Cerro Calán
Observatorio Astronómico Nacional

On the fate of Super Massive Black Holes in galaxy mergers

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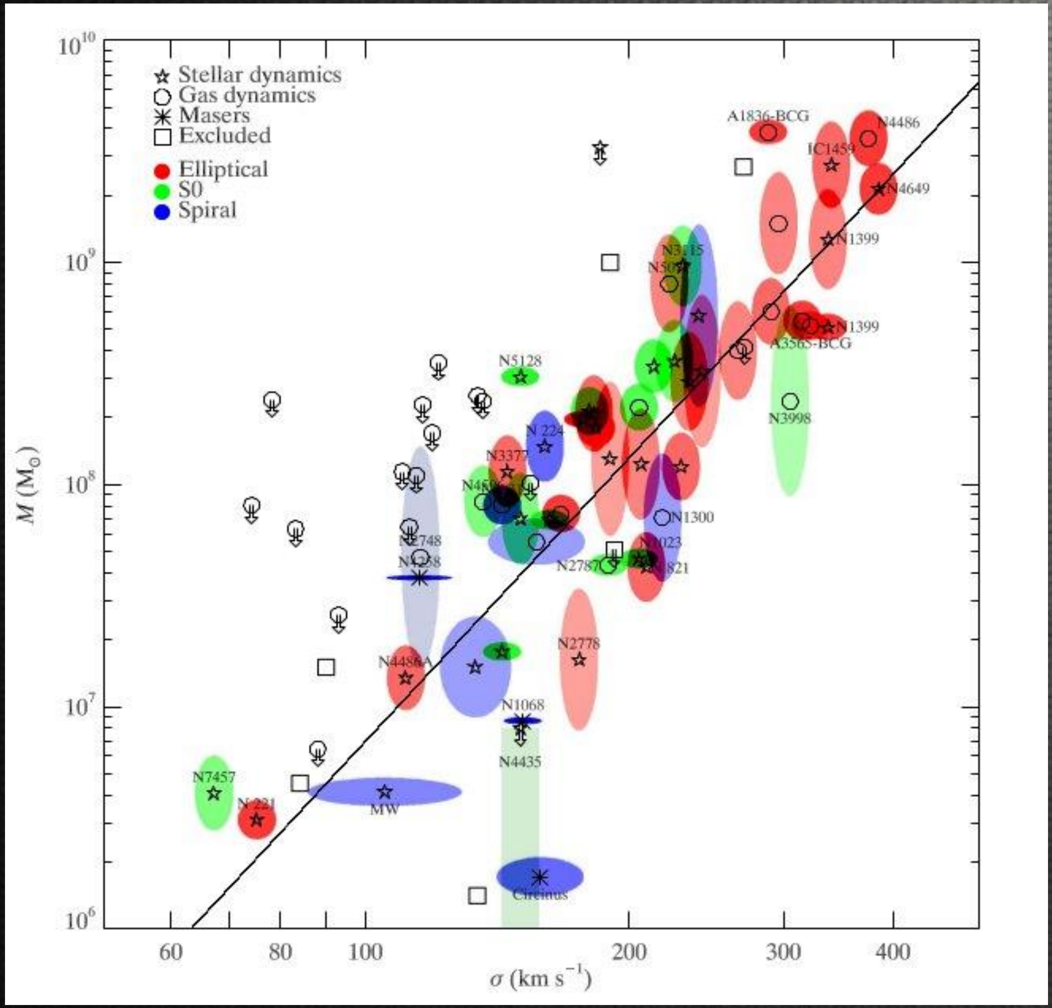
SMBHs in galaxies



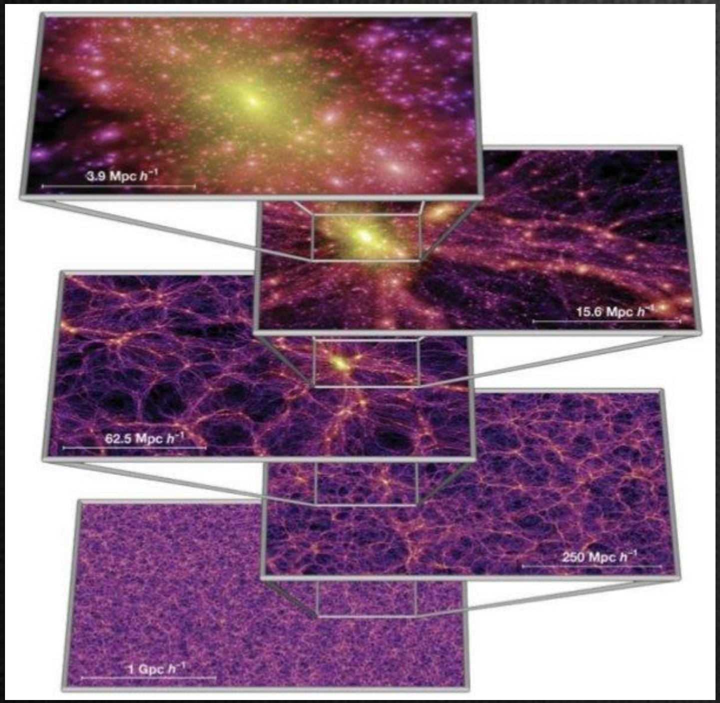
Gultekin etal 2009

Every galaxy with a significant bulge host a massive black hole (MBH) at its center

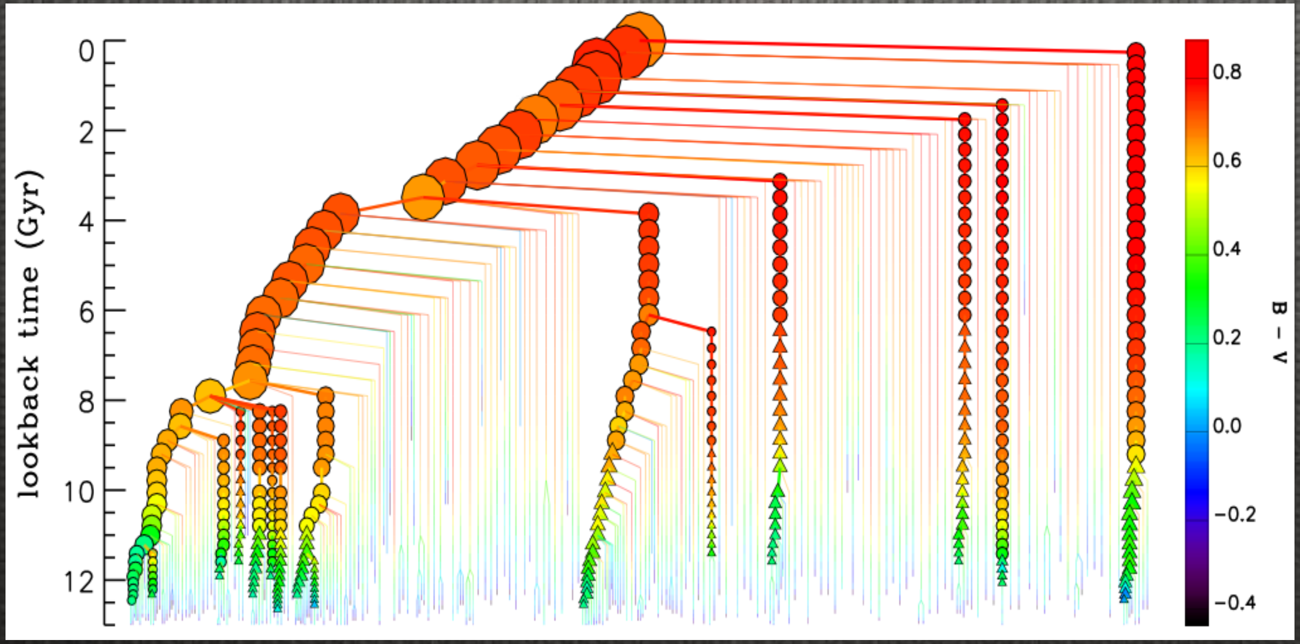
(Richstone etal. 1998, Margorrian etal. 1998 , Ferrase & Ford 2005, Gultekin etal. 2009)

