The Fate of Massive Black Holes (MBH) in Gas-Rich Galaxy Mergers

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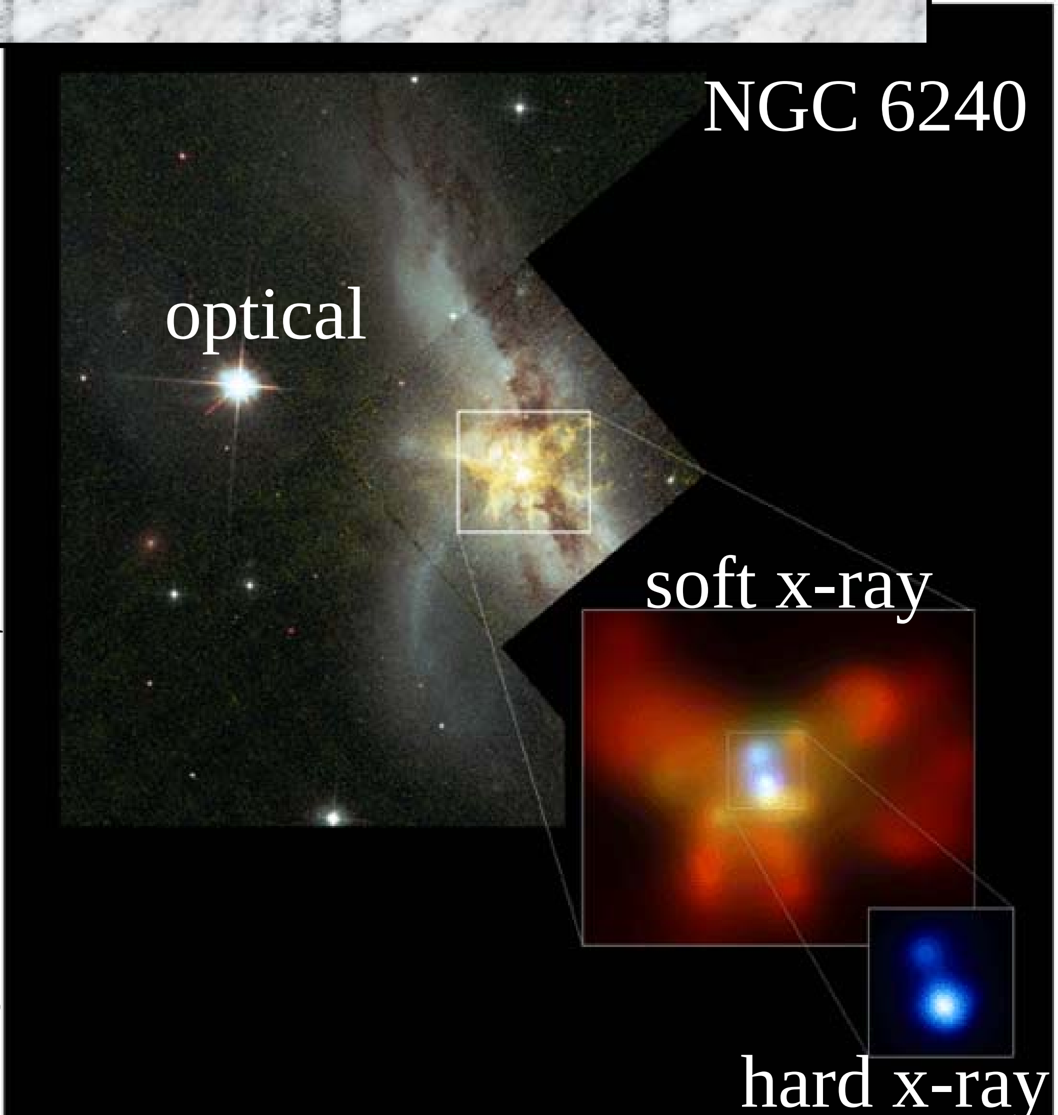
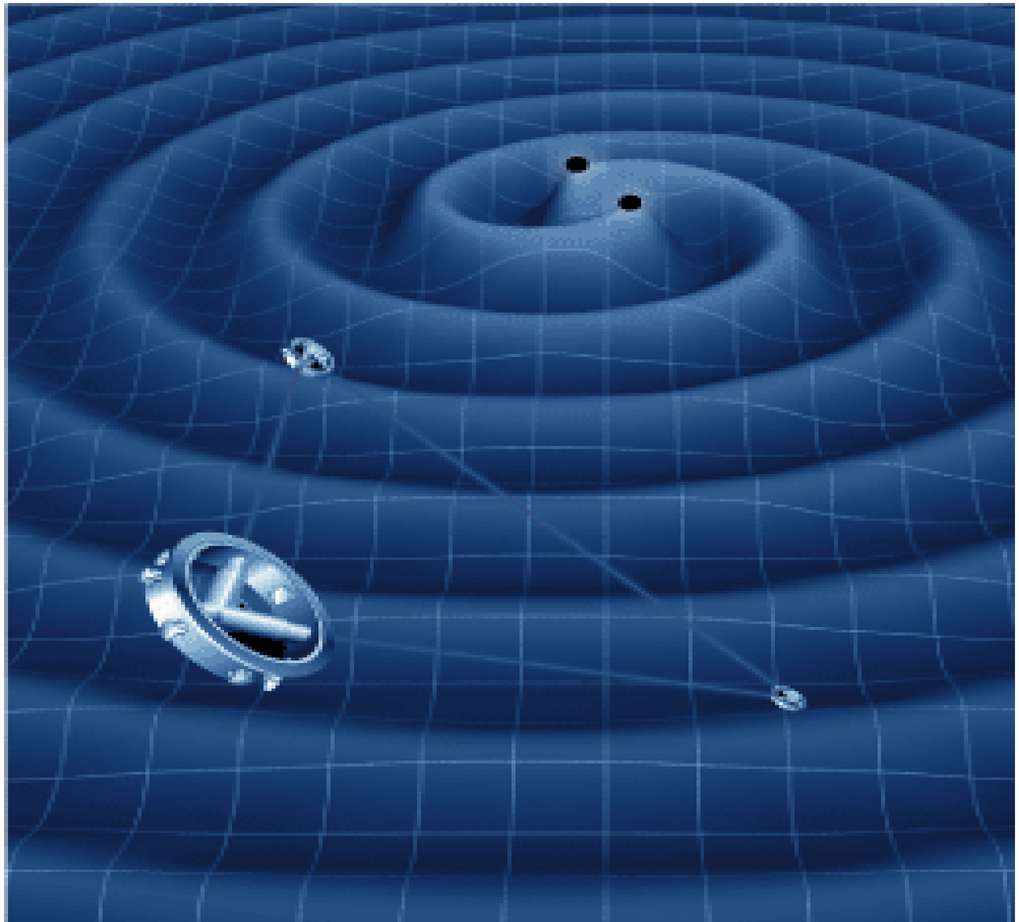
Galaxy Mergers and MBH´s

- Galaxy mergers are common events in the universe.
- Each galaxy with a sizeable bulge is expected to have a MBH.
- What is the fate of the BHs? Will also Coalesce?



