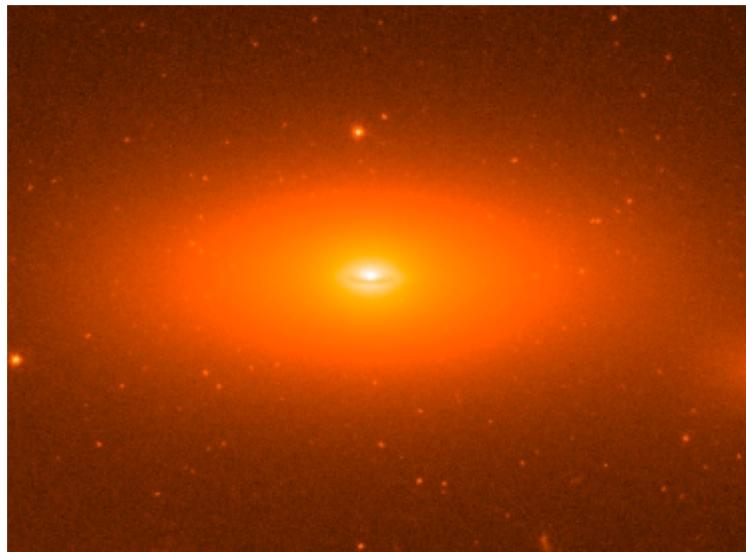


(Kormendy et al. 1996)

Supermassive black holes

Evidence for existence

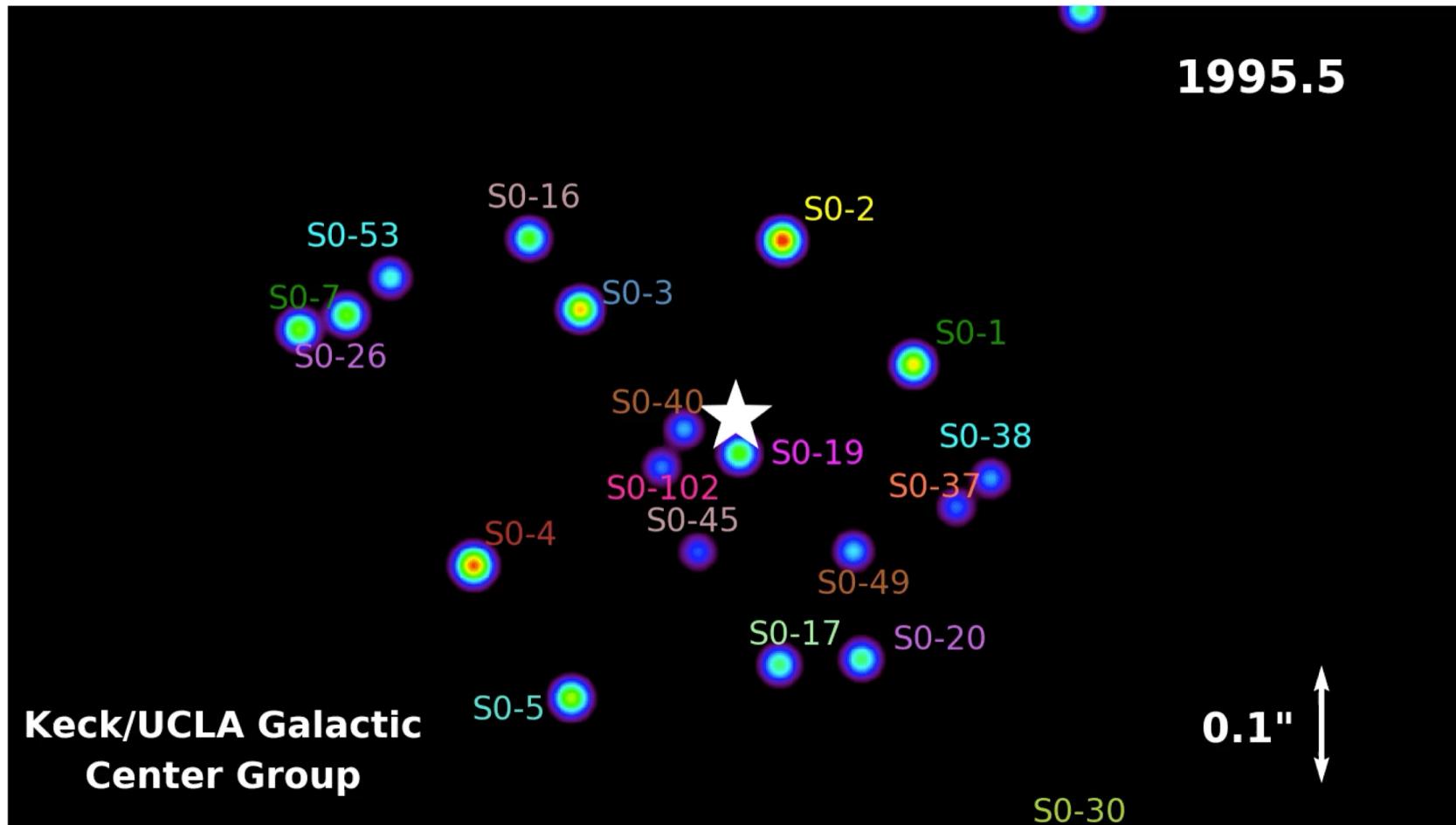
High resolution imaging of elliptical/spheroid galaxies taken with the Hubble Space telescope



(van den Bosch et al. 2012)

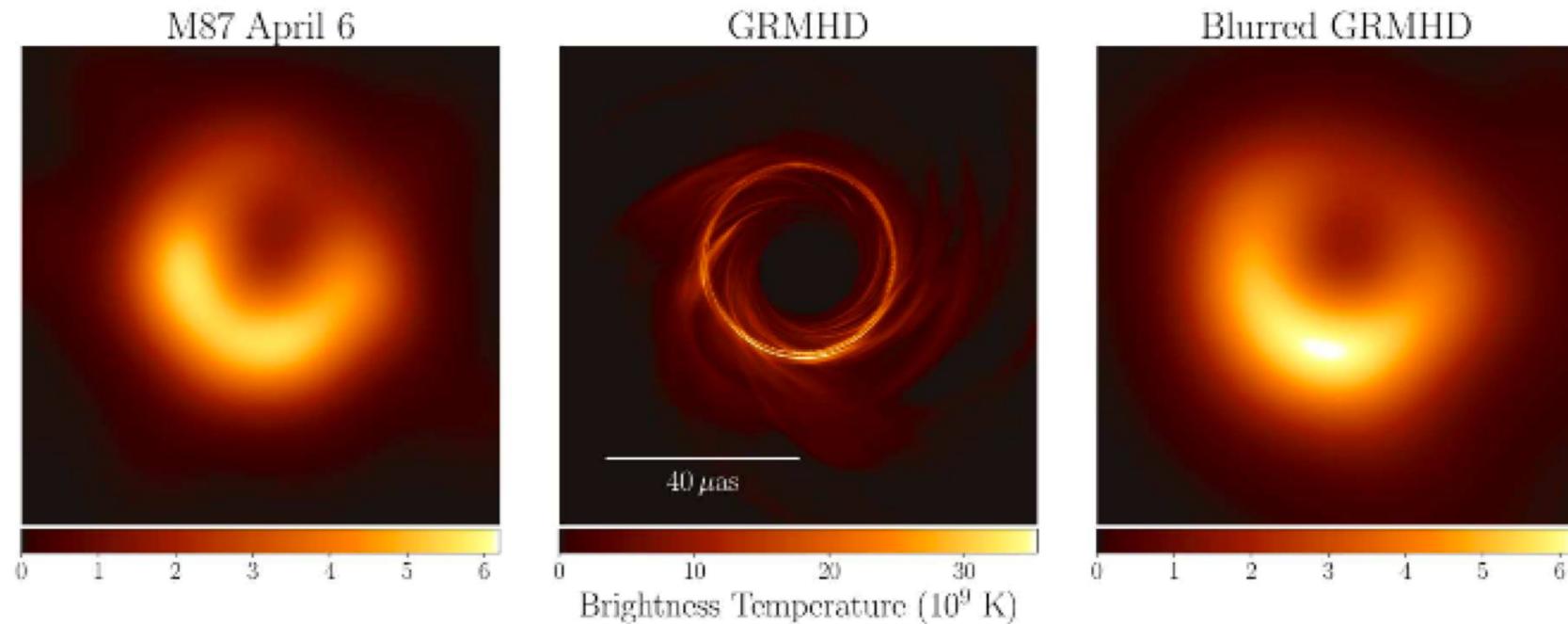
Supermassive black holes Evidence for existence

Milky Way



Supermassive black holes Evidence for existence

Direct imaging

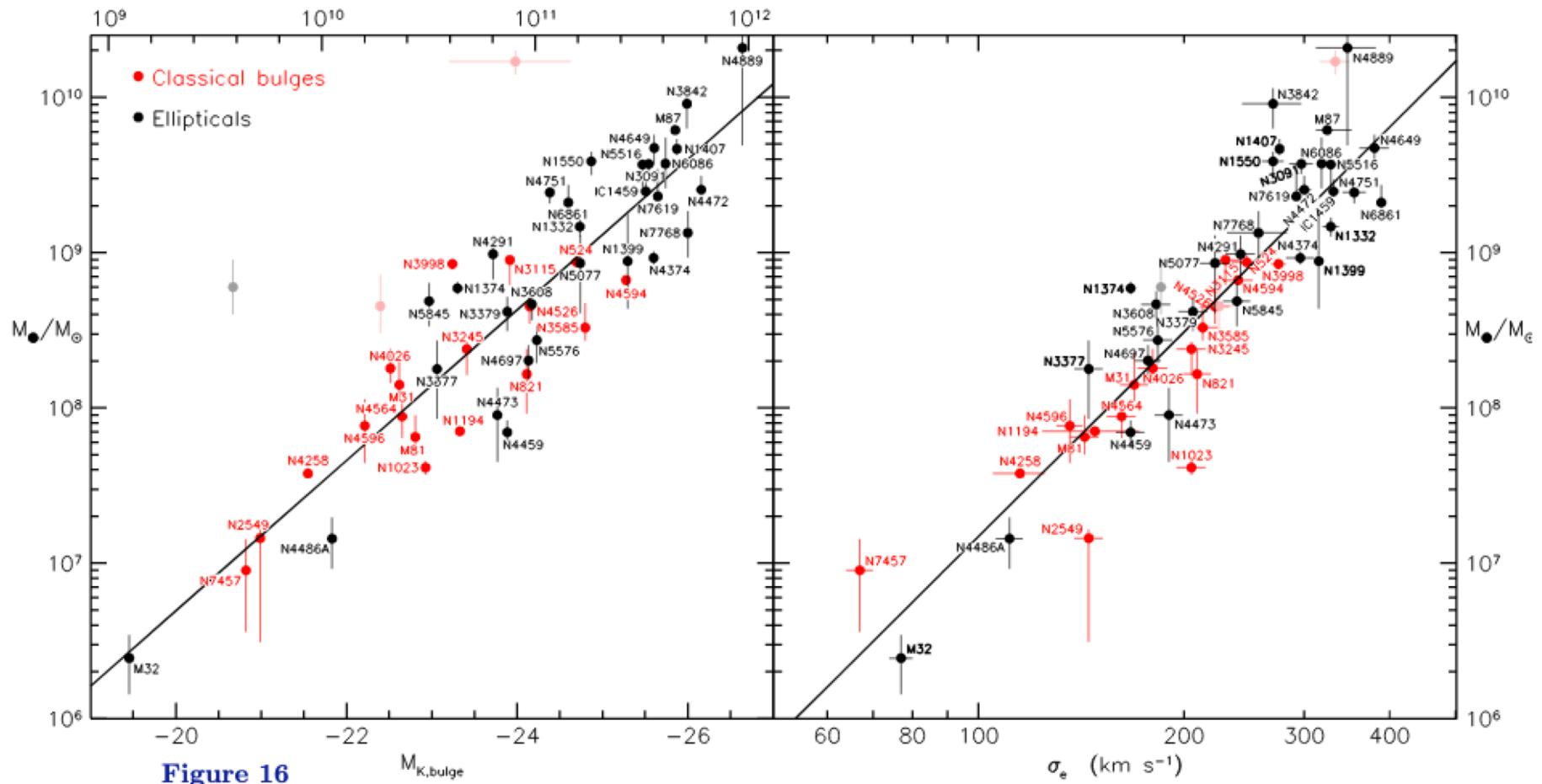


(Event Horizon Telescope 2019)

