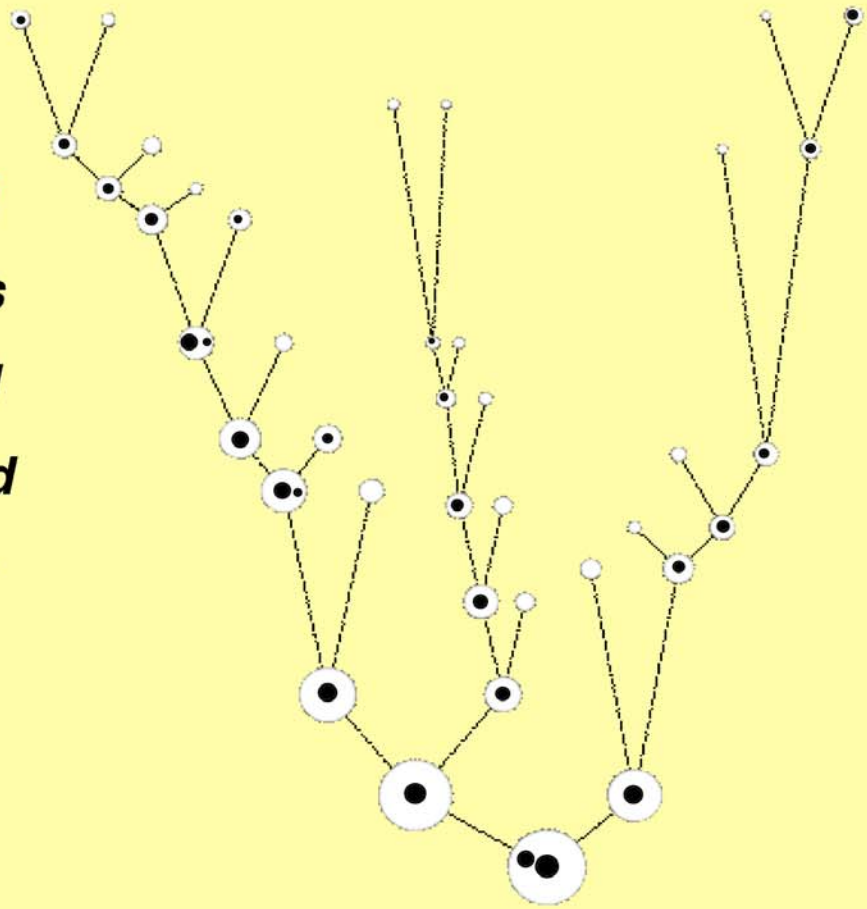
Supermassive black hole hierarchical evolution

NASA/CXC animation

THE MODEL

SMBHS are grown from seed pregalactic BHs. These seeds are incorporated in larger and larger halos, accreting gas and dynamically interacting after mergers.

Note: in most of what follows I'll consider seeds which are the endproduct of the first stars. **Results at low-z are unchanged**

