Massive black hole binaries in the remnants of gas-rich galaxy mergers

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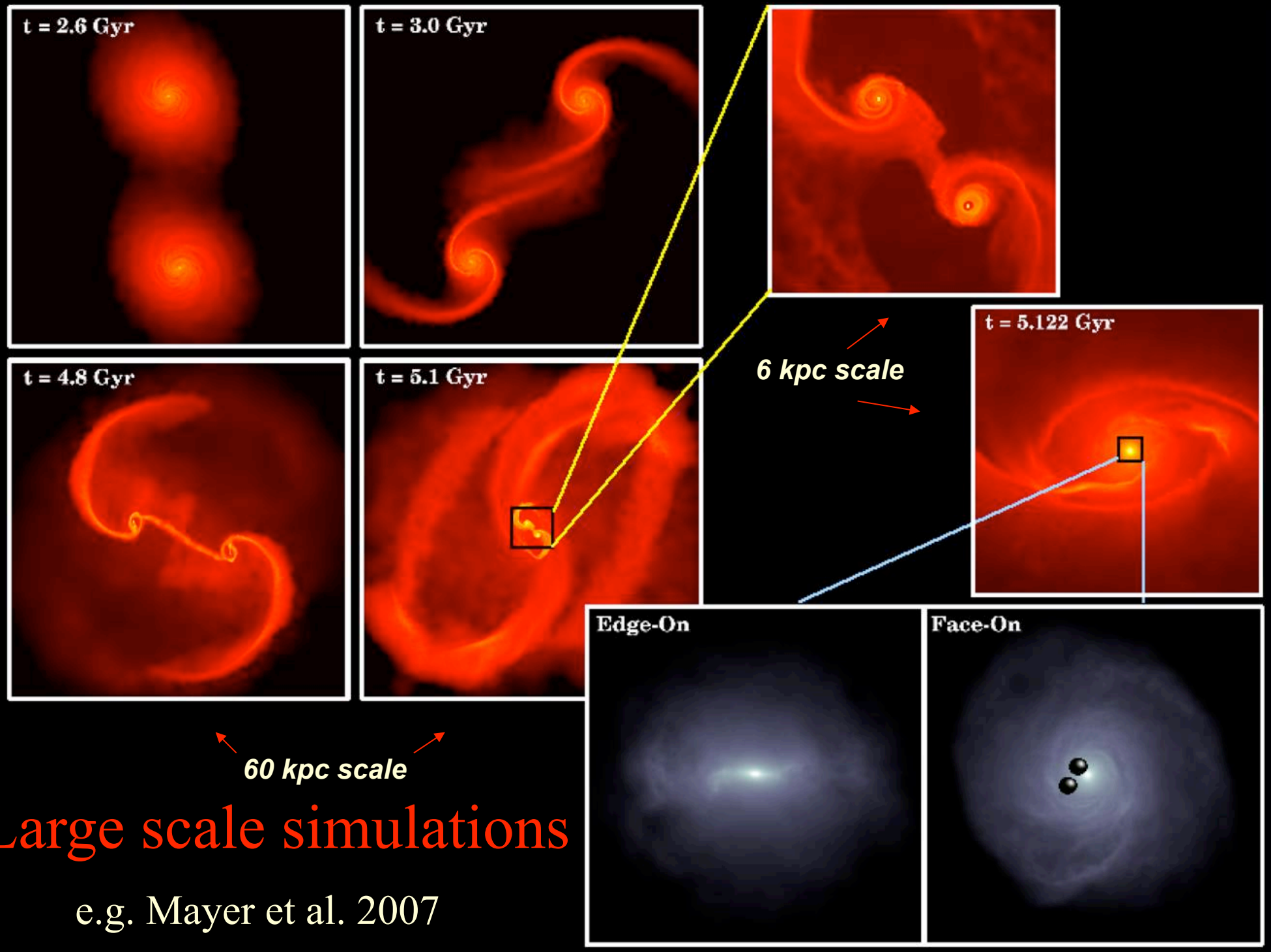
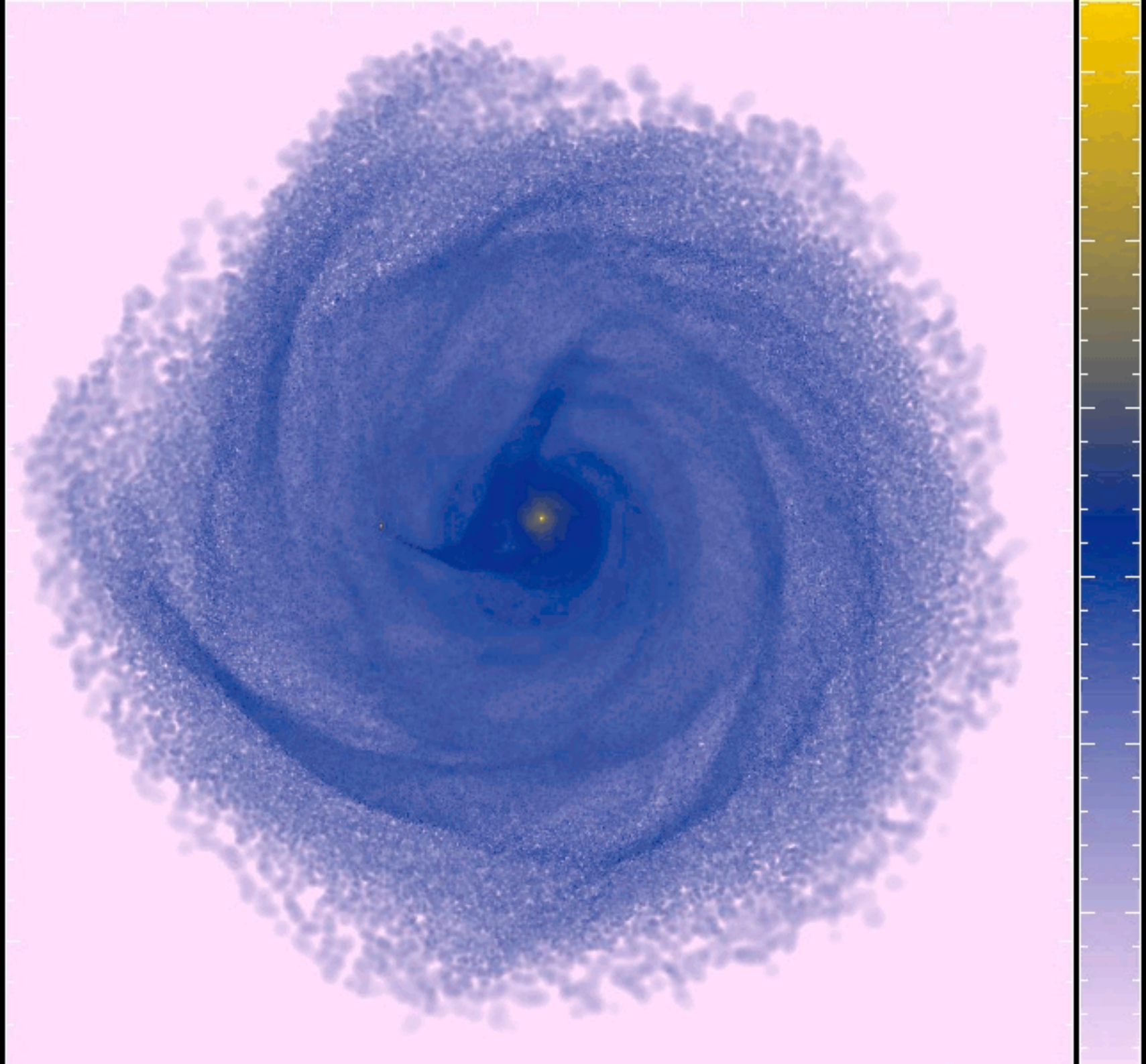


Large scale simulations

e.g. Mayer et al. 2007



MBHs evolution in gaseous backgrounds

FAQ:

Do the MBHs reach the final coalescence?