Supermassive black holes

Evidence for feedback

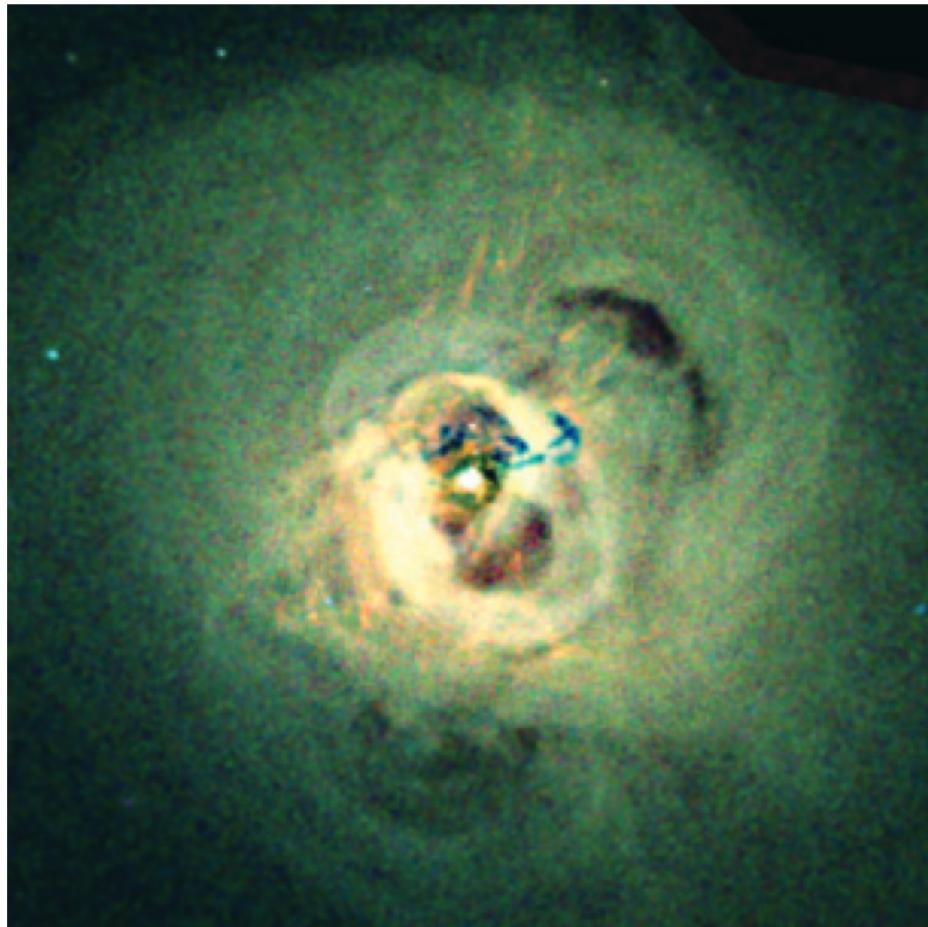
Black hole scaling relations



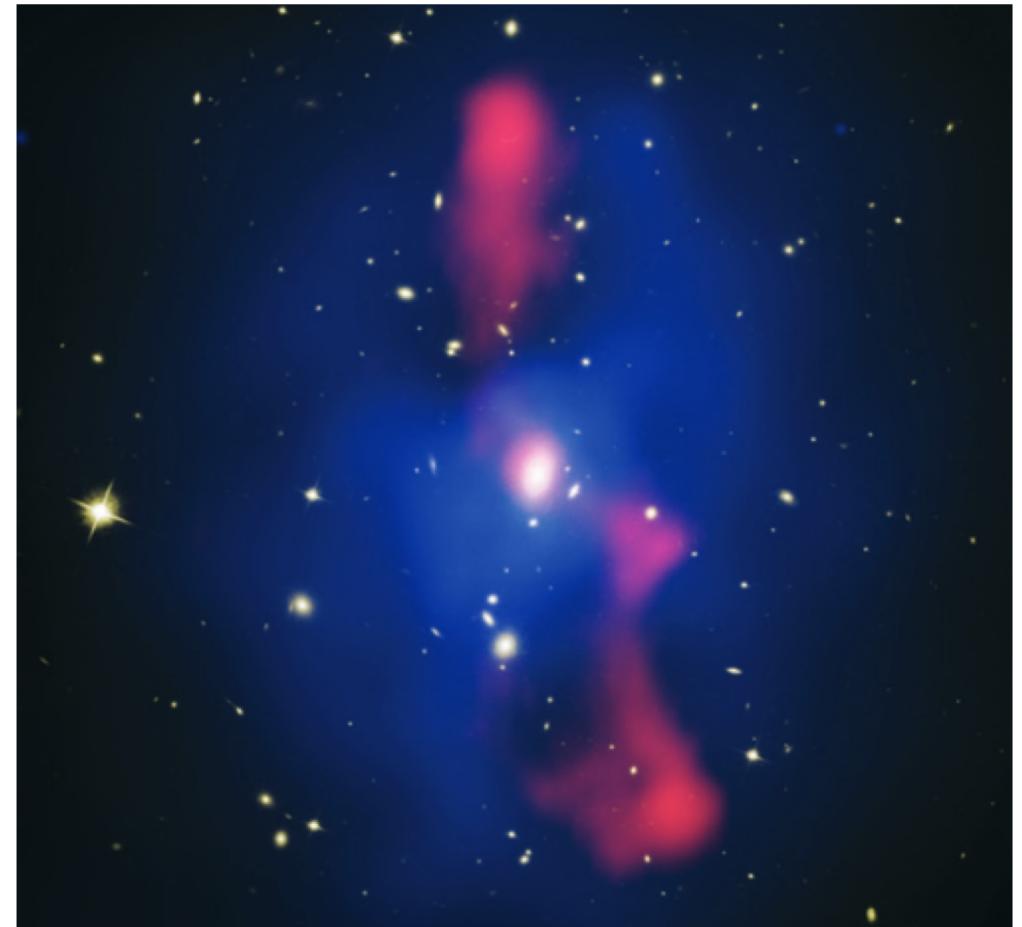
(Kormendy and Ho, 2013)

Supermassive black holes Evidence for feedback

Intracluster gas



(Fabian et al., 2006)

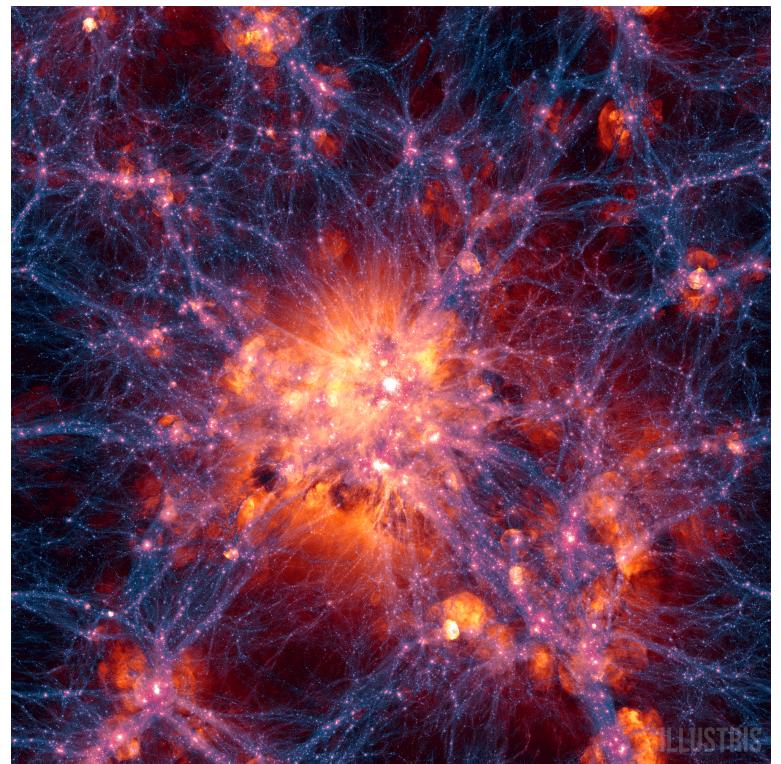
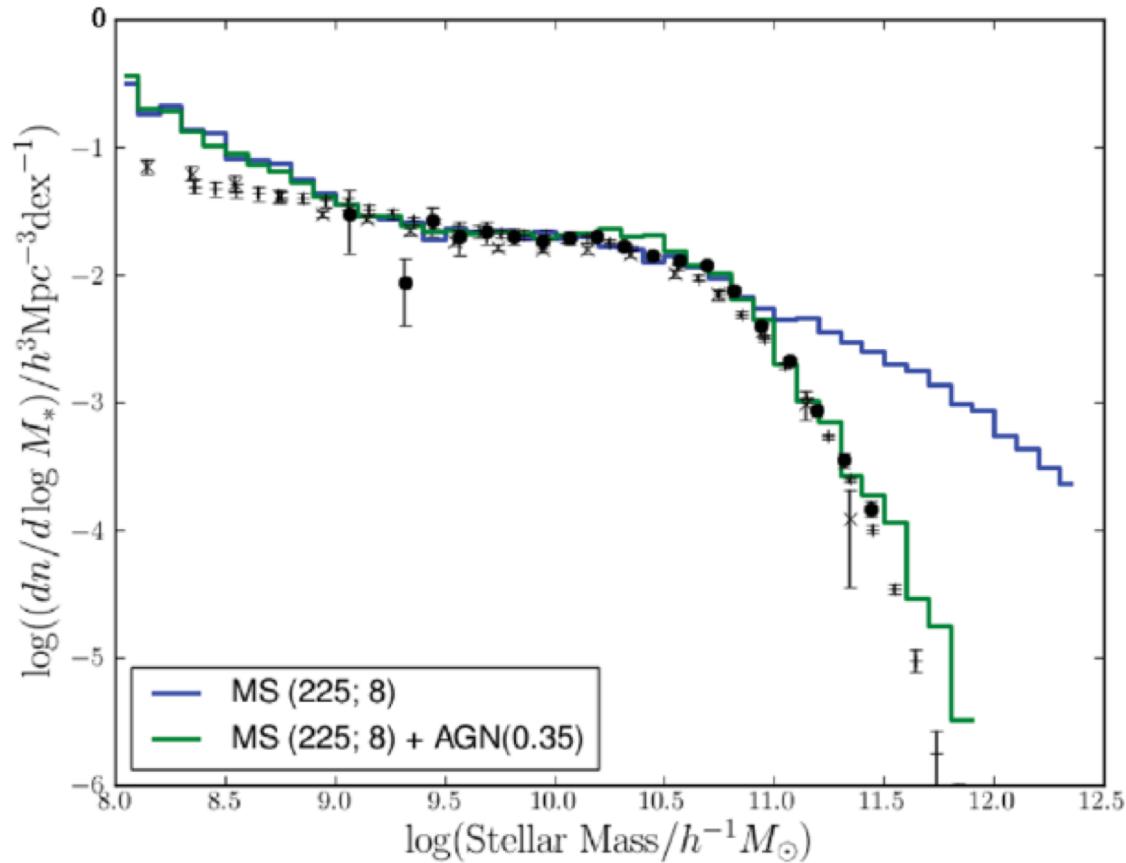


(Mcnamara et al., 2008)

Supermassive black holes

Evidence for feedback

Numerical Simulations



(Bower et al., 2012)

Supermassive black holes

Unsolved problems

How do the first massive black hole seeds form? Where do they first appear, and when?

