Mass ratios and the final spin in supermassive black hole mergers

László Árpád GERGELY

University of Szeged, Hungary

with Peter L Biermann

(MPI for Radioastronomy Bonn)

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Accretion vs. mergers

- Both increase the mass
- Accretion increases the spin too
- Mergers may easily reduce the spin

Various scenarios leading to the same SMBH mass distribution

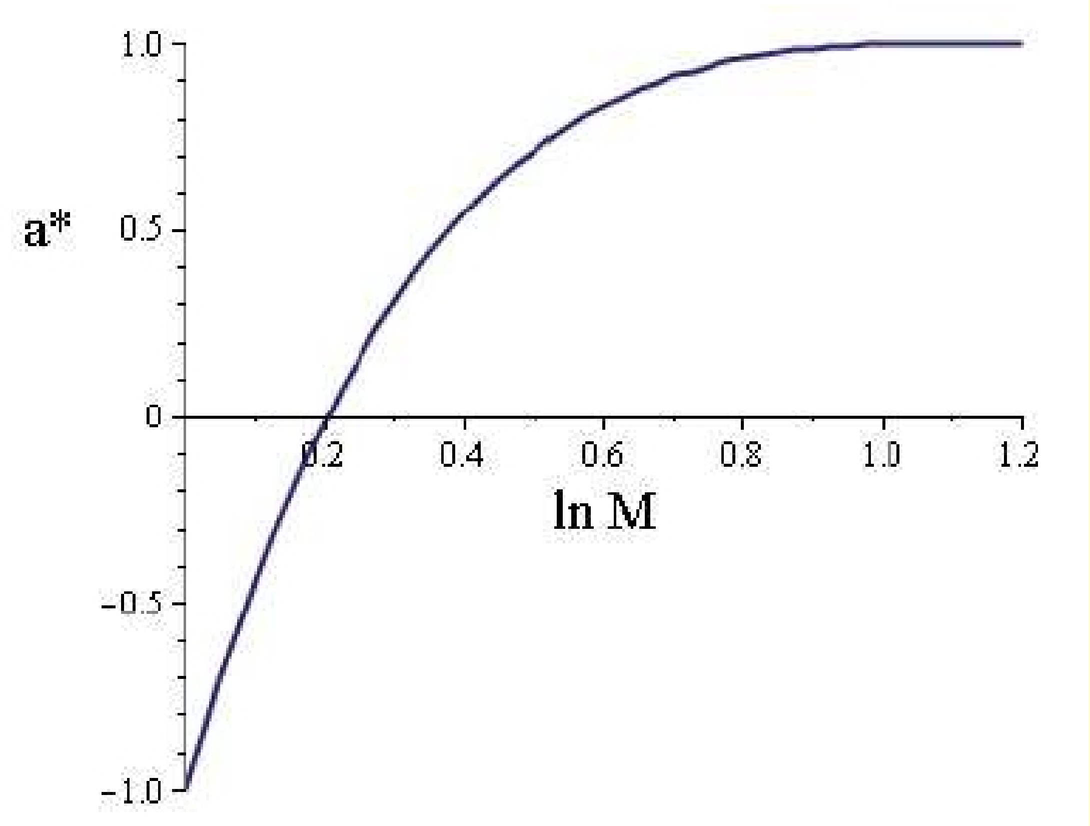
lead to different prediction of the spin distribution

BHs rotate fast due to accretion

Bardeen accretion spins up BHs.

Mass increase by a factor of 3, when changing BHs spin from maximal counter-rotation to maximal rotation.

Efficiency of accreted rest mass conversion into outgoing electromagnetic radiation is 42.3%.



