

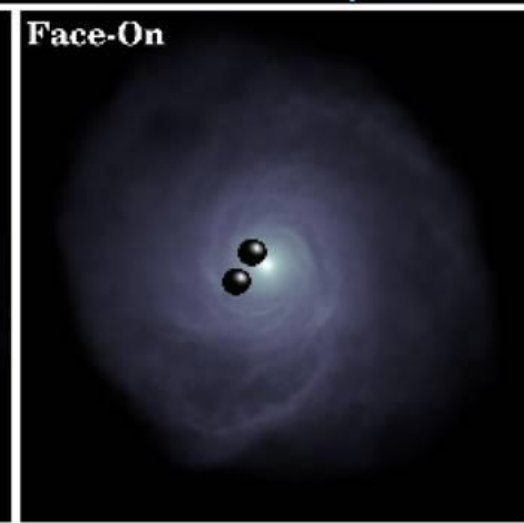
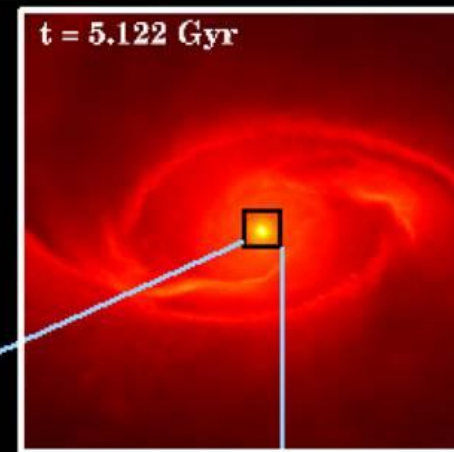
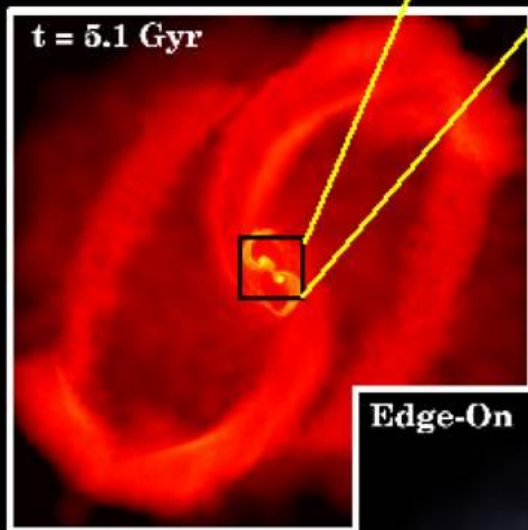
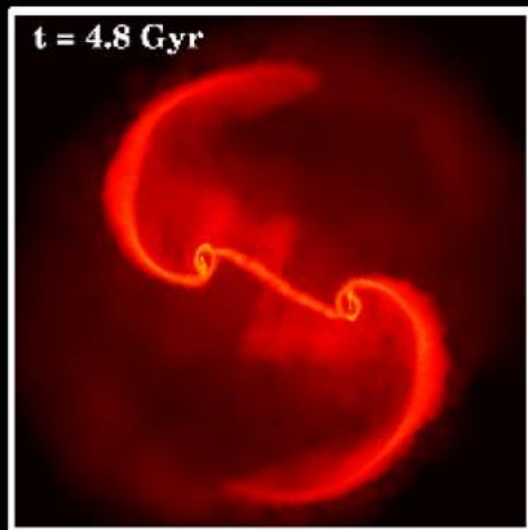
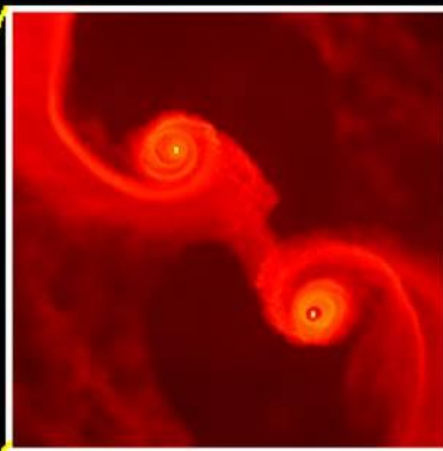
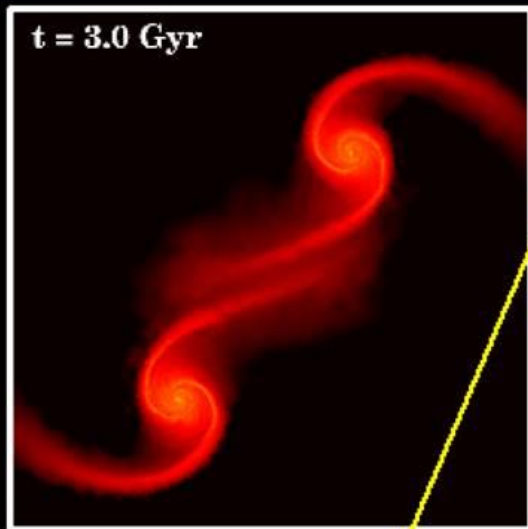
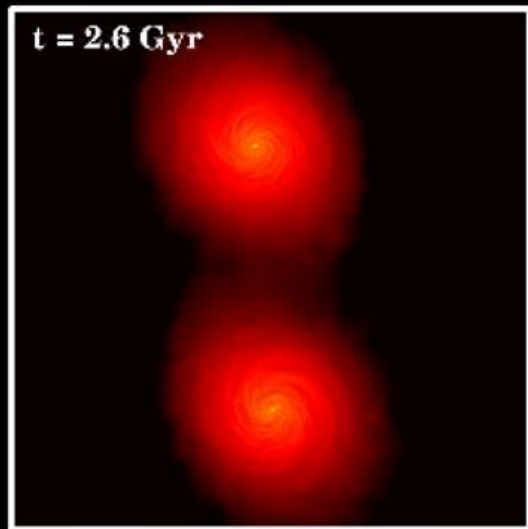
Massive black hole binaries in circumnuclear disks

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MPA



60 kpc scale

Large scale simulations

e.g. Mayer et al. 2007

160 pc scale

MBHs evolution in gaseous backgrounds

FAQ:

**Do the MBHs reach
the final coalescence?**

**What is the effect of CNDs
on MBH masses and spins?**

Why spins?