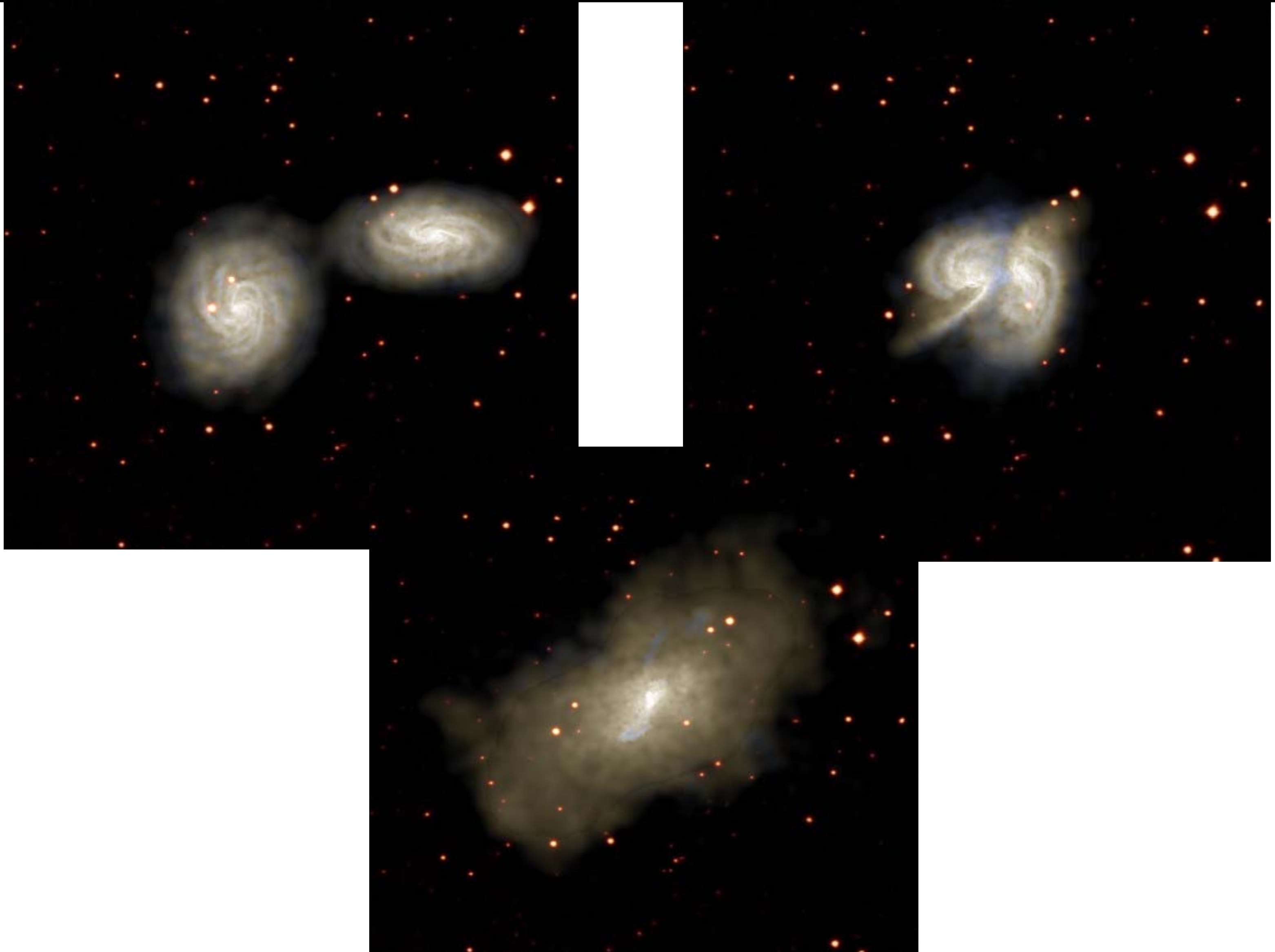
Final Coalescence: Gravitational Waves

LISA :

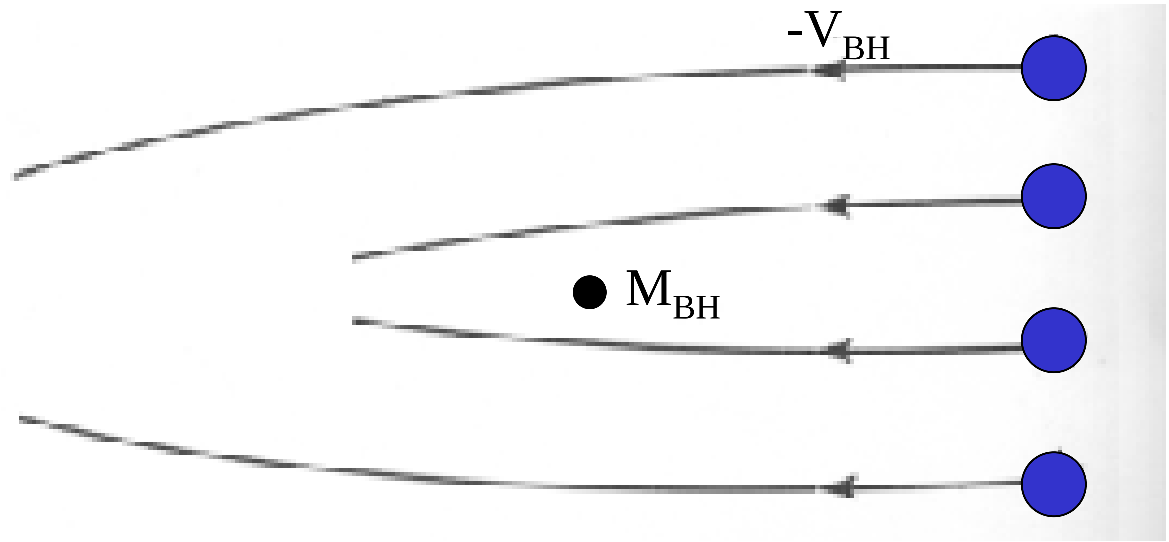


Mergers of Galaxies & MBHs

(Begelman, Blandford & Rees 80’)