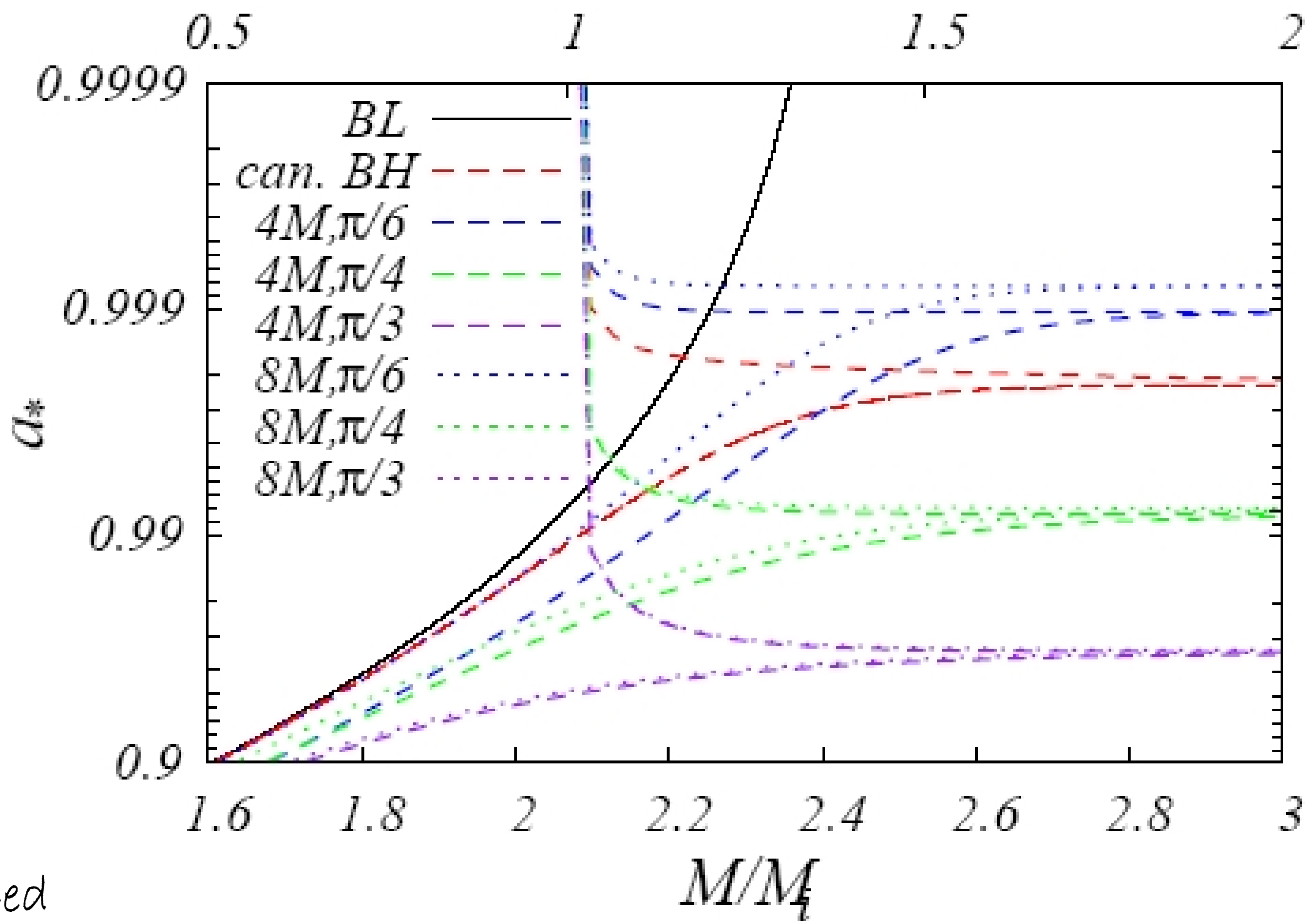
Accretion and efficiency refined

Corrections from:

- photon capture (canonical BH)
- open magnetic fields
- inner truncation of the disk radiation due to a jet