MBH binaries: spins affect the GW waveform

→ recoil velocity of the MBH remnant

MBH in general:

jet production and radio-loudness

spin distribution encodes the accretion history of MBHs

(e.g. Berti et al. 2008)

Why spins (II: from the discussion points)?

Q(N): Does the environment of the binary have an effect on the recoil at merger?

Q(N-1): What is the likelihood of significant recoil at merger and how does this affect the search for EM counterparts?

Q(13): How will observations of spins, masses, and mass ratios inform us about SMBH and Galaxy evolution?

Initial conditions

Central MBH of $4 \times 10^6 M_{\odot}$

Gaseous disk (Mestel):

$$\Sigma_{\text{Disk}}(R) = \frac{\Sigma_0 R_0}{R}$$

$$\begin{cases} M_{\text{Disc}} = 10^8 M_{\odot} \\ R_{\text{Disc}} = 100 \text{ pc} \end{cases}$$

Pure adiabatic evolution $\gamma=5/3; 7/5$

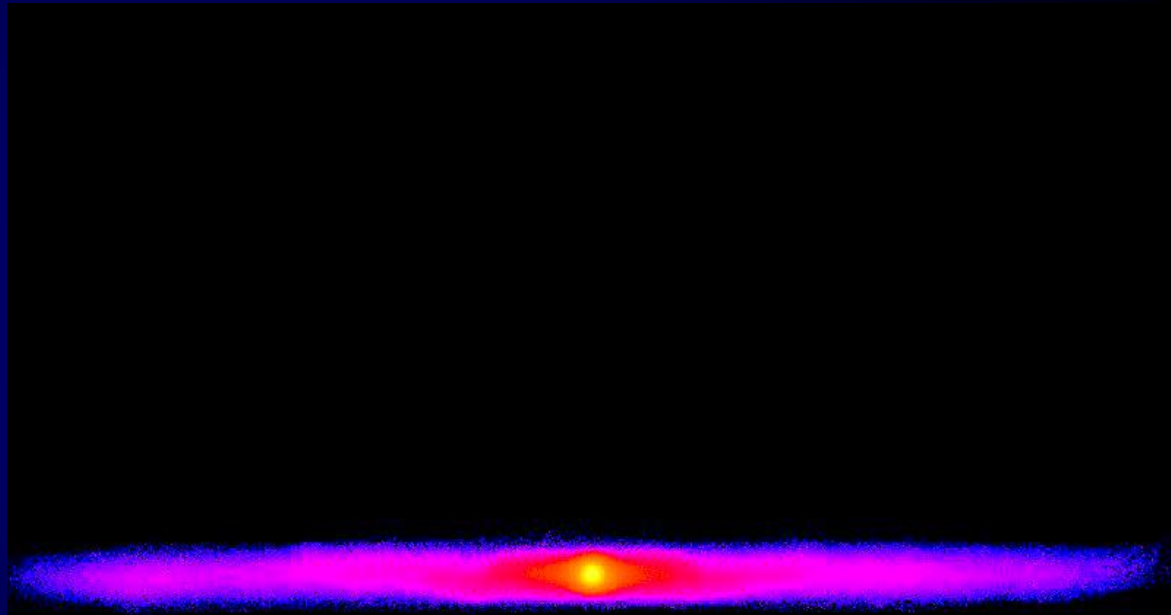
Stellar bulge (Plummer):

$$\rho(r) = \frac{3}{4\pi} \frac{M_{\text{Bulge}}}{a^3} \left(1 + \frac{r^2}{a^2}\right)^{-5/2}$$

$$\begin{cases} M_{\text{Bulge}} = 7 \times 10^8 M_{\odot} \\ a = 55 \text{ pc} \end{cases}$$

Equal mass merger:

second MBH of $4 \times 10^6 M_{\odot}$ and $e \approx 0.7$
co- or counter- rotating



Accretion

Each set of initial conditions has been used for two different runs:

MBHs can accrete gas particles

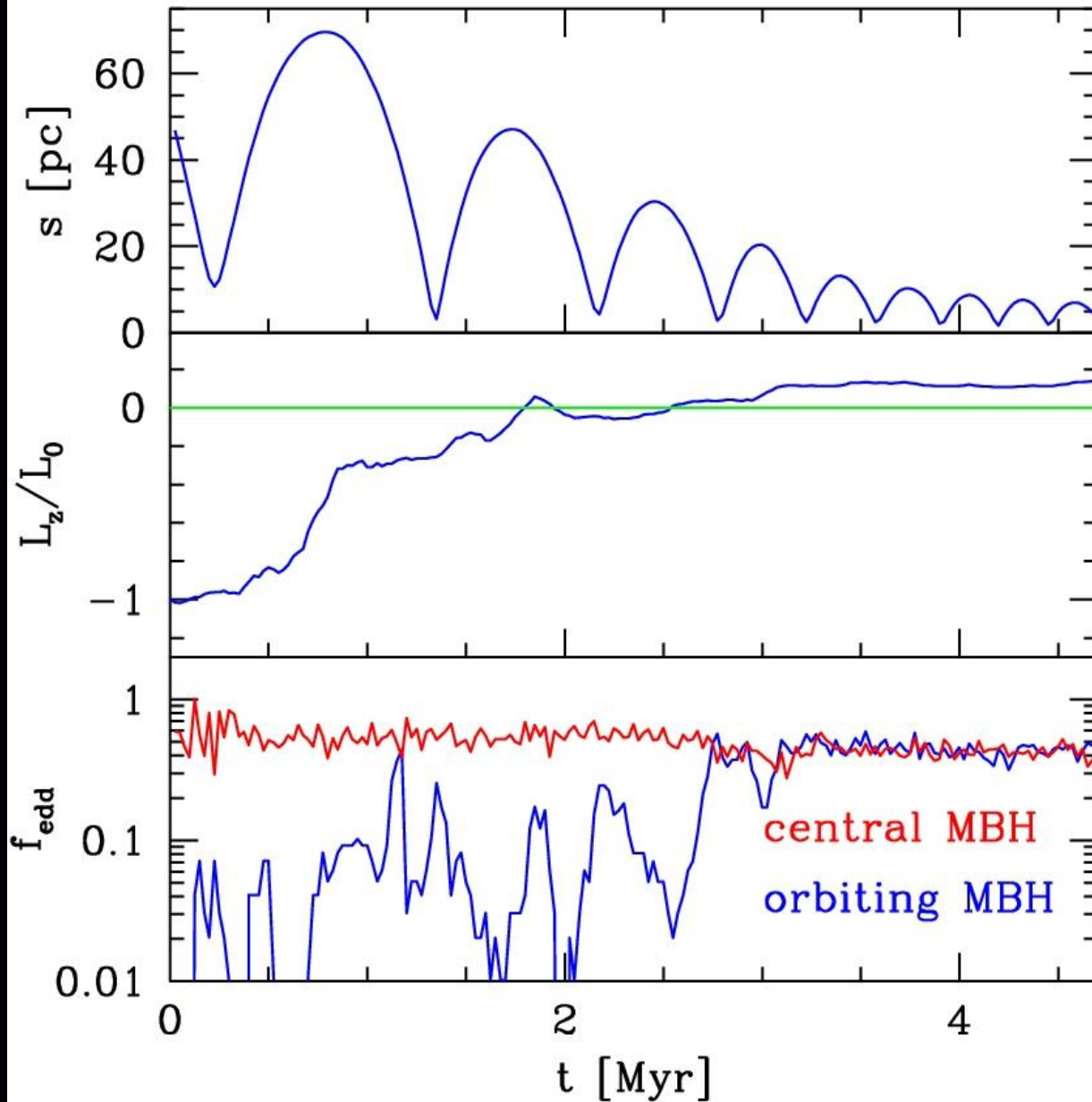
MBHs can not accrete gas particles

gas particles are accreted only if their total energy
(kinetic+thermal+potential, in the reference frame of the MBHs)
is less than a fixed fraction ϵ of the (negative) gravitational energy
($\epsilon > 0.5$, accretion possible only resolving the BHL radius of the MBHs!)

No feedback

Counter-rotating MBH ($\gamma=5/3$; $h=0.1$ pc)

MD et al. 2009



MBH accretion rate depending on the sign of the angular momentum

$$\langle f_{\text{Edd}}(t < 3 \text{ Myr}) \rangle \approx 0.1$$

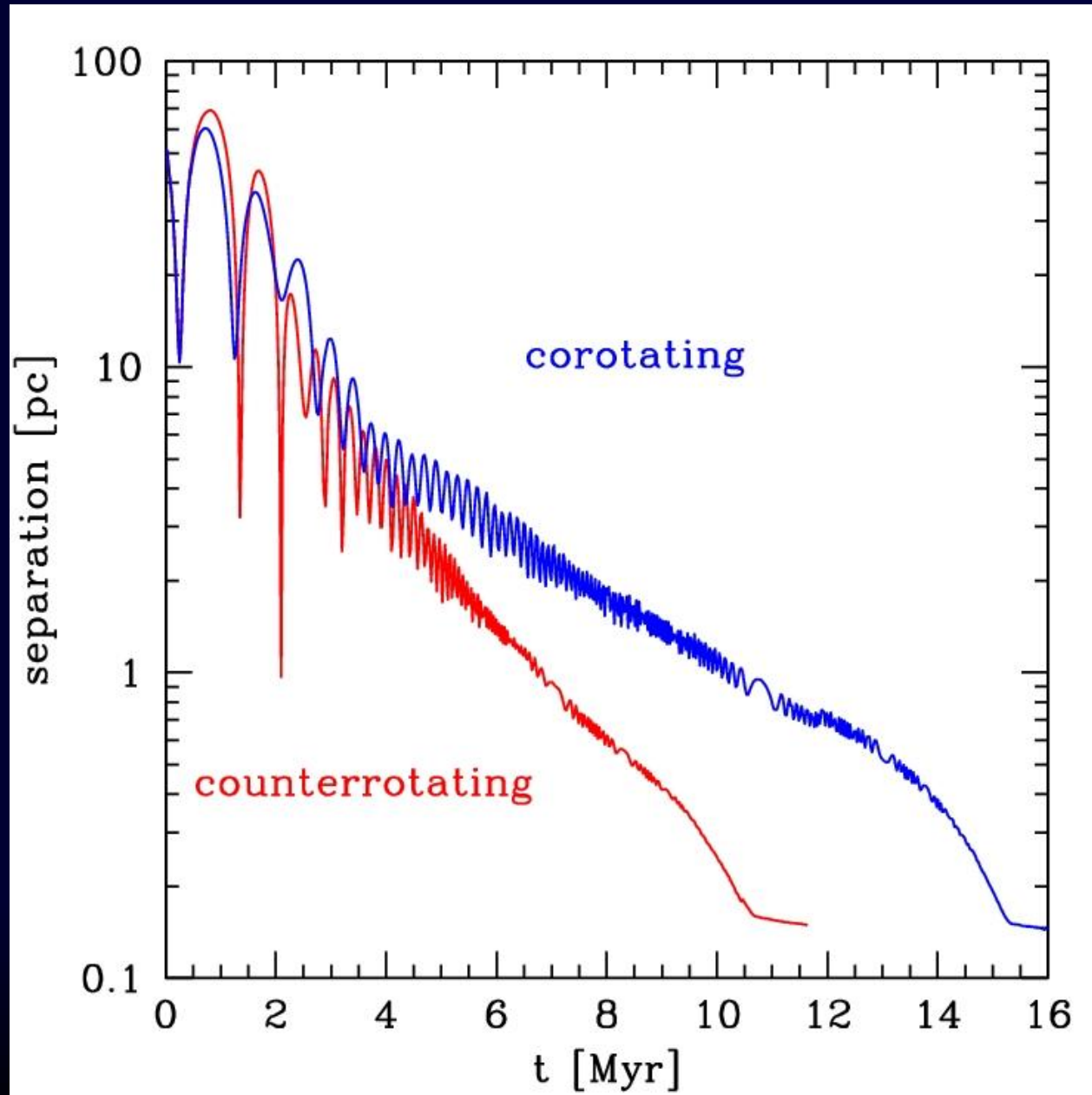
$$L_{\text{bol}} \approx 5 \cdot 10^{43} \text{ erg/s}$$