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

Initial conditions

Central MBH of 4×10^6 M⊙

Gaseous disk (Mestel):

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

$M_{\rm Disc} = 10^8$ M⊙

$R_{\rm Disc} = 100$ pc

Adiabatic evolution γ=5/3; 7/5
(+ shock heating)

Stellar bulge (Plummer):

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

$M_{\rm Bulge} = 7 \times 10^8$ M⊙

$a = 55$ pc

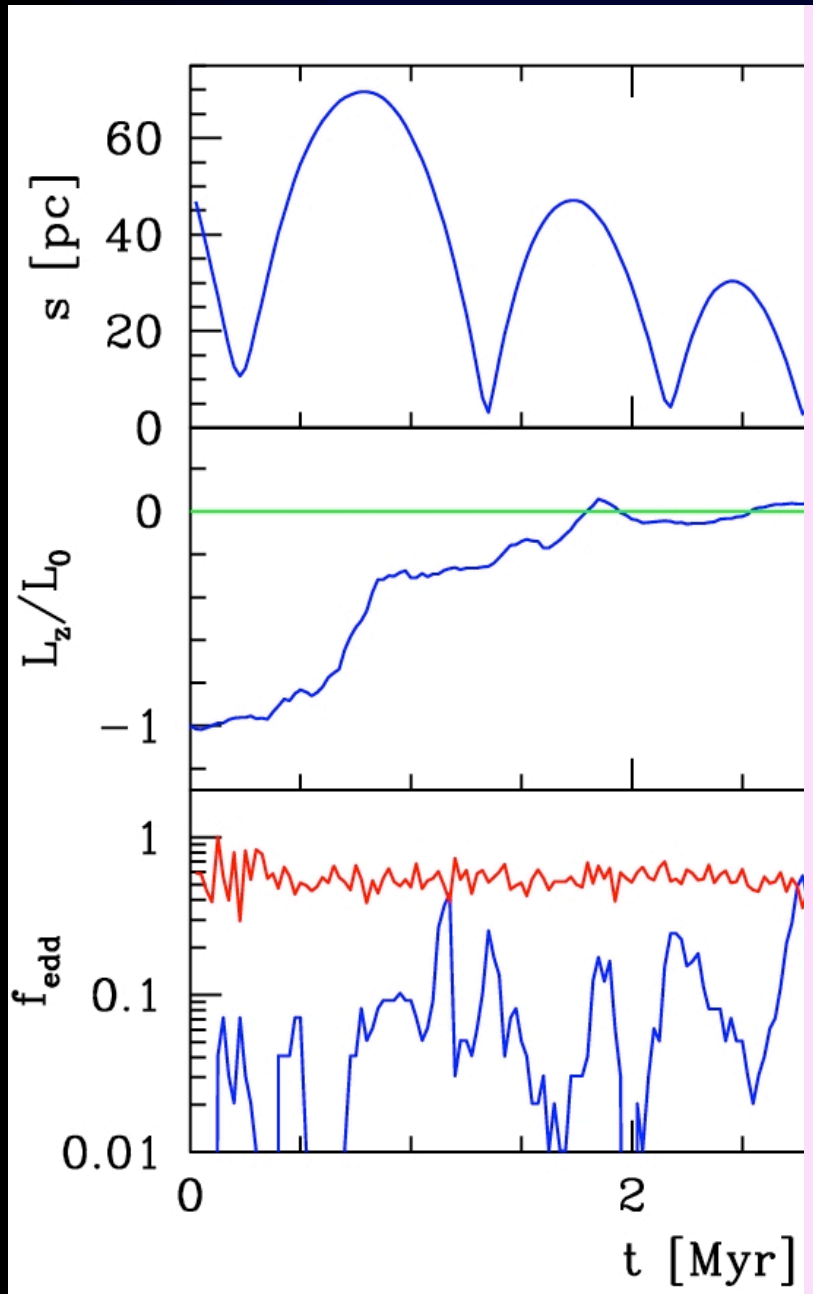
Equal mass merger:
second MBH of 4×10^6 M⊙ and $e \approx 0.7$
co- or counter- rotating

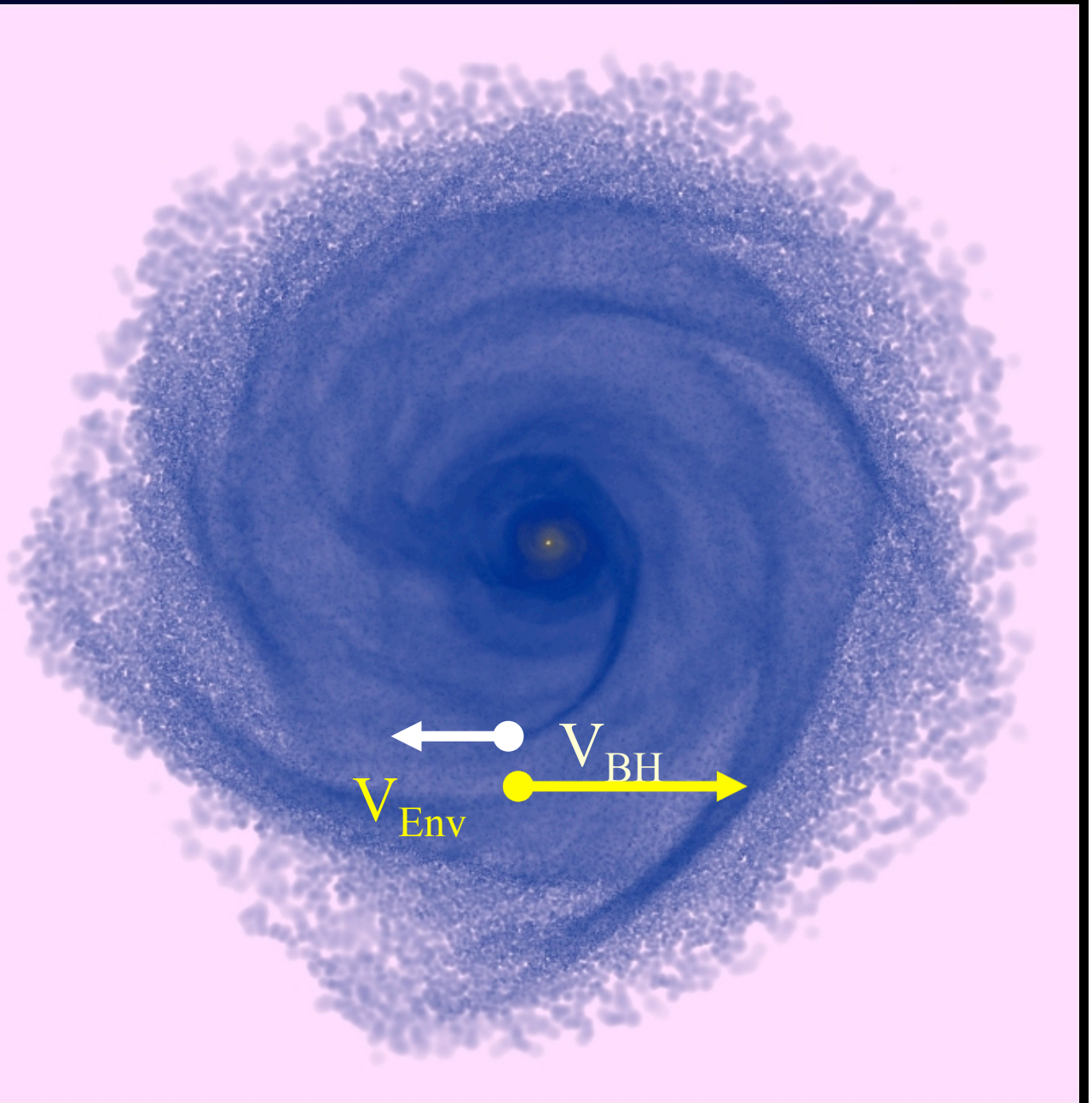
gas particles are accreted only if their total energy (kinetic + thermal + potential, in the reference frame of the MBHs) is less than a fixed fraction ε of the (negative) gravitational energy