Galaxy mergers

In the context of hierarchical structure formation (White & Frenk 1991, Springel etal 2005) the galaxies are sculpted by a sequence of mergers and accretion events

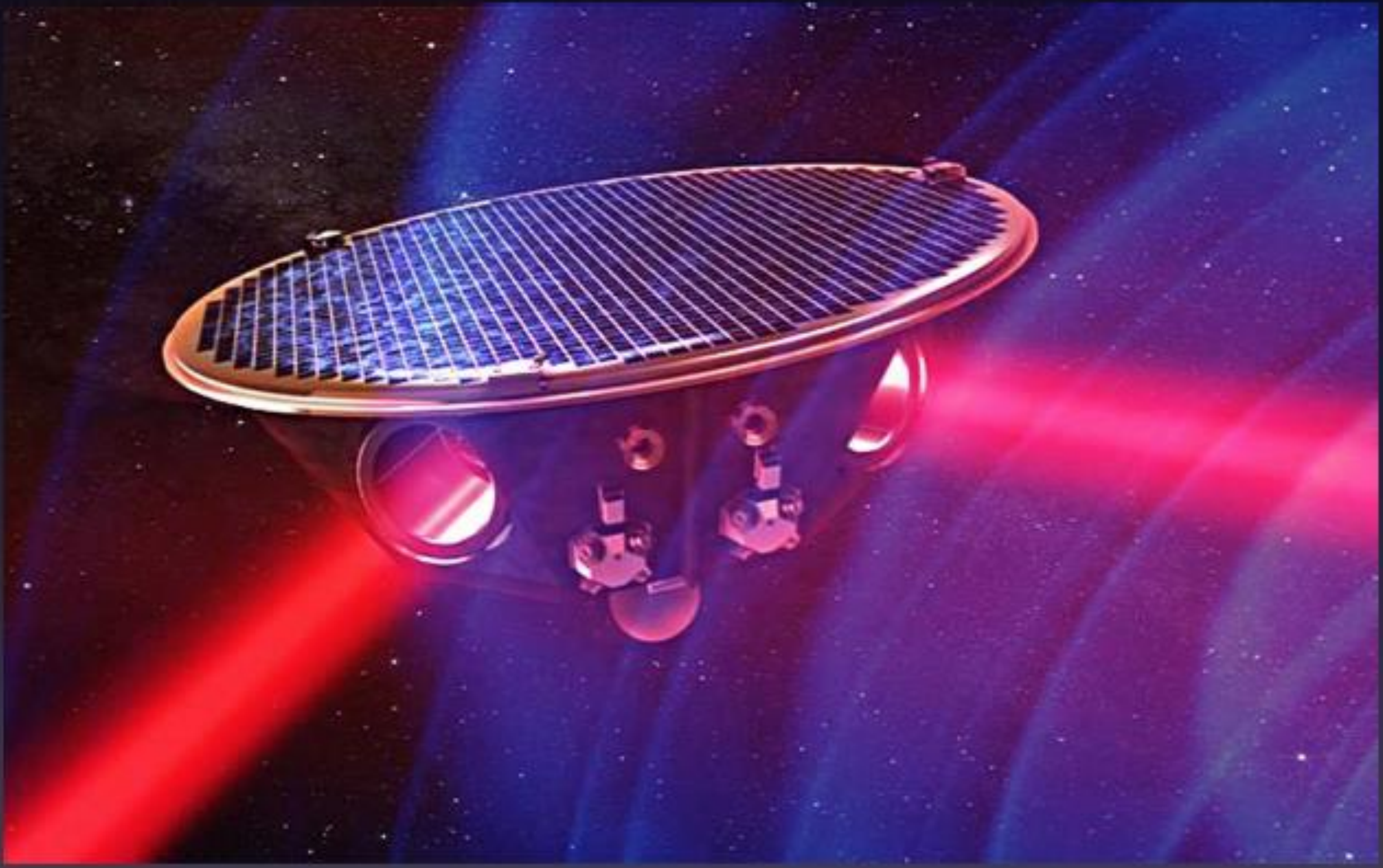


Springel etal 2005

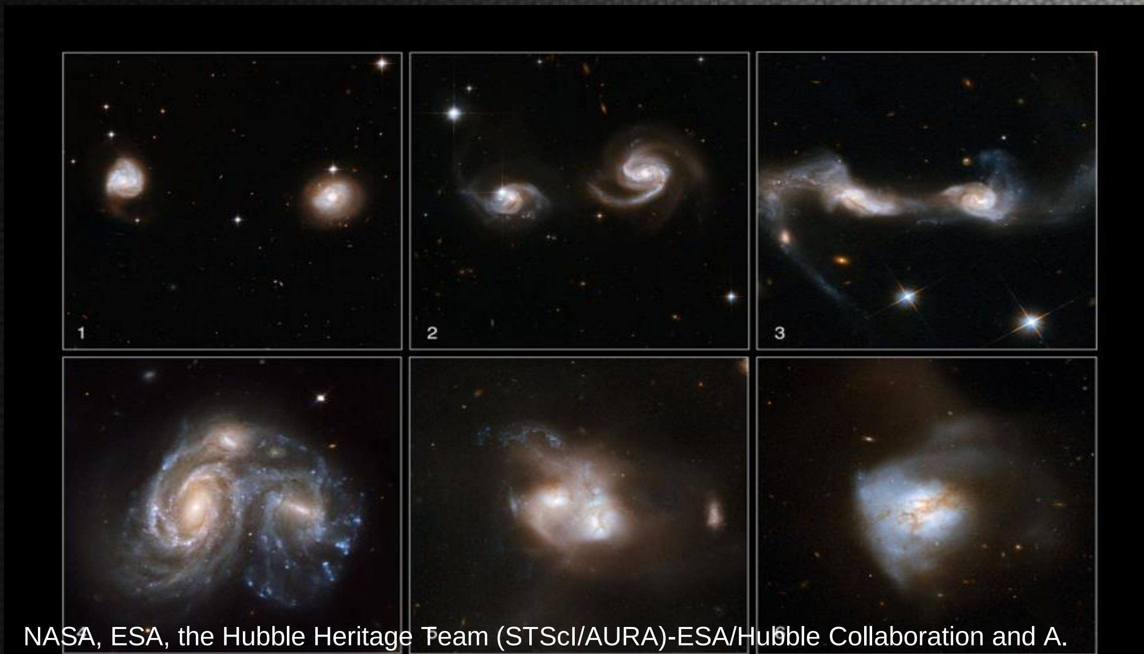


de Lucia & Blaizot 2007

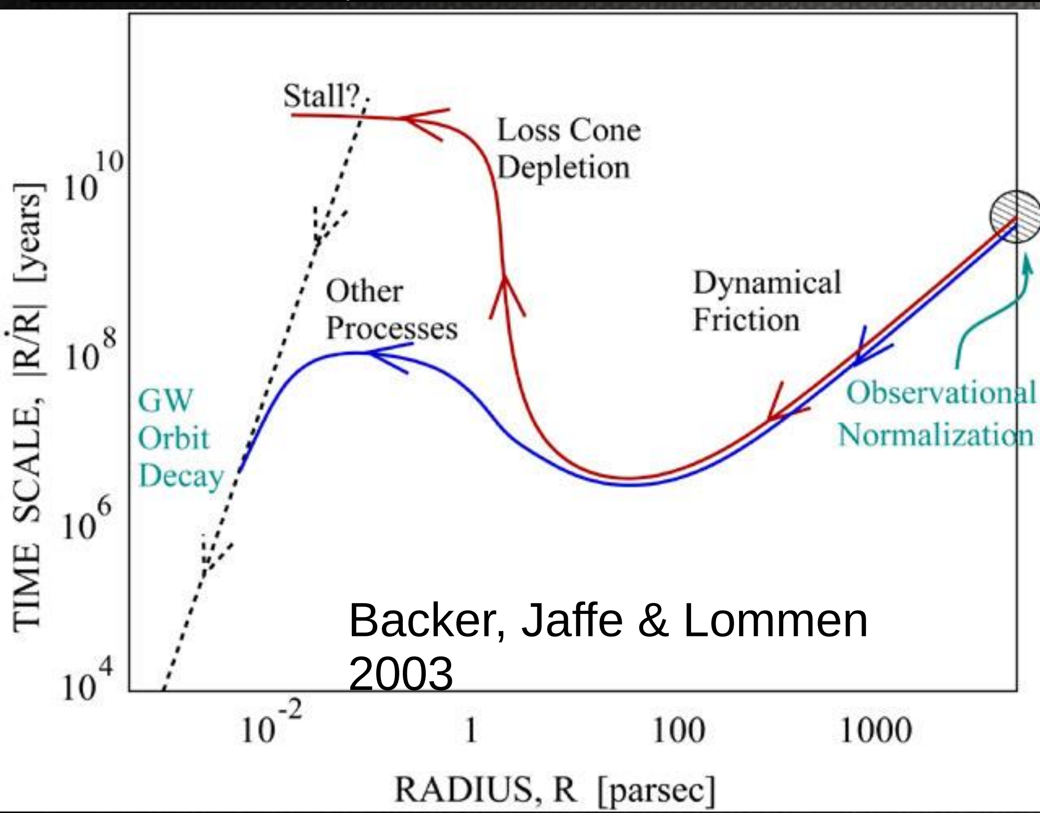
If this Galactic Mergers lead to coalescence of their MBHs: Sources for eLISA



Artist's impression of eLISA satellite. Credit: AEI/MM/exozet/NASA/Henze.



NASA, ESA, the Hubble Heritage Team (STScI/AURA)-ESA/Hubble Collaboration and A. Evans, K. Noll, & J. Westphal.



Backer, Jaffe & Lommen 2003

Begerman, Blandford & Rees 1980:

In the early evolution of the merger, the MBHs follows the centers of each galactic core until they merge and forms a new virialized core.

Afterwards, the pair of MBHs sink to the center by dynamical friction against the stellar background.

Then the binary begins its hardening due to dynamical friction until it becomes inefficient (hard binary).

Stellar loss-cone depletion by 3-body kicks implies stalling of MBH binary at sub-parsec for a spherical system.

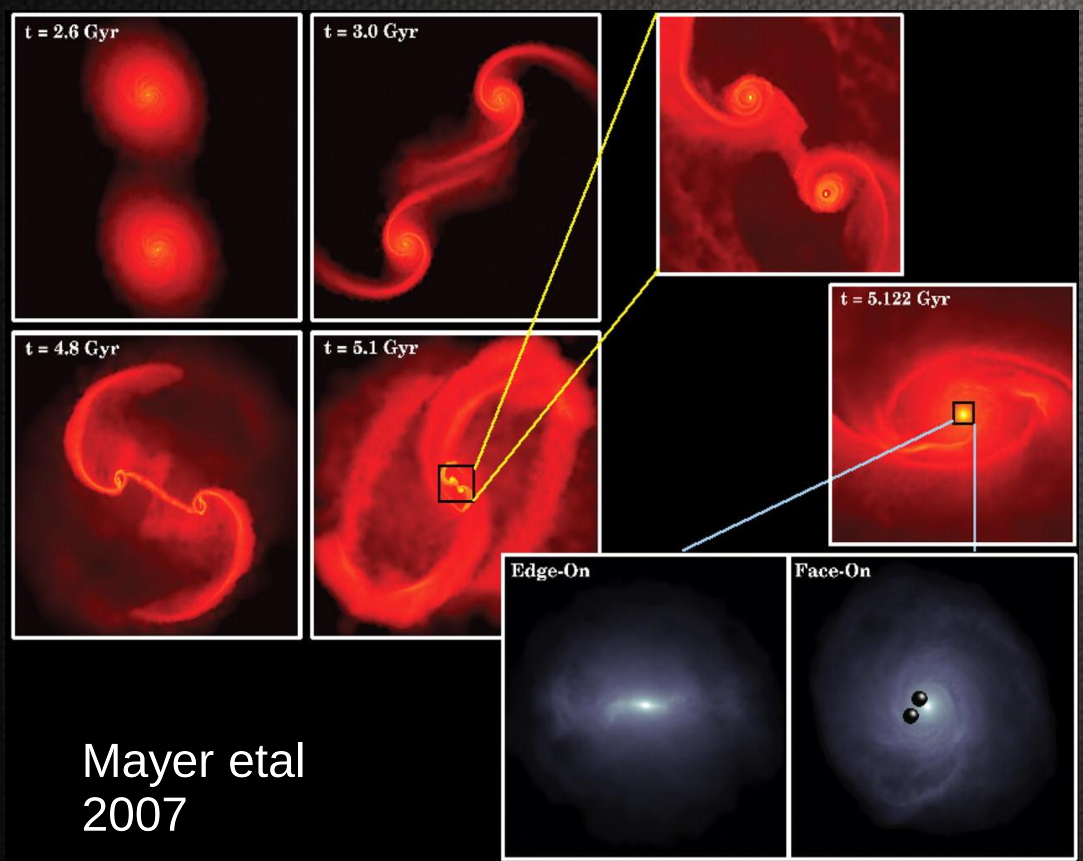
However for triaxial ones: Shrinking time ~ 5-7 Gyrs (Khan et al 2011).

Central kiloparsec of merger remnant

In gas-rich galaxy mergers large amount of gas (50 - 90 %) reach the central kilo-parsec of the new system.