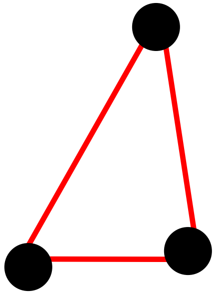


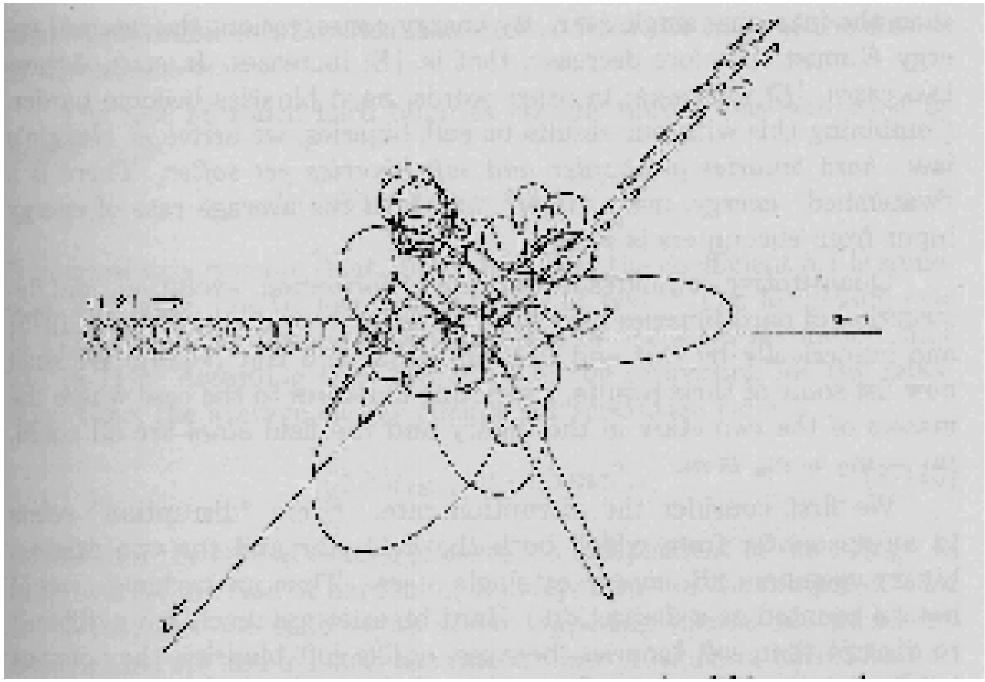
Gravitational Drag



$$F_{DF} = -4\pi \, (GM_{BH})^2 \, \rho \, v_{BH}^{-2} \, \ln\Lambda \, F(v_{BH}/\sigma)$$

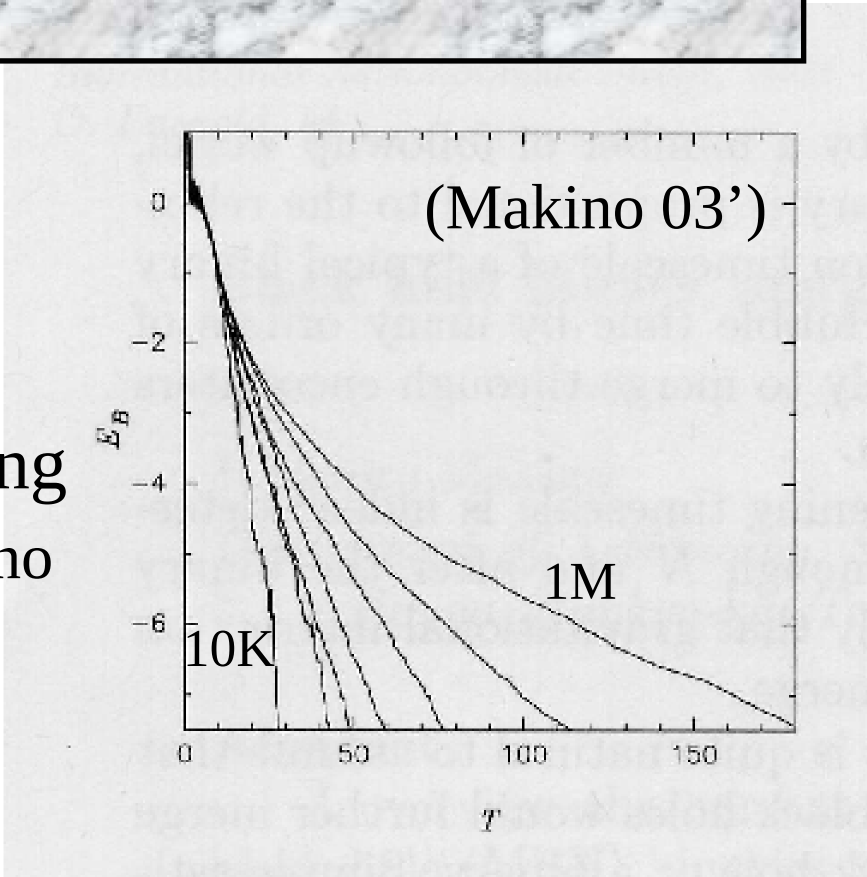
3-Body Interactions





Coalescence Stalls.

- 3-body interactions eject stars from the galactic nuclei, depleting the phase-space loss cone (Makino 03’, Berczik et al. 05’).



- The coalescence is expected to stall at distances of 0.01-1pc. Gravitational radiation coalescence timescale larger than the age of the universe.

Gas in Merging Galaxies

- Gas mass fraction in disk galaxies is between 1% (Sa) to 50% (Scd) (Young et. al. 95’).

Gas in Merging Galaxies

- Most of the gas (2/3) originally present in the merging galaxies ends up in a very massive nuclear disk (Barnes & Hernquist 96').
- M_{BH} - M_{Bulge} Relation: $M_{BH} = 0.15\% \, M_{Bulge}$

$$\longrightarrow \quad M_{gas} > 10 \, M_{BH}$$

Massive Nuclear Disk

- Observations (Downes & Salomon 98') suggest the existence of a smooth inter-cloud medium with dense clumps that accounts for less than the half of the total mass.