(ε > 0.5, accretion possible only resolving the BHL radius of the MBHs!)

Counter-rotating MBH (γ=5/3; h=0.1 pc)

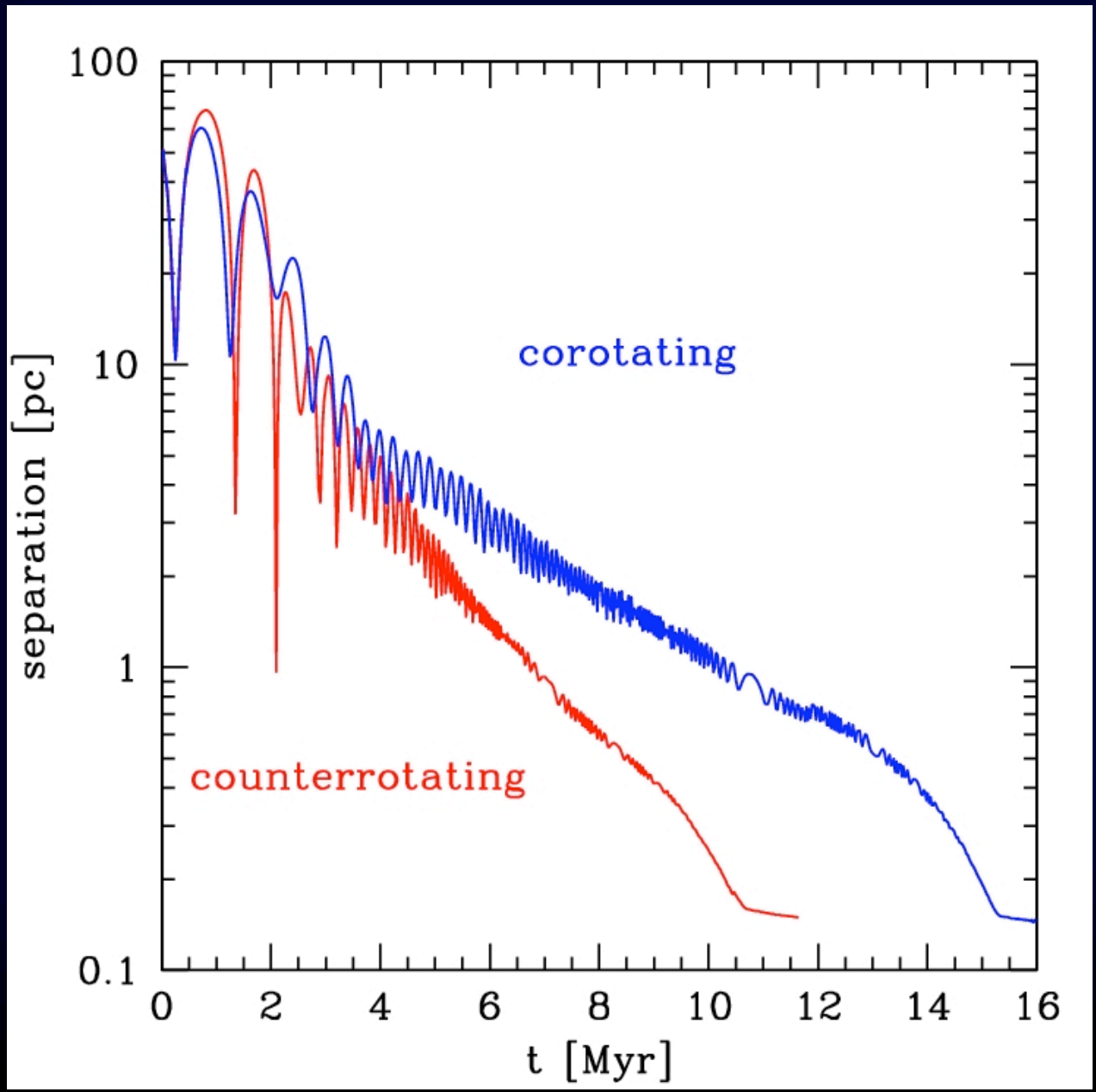
MD et al. 2009



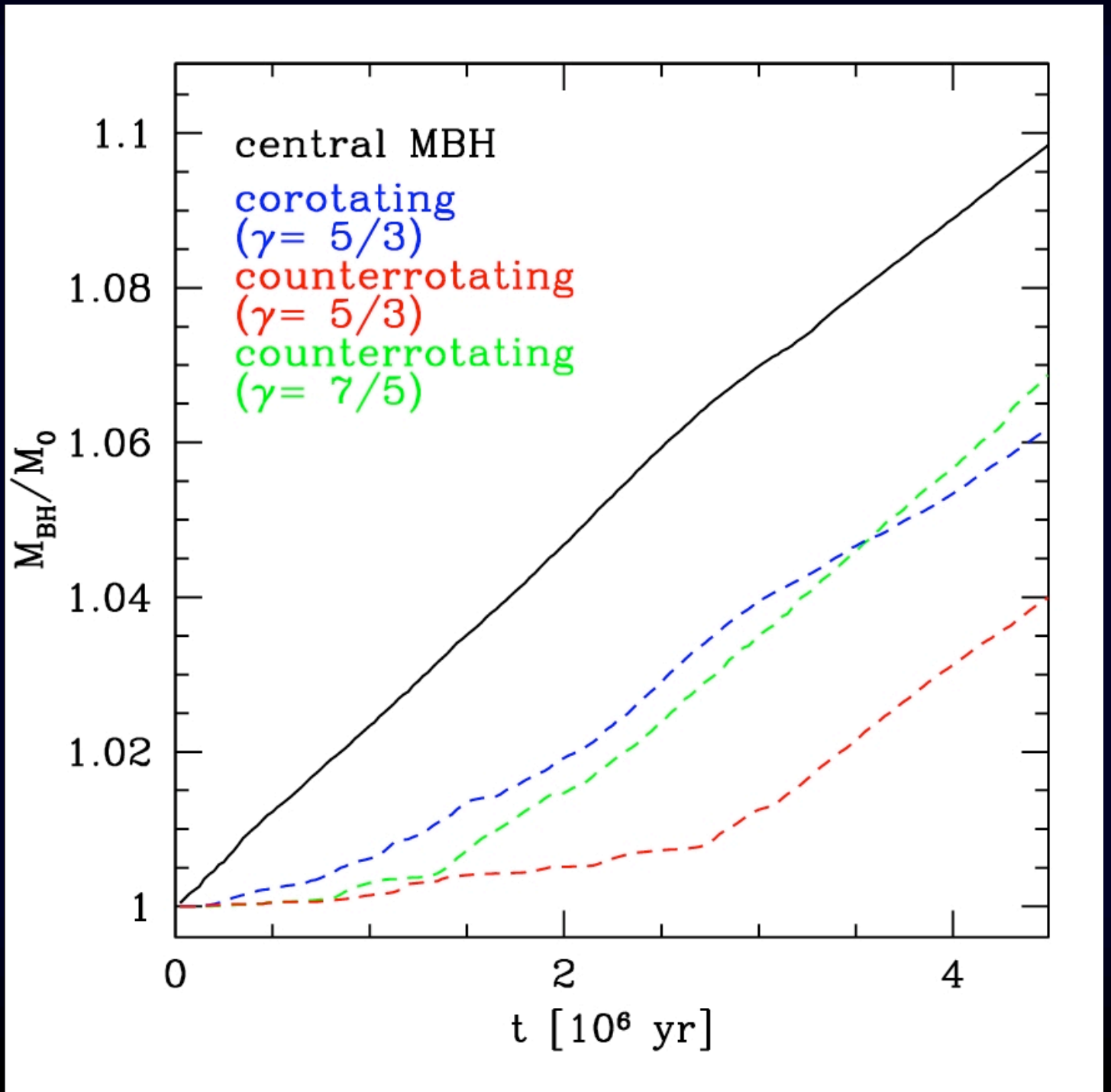


Co-rotating vs counter-rotating MBHs

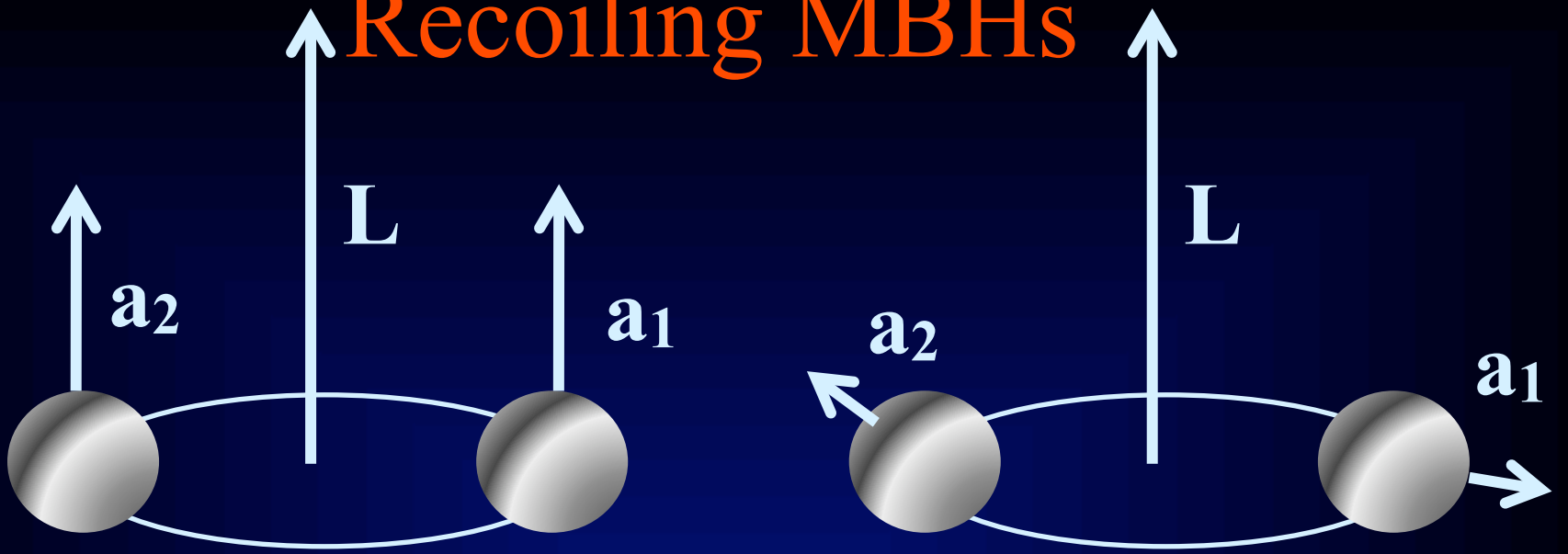
(γ=7/5; h=0.1 pc; only non accreting MBHs)