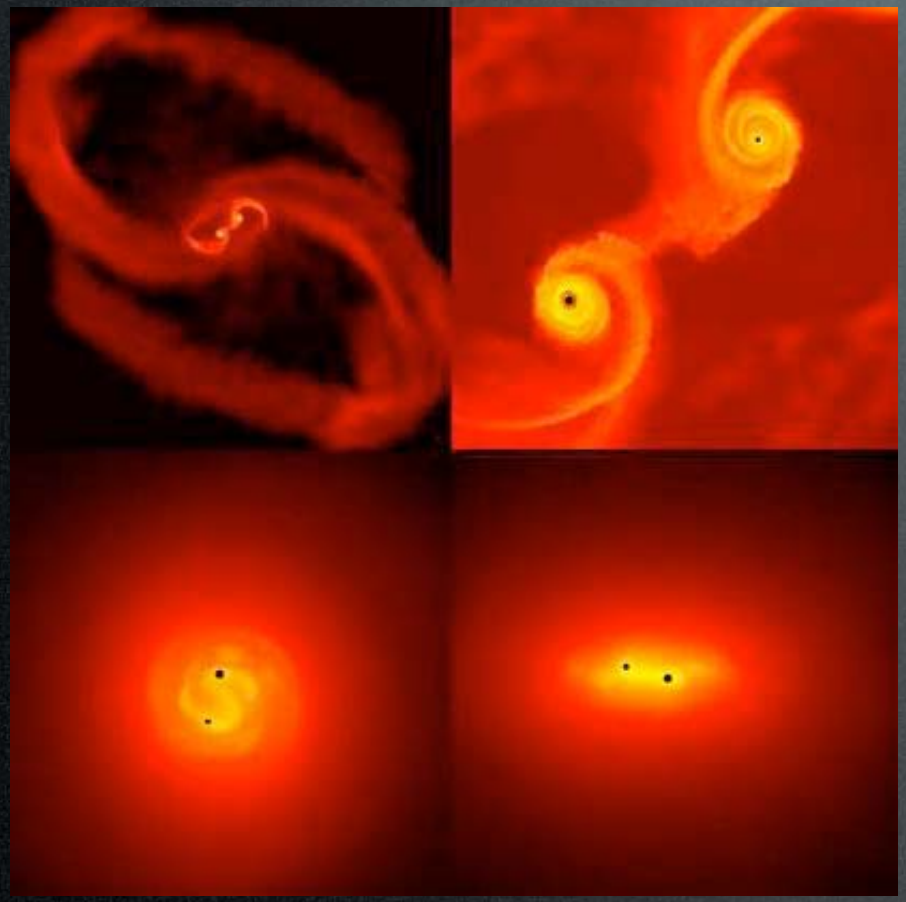


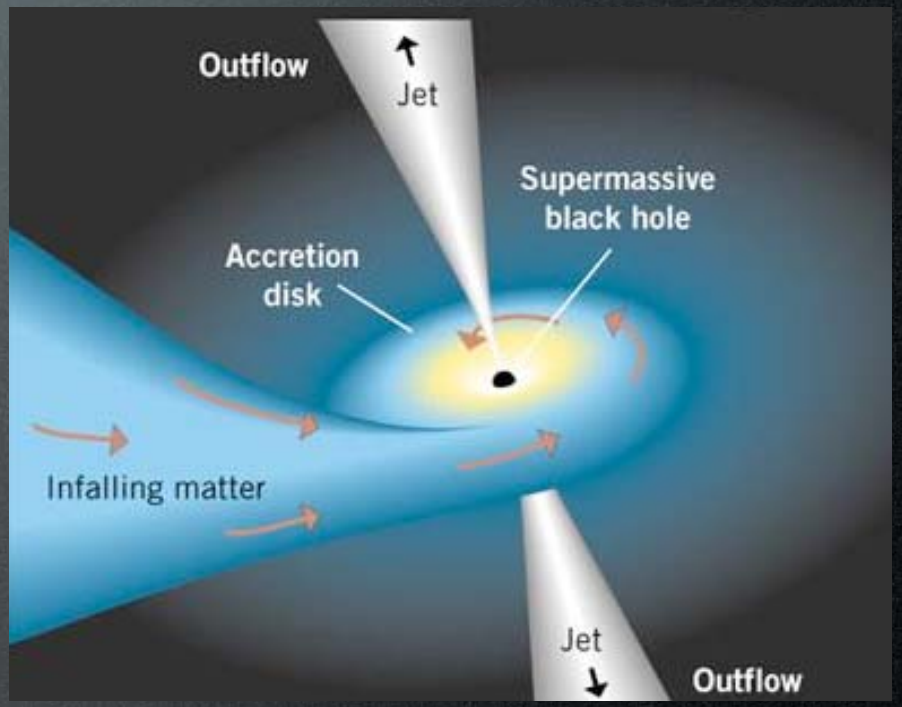
Volonteri, Haardt & Madau 2003

How does the SMBHs mass grow along the cosmic history?

➡ Mergers

➡ Accretion





To recover the local M_{BH}- σ & the quasar LF @ z <6:

✓only during major mergers { space density of quasars; SMBHs-bulges connection

✓ the accreted mass is a fixed fraction of the M_{BH}- σ relation { *B*H growth limited by feedback (cfr. Di Matteo et al.)

✓ Eddington accretion rate { a sensible assumption?

Dynamical evolution of BH pairs

1. dynamical friction

✓ efficient only for major mergers against mass stripping

✓ efficient down to ~pc scale

2. hardening of the binary

the binding energy of the BHs is larger than the thermal energy of the stars

✗ 3 bodies scattering between the binary and the surrounding stars

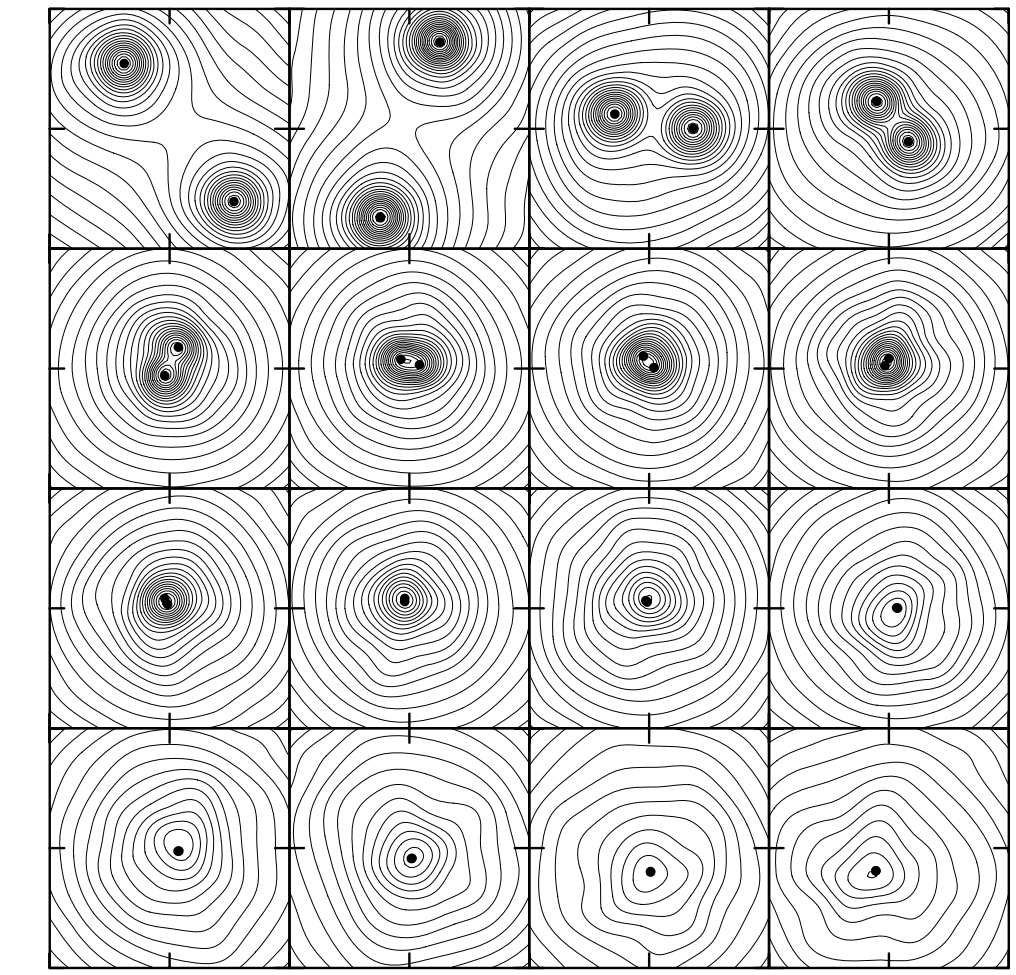
✗ interaction with gas/accretion disc

3. emission of gravitational waves

Takes over at subparsec scales...

As the binary shrinks ejecting stars the central density drops

Numerical simulations do not have the required resolution yet to follow the binary down to the GW emission stage



Miloslavljevic & Merritt 2001

We can model the mass growth of MBHs as traced by evolution of the quasar LF

Black holes have mass but also spin

What is the typical BH spin predicted by the hierarchical evolution?

What is the typical radiative efficiency value?
Are BHs rapidly spinning?