- Initial Conditions :

$M_{gas} = 5\ 10^{9}\ M_{O}$

$R_{disk} = 400$ pc

$H_{disk} = 40$ pc

$M_{dyn} = 6\ M_{gas}$

$M_{BH} = (0.01\text{-}0.5)\ M_{gas}$

$P = K\ \rho^{5/3}$

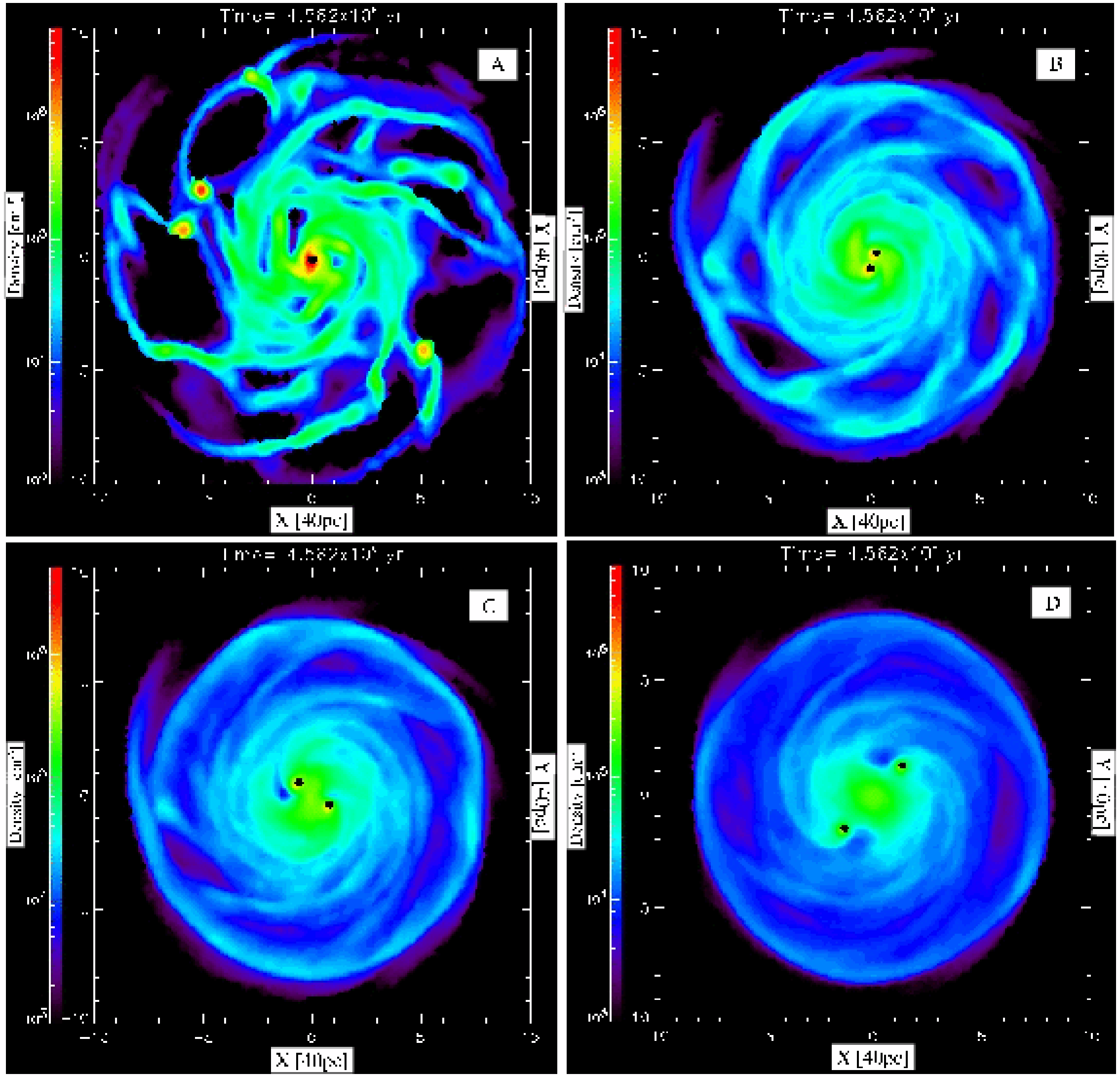
$M_{BH1} / M_{BH2} = 1, ..., 1/10$ (priya's talk: extreme mass ratios)