How do these seeds grow through time?

What effect do they have on their host galaxies and the environment?

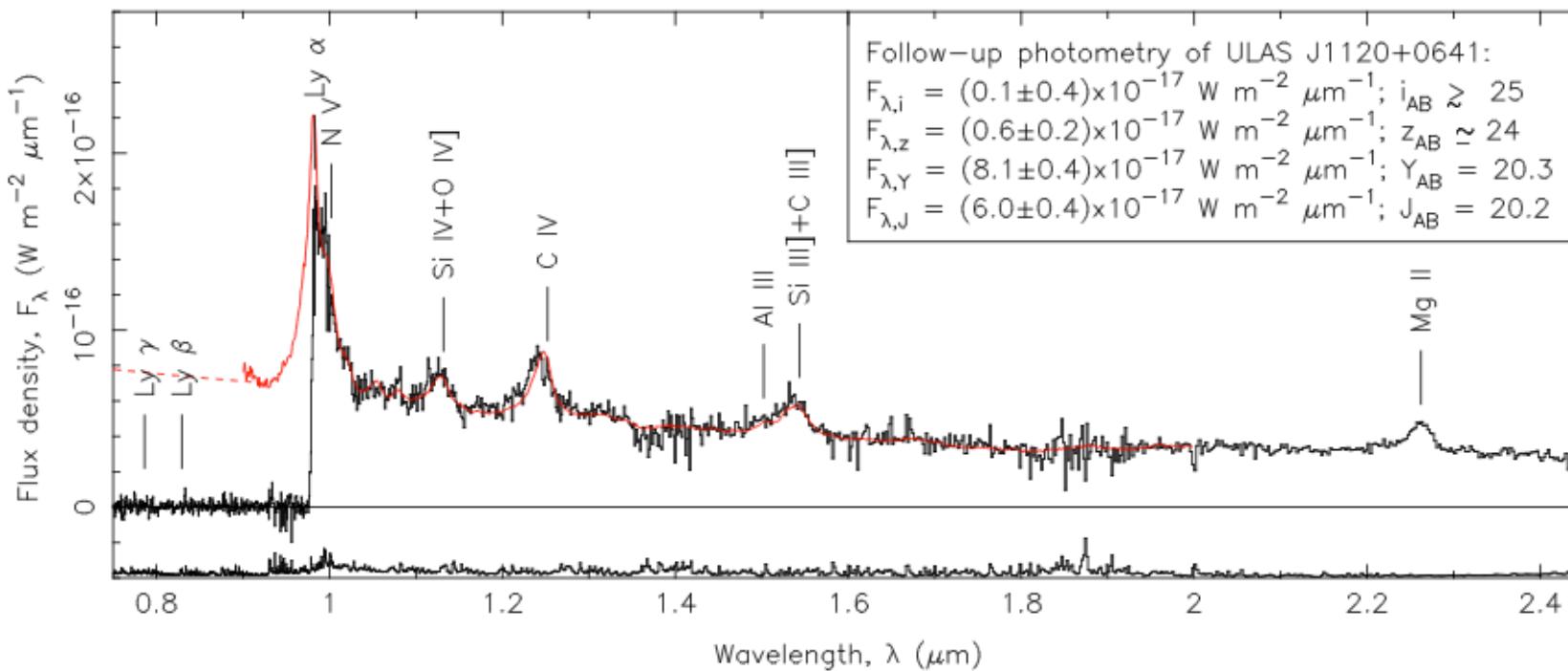
Supermassive black holes

The seed problem

The early black hole problem

Highest redshift quasar, $z=7.1$. $L \sim 6 \times 10^{13} L_\odot$. Inferred $M_{\text{bh}} = 2 \times 10^9 M_\odot$.

How is a $10^9 M_\odot$ black hole formed in $t=750 \text{ Myr}$?



(Mortlock al., 2011)

Supermassive black holes

The seed problem

Highest redshift quasar, $z=7.1$. $L \sim 6 \times 10^{13} L_\odot$. Inferred $M_{\text{bh}} = 2 \times 10^9 M_\odot$.

How is a $10^9 M_\odot$ black hole formed in $t=750 \text{ Myr}$?

Black hole growth is hindered by the outflowing radiation

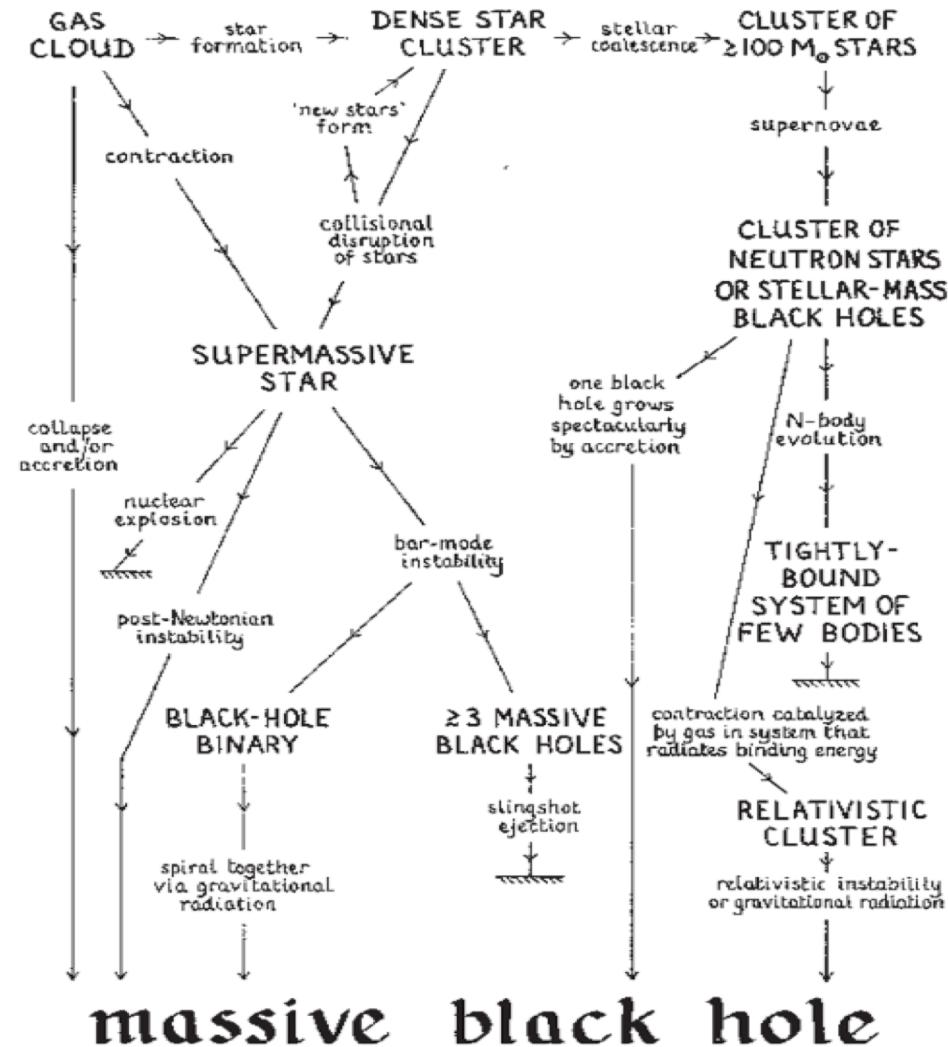
$$m_0 = m_{\text{BH}}(t) \exp \left[- \frac{1 - \epsilon}{\epsilon} \frac{t(z)}{t_e} \right]$$

where $t_e = [4\pi G \mu m_p / \sigma_e c]^{-1} = 0.45 \text{ Gyr}$

Implies that initial black hole seeds were > 400 solar masses

Supermassive black holes

Origin of seeds

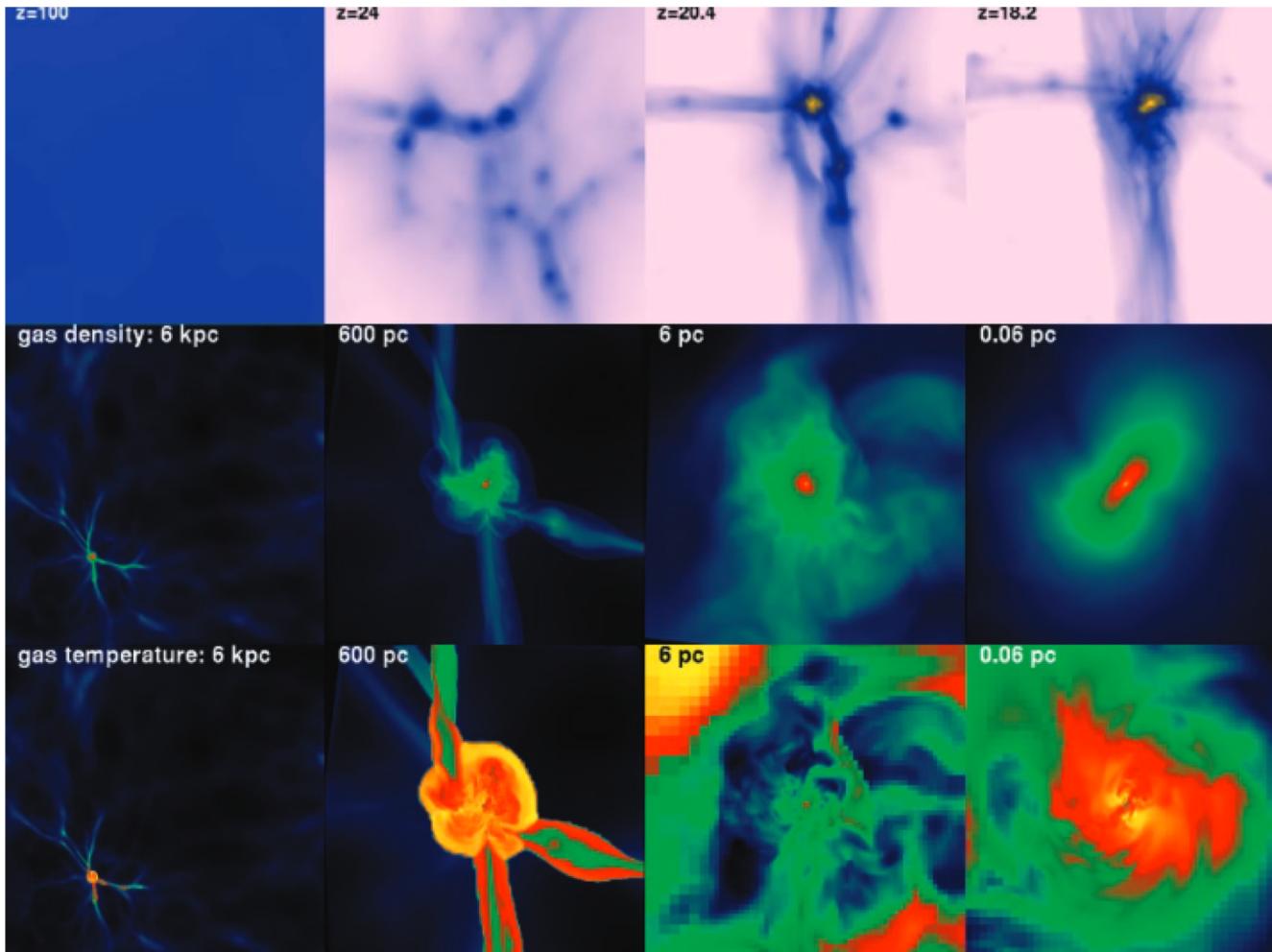


(Rees al., 1980)