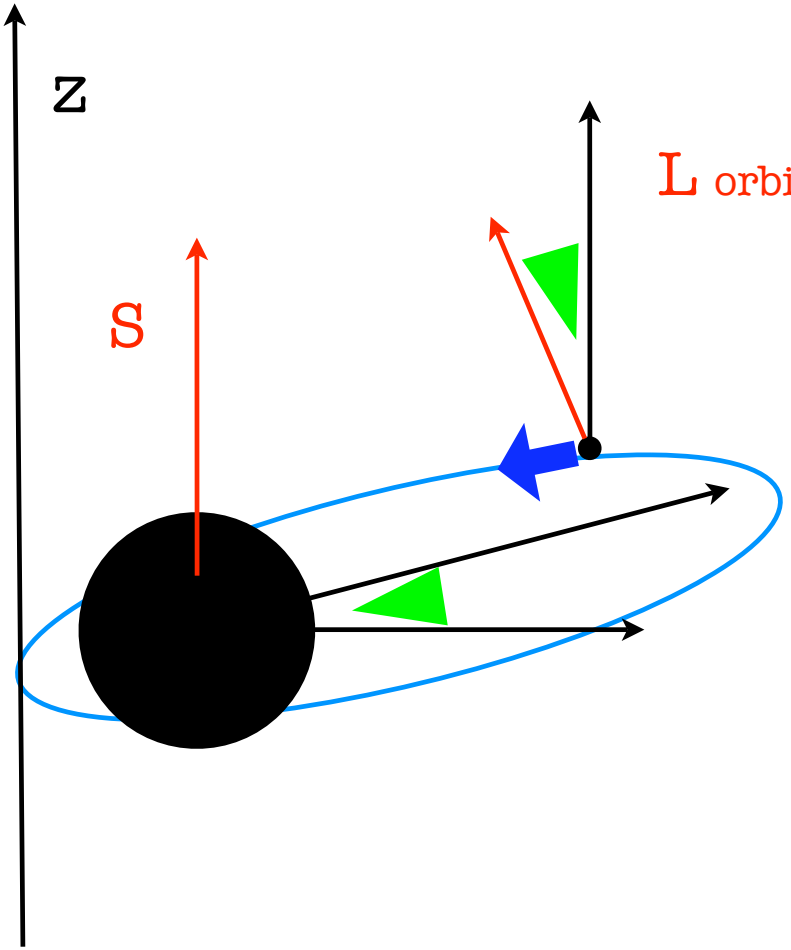
BHs spin is modified by BH mergers and the coupling with the accretion disc

- ✓ mergers can spin BHs either up or down
- ✓ alignment with a thin disc spins up

… but BH mergers are rare events!

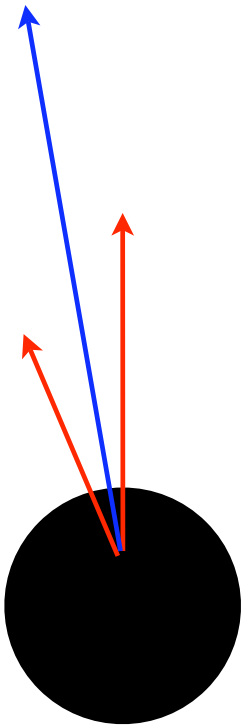
Volonteri, Madau, Quataert & Rees 2005

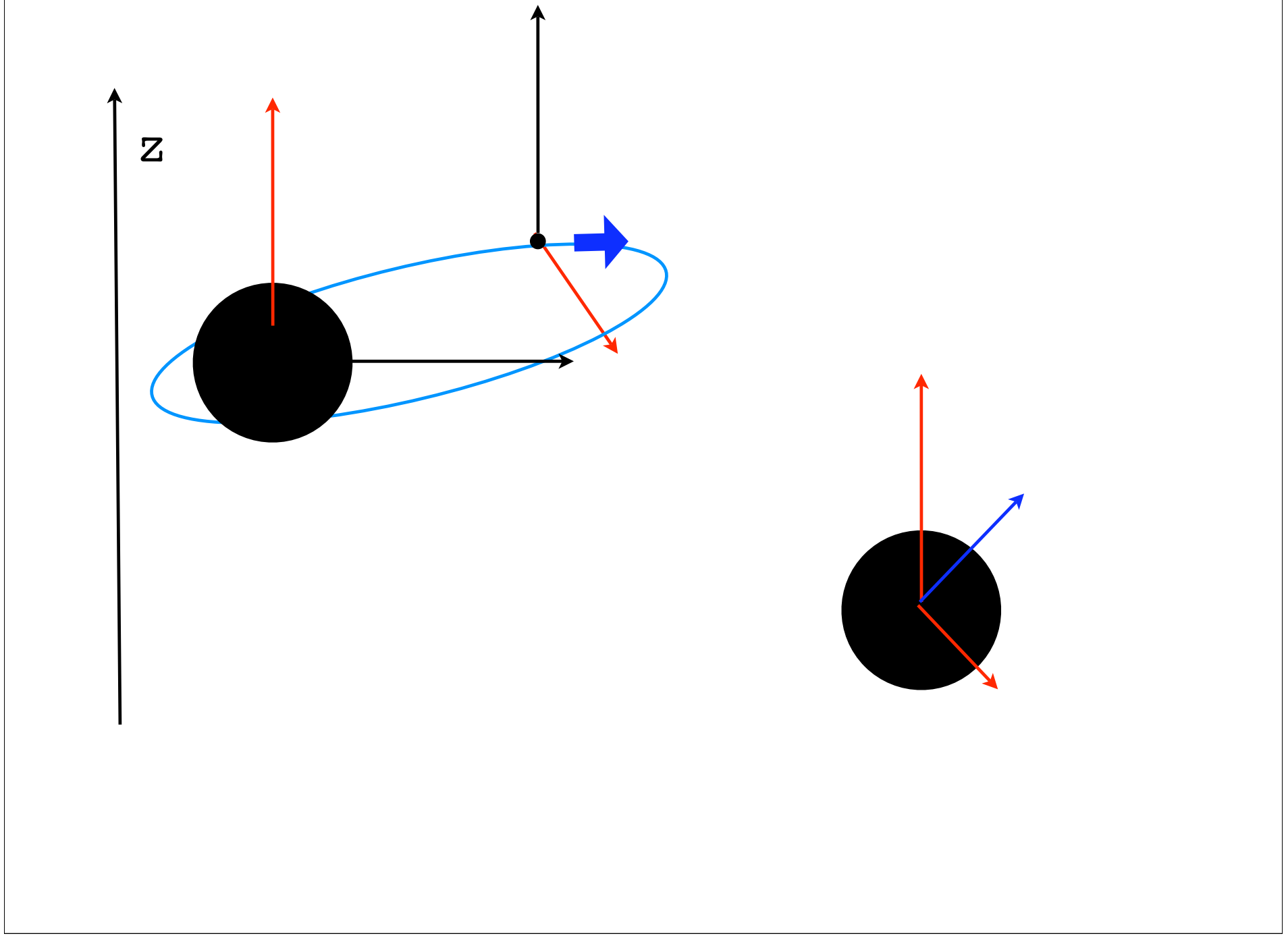
Evolution of BH Spin: MERGERS



L orbital angular moment

μ=cos(inclination)