Parameter Exploration: Clumpiness

h=20pc

h=25pc

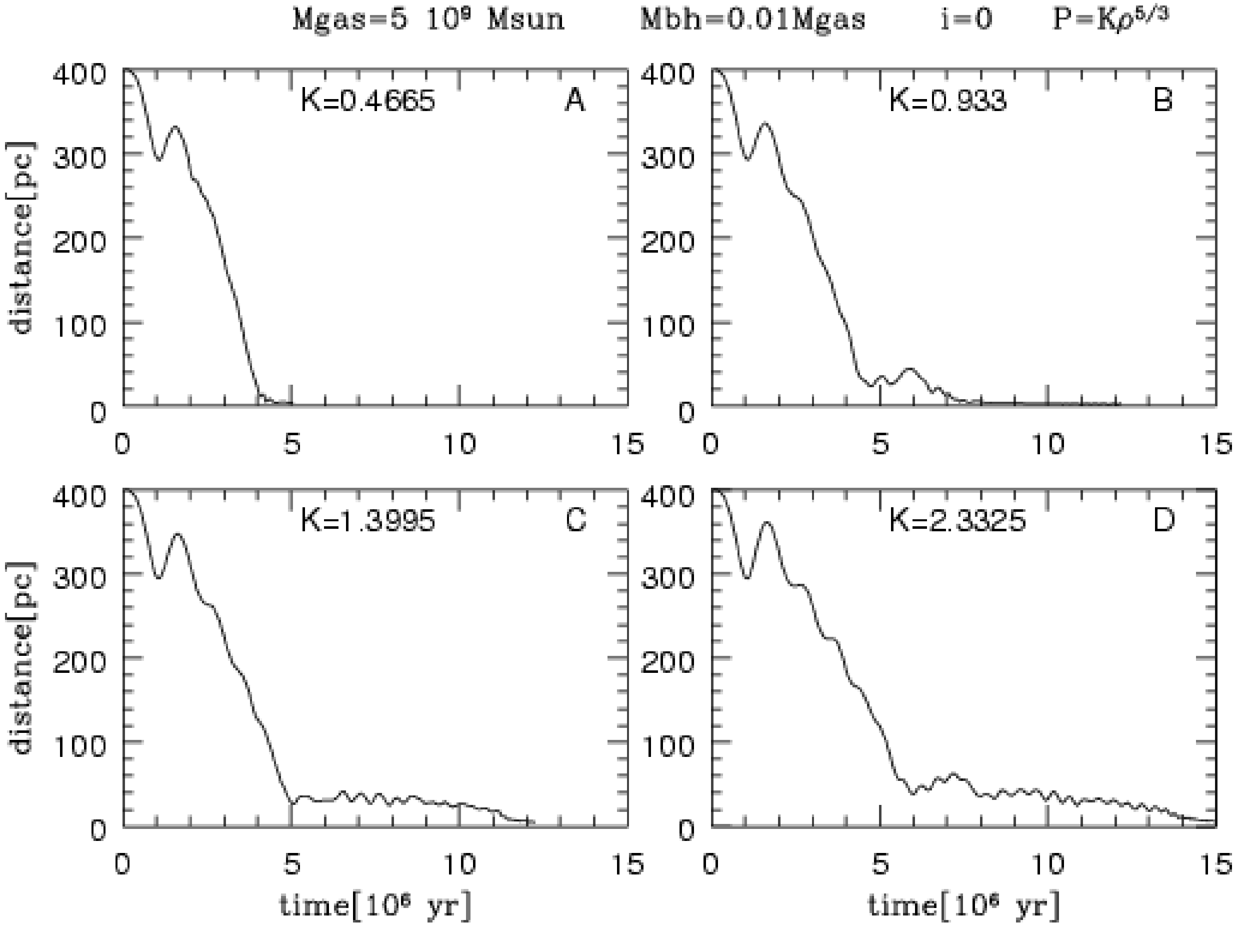
$$P = K\,\rho^{5/3}$$



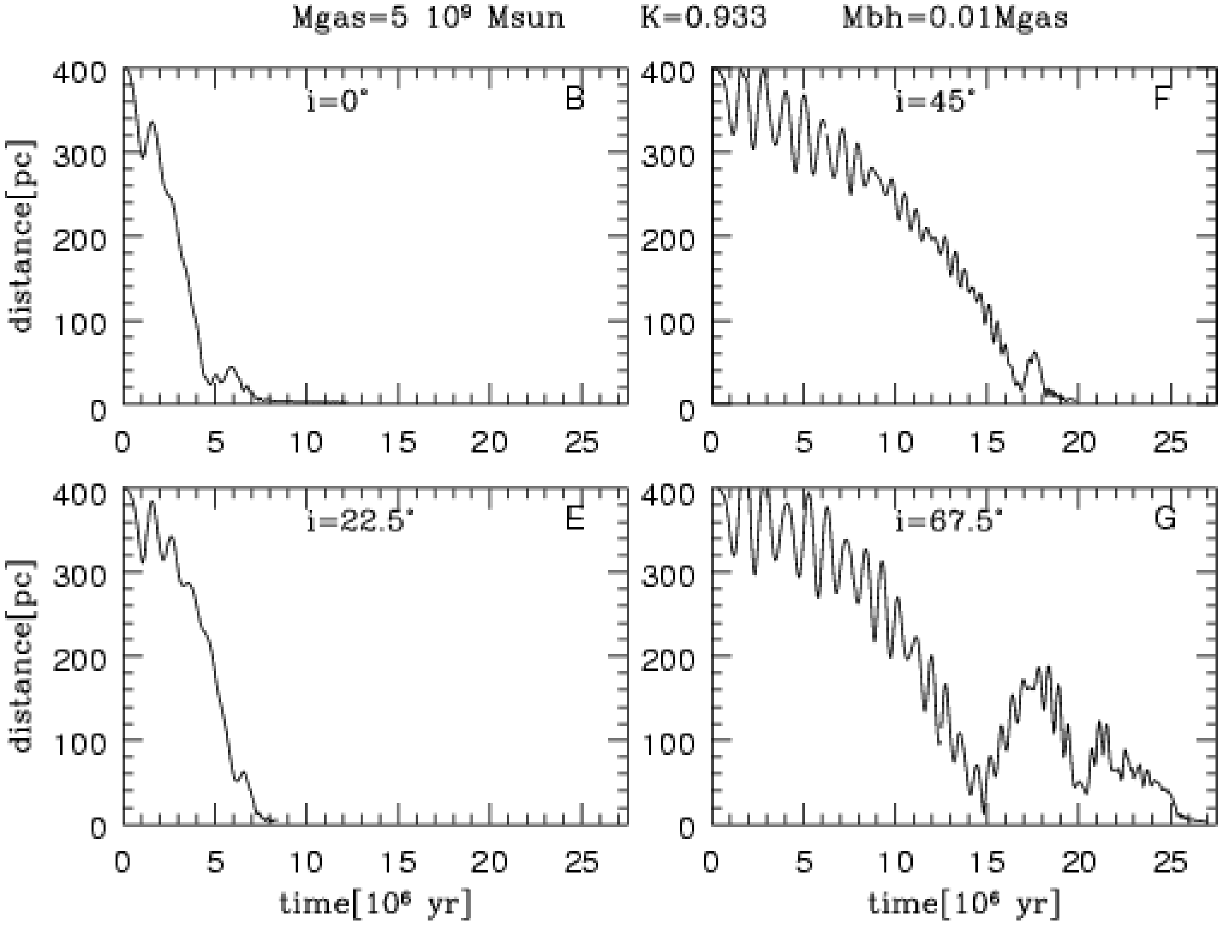
h=30pc

h=40pc

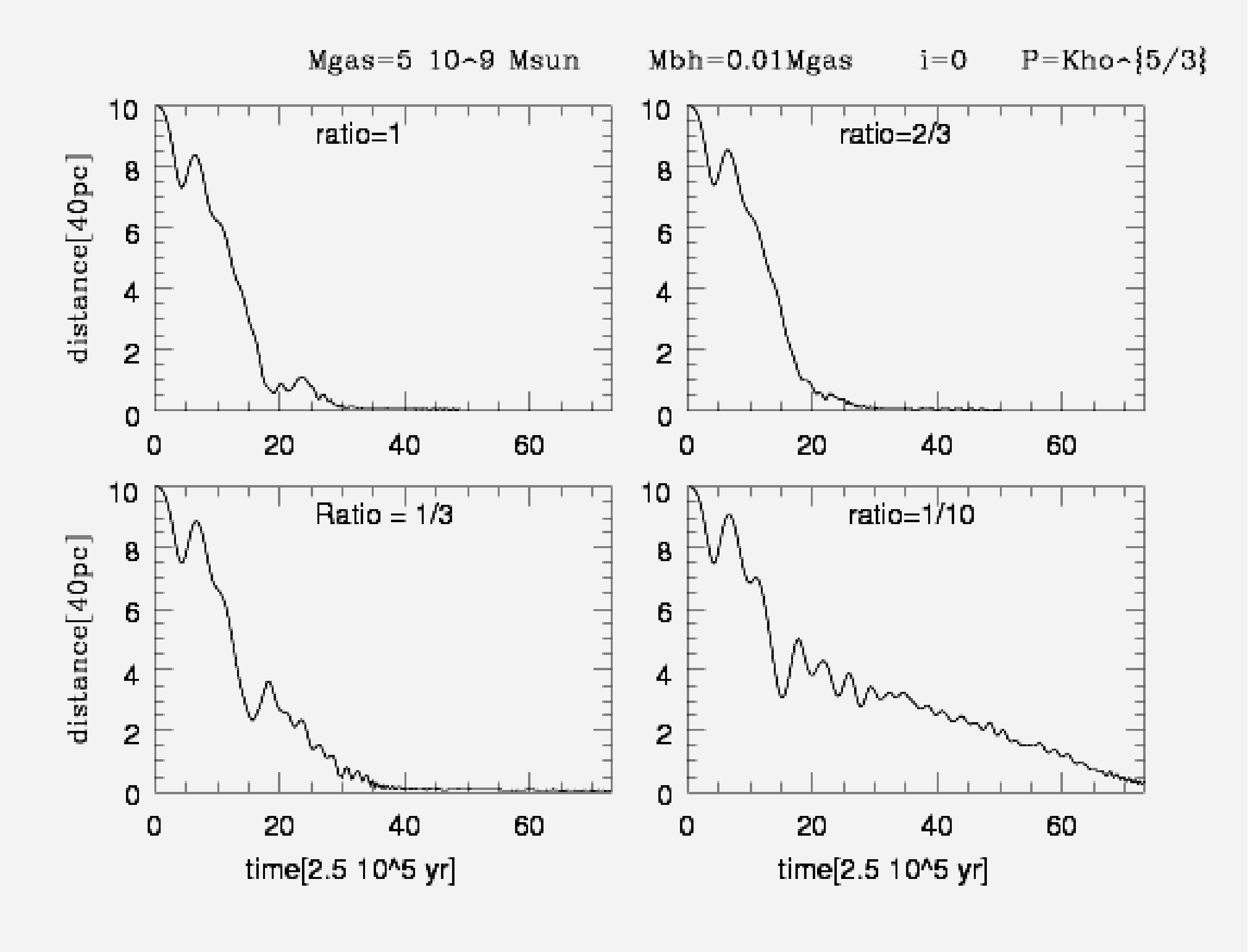
Gravitational Drag