Supermassive black holes

Origin of seeds

Population III remnants



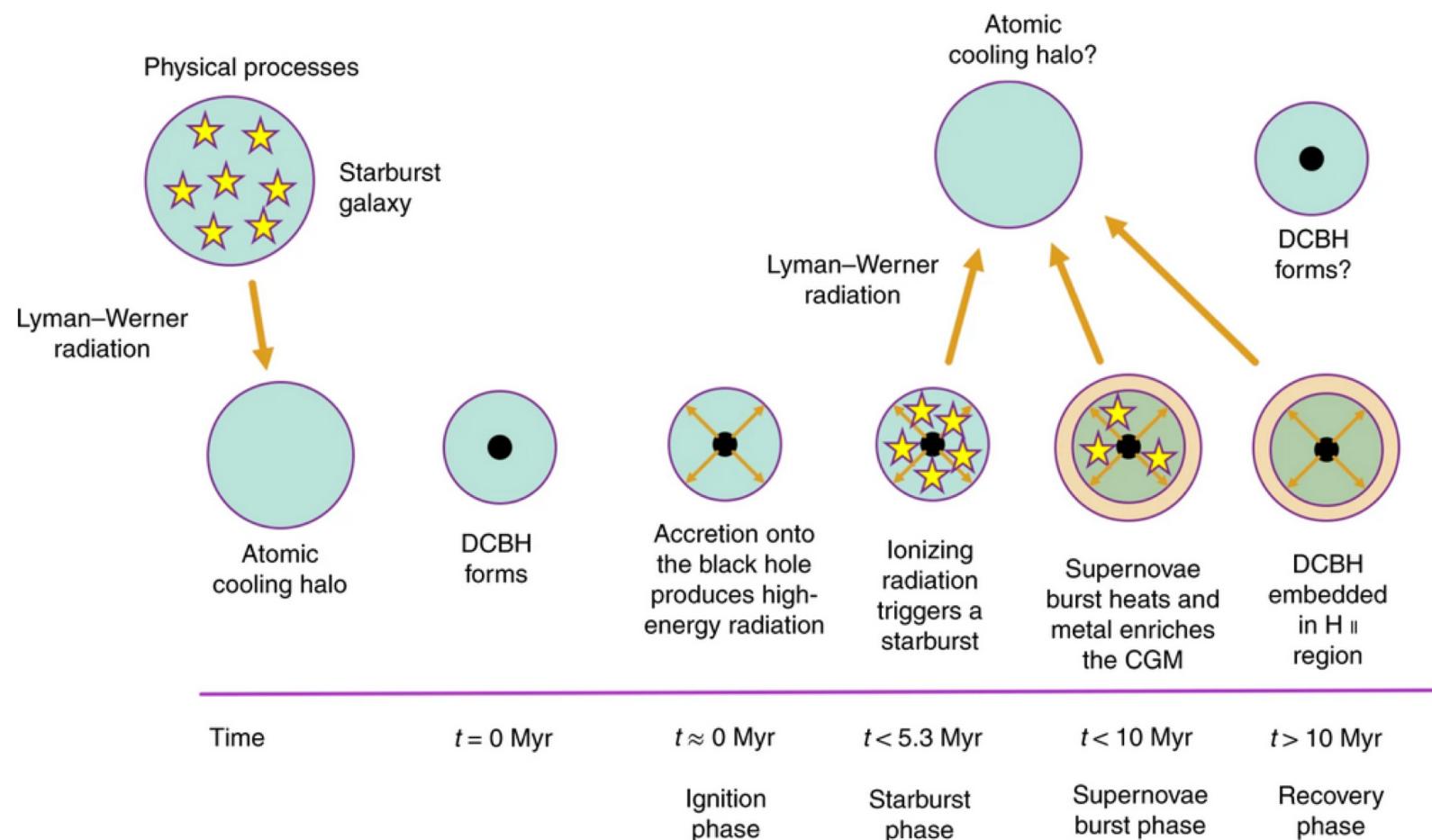
(Abel al., 2002)

'Light' seeds ~ 100 Msolar

Supermassive black holes

Origin of seeds

Direct Collapse black hole



(Barrow al., 2018)

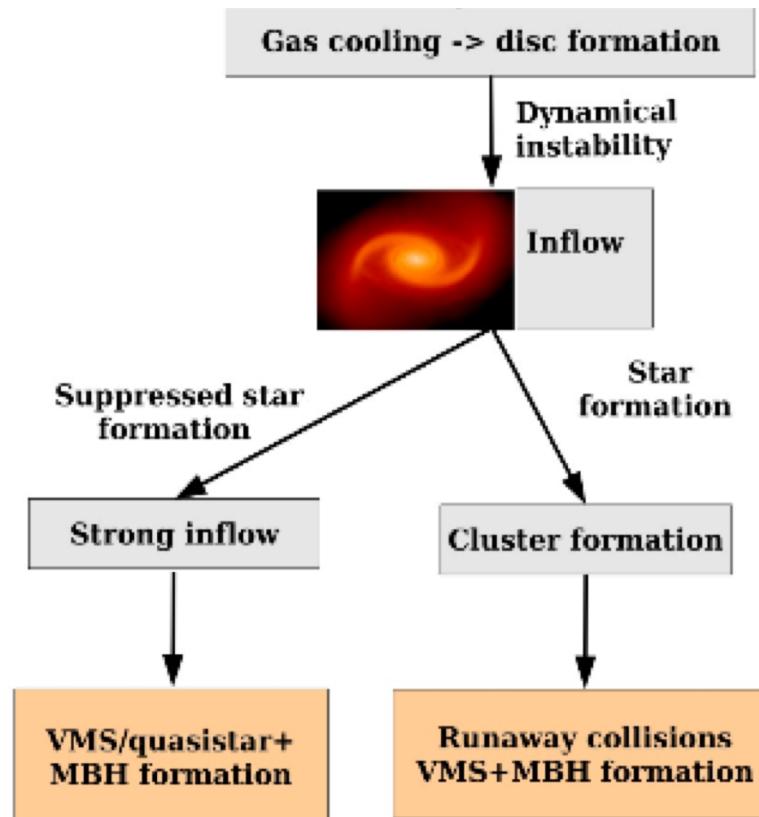
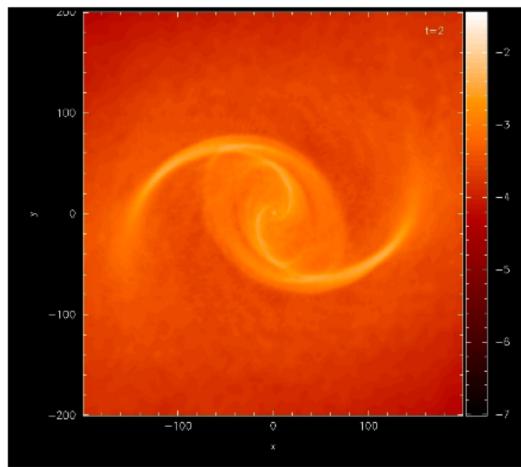
‘Heavy’ seeds $\sim 10^5$ Msolar

Supermassive black holes

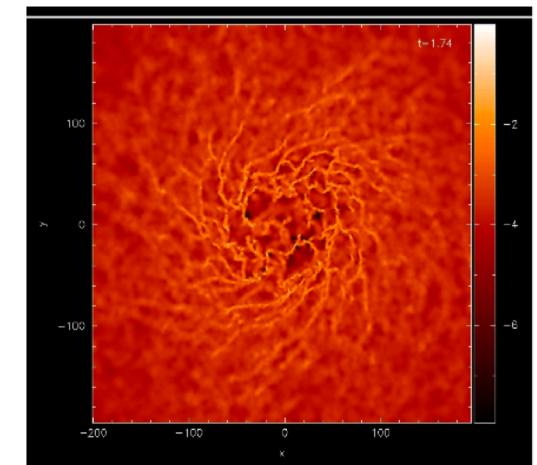
Origin of seeds

Disk – star formation

Direct collapse



Intermediate BH



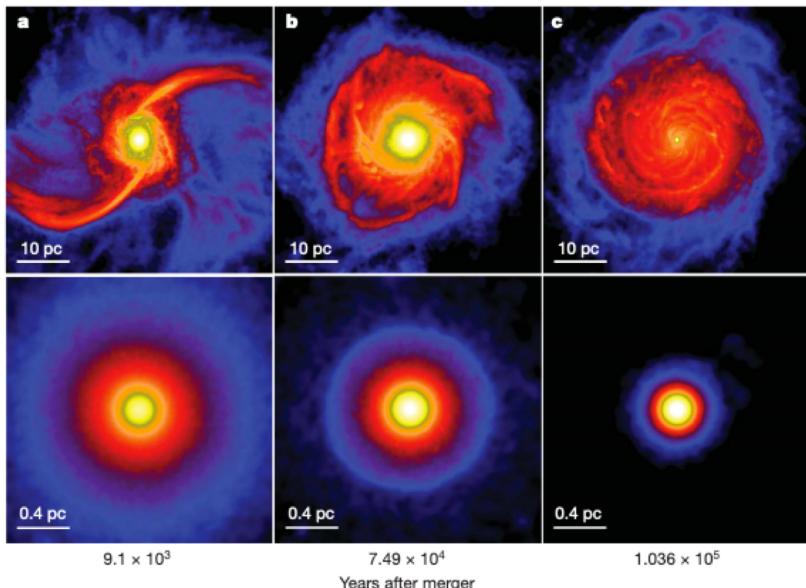
'Intermediate' seeds $\sim 10^3$ Mbh

(Volonteri, 2010)

Supermassive black holes

Origin of seeds

Galaxy Mergers



There have been suggestions that galaxy mergers could set off extreme gas inflow that could rapidly form a seed