Spin limit

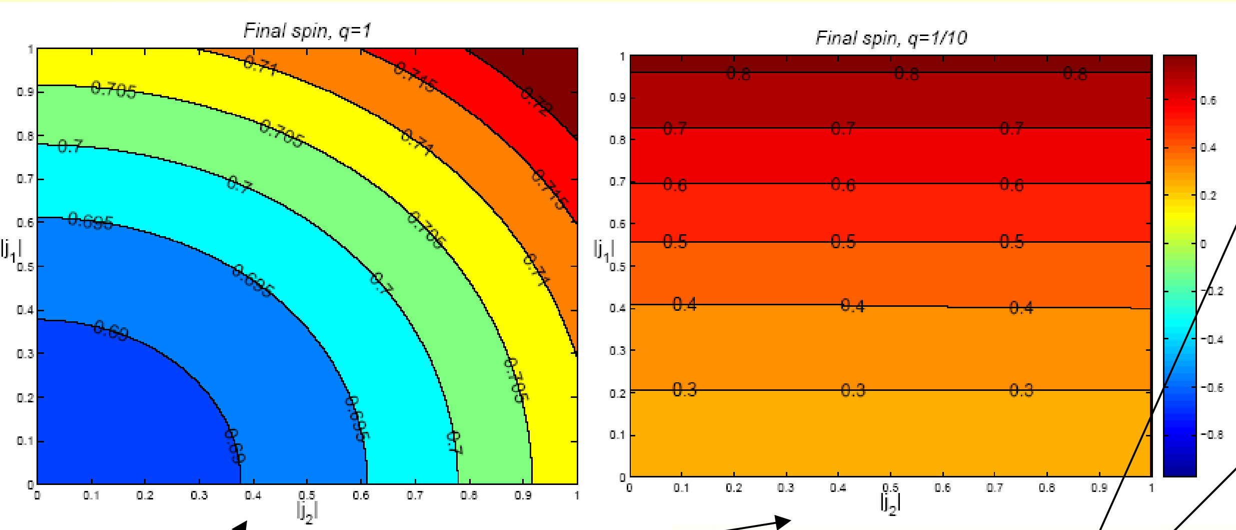
slightly reduced

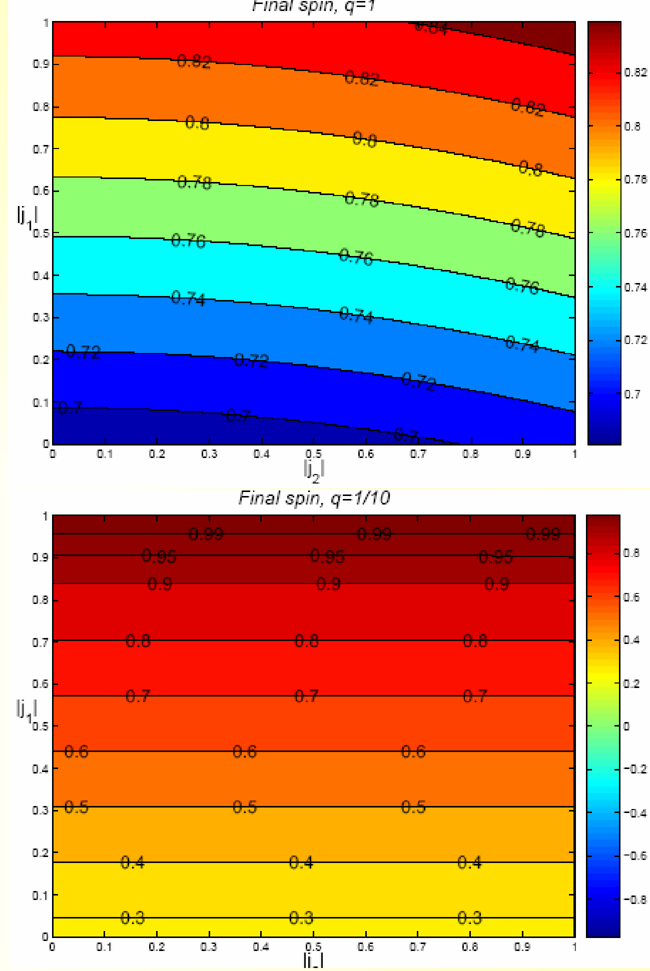


Efficiency reduced to 25% - 35 %

Kovács, LÁG, Biermann: MNRAS (2011), arXiv: 1007.4279 [astro-ph.CO]

Spin evolution in mergers





Dry merger scenario

Wet merger scenario

Berti, Volonteri: Astrophys. J. 684: 822 (2008)

In dry mergers the spin configuration is random → spin reduced

In wet mergers the spins are aligned with the orbital angular momentum (Bardeen-Petterson effect) → no drastic reduction of the spin