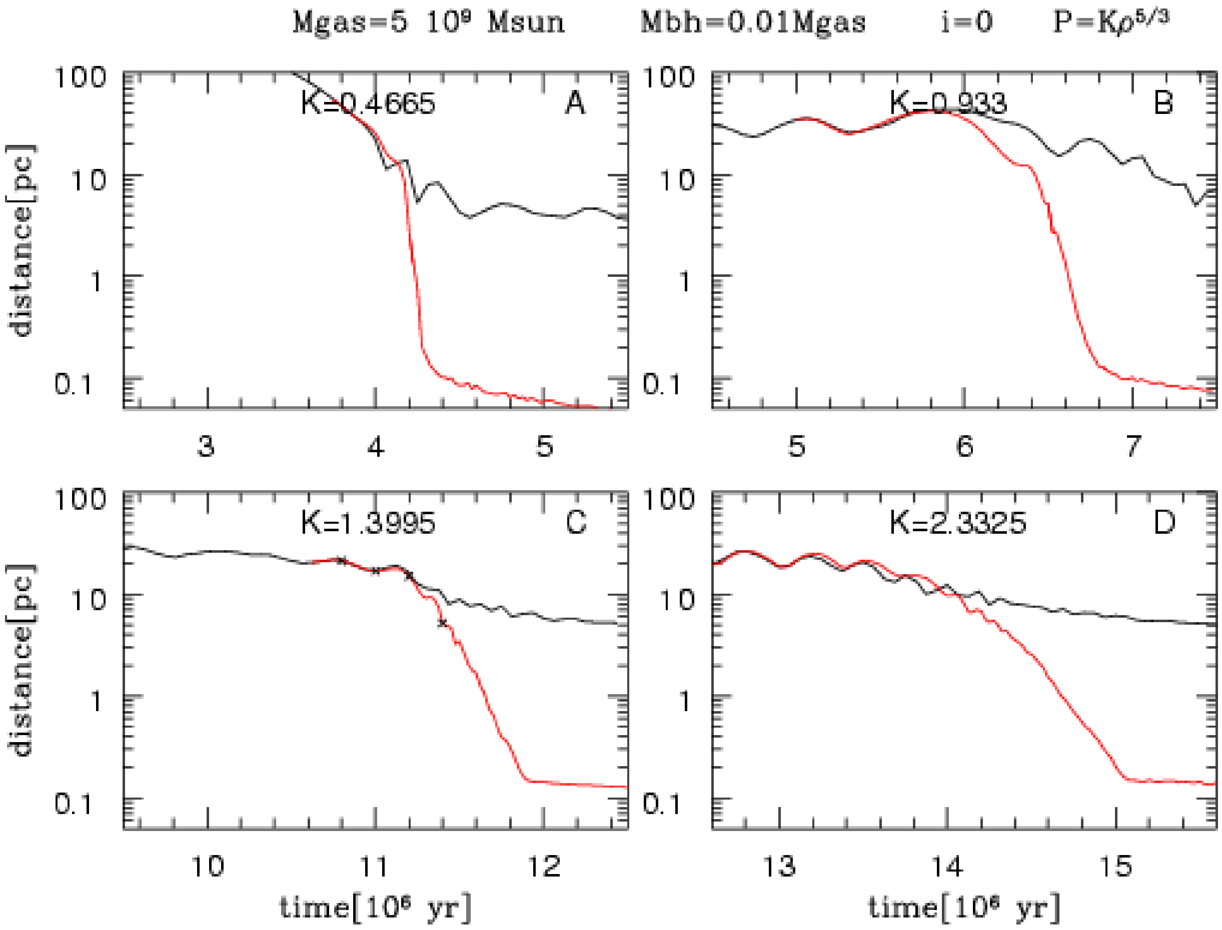
Parameter Exploration: Angle



Parameter Exploration: Mass Ratio

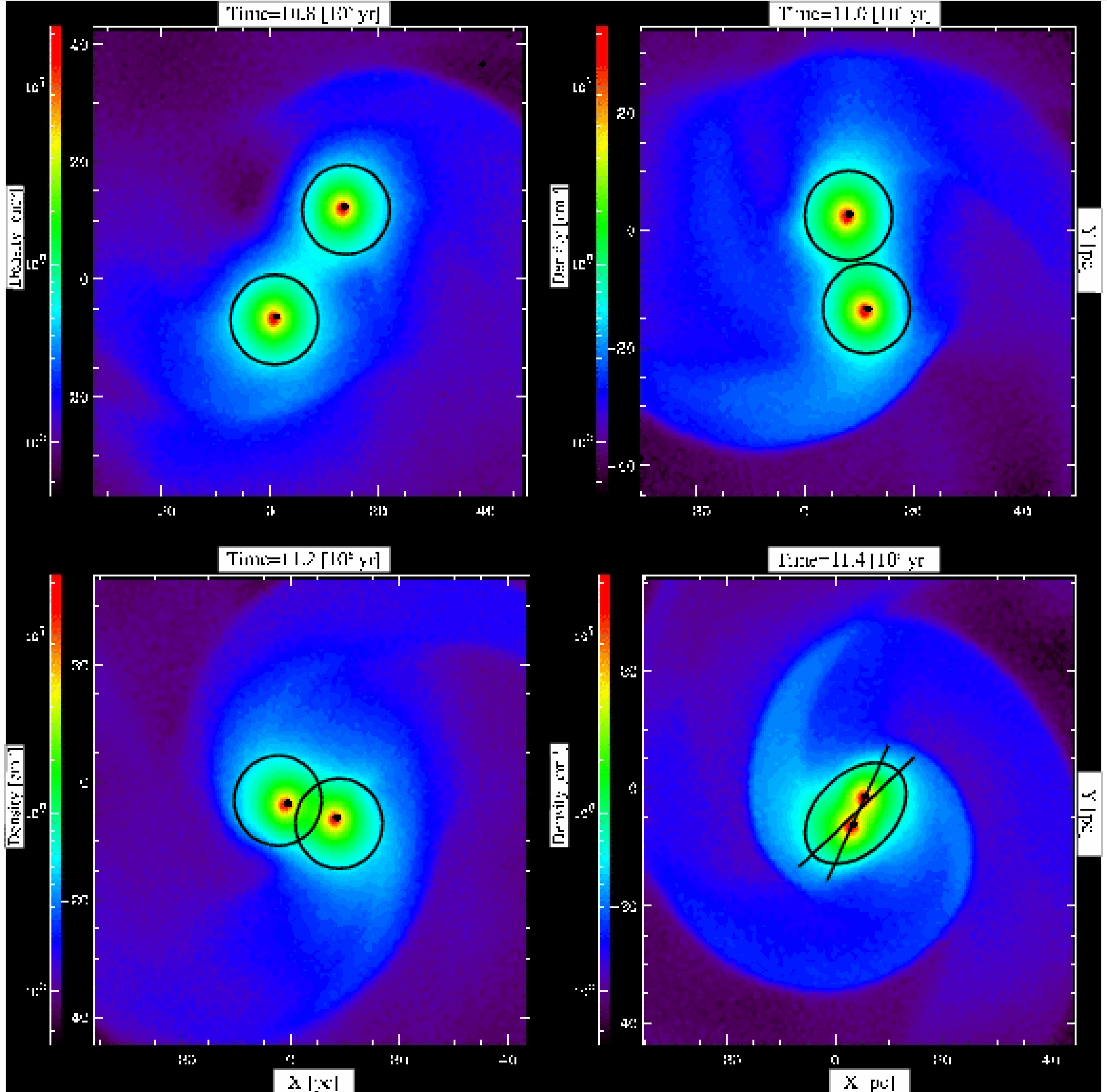


Gravitational Torque from an Ellipsoid

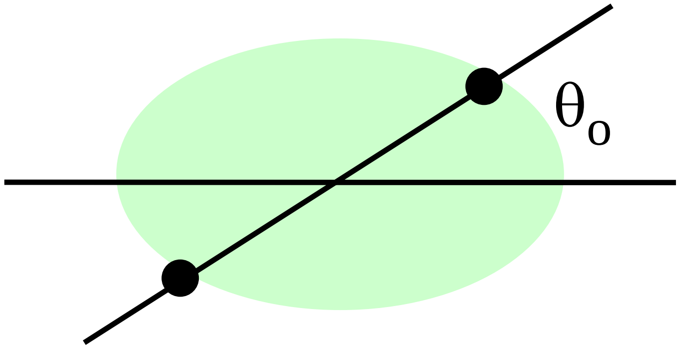


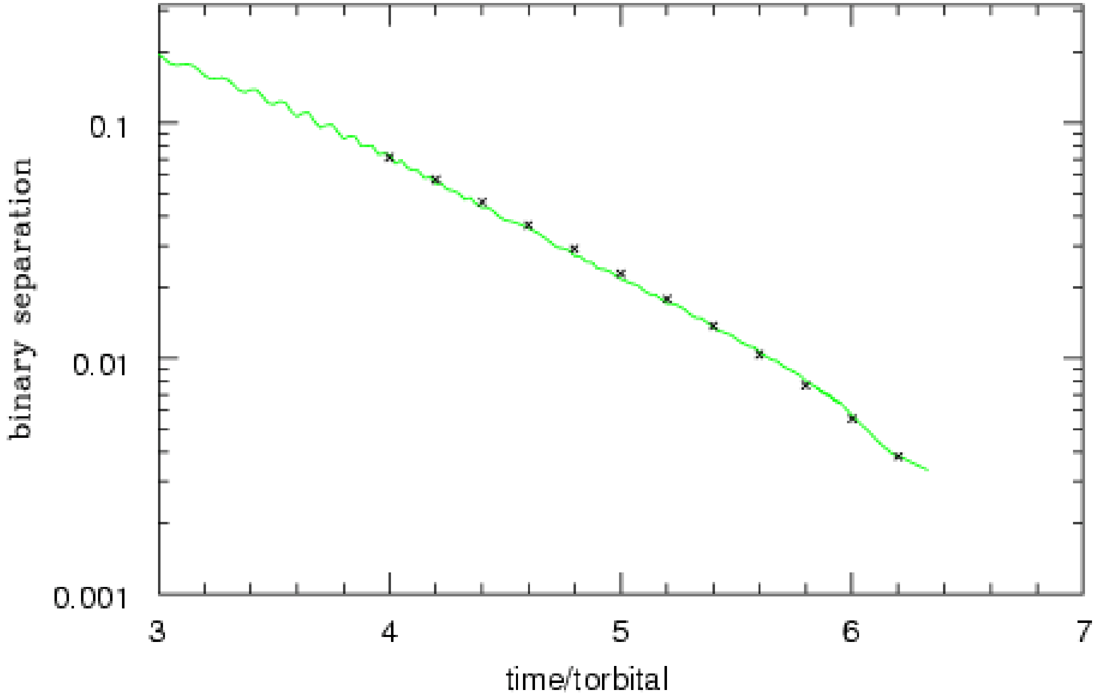
Formation of the Ellipsoid

$$R_{inf} = \frac{2\,GM_{BH}}{v_{BH}^{2} + c_{S}^{2}}$$



Comoving Ellipsoid Model





This mechanism is able to reduce binary separation down to distances where gravitational radiation is efficient.