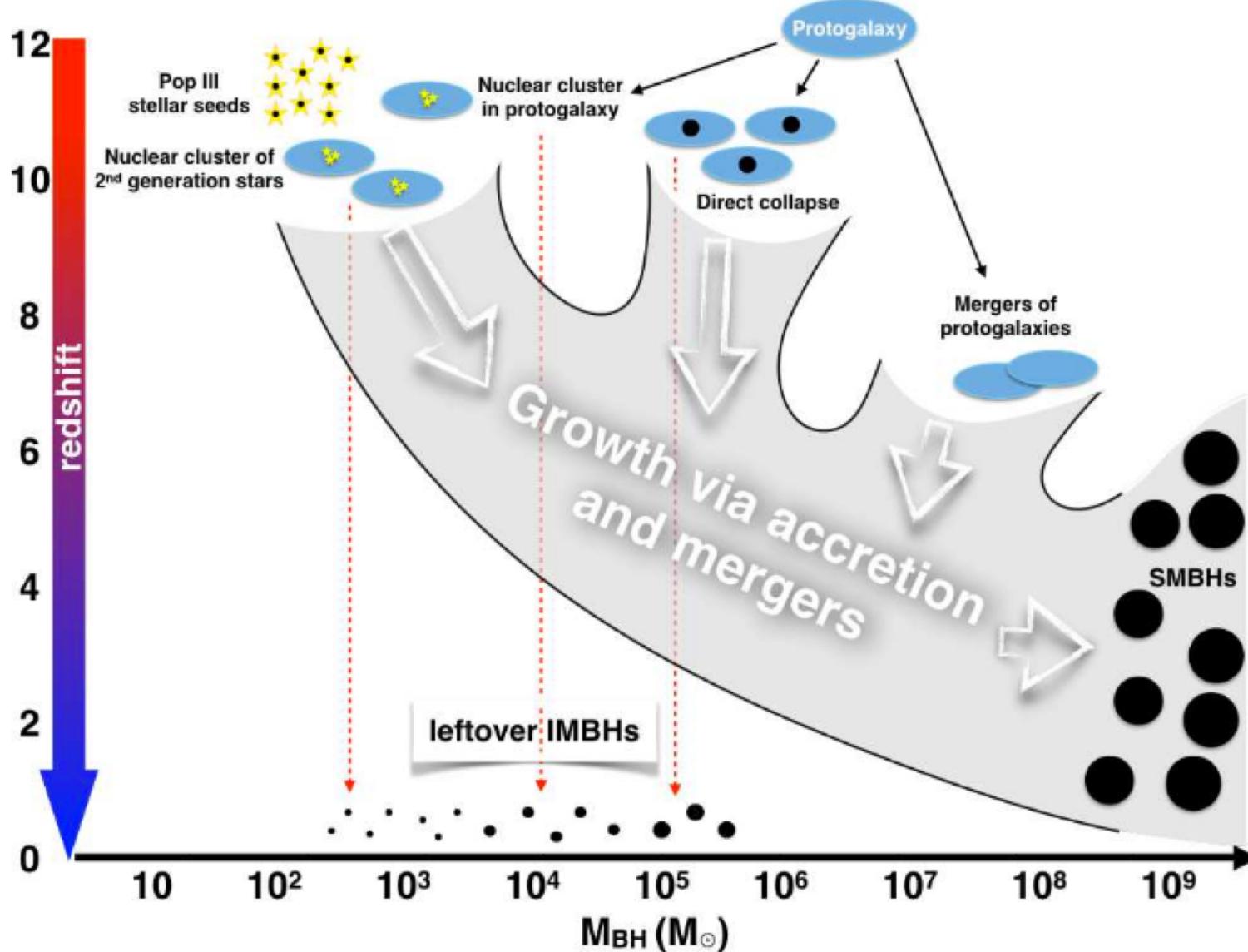
(Mayer et al., 2010)

Primordial Black holes?

It's possible a population of primordial black holes could be the seeds. Constraints from CMB, ultra-faint dwarfs, etc rule out >10² Mbhs as the dark matter.... But not of supermassive BH seeds.

Supermassive black holes

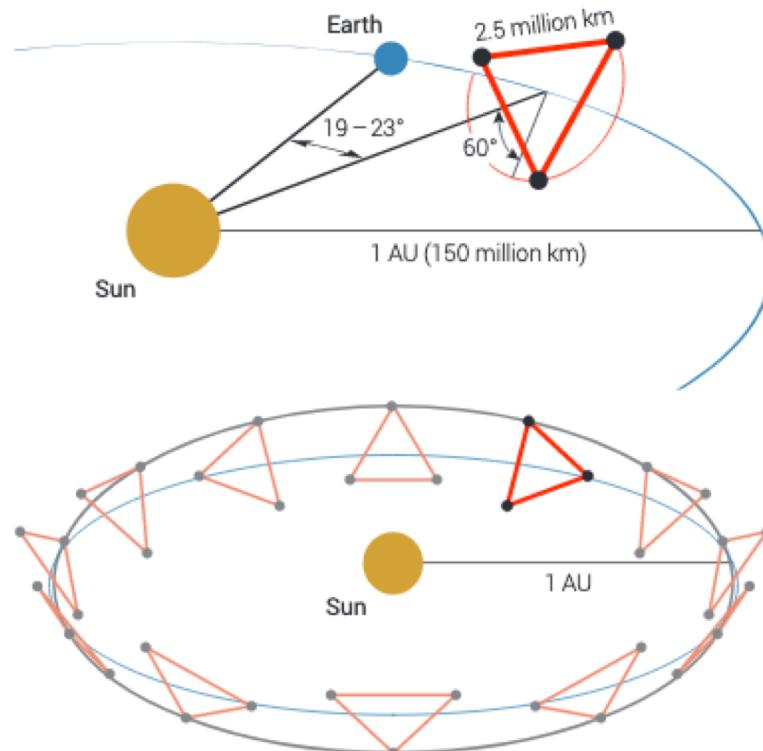
Origin of seeds



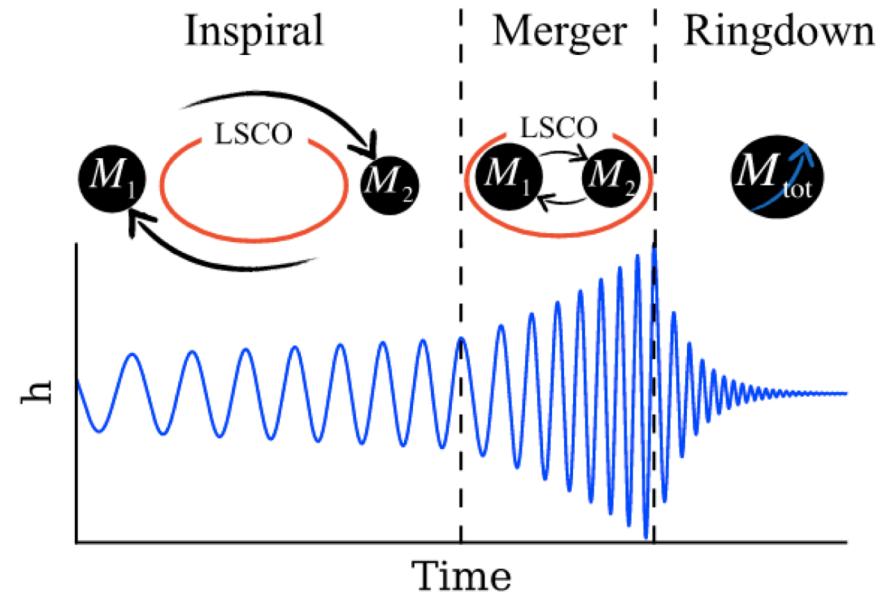
Supermassive black holes

LISA

Sensitive to the mHz frequency – massive black hole binary observed through the full inspiral/merger/ringdown



3 satellites following Earth's orbit
2.5 Million Km arms
~ 4 year lifetime

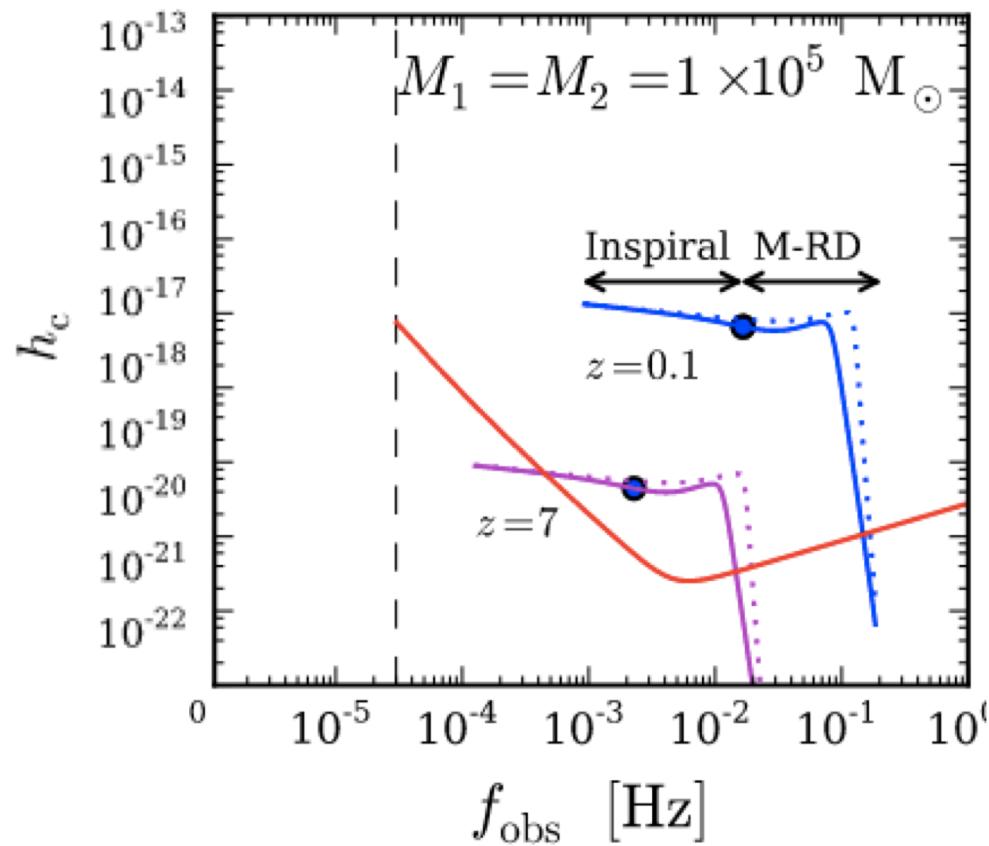


(Mortlock al., 2011)