MBH mass accretion

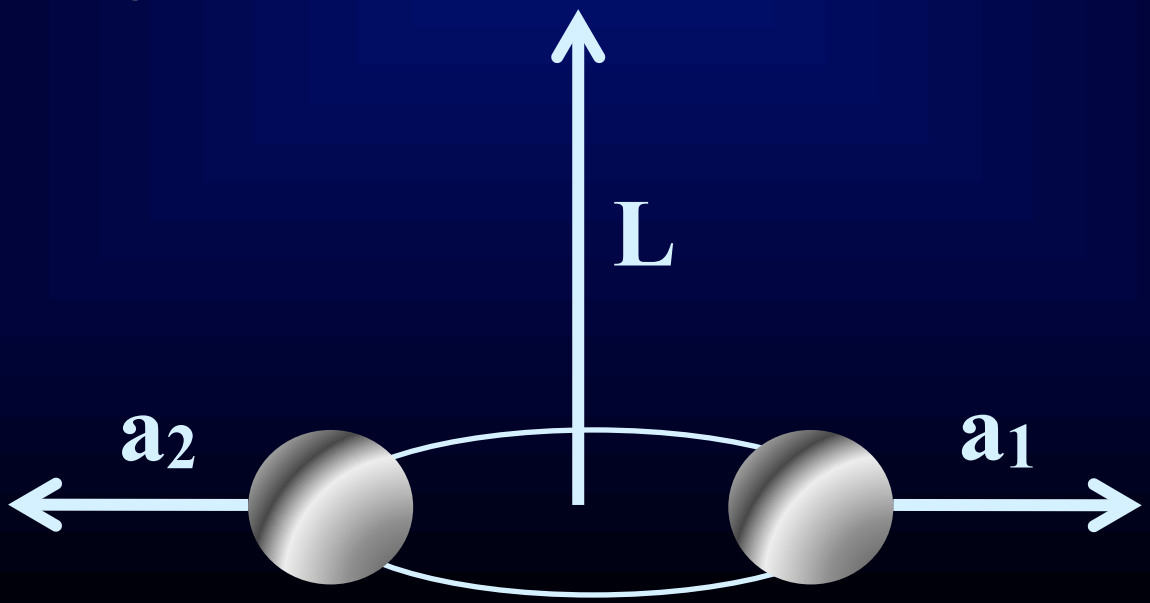


Recoiling MBHs

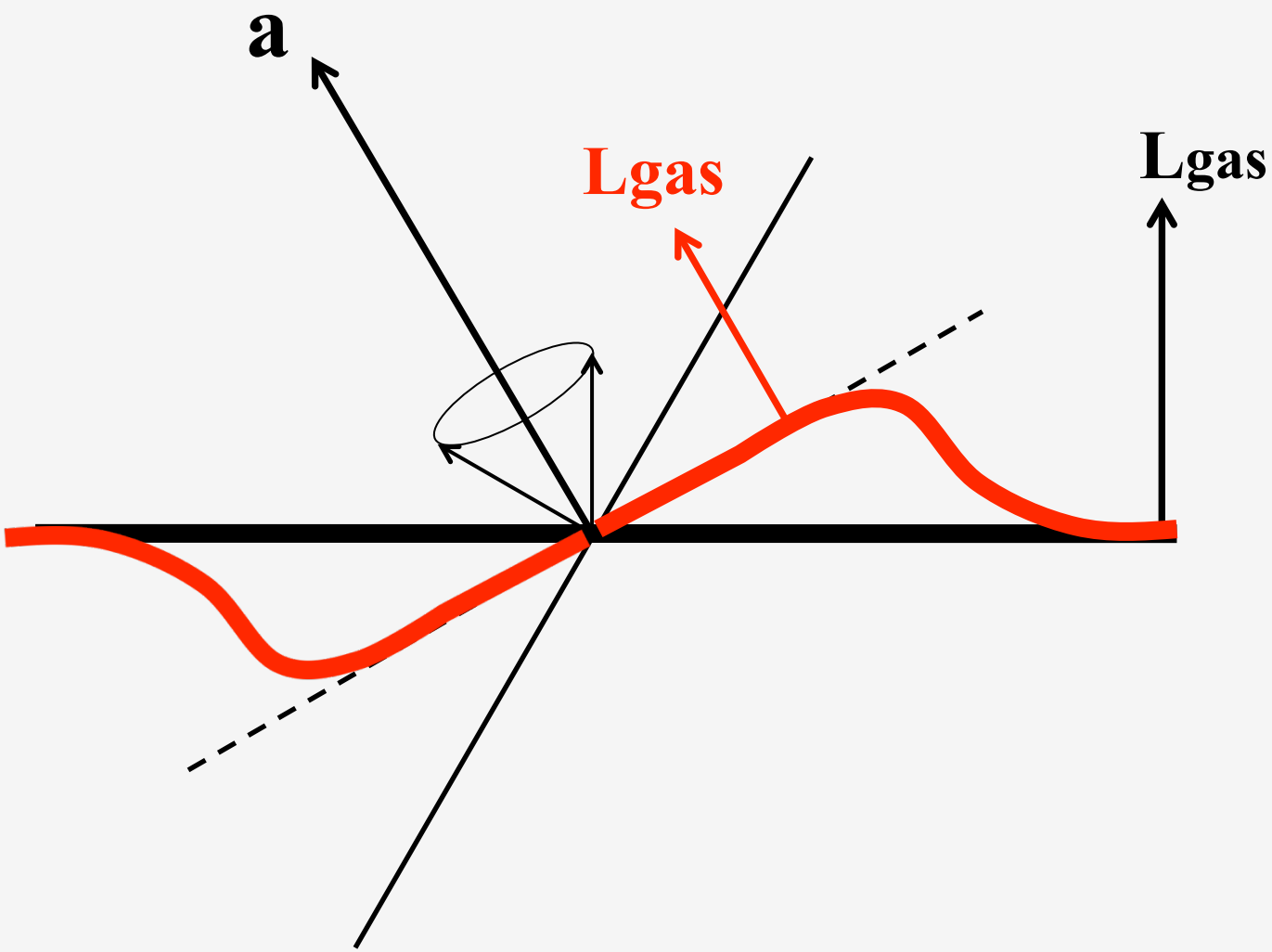


Low kick velocities (~100 km s^{-1})

High kick velocities (~1000 km s^{-1})