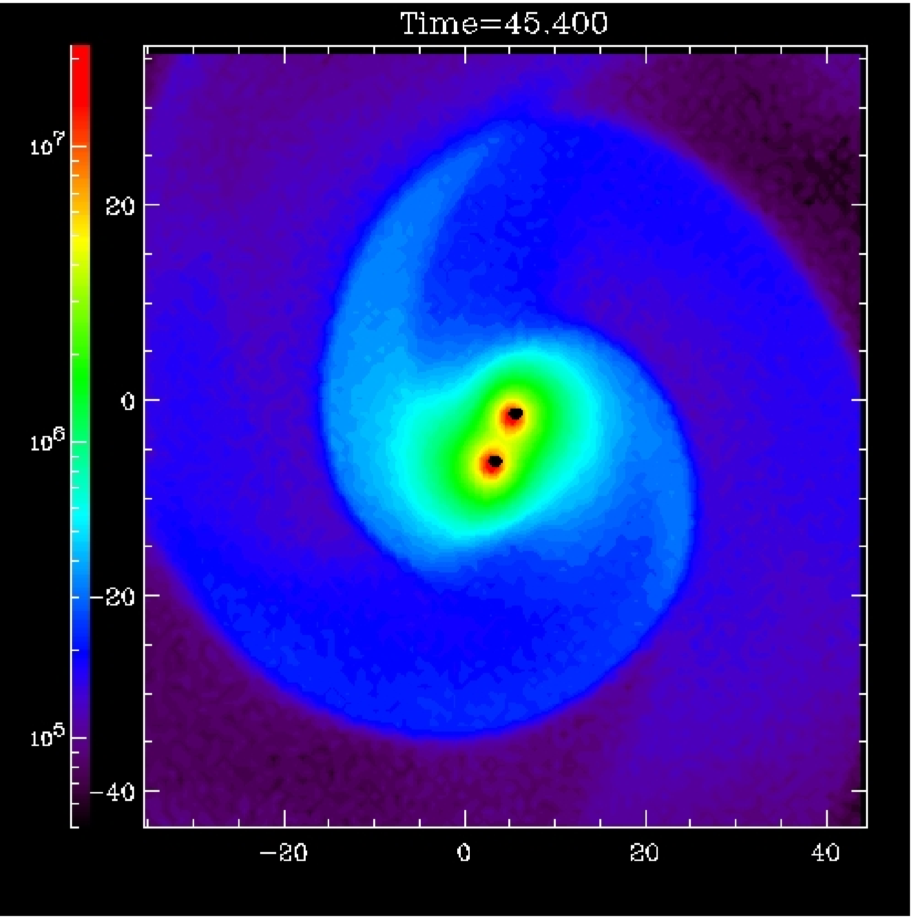
Gravitational Radiation

- Gravitational Radiation Coalescence timescale (Peters 1964):

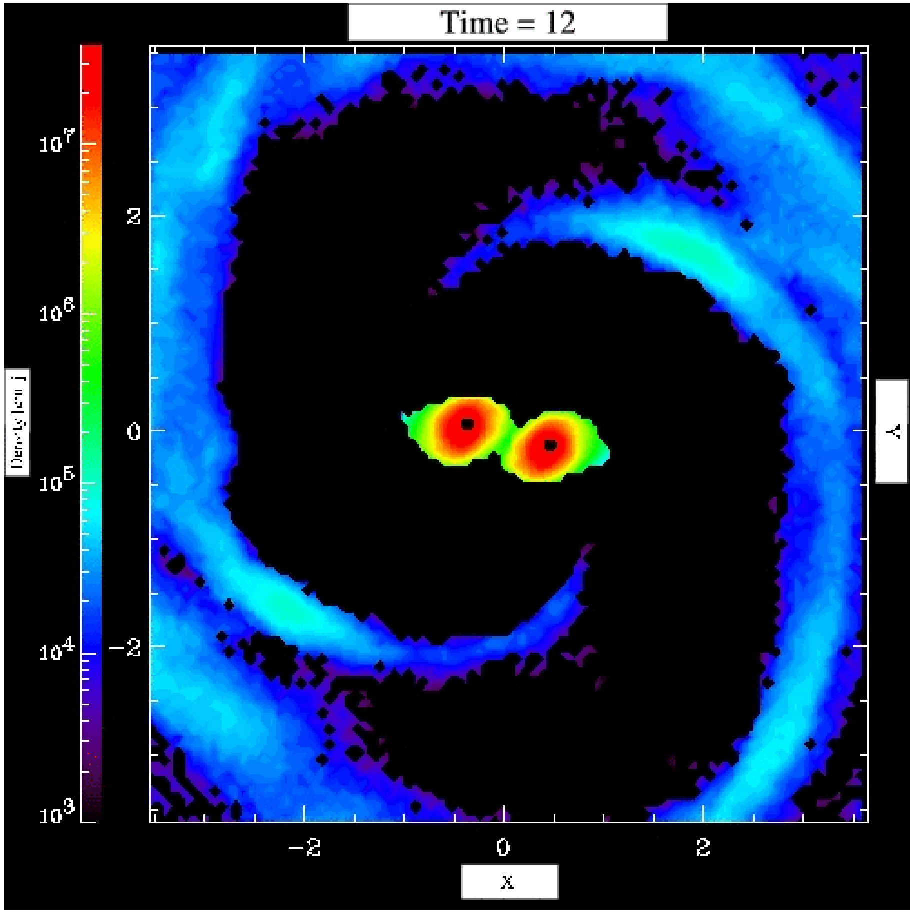
$$t_{GR} = 2.6\ 10^{6}\ \mathrm{yr}\ \left(\frac{a}{0.01\mathrm{pc}}\right)^{4} \left(\frac{10^{8}\ M_{O}}{M_{BH}}\right)^{3}\ F(e)$$

$$t_{GR}\,(0.1\mathrm{pc}) \sim 10^{10}\ \mathrm{yr} < \text{Hubble Time}$$

How Little Gas will Do the Job?



Escala et al (2004, 2005)
Dotti et al (2006)



Artymowicz & Lubow (1994)
Milos ??

How Little Gas will Do the Job?

- The MBHs will efficiently merge as long as the formation of a stable ☐circumbinary gap is prevented.

- Only Two Limiting Cases Studied so Far:

I) Massive ‘Thick’ Disks (R/H~10; present in Starburst Galaxies).

II) 2-D Accretion Disks (Negible Mass, valid only @ separations < $1000R_S$ (Goodman 2003)).

- New Simulations are needed to determine a Gap-Opening Criteria (in terms of H, Mgas/Mbh, etc).

Summary

- Gravitational interaction with the gaseous background is able to reduce the binary separation to distances where gravitational radiation is efficient.
- No signature of coalescence stalling as expected in a stellar background.
- Gas-rich merging galaxies (ULIRGs) good candidates for LISA events.