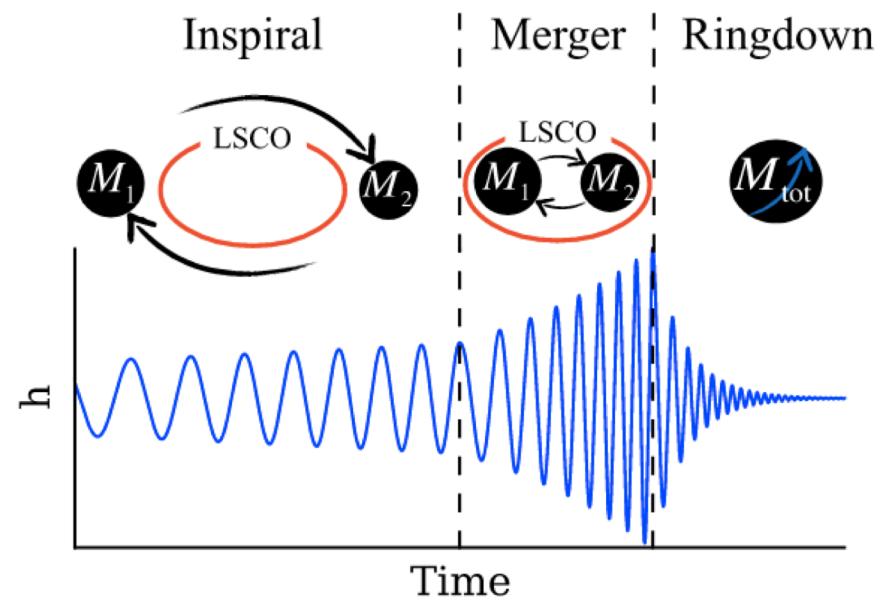
Supermassive black holes

LISA

Black hole growth is hindered by the outflowing radiation



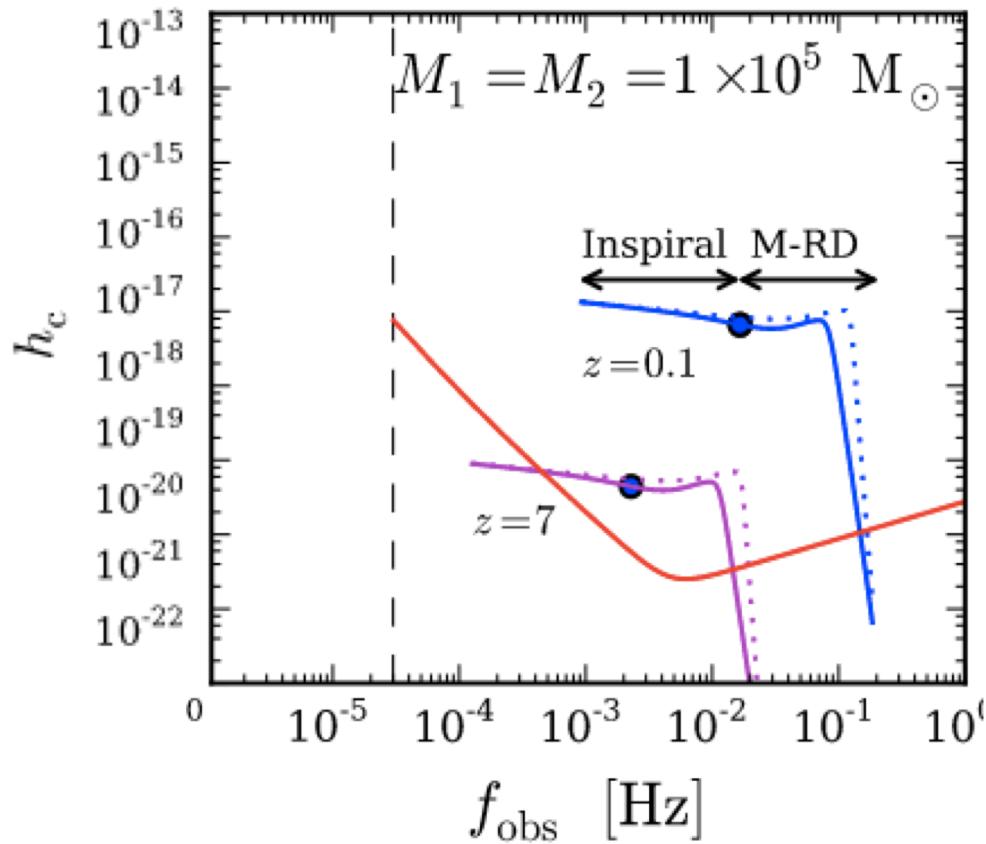
(Salcido al., 2016)



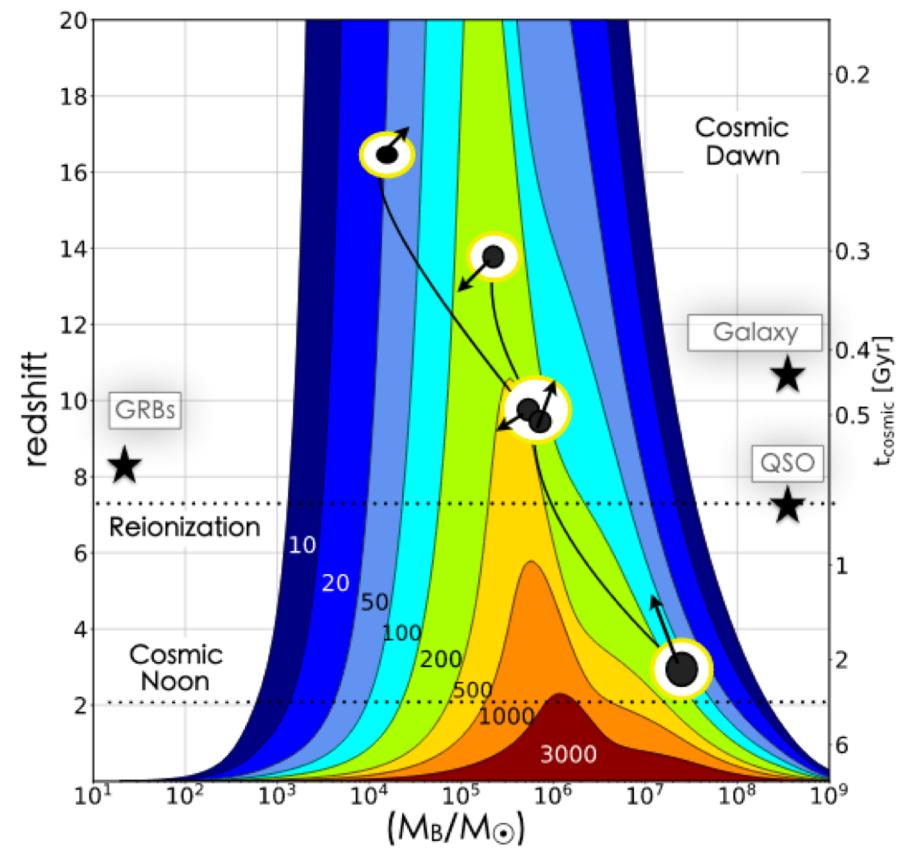
Supermassive black holes

LISA

Black hole growth is hindered by the outflowing radiation



(Salcido al., 2016)