Z

The magnitude |L| is small for prograde orbits (L_{min}=2/3) and large for retrograde orbits (L_{max}=22/3)

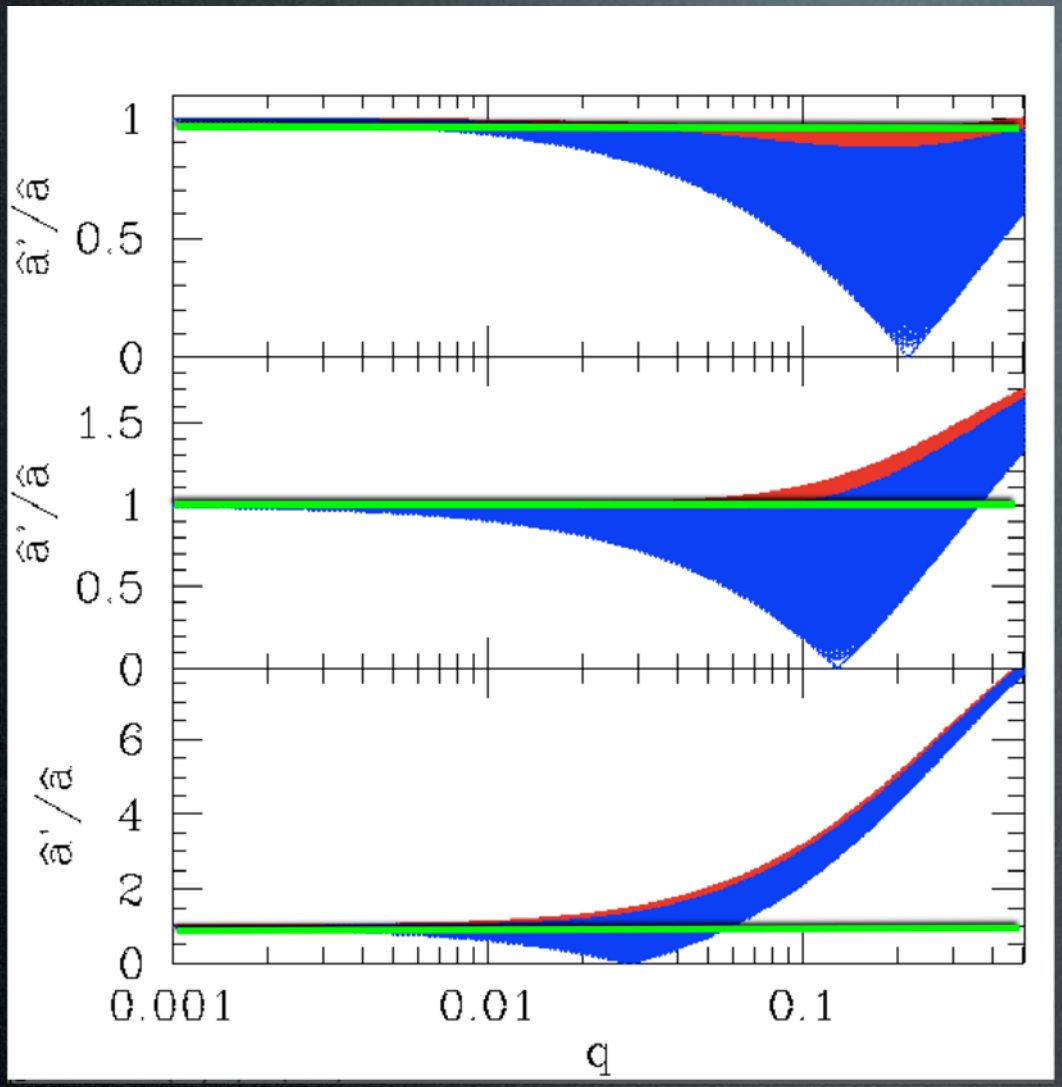
When S and L point in the same direction, i.e. the BH is spun up, |L| tends to be small and therefore the total change in spin is small

When S and L point in opposite directions, i.e. the BH is spun down, |L| tends to be large, and the total change is large

On average, the hole tends to spin down

q>0.1 : when L overwhelms S. The spin of the remnant is then dominated by the orbit at plunge.