Simulations -> (Barnes & Hernquist 1992, 1996 Mihos & Hernquist 1996; Barnes 2002; Mayer et al. 2007, 2010)

Observations -> (Sanders & Mirabel 1996; Downes & Solomon 1998; Davies, Tacconi & Genzel 2004)

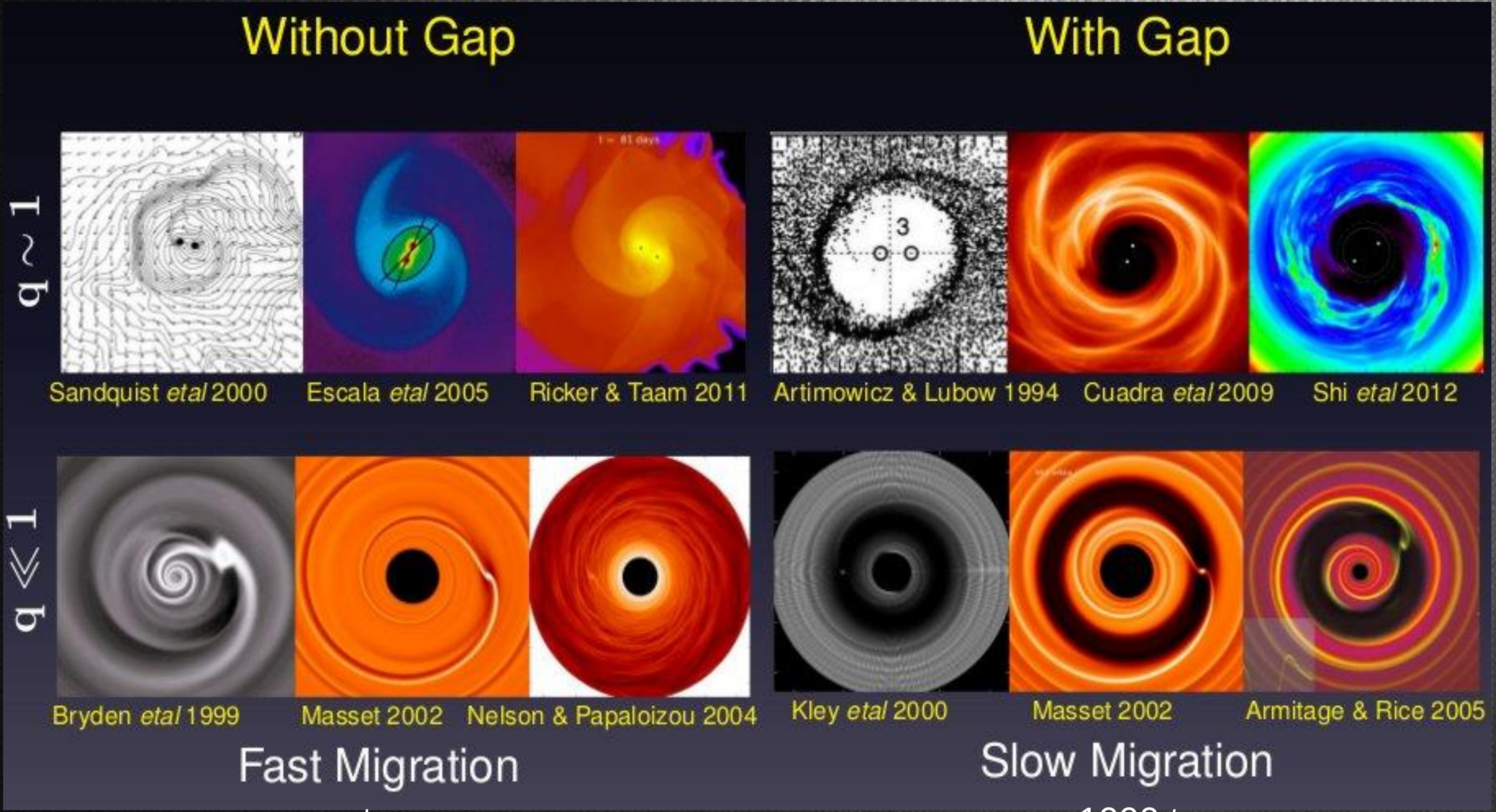


Mayer etal 2007

If the galaxies involved in a galaxy merger have a gas fraction of at least 1%

Mgas > 10 MBH

Binary-Disk interaction on the literature



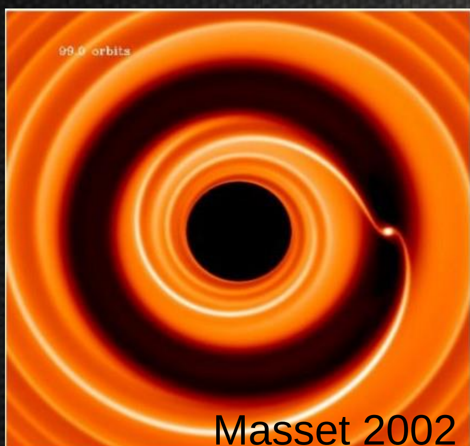
$\tau \sim t_{orbital}$ $\tau \sim 1000\ t_{orbital}$

Gap opening criterion

Analytical estimates for a Gap Opening condition can be computed by comparing the timescales for closing and opening a Gap.

$$\Delta t_{\rm close} = (\Delta r)^2/\nu$$

$$\Delta t_{\rm open} = \Delta L/\tau$$



Masset 2002

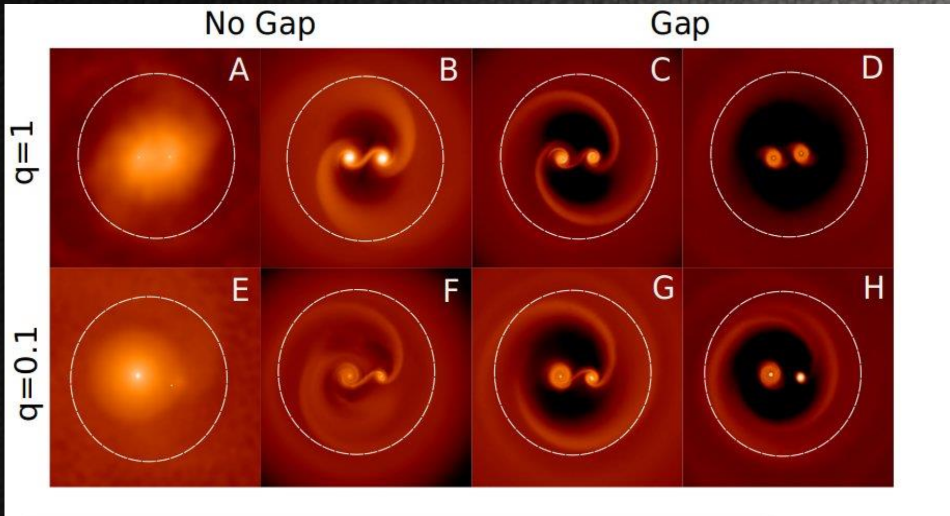
$$\tau = \sum_m T_{ILR} + \sum_m T_{OLR} + T_{CR}$$

Resonant process: Several orbits needed (q<<1)