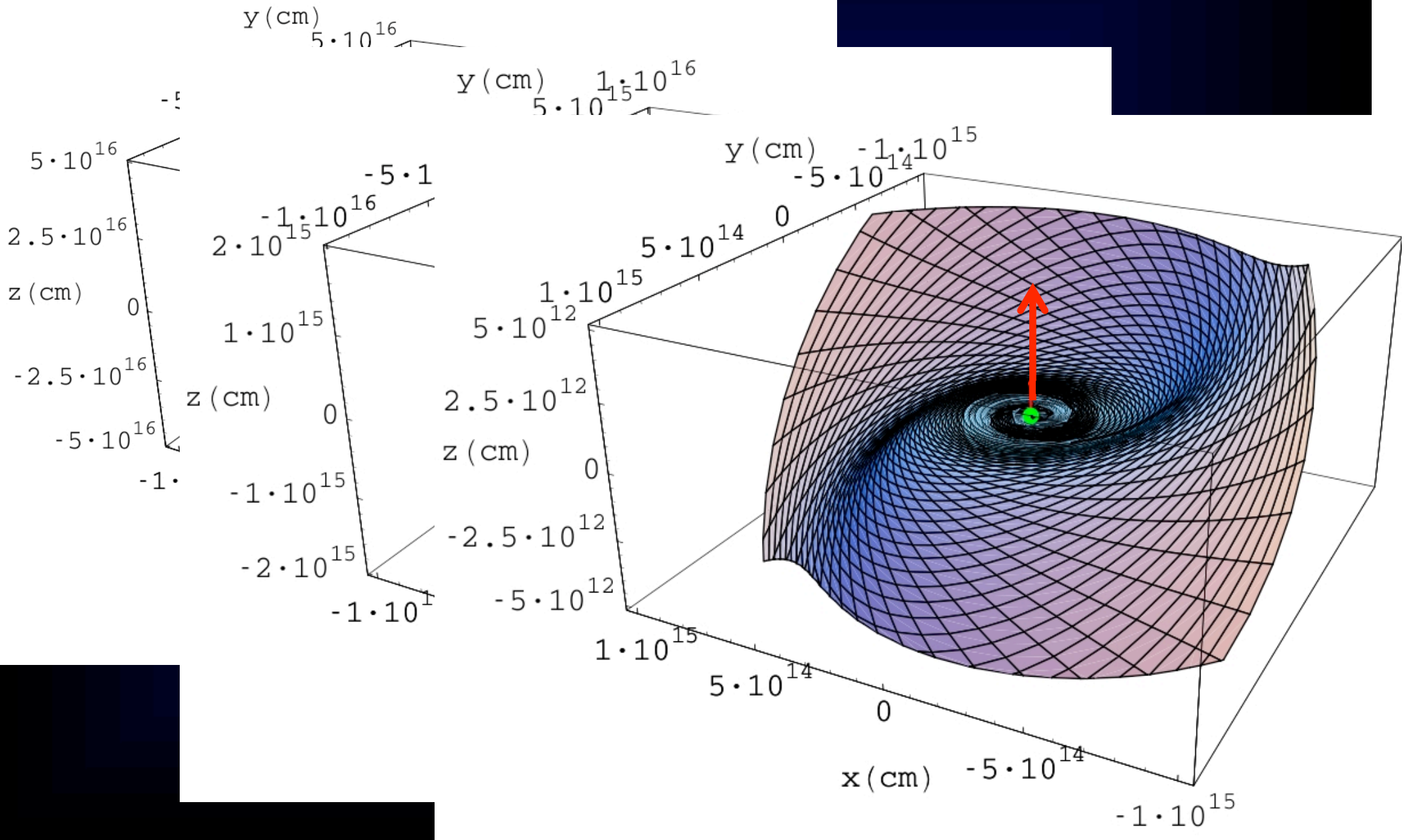


BP effect: interpretation



Spin evolution: Bardeen-Peterson effect

Perego et al. 2009



Spin evolution

MD et al. 2010