A simple model

- Assume dry mergers (random spin orientations)
- Assume a simple final spin magnitude formula
- Fold with the mass ratio probability, derived from the SMBH mass function
- Integrate above mass ratios and spin configurations

→ typical final spin

(function of initial spins only)

Typical mass ratios

- Mass distribution of central galactic BHs (Lauer et al 2006, Wilson & Colbert 1995)
  → broken power law from about $m_a \simeq 3 \times 10^6\ M_\odot$ to about $m_b \simeq 3 \times 10^9\ M_\odot$, with a break near $m_\star \simeq 10^8\ M_\odot$ (power -1 below, -3 above)
- Mass of the central massive BH scales with the (Benson et al. 2007)
  - mass of the spheroidal component,
  → merger rate of galaxies ≈ merger rate of the central BHs.
- The probability for a specific mass ratio is an integral over the BH mass distribution, folded with the rate to merge (depending on cross section and relative velocity of the two galaxies, the latter negligible, as the universe is not old enough for mass segregation)
- Factor of 10 in radius (10^2 in cross-section) for a factor of about 10^4 in mass
  → Cross-section $F \sim \eta^\xi$ with $\xi = 1/2$ as first approximation

Mass ratio dependent merger probabilities

$N_{1 \div 3} = 21\%$

$N_{3 \div 30} = 66\%$

$N_{30 \div 1000} = 13\%$

A simple final spin formula

From simple arguments (angular momentum conservation; cosmic censorship observed; zero efficiency of mass conversion into gravitational radiation) we (under)estimate as:

$$\chi_f = \frac{\nu}{(1+\nu)^2}\left[4 + 4\sum_{i=1,2}\nu^{2i-3}\chi_i\cos\kappa_i + \sum_{i=1,2}\left(\nu^{2i-3}\chi_i\right)^2 + 2\chi_1\chi_2\cos\gamma\right]^{1/2}$$

(green surfaces) and compare with the much cumbersome formula (magenta), derived from fitting with elaborate numerical runs (Barrausse, Rezzolla APJL 2009)