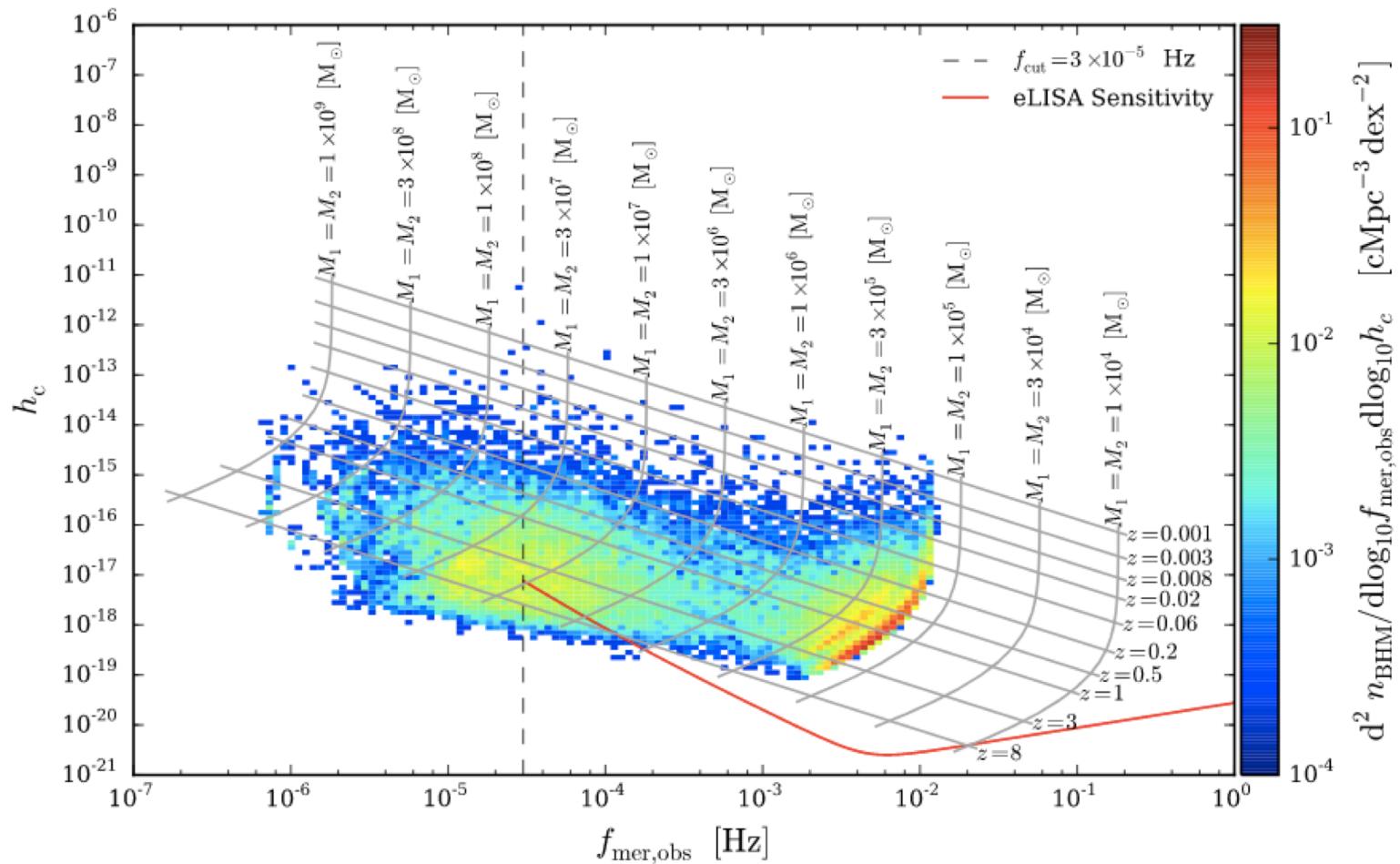


Supermassive black holes

LISA

Milky Way

Black hole growth is hindered by the outflowing radiation

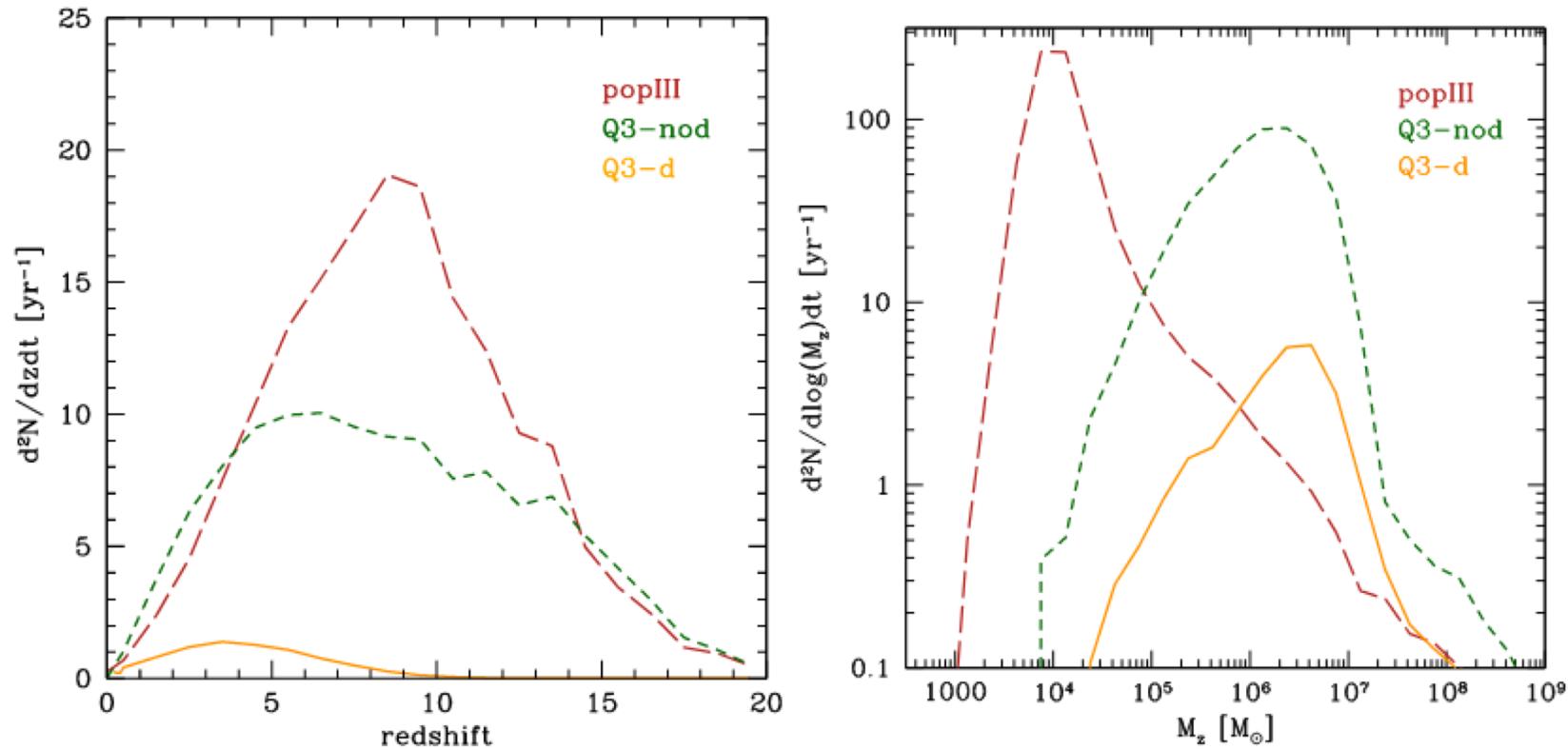


Supermassive black holes

LISA

Milky Way

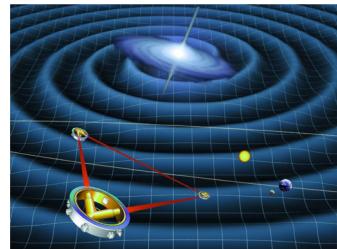
The merger rate depends crucially on the underlying seed model



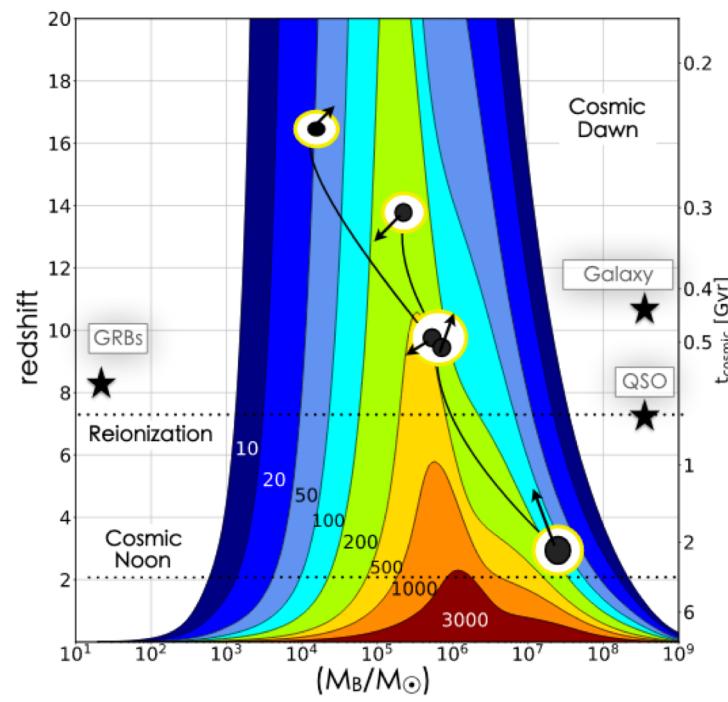
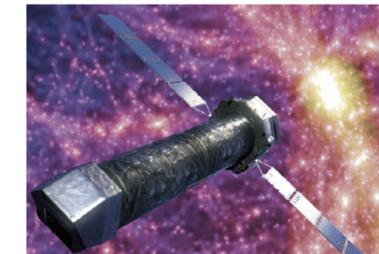
Supermassive black holes

LISA – ATHENA: a complete picture of BH growth

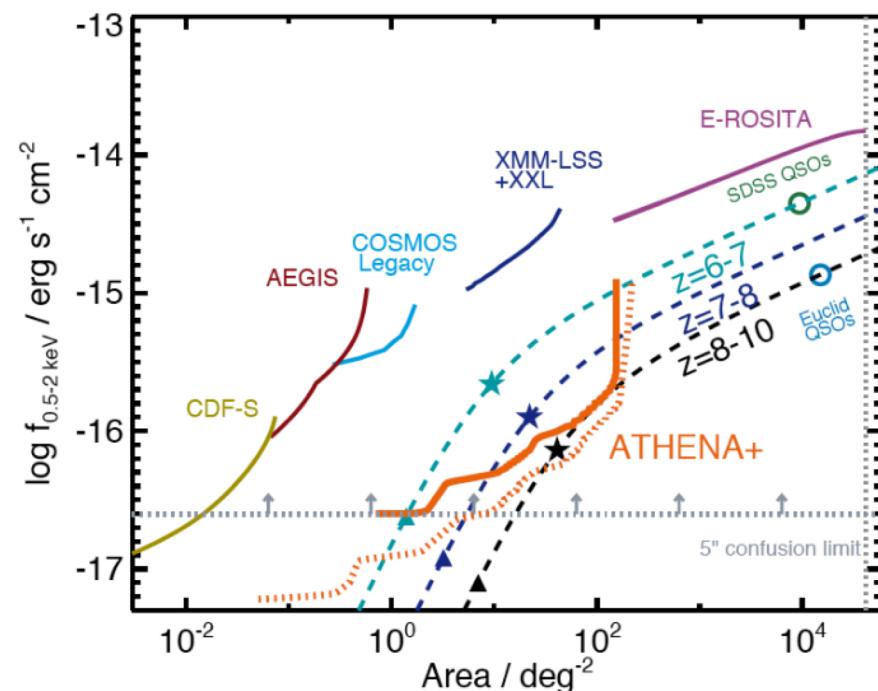
Mergers with LISA



Accretion with ATHENA

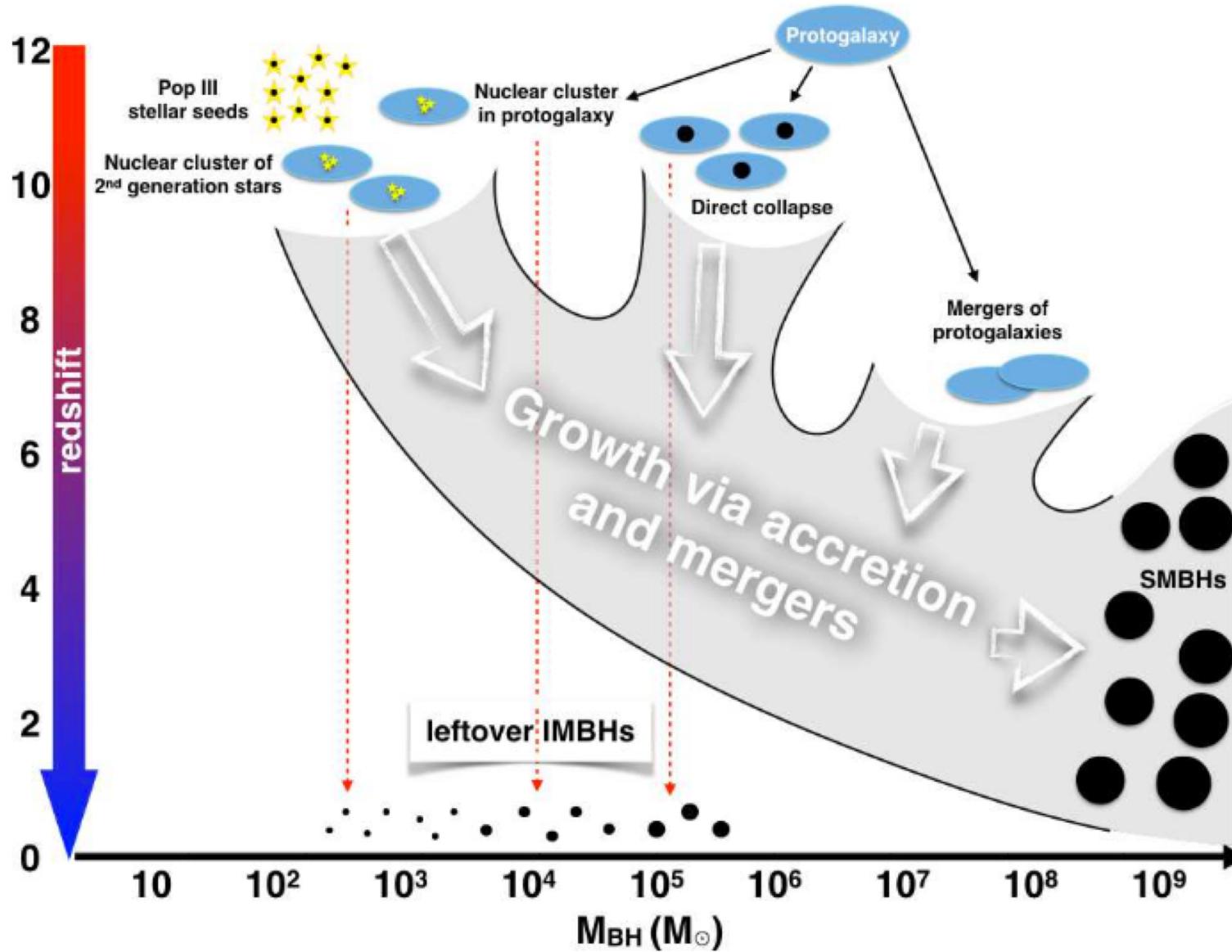


((Milosavljevic & Phinney, 2005))