From the simulations

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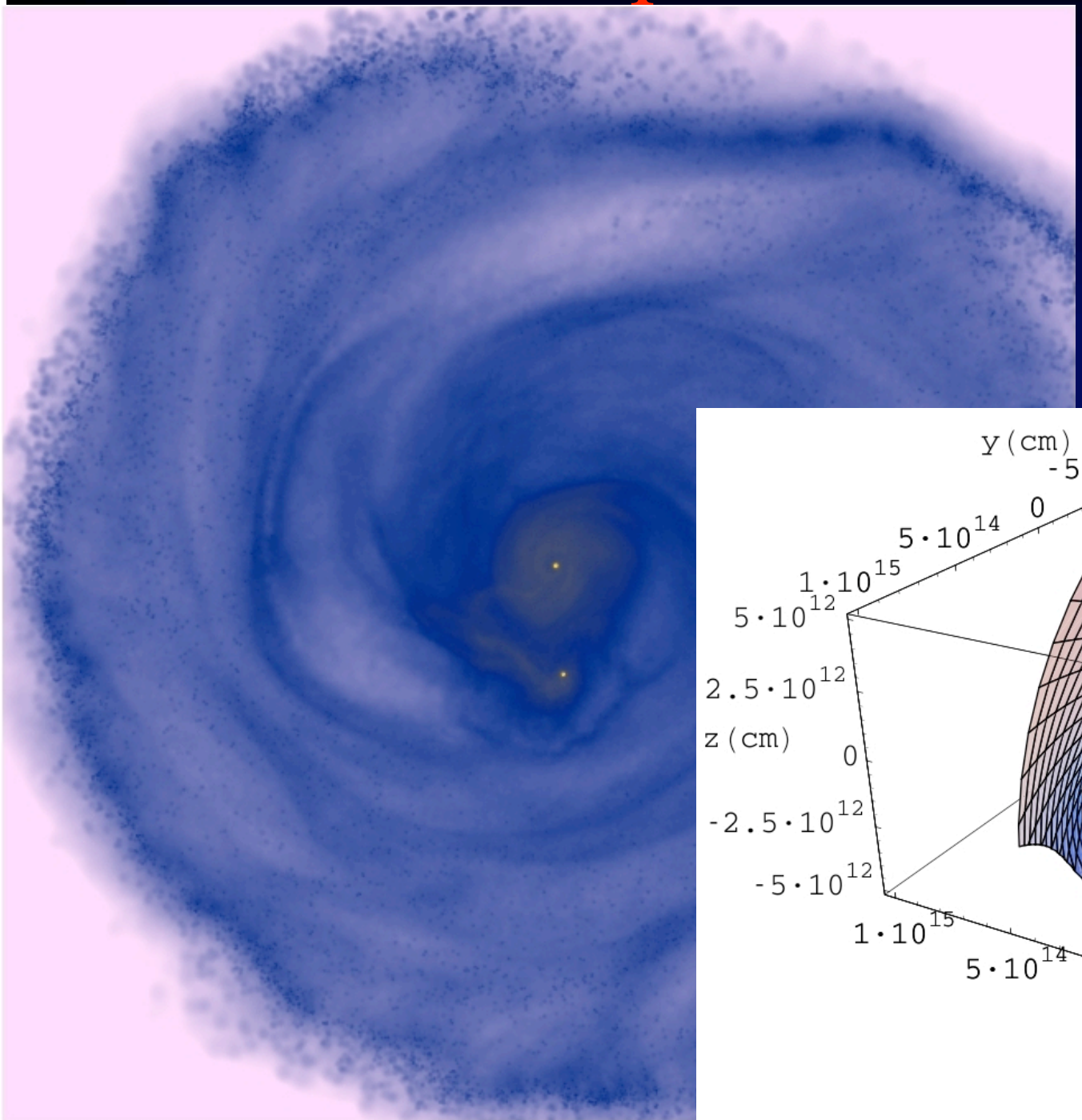
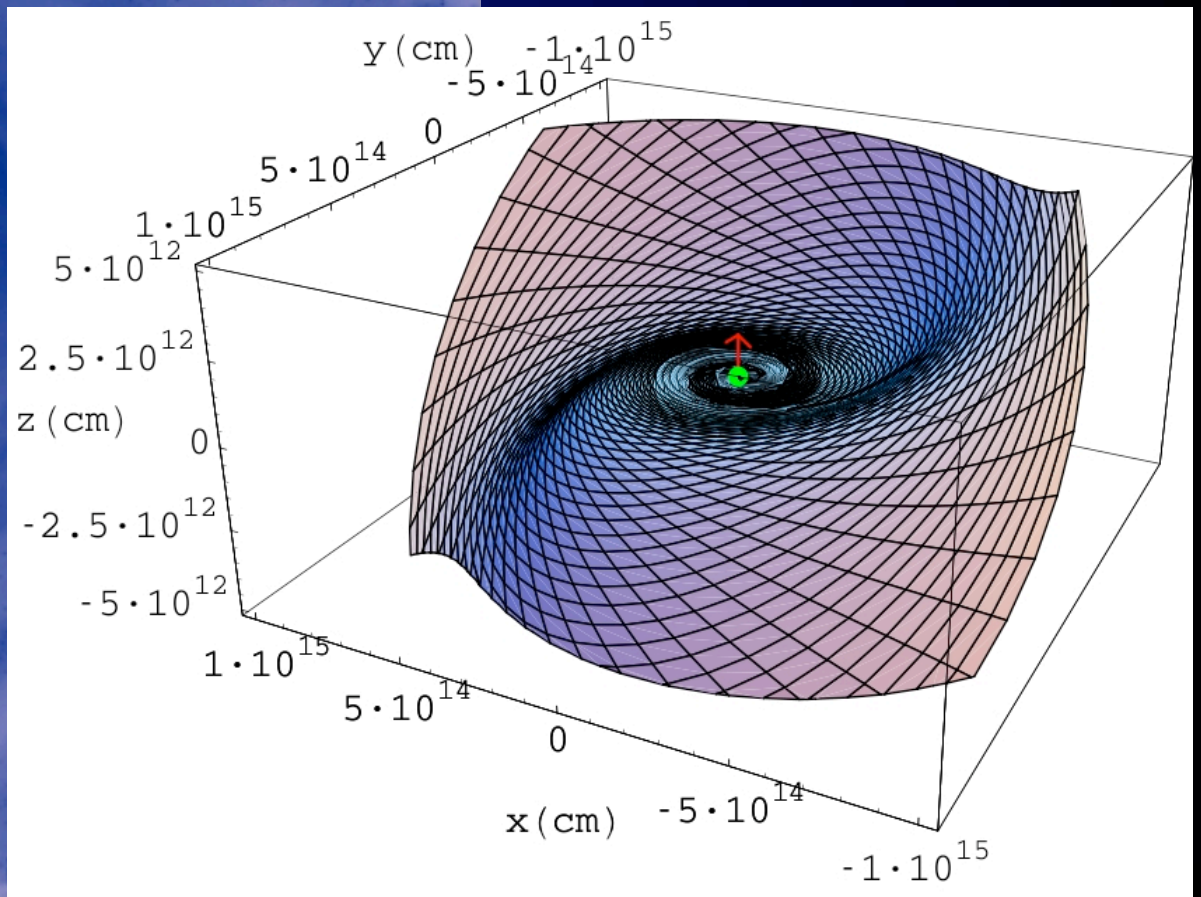
{ accretion rate