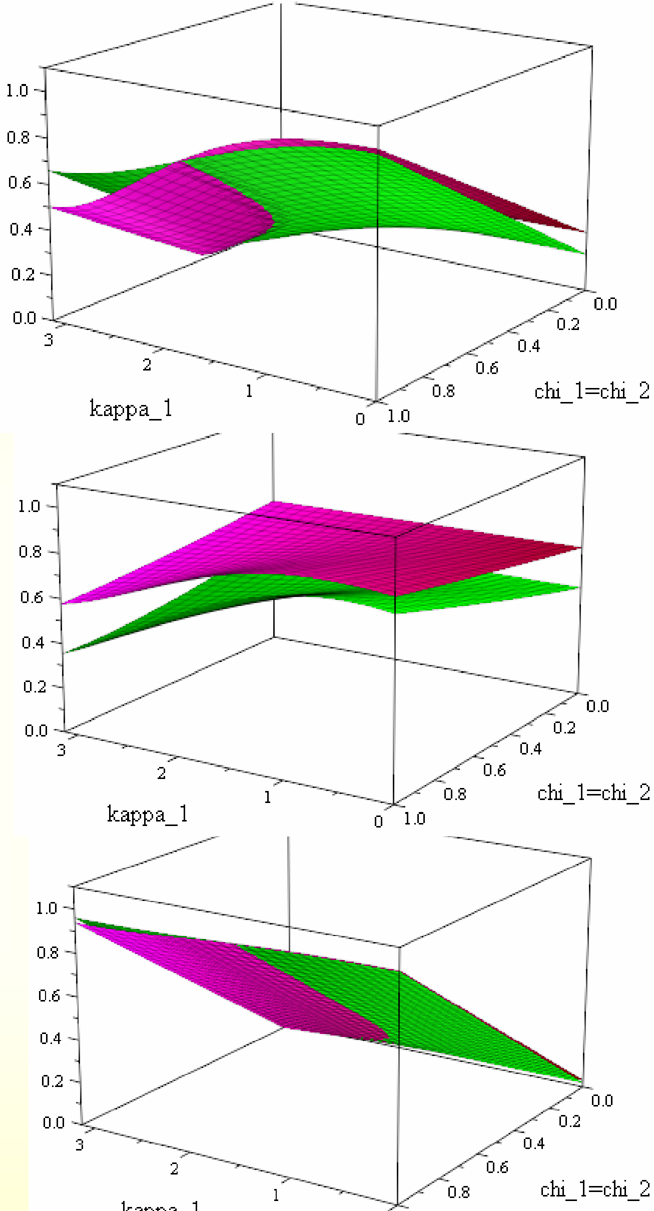
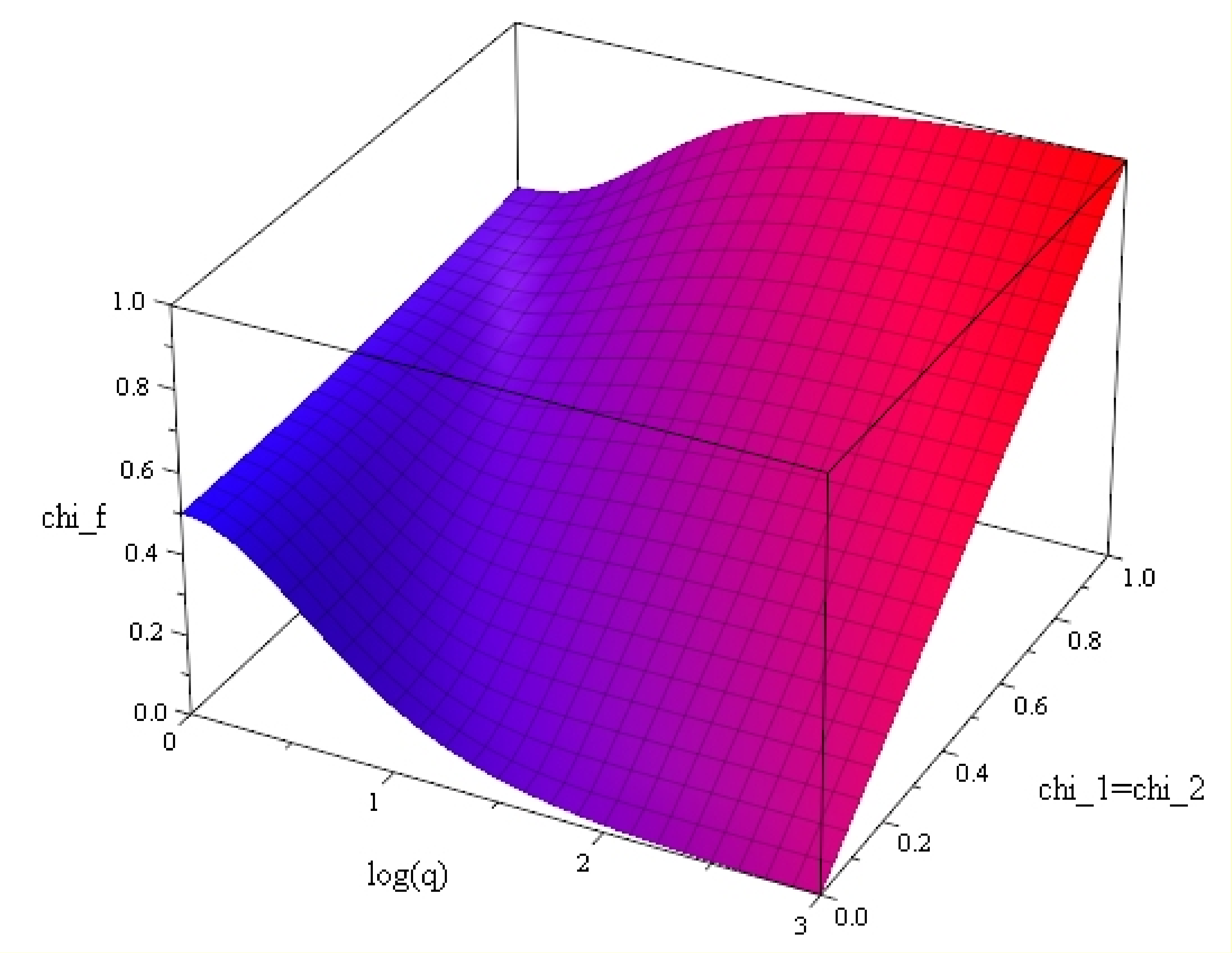
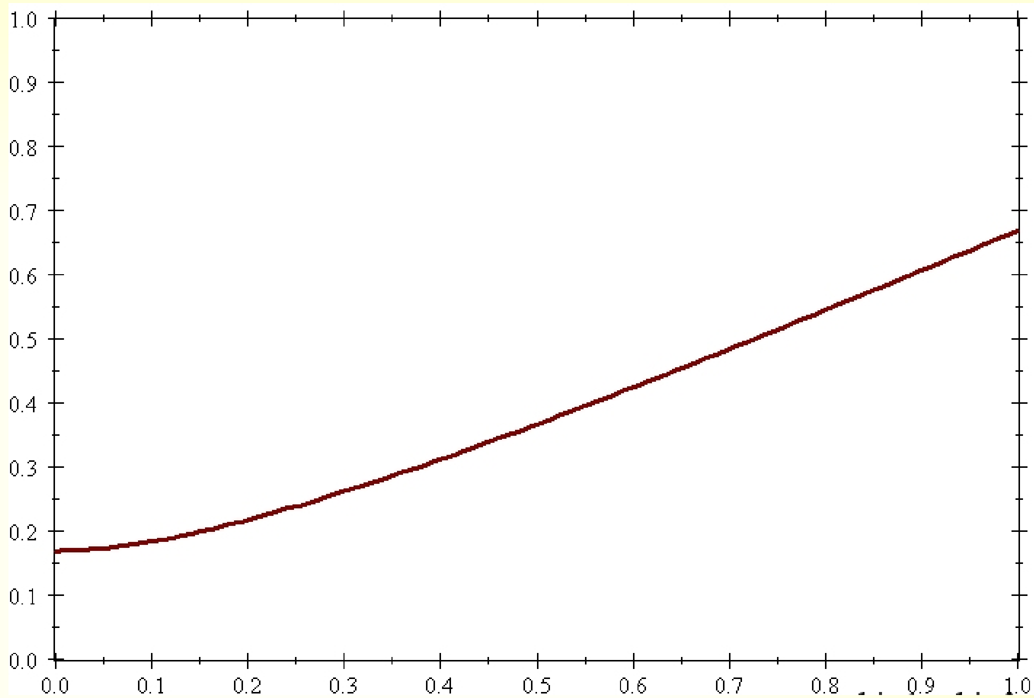