Escala etal 2005

$$\tau = a^2\,\mu\,\rho\,G\,K_{\rm q}$$

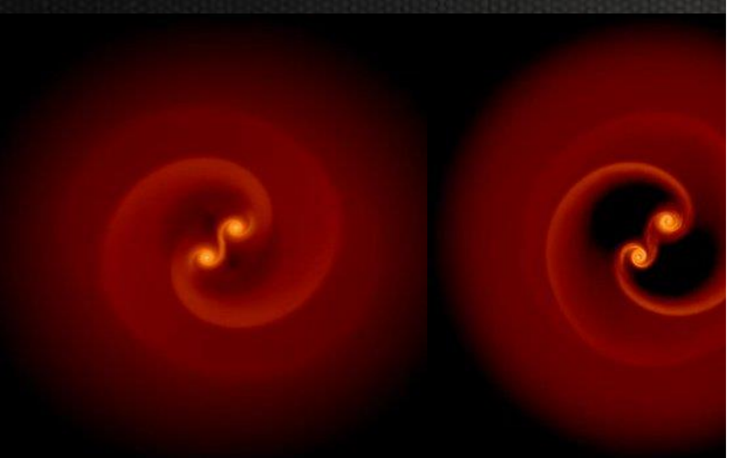
Tidal process (q ~ 0.1-1) (Del Valle & Escala 2012)



Binary-Disk simulations

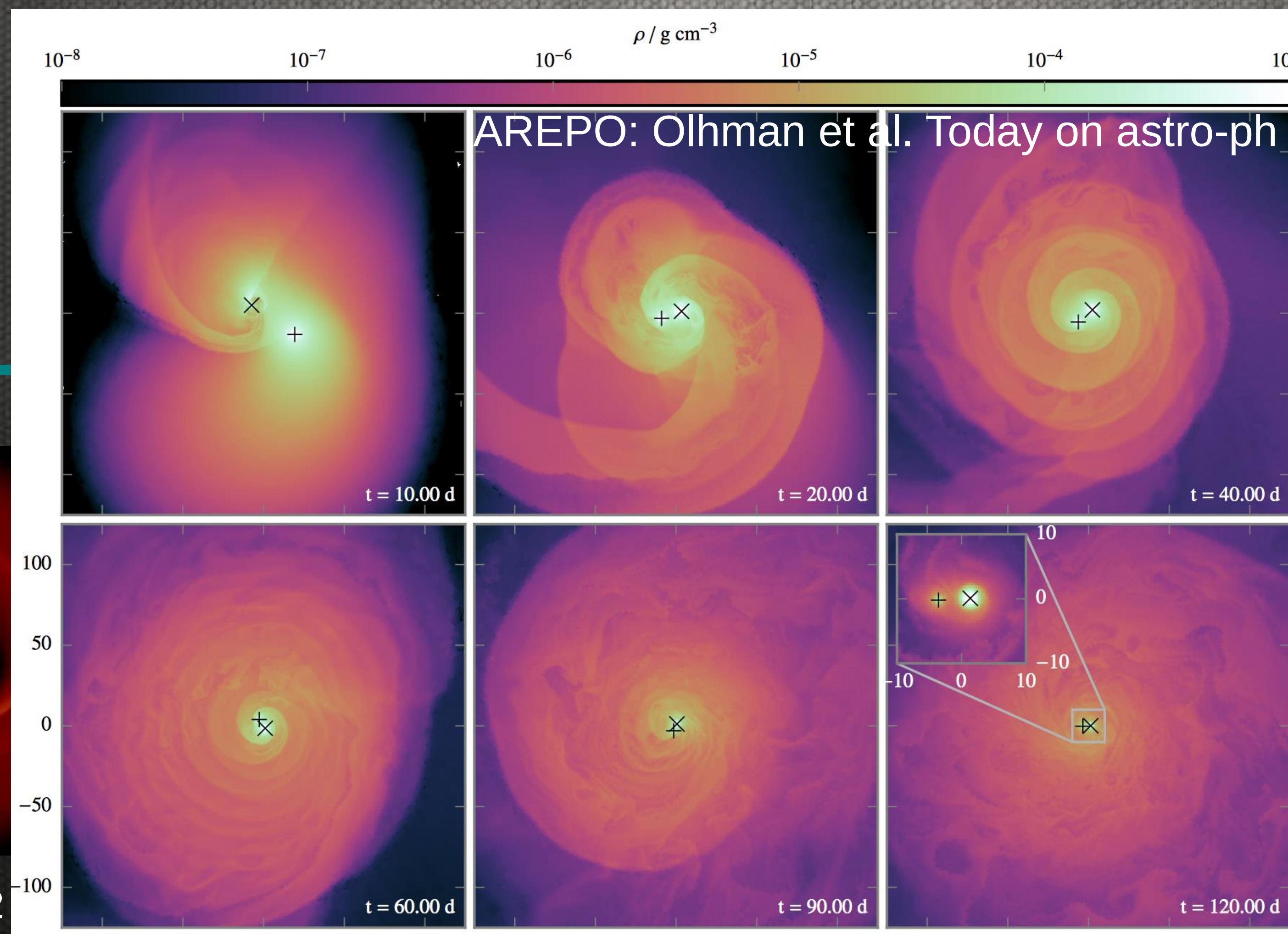
Del Valle & Escala 2014

Gap-opening criterion test



Cs ~ 8

Cs ~ 2



AREPO: Olhman et al. Today on astro-ph

What would happen in a real galaxy merger?

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↓

We simulate a galaxy merger and follow the evolution of the SMBHs

Galaxy mergers simulations

Two Milky-Way like galaxies of the same mass (major merger).

Our simulations include star formation, radiative cooling and heating due to supernova explosions
(Gadget-3, Springel etal 2005)

Two set of mergers with different MBH masses

Geometry	i_1	ω_1	i_2	ω_2
DIRect	0	–	71	30
RETrograde	180	–	−109	30
POLar	71	90	−109	90
INClined	71	−30	−109	−30