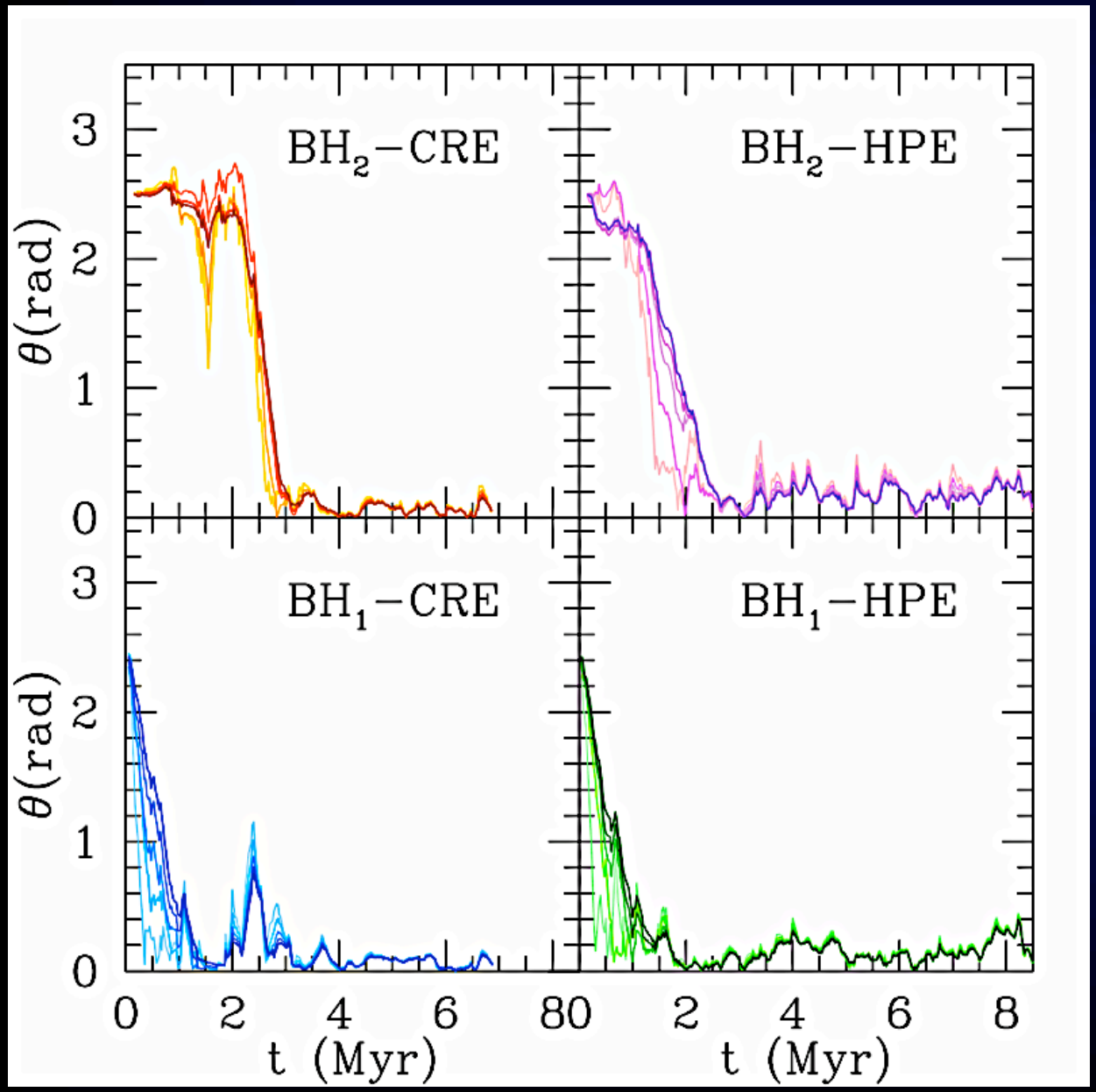
{ **L** of the accreting flow

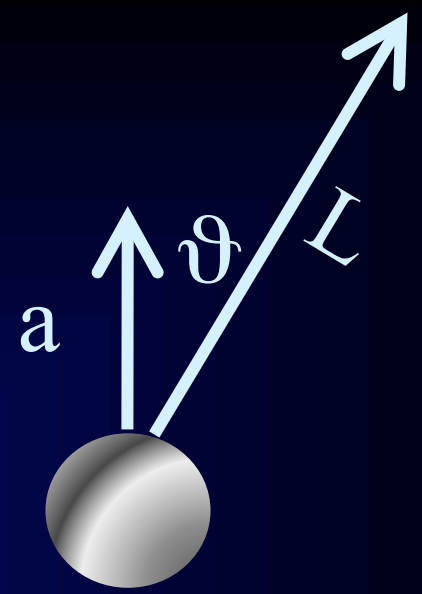
Perego et al. 2009





Spin evolution



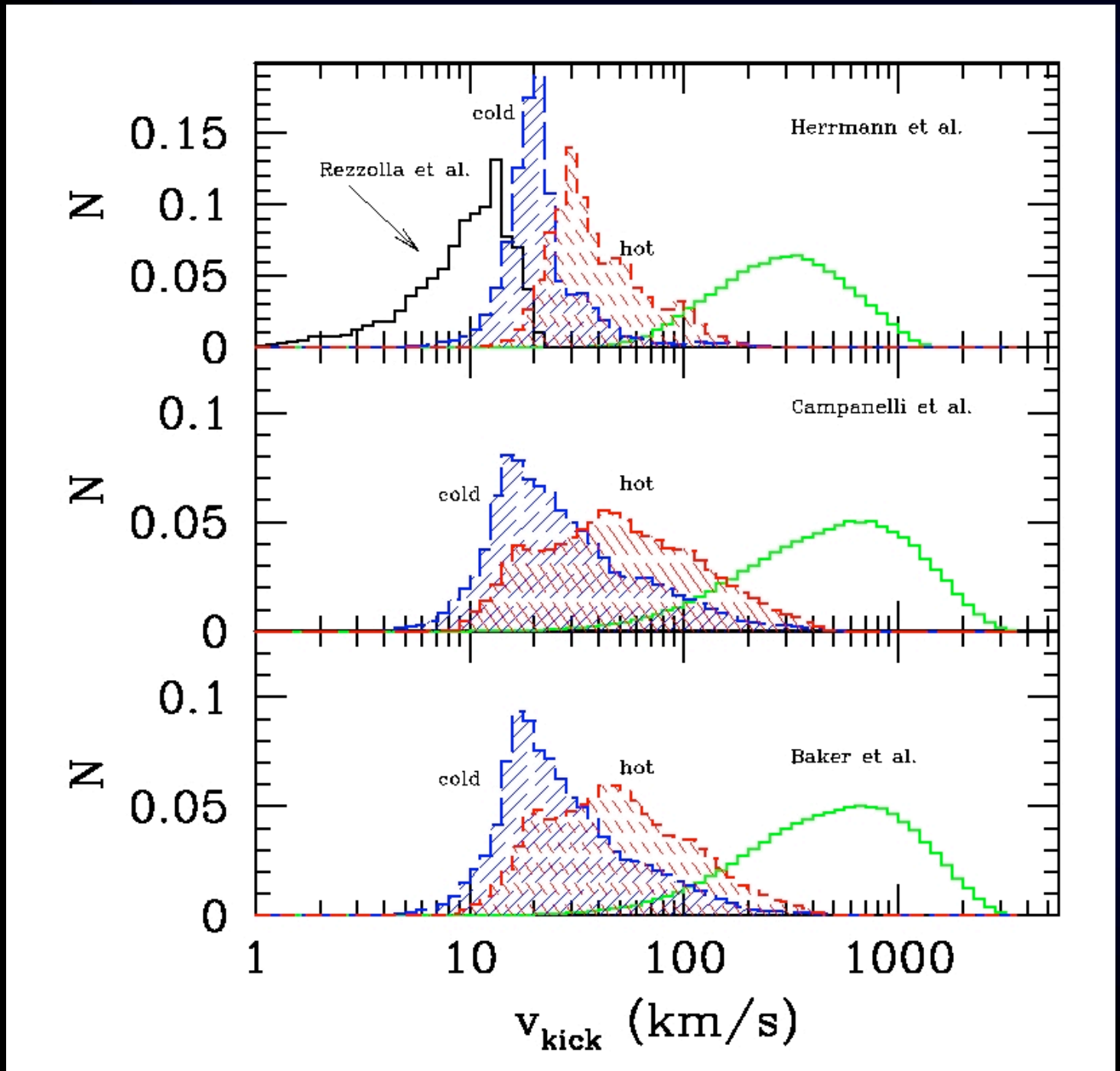


Secondary BH

Primary BH

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

Recoiling MBHs



MD et al. 2010

Conclusions

- MBH binary formation

- Circularization in circumnuclear disks (co-rotating MBHs)