"doctrine of original spin": $S = aM^2$
remains roughly constant while M grows



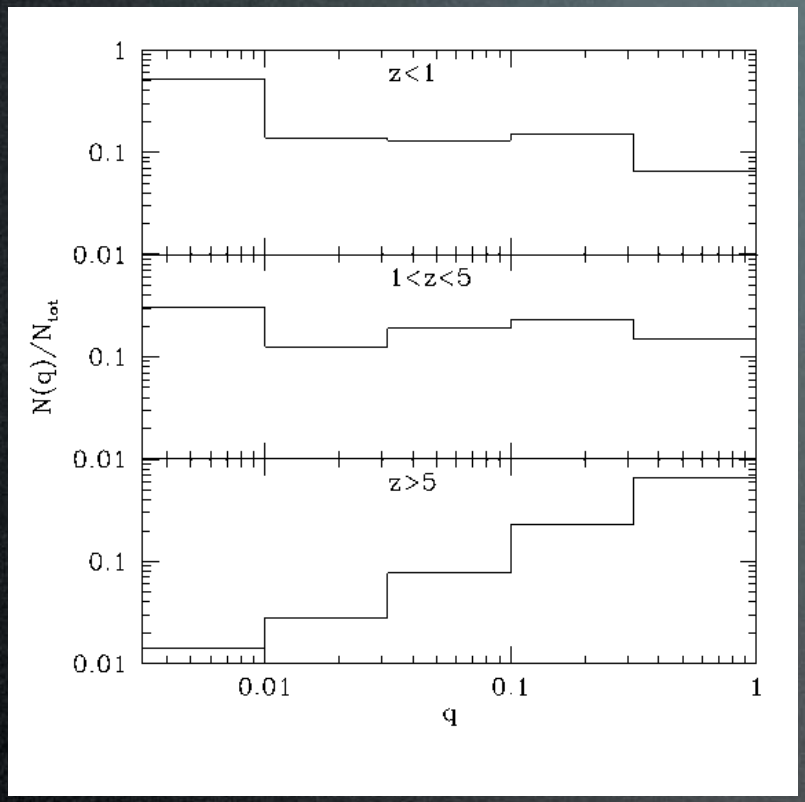
a_{in}=0.9

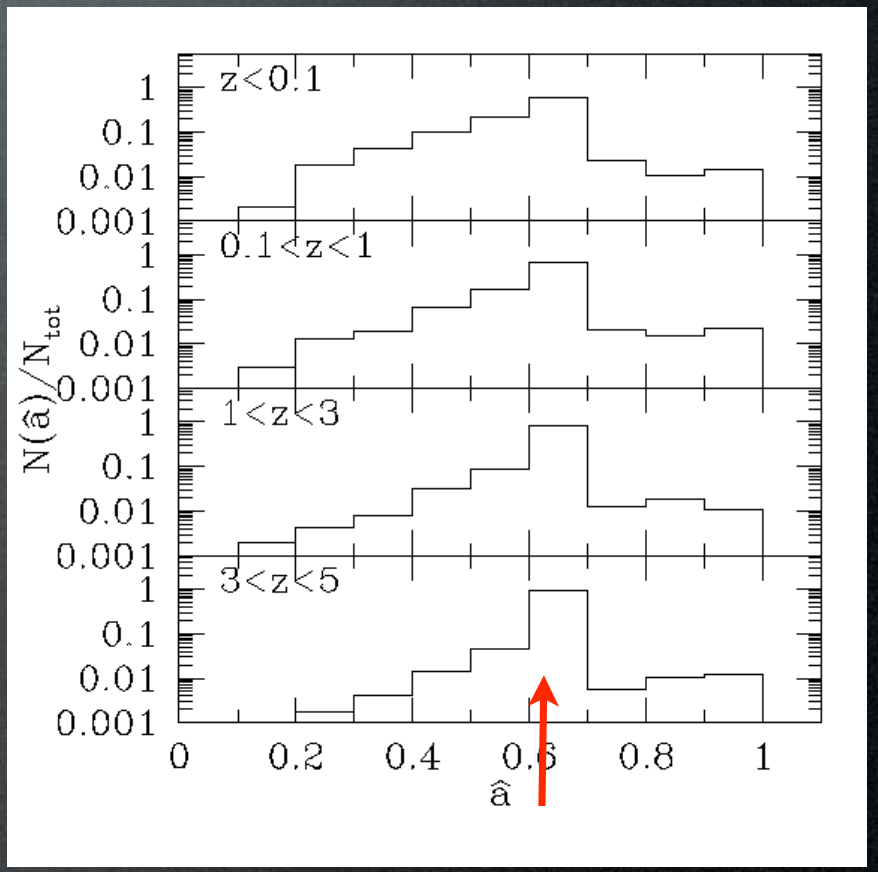
a_{in}=0.5

a_{in}=0.1

"doctrine of original spin": $S = aM^2$
remains roughly constant while M grows

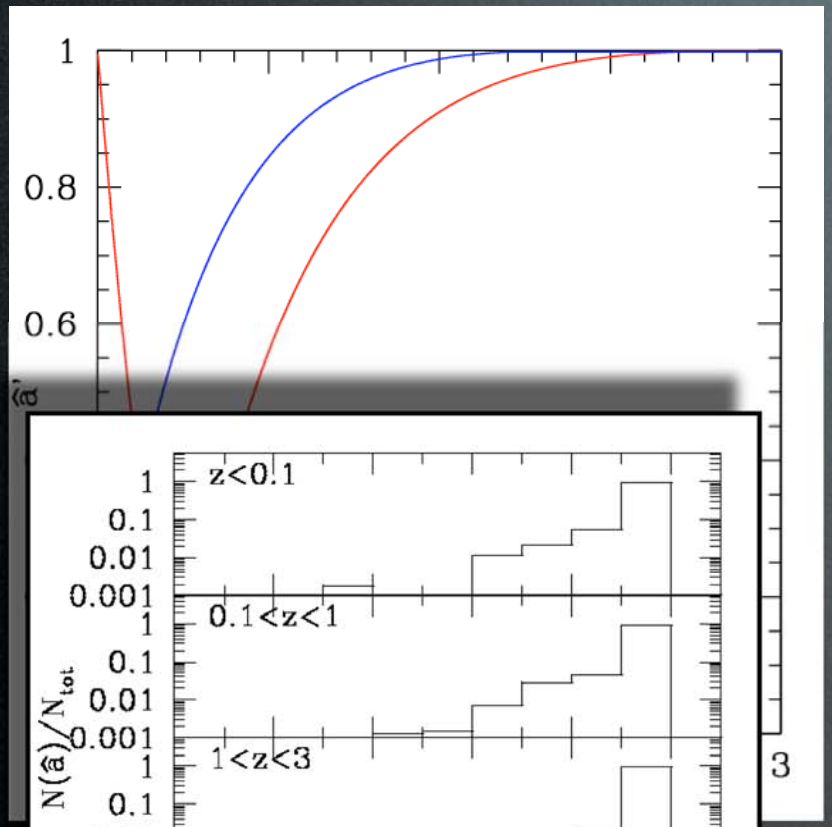
Distribution of black hole mass ratios from the whole cosm. evolution $q=m_2/m_1<=1$

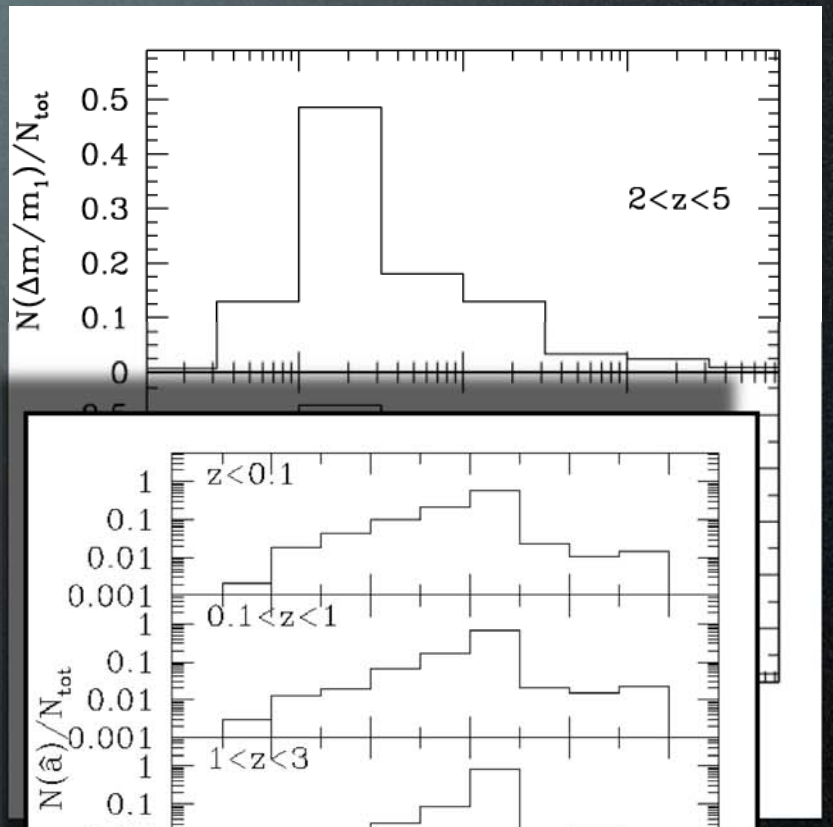




Distribution of black hole spins if only mergers influence them

Evolution of BH Spins





Mergers + coupling with disc a.m.