$$\langle f_{\text{Edd}}(t > 3 \text{ Myr}) \rangle \approx 0.45$$

$$L_{\text{bol}} \approx 2.4 \cdot 10^{44} \text{ erg/s}$$

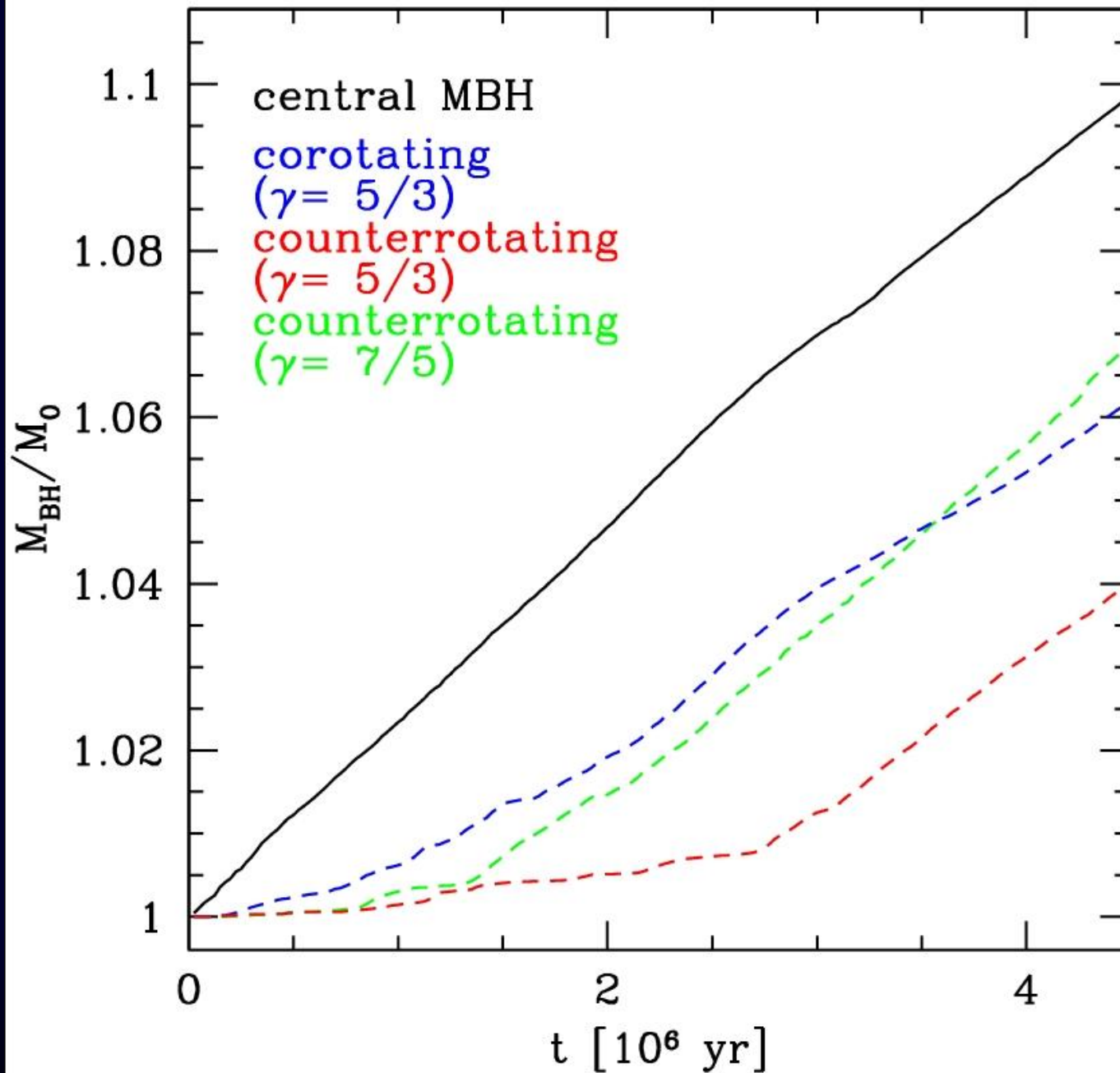
Co-rotating vs counter-rotating MBHs

($\gamma=7/5$; $h=0.1$ pc; only non accreting MBHs)