Supermassive black holes

LISA – ATHENA: a complete picture of BH growth



Supermassive black holes

Electromagnetic signatures of MBHB mergers

Analytic estimates of the MBHB merger suggest that the binary ‘hollows out’ surrounding gas ultimately resulting in the merger occurring inside a hollow disk of gas. Implies there will be no signature coincident with the merger but the subsequent accretion will cause an X-ray source of

$$L_x \sim 10^{43.5} \frac{M}{10^6 M_\odot} \text{ ergs s}^{-1}$$

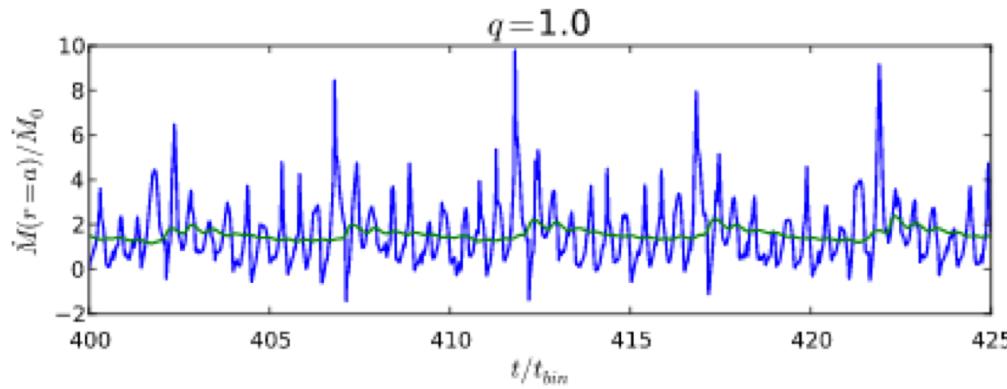
on a timescale of

$$t \sim 7(1 + z) \left(\frac{M}{10^6 M_\odot} \right)^{1.32} \text{ yr}$$

Supermassive black holes

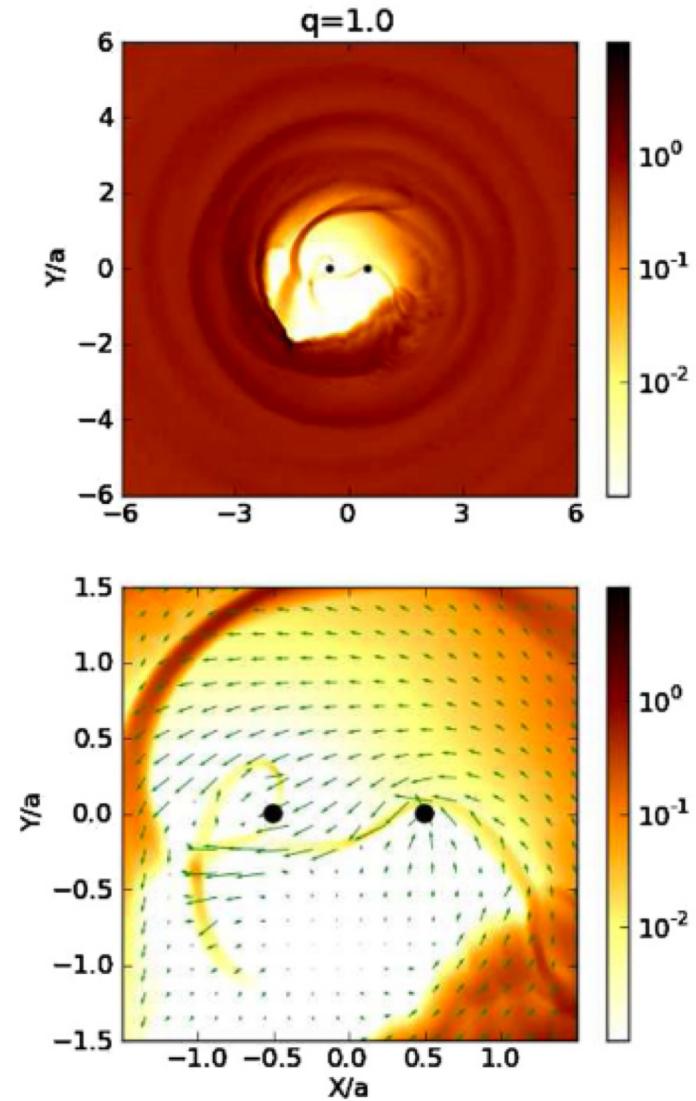
Electromagnetic signatures of MBHB mergers

Detailed numerical simulations show that mass accretion and inflow continues to occur



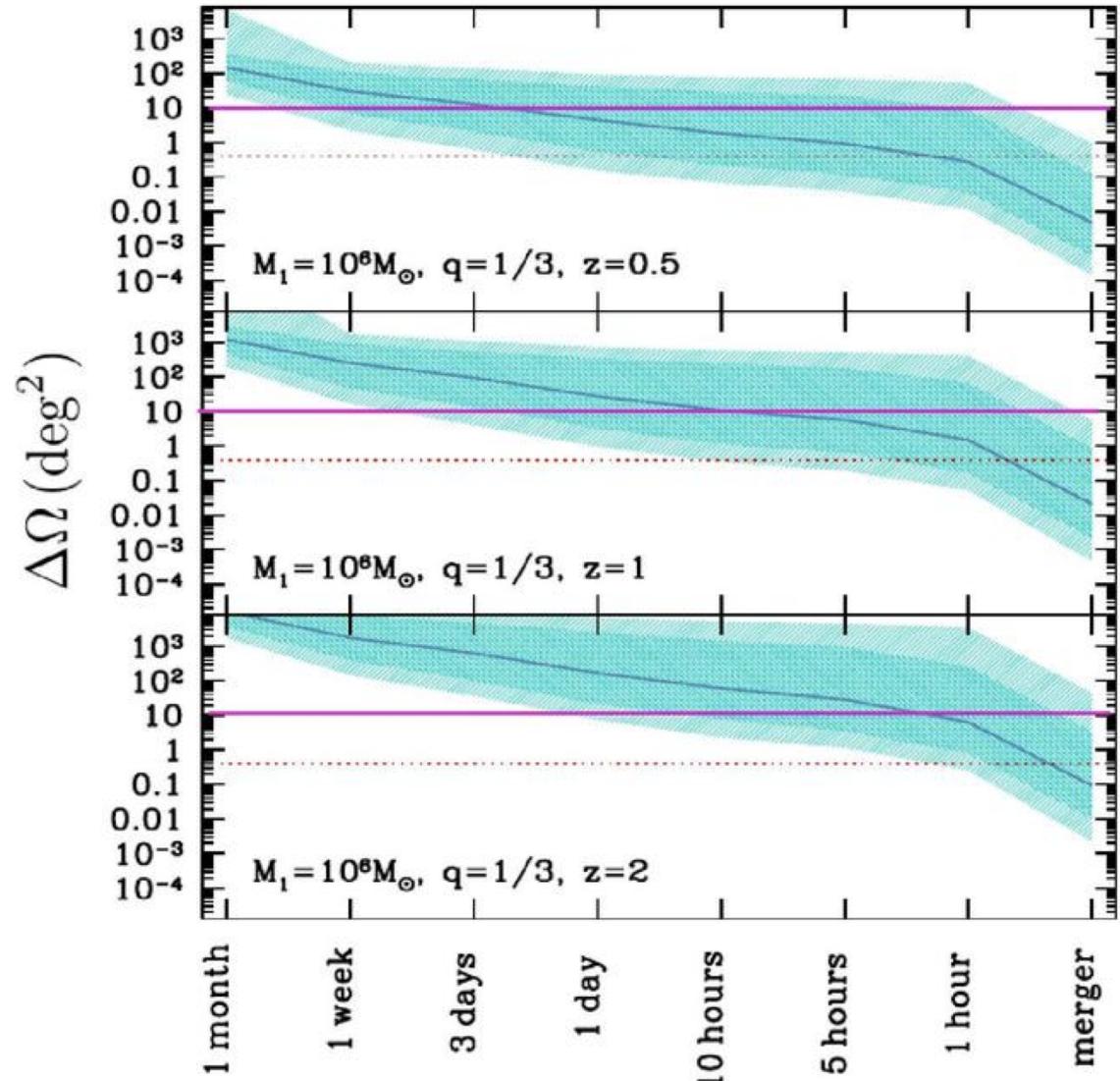
((Farris et al. 2014))

Conservative method would be to parametrise signal as a function of Eddington luminosity



Supermassive black holes LISA localization

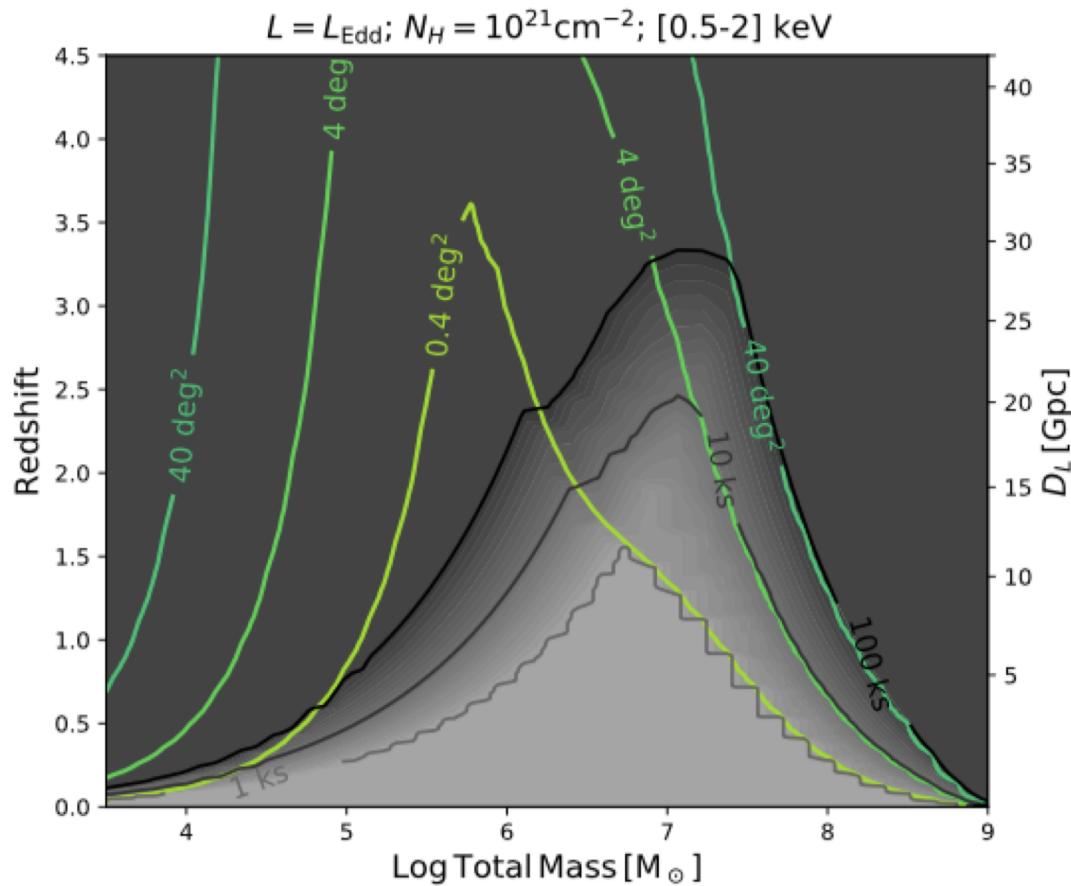
Sky localization will get better with time. A lot of the information coming just prior to the merger



Supermassive black holes

LISA - Athena

Athena will let us stare at the location of the BH merger



(McGee al., 2019)