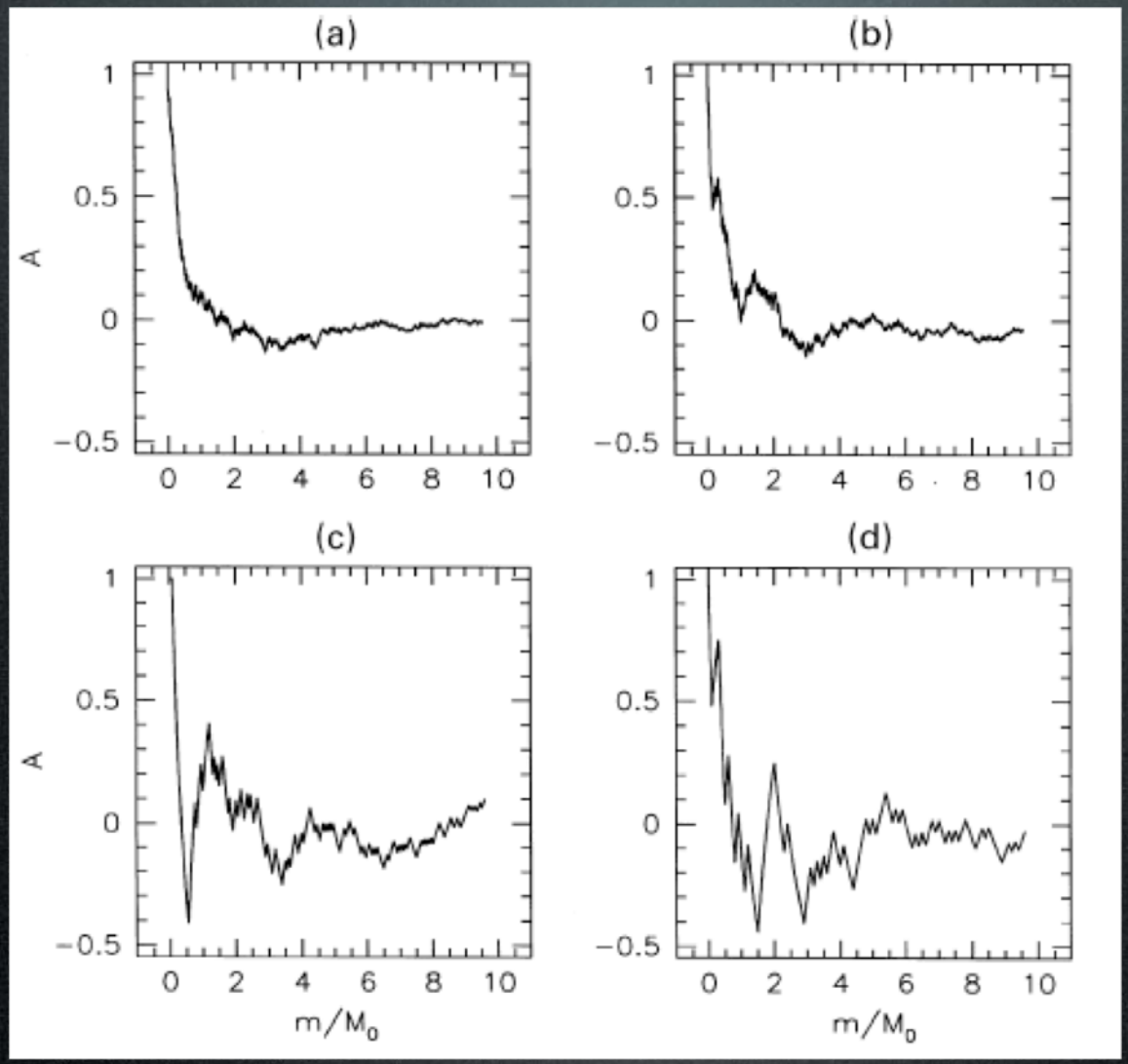
Mergers only

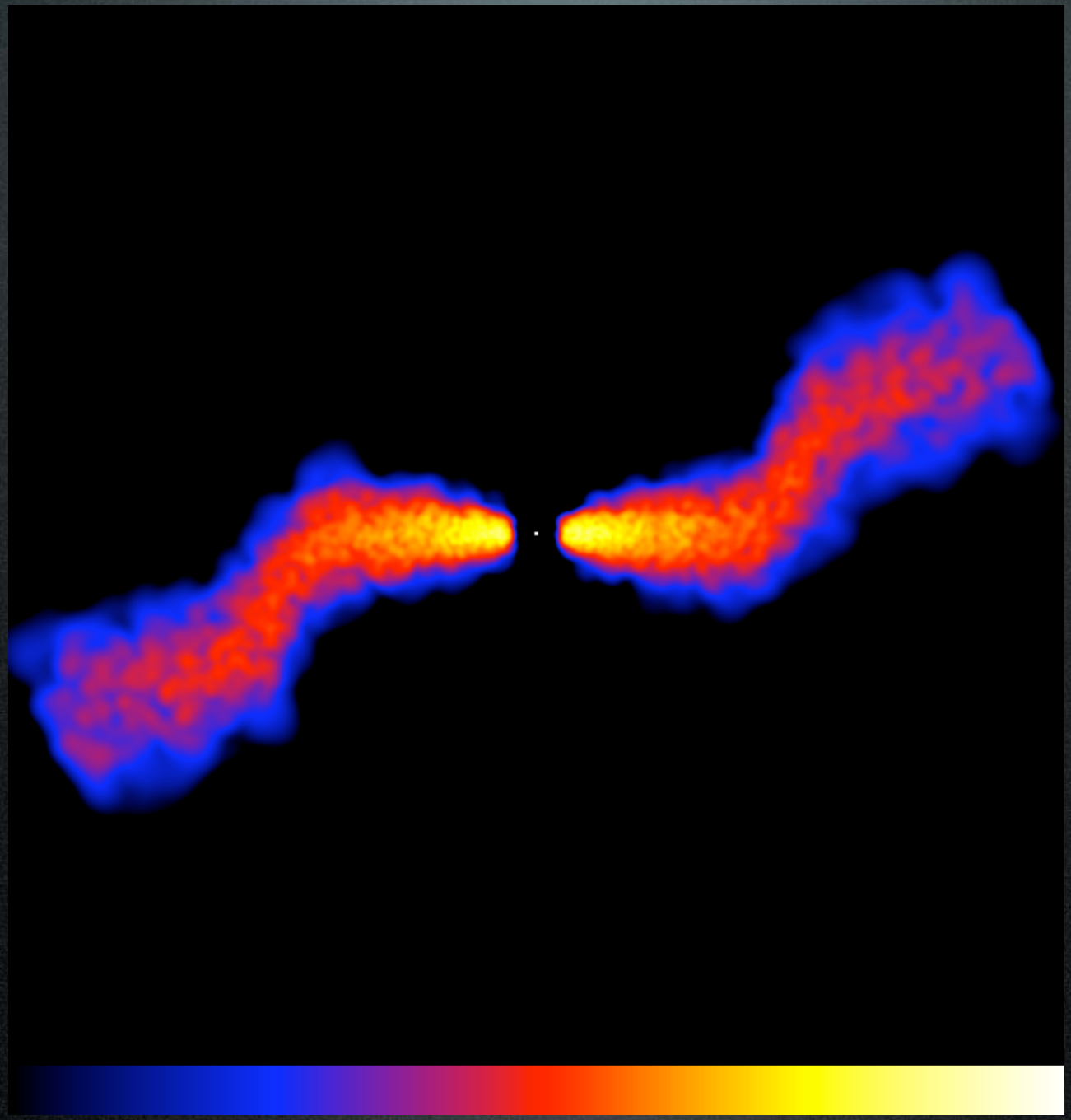