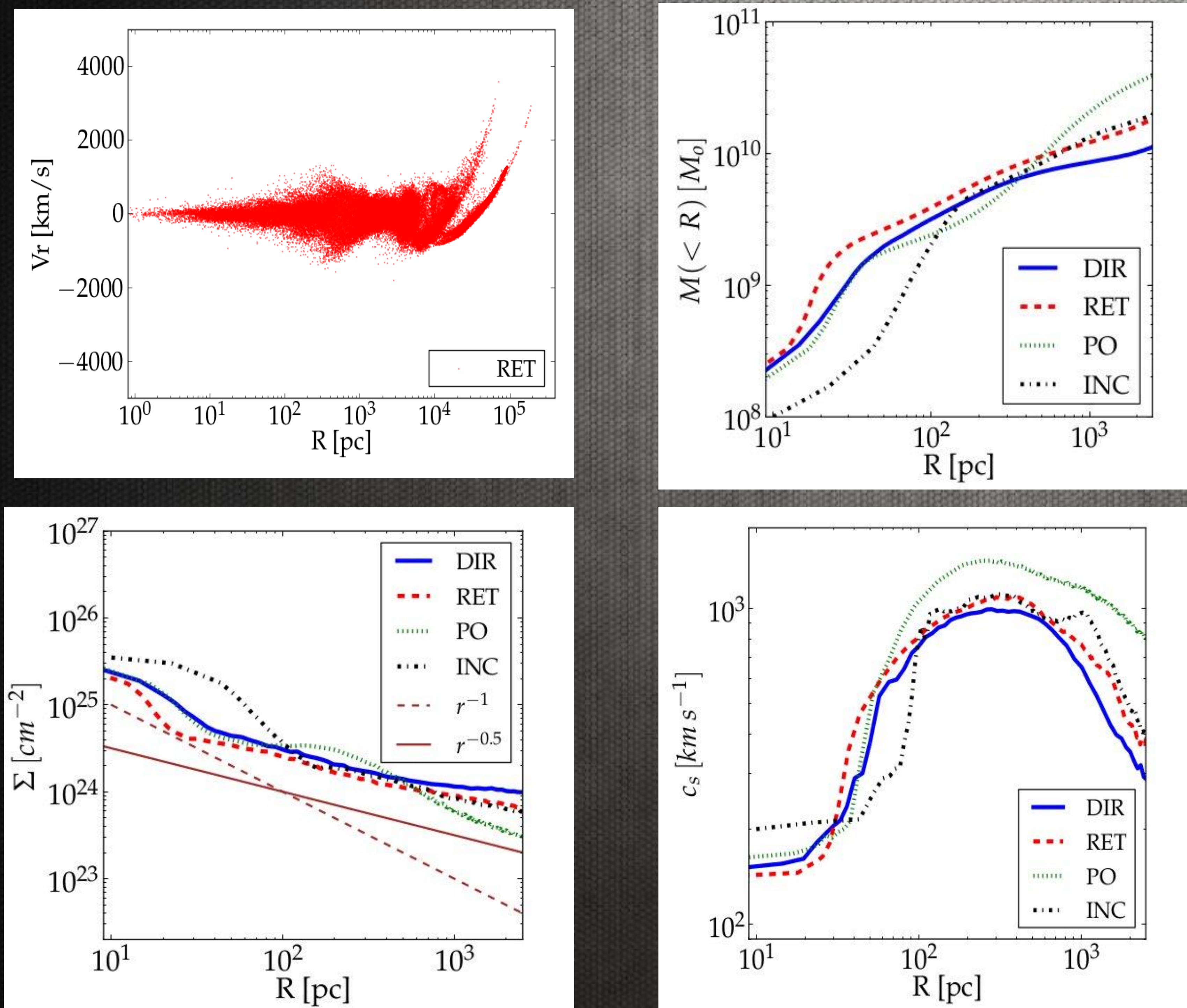
Barnes 2002

$$M_{BH} \propto M_{Bulge}$$

(Late accretion)

$$M_{BH} \propto M^{Remnant}_{r<2kpc}$$

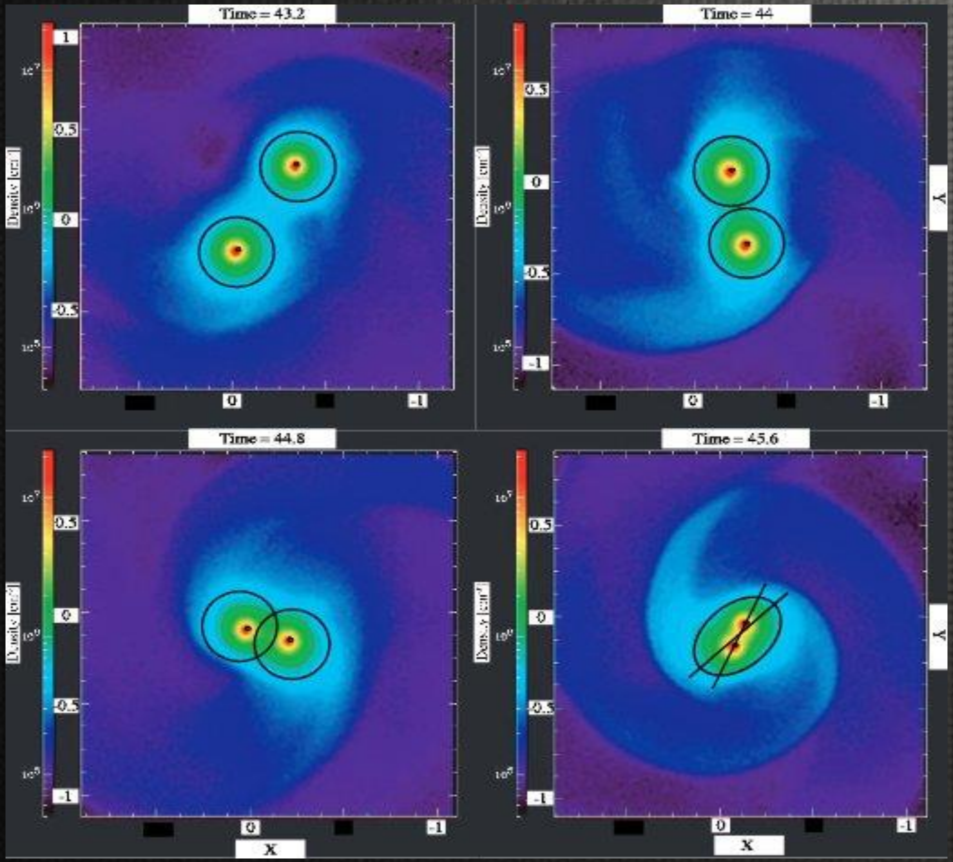
(Early accretion)

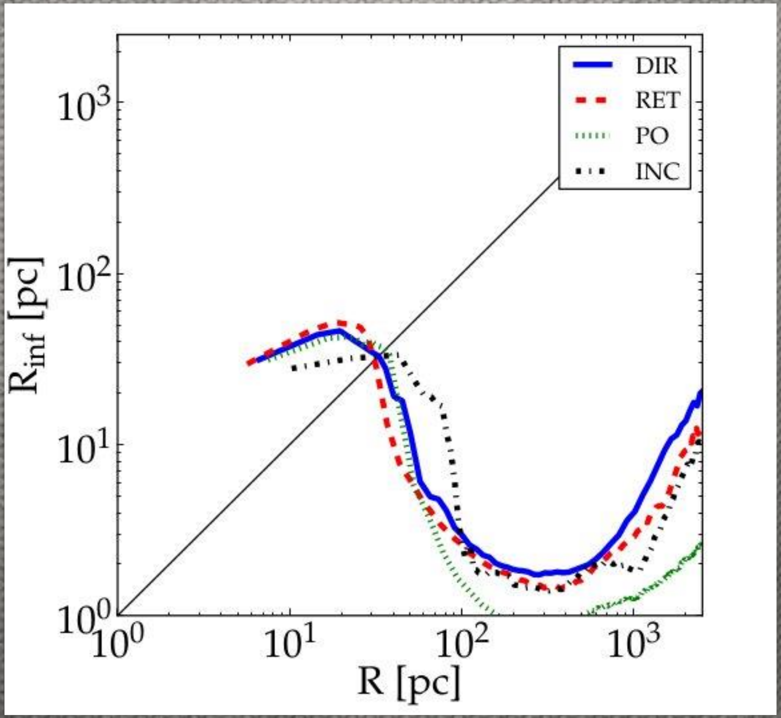


Vr [km/s]
4000
2000
0
−2000
−4000
RET
10^0 10^1 10^2 10^3 10^4 10^5
R [pc]
$M(<R)\ [M_o]$
10^{11} 10^{10} 10^9 10^8
DIR
RET
PO
INC
10^1 10^2 10^3
R [pc]
$\Sigma\ [cm^{-2}]$
10^{27} 10^{26} 10^{25} 10^{24} 10^{23}
DIR
RET
PO
INC
r^{-1}
$r^{-0.5}$
10^1 10^2 10^3
R [pc]
$c_s\ [km\ s^{-1}]$
10^3 10^2
DIR
RET
PO
INC
10^1 10^2 10^3
R [pc]