  orbital angular momentum flip (counter-rotating MBHs)

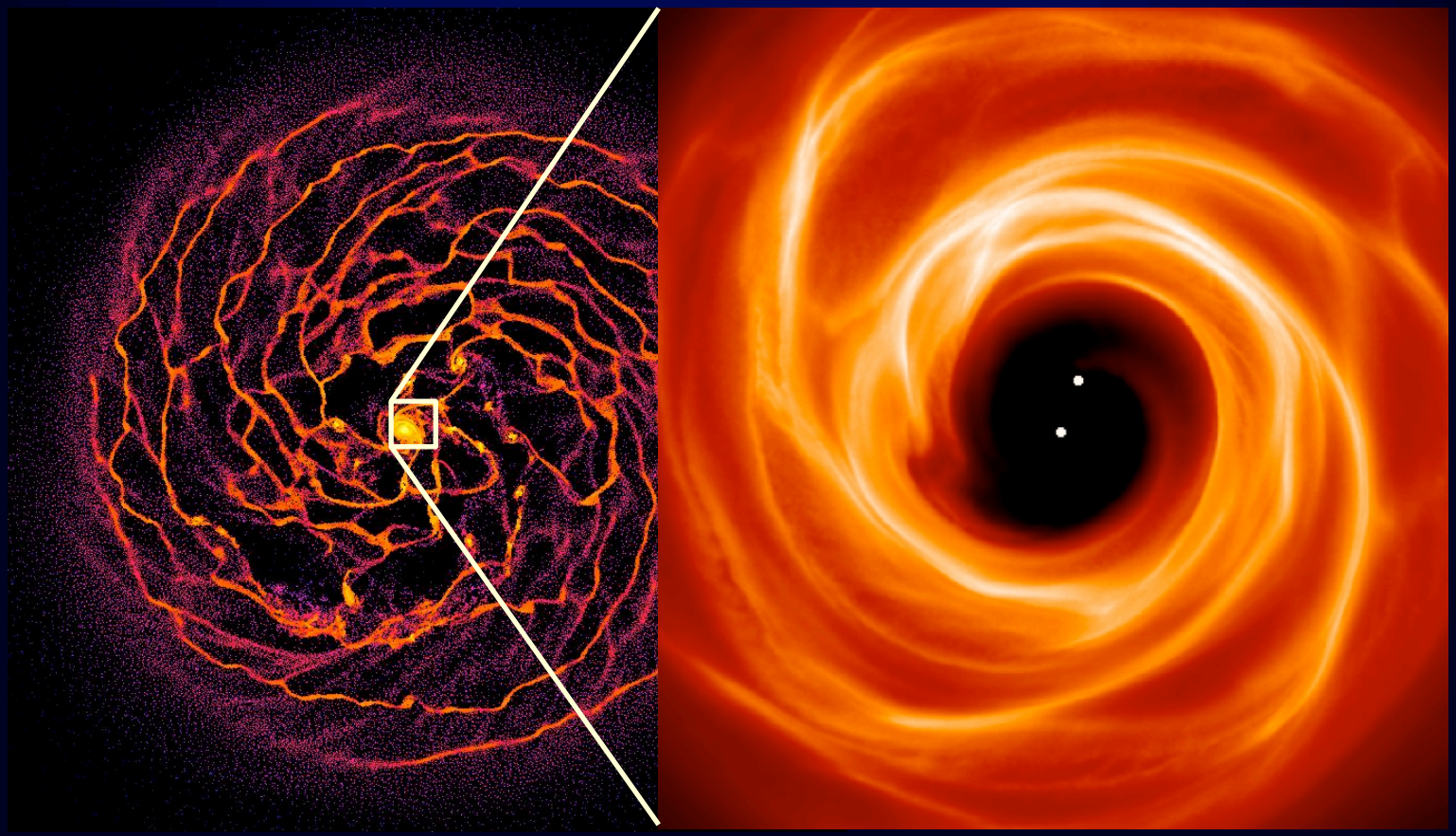
- Predicted (variable) accretion processes during the inspiral

- Spins of the two MBHs align before they form a binary
  (Low kicks)

Future steps

cosmologically motivated ICs

implementation of radiative cooling, SN and AGN feedback



Armitage & Natarajan 2002, 2005
Cuadra et al. 2009