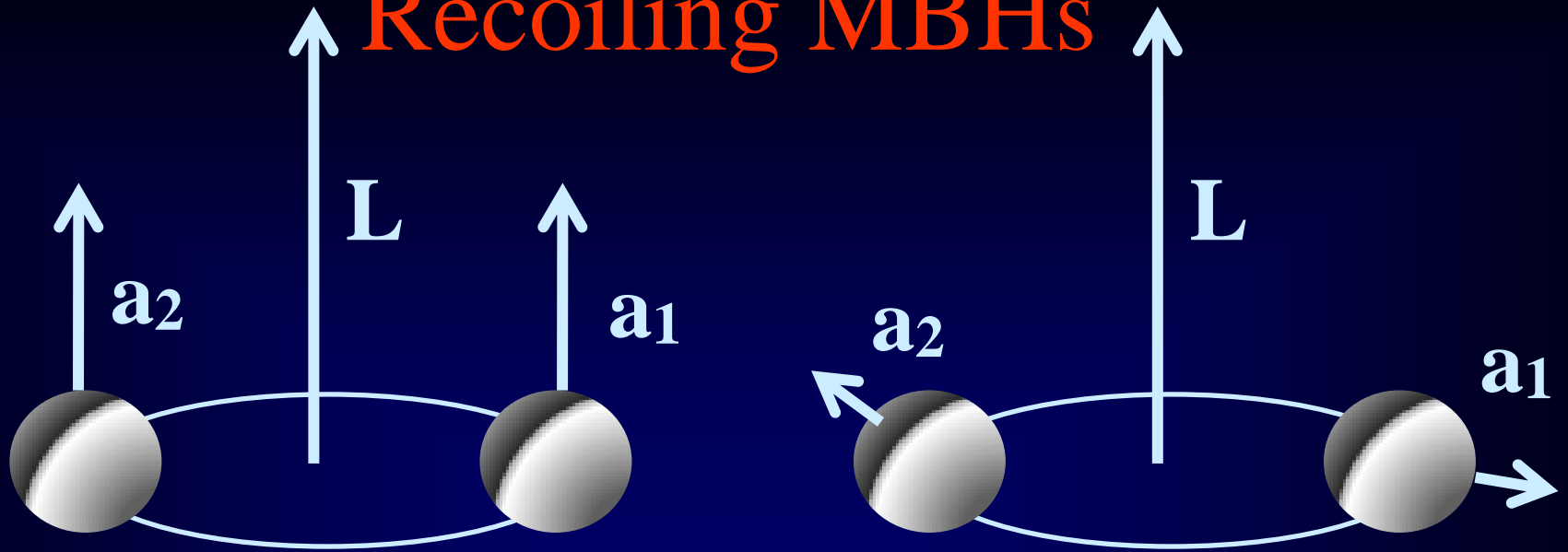


MD et al. in prep.

MBH mass accretion

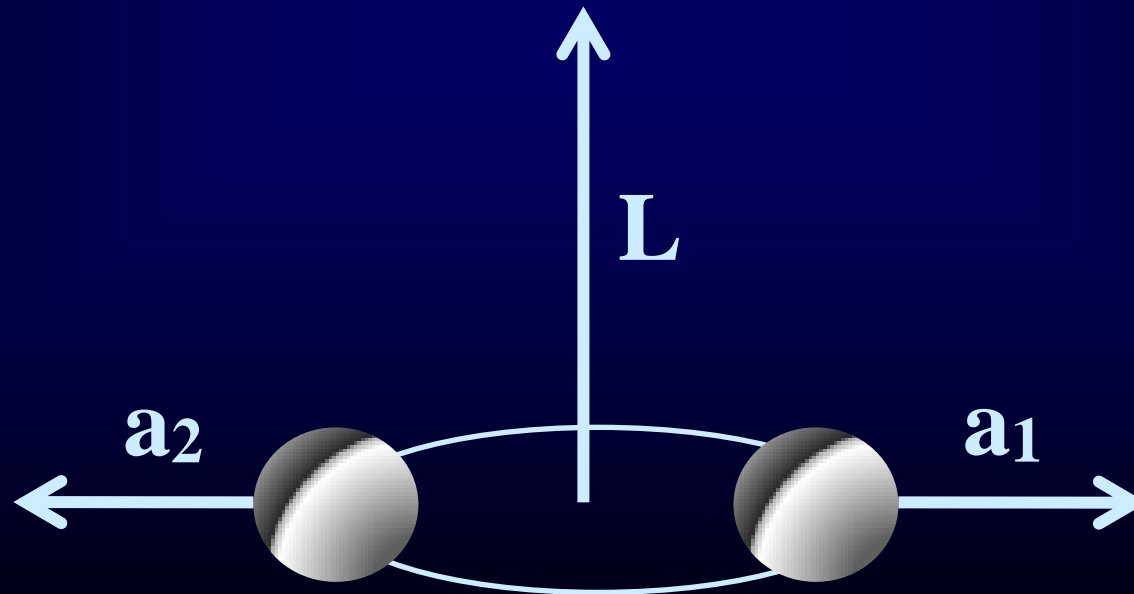


Recoiling MBHs



Low kick velocities ($\sim 100 \text{ km s}^{-1}$)

High kick velocities ($\sim 1000 \text{ km s}^{-1}$)