Binary forms when a_{bin} ~ 35 pc

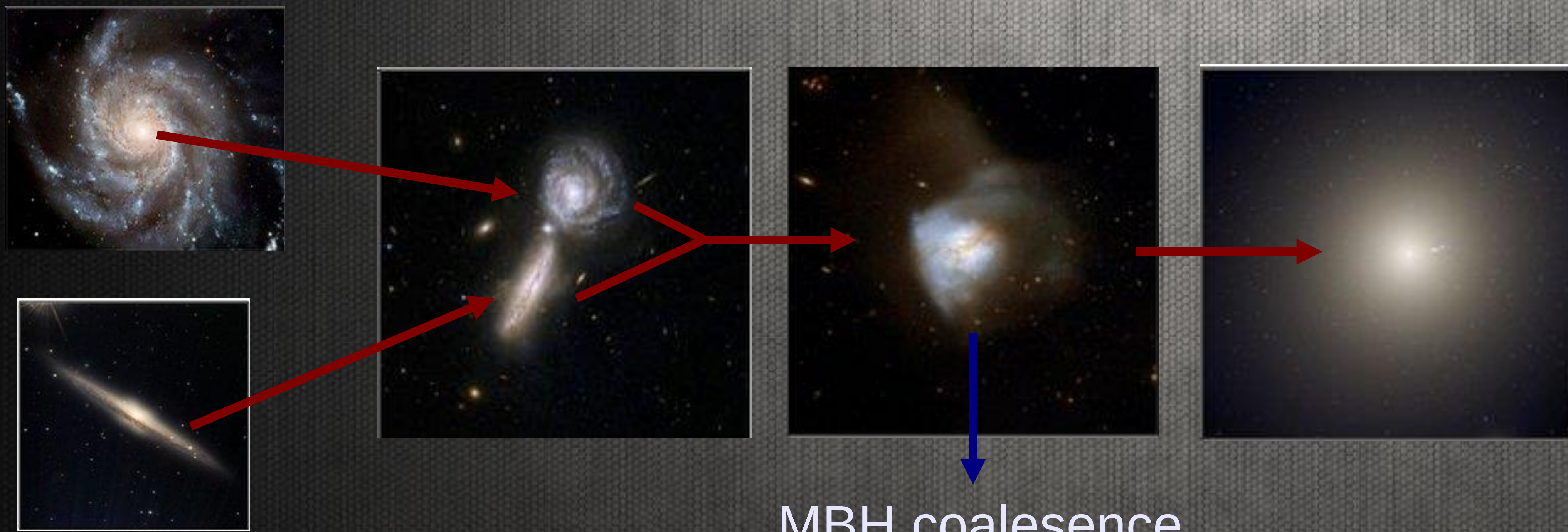
$$R_{\rm inf} = 2GM_{\rm BH}/(v_{BH}^2 + c_s^2)$$





Conditions below 100 pc consistent with observations of ULIRGs (Downes & Solomon 1998; Ueda etal 2014)

Accretion limits



MBH coalescence

Early accretion

$$M_{BH} \propto M_{r<2kpc}^{Remnant}$$

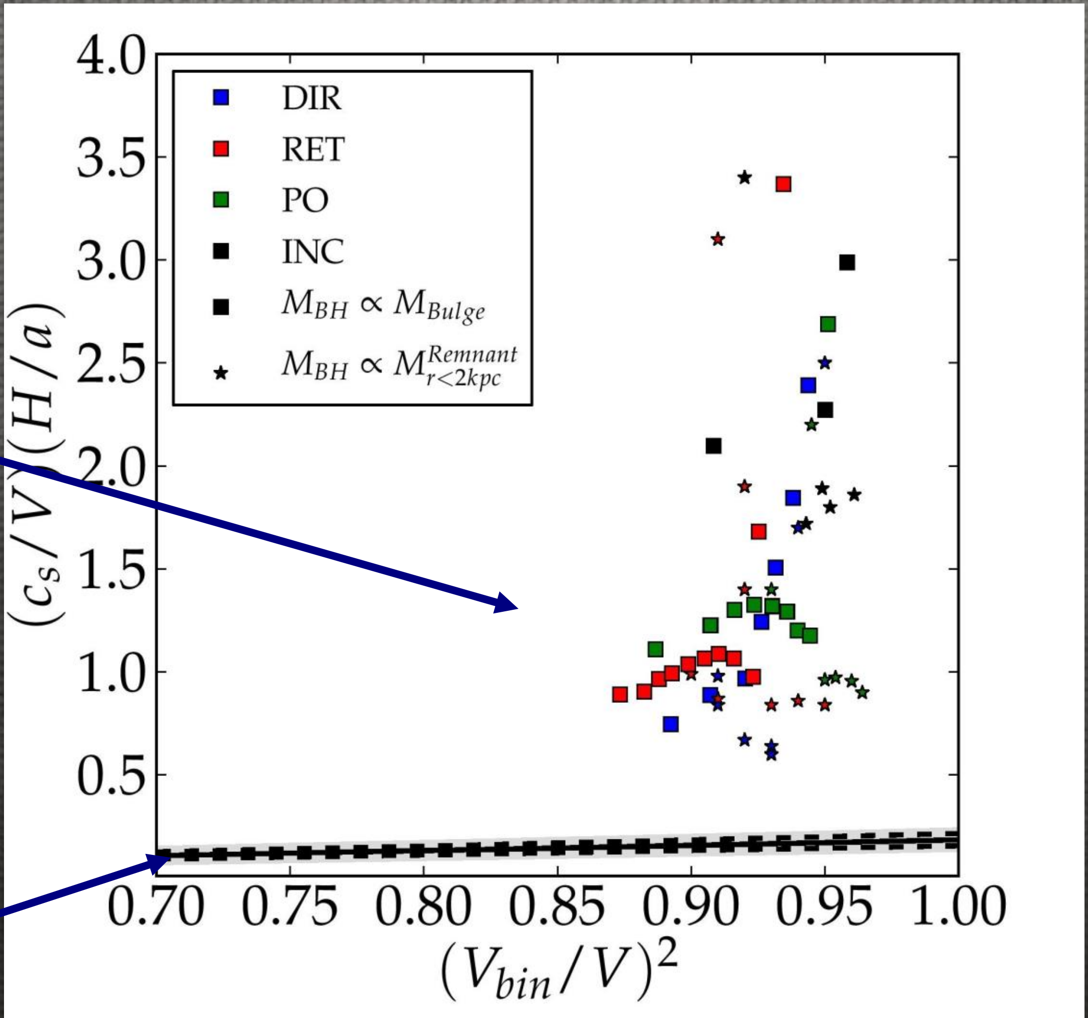
Late accretion

$$M_{BH} \propto M_{Bulge}$$

Evaluating the gap-opening criterion in the galaxy mergers

Even if SMBH accretion occurs before they form a bound binary → No Gap formation → Fast shrinking