✔ via br

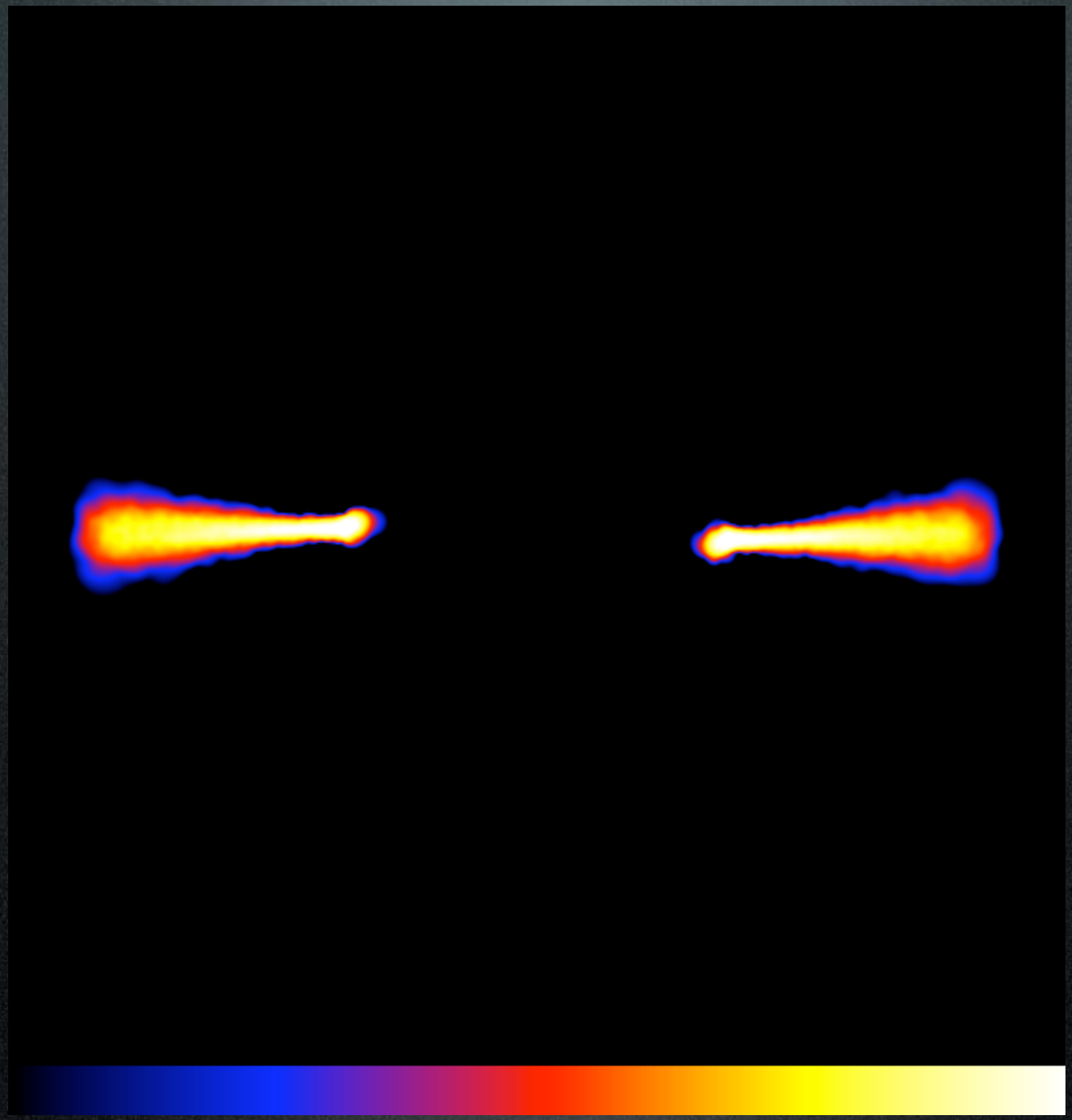
✔ the sof

et al 2005)