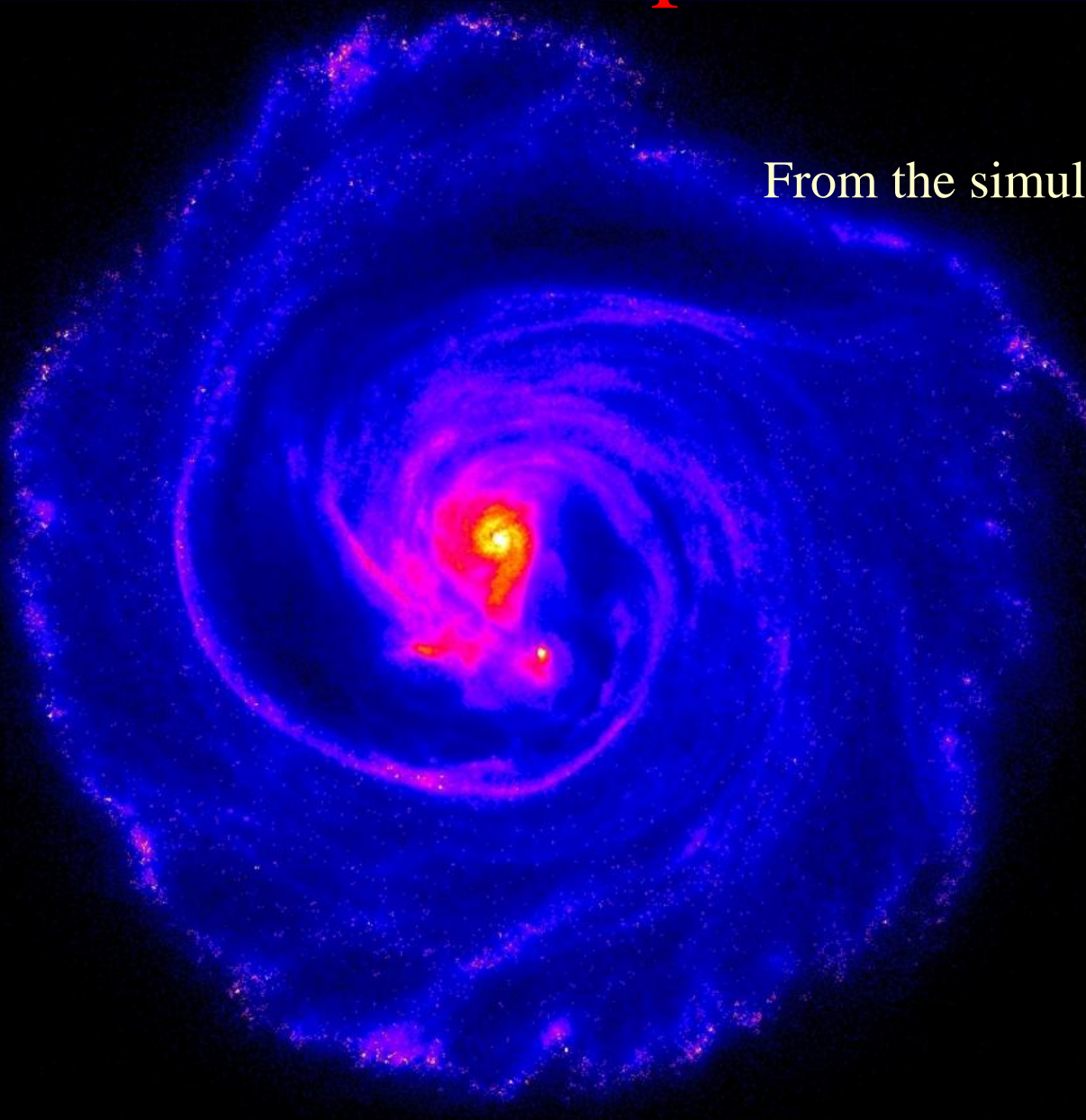
Spin evolution

MD et al. 2010

From the simulations →

accretion rate

\underline{L} of the accreting flow

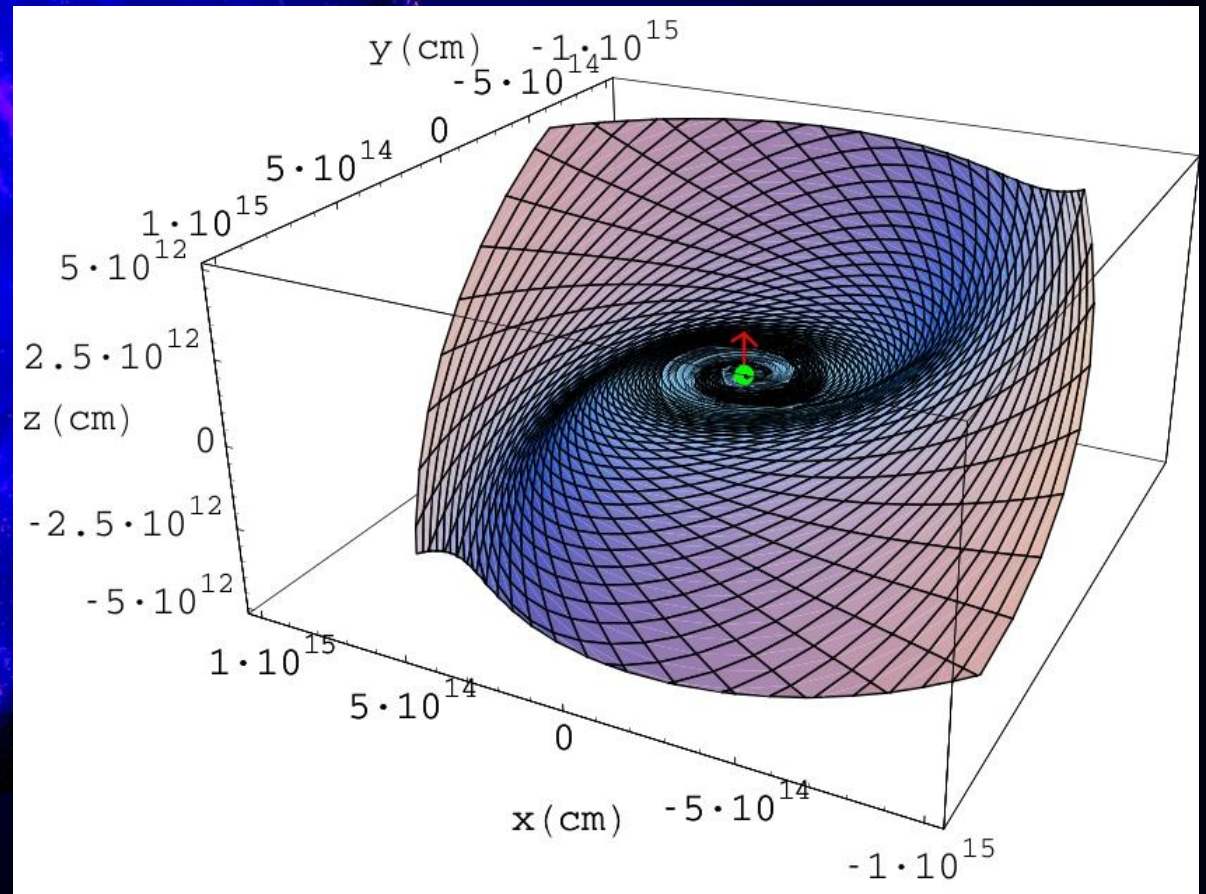
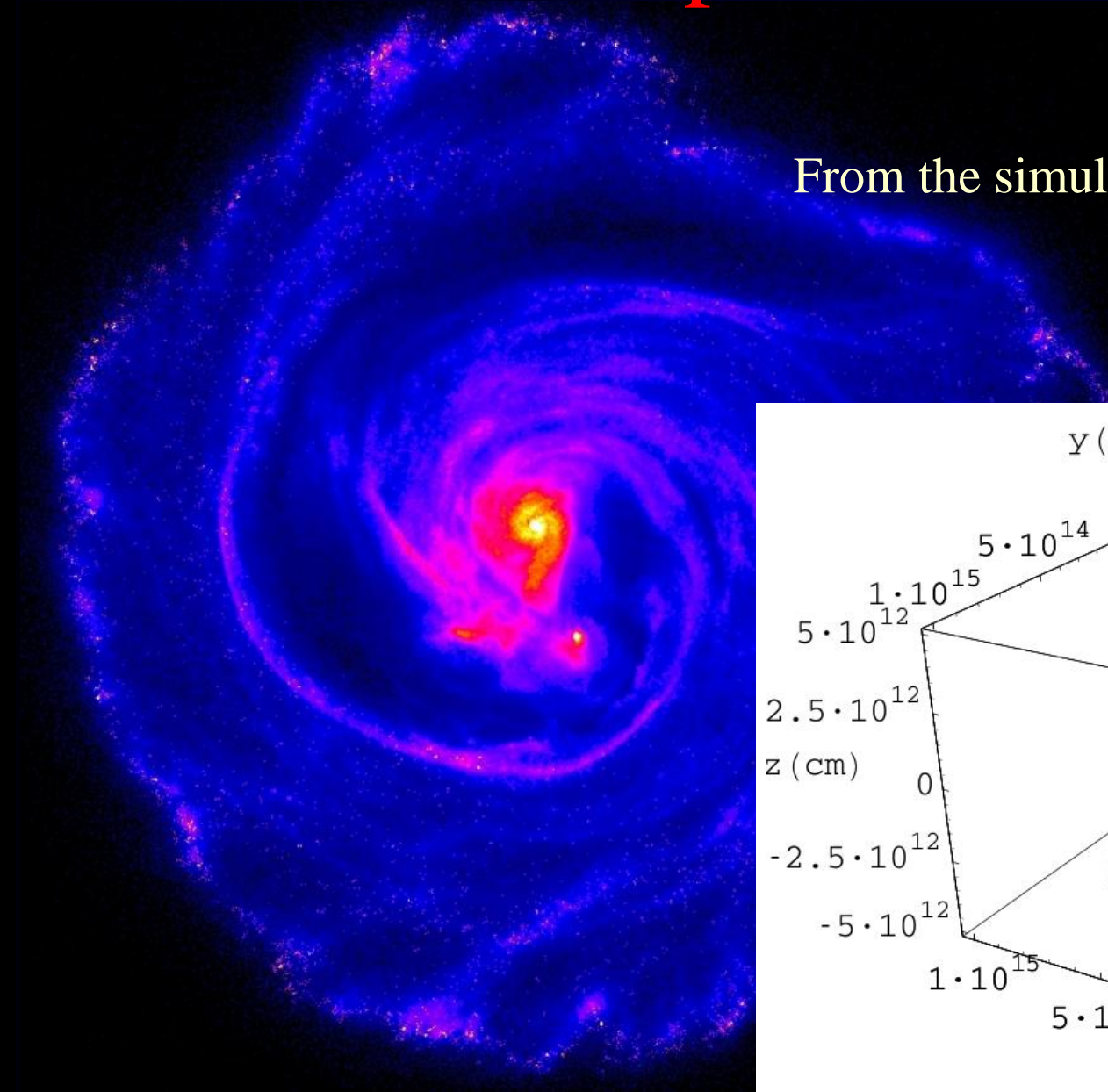