FIG. 2: The final spin estimates χ_f (green surfaces) and χ_f^{BR} (magenta) as function of $\chi_1 = \chi_2$ and κ_1 for mass ratios $\nu = 1$ (upper row), $\nu = 0.1$ (middle row) and $\nu = 0.01$ (lower row). The represented configuration has the (smaller) spin confined to the plane of motion and the (larger) spin lying in the plane span by the smaller spin and orbital angular momentum. The agreement increases with decreasing ν (with $\chi < \chi^{BR}$ at large ν); is better in the high spin regime (visible on the right panel), then for low spin (left); is also better for configurations with $\kappa_1 \in [0, \pi/2]$ than for the severely misaligned configurations.

Typical final spin for mass ratio q=ν^{-1}



Typical spin evolution by mergers



For $\chi_1=\chi_2=0.998$ (canonical spin = spin limit by accretion + e.m. radiating disk) the final spin is:

Then the mass to be accreted in order to increase this spin to the canonical limit is:

$\chi_{final}=0.666$

70% of the BH mass

What do we plan next ?

(collaboration with L Caramete, PL Biermann)

- Allow for partially wet mergers
- Employ more accurate mass function
- Employ the (more complicated) final spin formula (Barrausse, Rezzolla APJL 2009) determined from the fit with a number of numerical simulations of BH mergers

Task: Correlate the typical degree of wetness with

- Observations of the SMBH spin magnitudes
- Amount of electromagnetic radiation available in the Universe