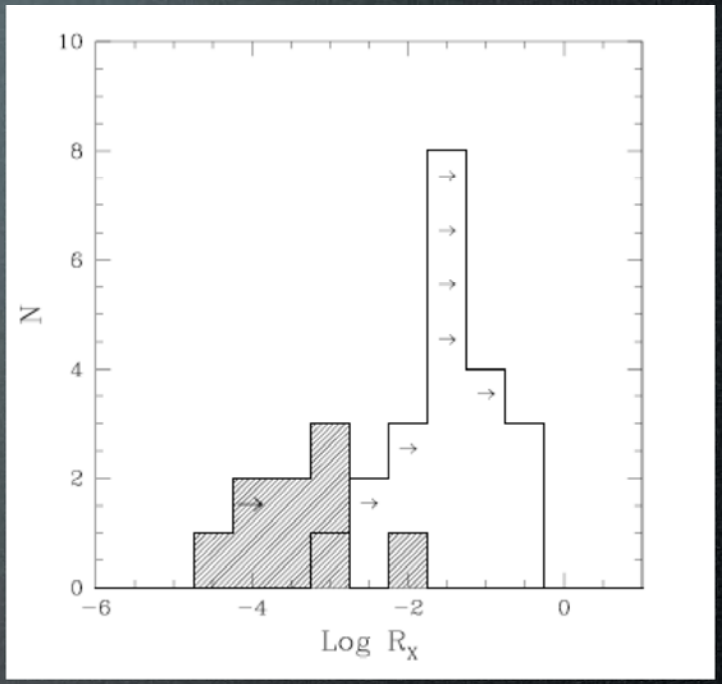
Chaotic accretion

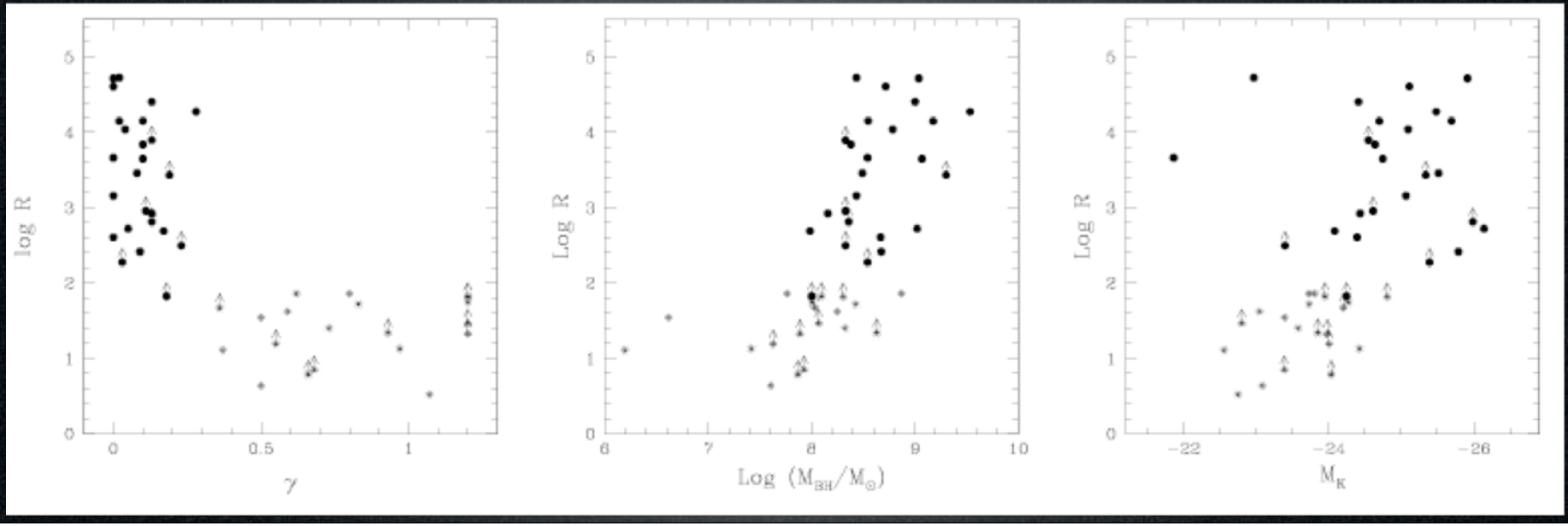




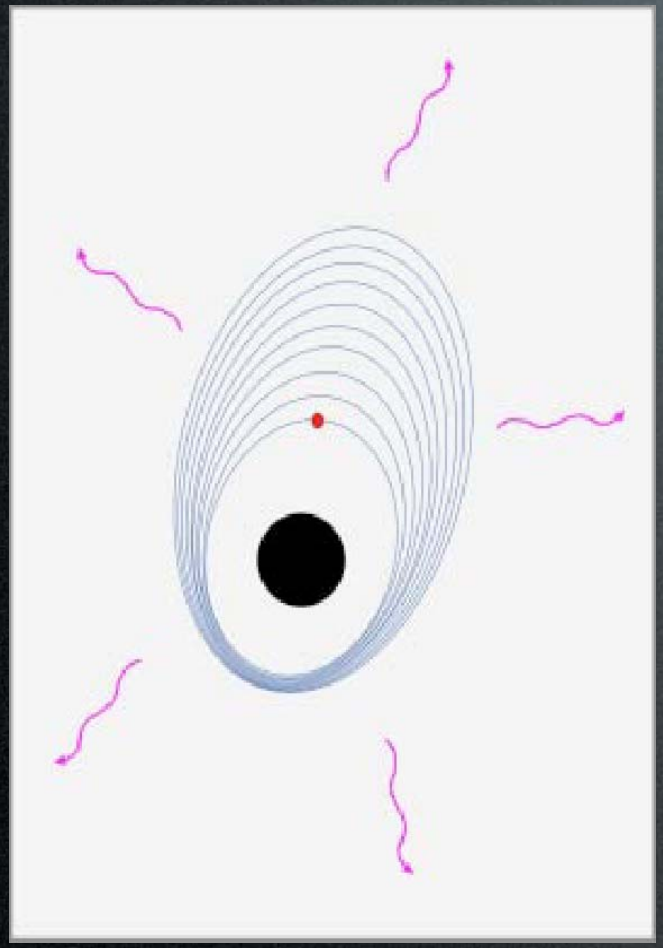


Radio loudness: spin paradigm? core paradigm?





Extreme mass ratio inspirals



Inspiral of a compact object (WD, NS, BH) into a supermassive black hole in the centre of a galaxy.

LISA can see $10M_{sun}$ + 10^6M_{sun} inspiral out to z~2 → can probe SMBH spin evolution if event rate is high enough!!

For a typical event with SNR~30, determine parameters with errors
(Barack & Cutler, Creighton et al.)

$\Delta M \sim 2 \times 10^{-4}$
$\Delta(S/M^2) \sim 10^{-4}$
$\Delta(\ln m) \sim 10^{-4}$
$\Delta(\ln D) \sim 0.05$