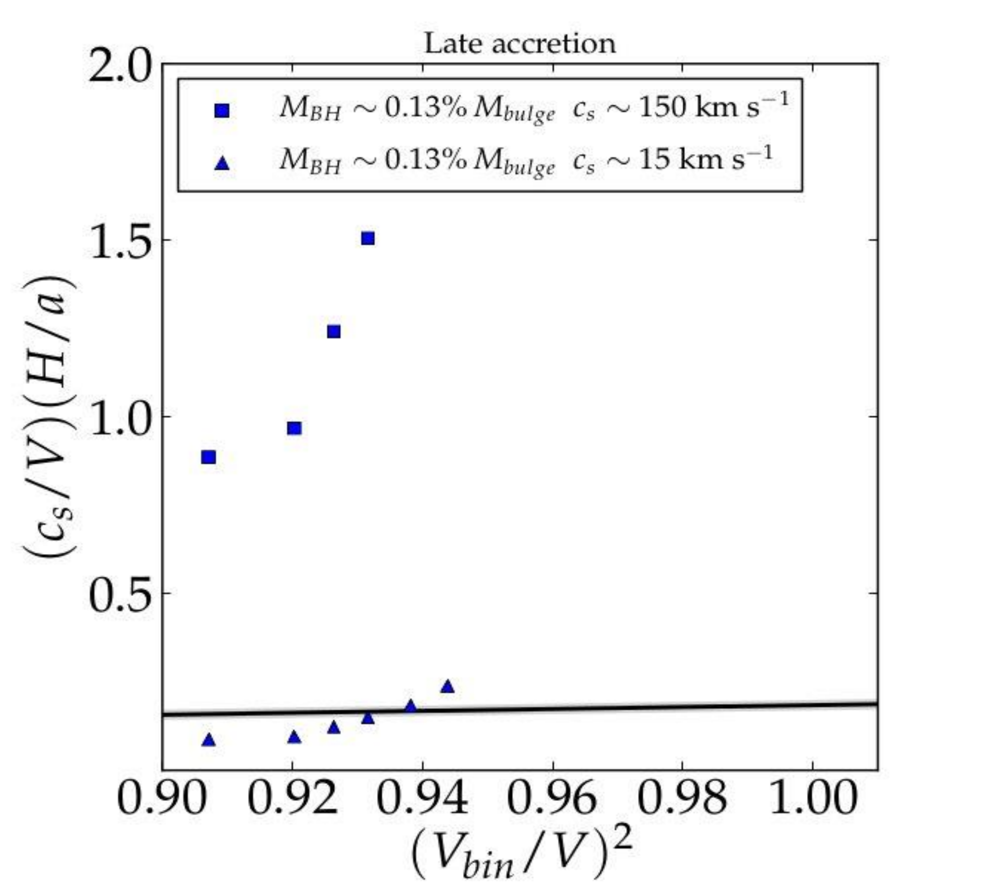
$$\frac{\Delta t_{\rm open}}{\Delta t_{\rm close}} = \frac{1}{0.33}\left(\frac{c_{\rm s}}{v}\right)\left(\frac{v}{v_{\rm bin}}\right)^2\left(\frac{H}{a}\right) \leqslant 1$$

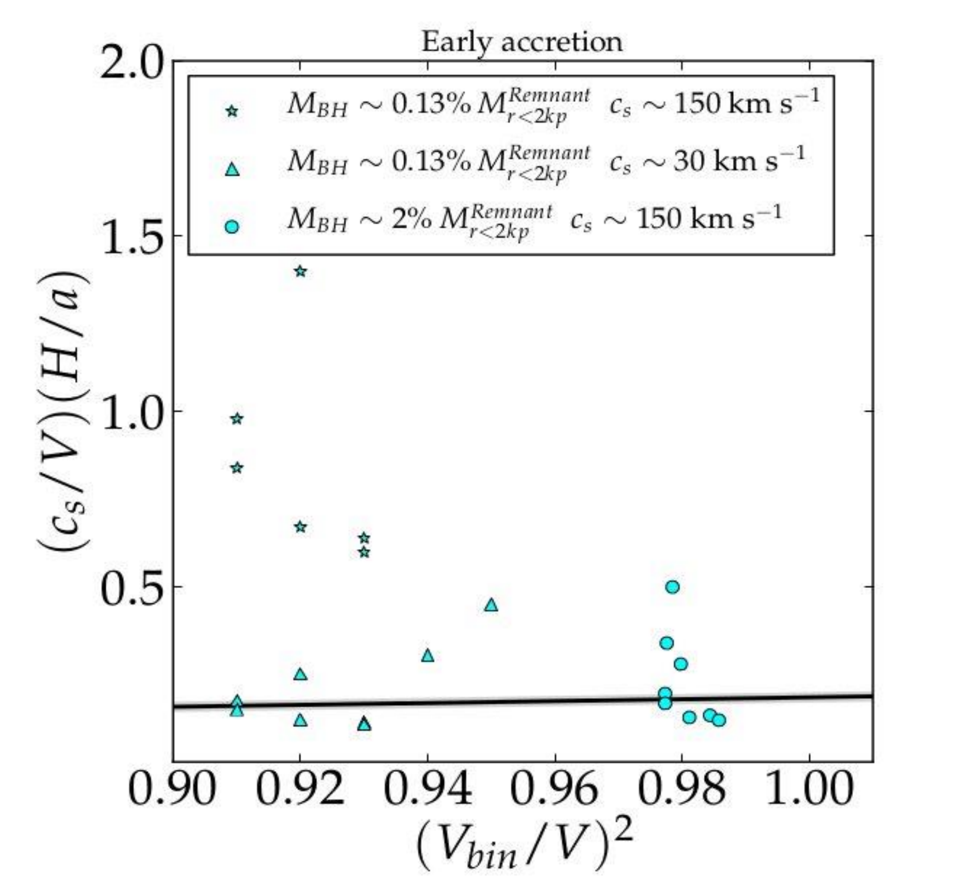


Conditions needed to open a gap

Turbulent velocity in the inner region of local spirals ~ 10 km/s

In ULIRGs ~ 100 km/s





Summary

- We study the fate of SMBHs in galaxy mergers. In major mergers the SMBHs form a binary and the separation of this binary will shrinks enough to merge in a timescale of the order of Gyrs if they interacts only with stars.
- If the galaxies involved in the galaxy merger have at least 1% of gas, the central kilo-pc of the remnant will contain ten to hundred times the mass of the SMBHs in gas. This gas can extract angular momentum from the binary.
- If the gas does not redistribute efficiently the extracted angular momentum will be pushed away from the binary and the shrinking will stall. We derive and test a criterion to determine under which condition the binary will evacuate a central cavity or not.
- We use this criterion in simulations of galaxy mergers and find that is very likely that the binary will NOT evacuate a central cavity, then the gas can drive a fast shrinking of the SMBHs binary down to scales where the emission of gravitational waves can drive efficiently the final coalescence.