Spin evolution

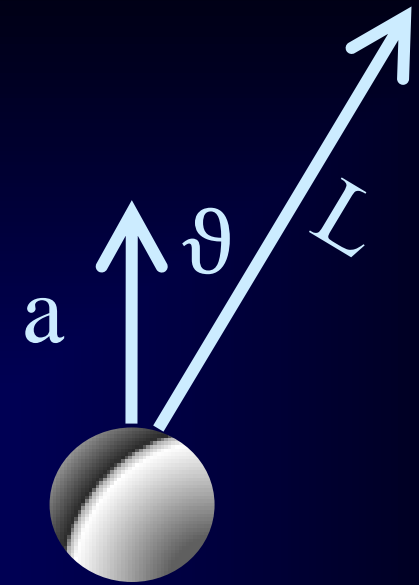
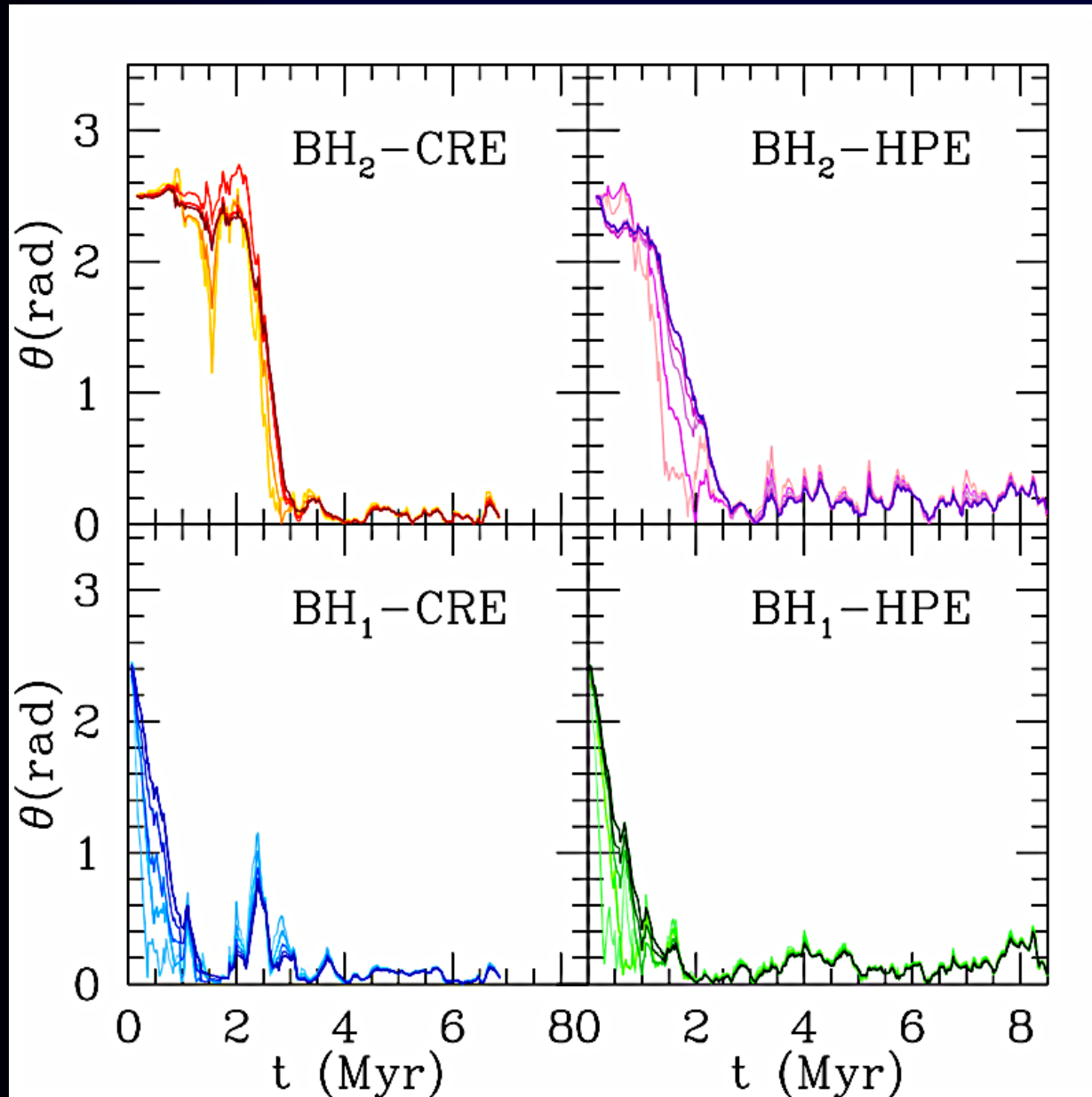
MD et al. 2010

From the simulations \rightarrow { accretion rate
 \underline{L} of the accreting flow

Perego, et al. 2009



Spin evolution

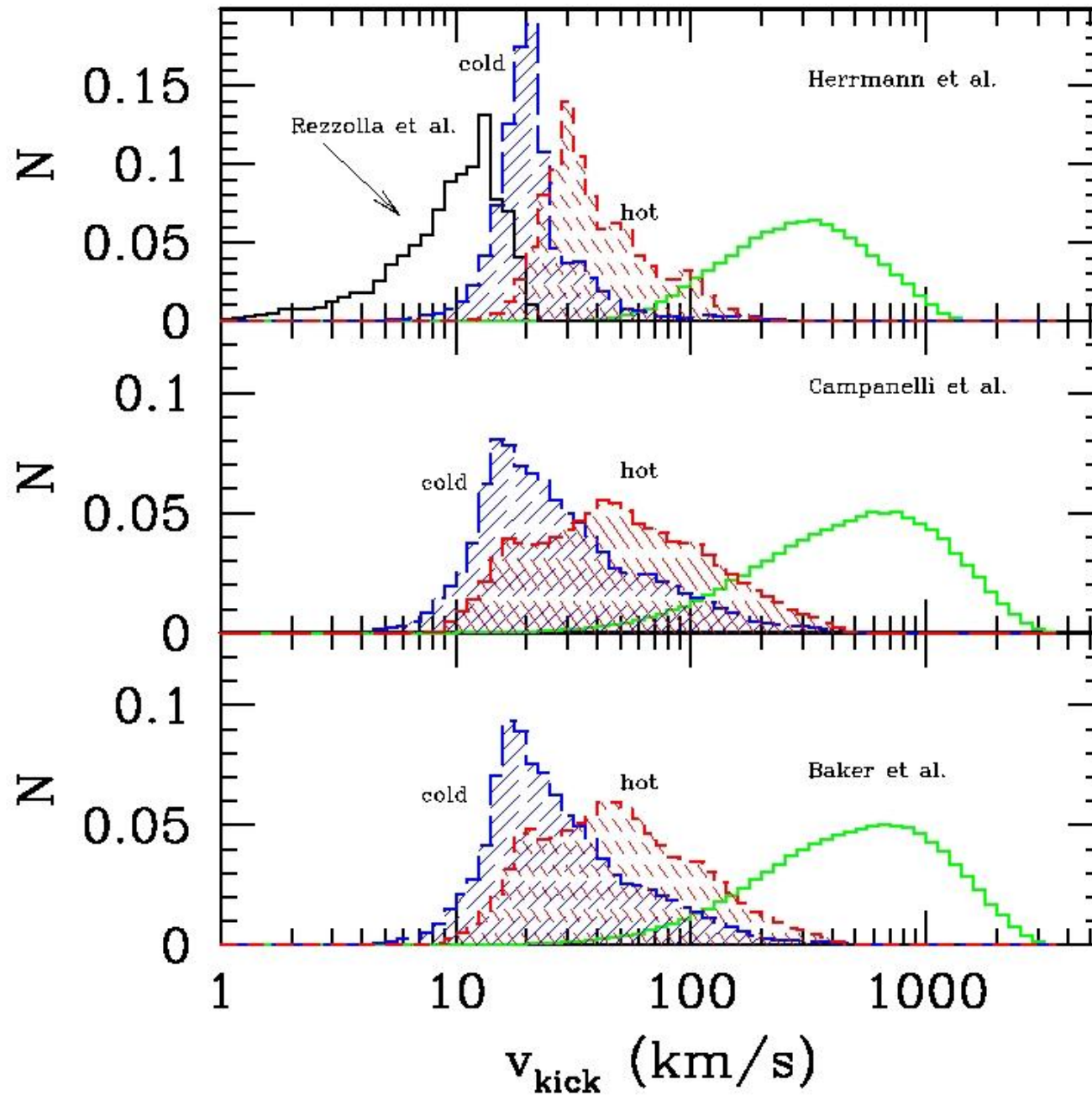


Secondary BH

Primary BH

CRE=cold disc,retrograde orbit
HPE=hot disc, prograde orbit

Recoiling MBHs



MD et al. 2010

Conclusions

MBH binary formation

- MBH binaries decay down to 0.1 pc in ~ 10 Myr
($\gamma=7/5$, no accretion)
- Predicted (variable) accretion processes during the inspiral
- Spins of the two MBHs align before they form a binary
(low kicks)