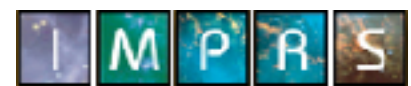


Black hole spin evolution in cosmological simulations with OpenGadget3



Luca Sala

Universitäts-Sternwarte München - LMU

Klaus Dolag

Milena Valentini

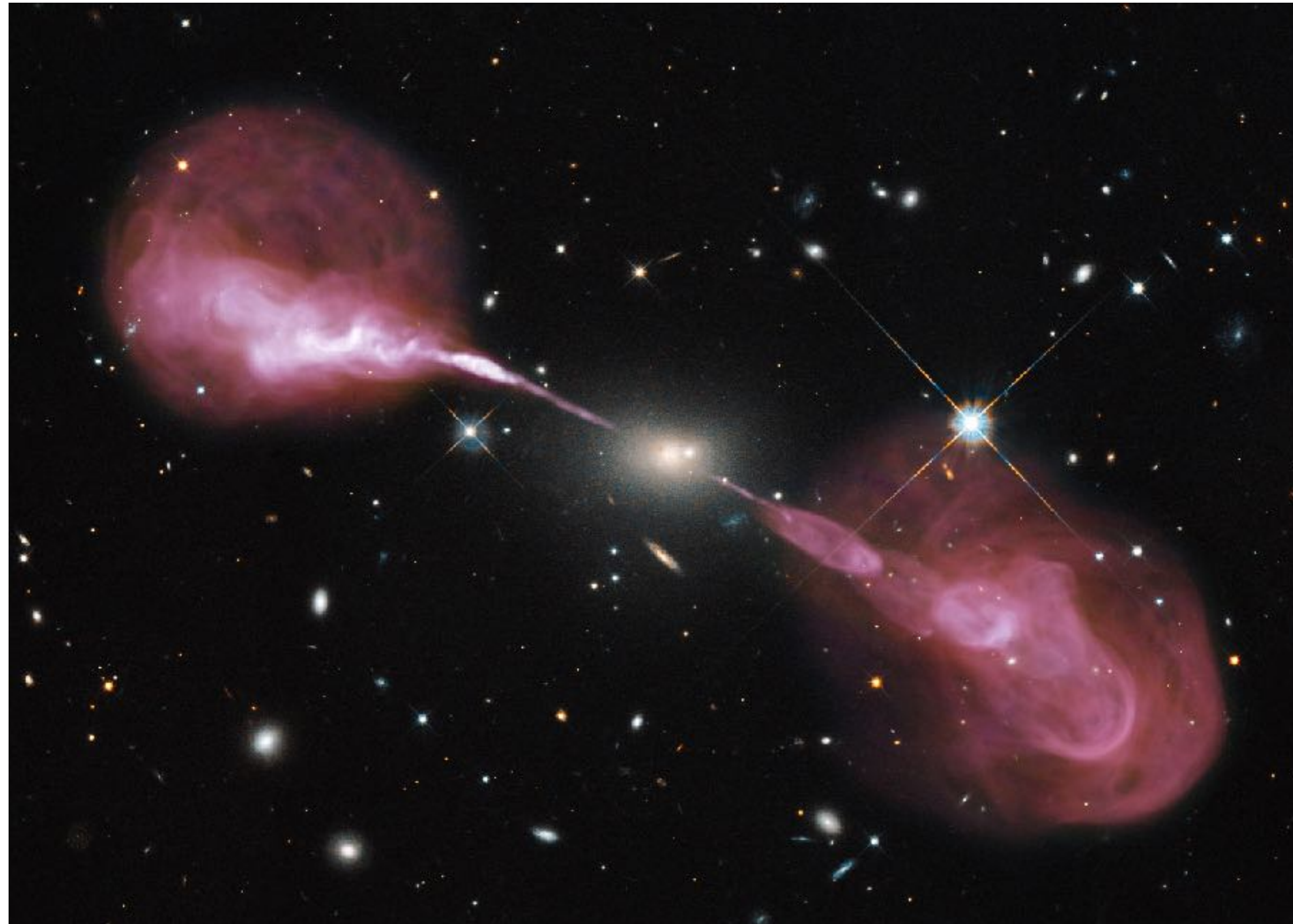
Veronica Biffi



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 860744.



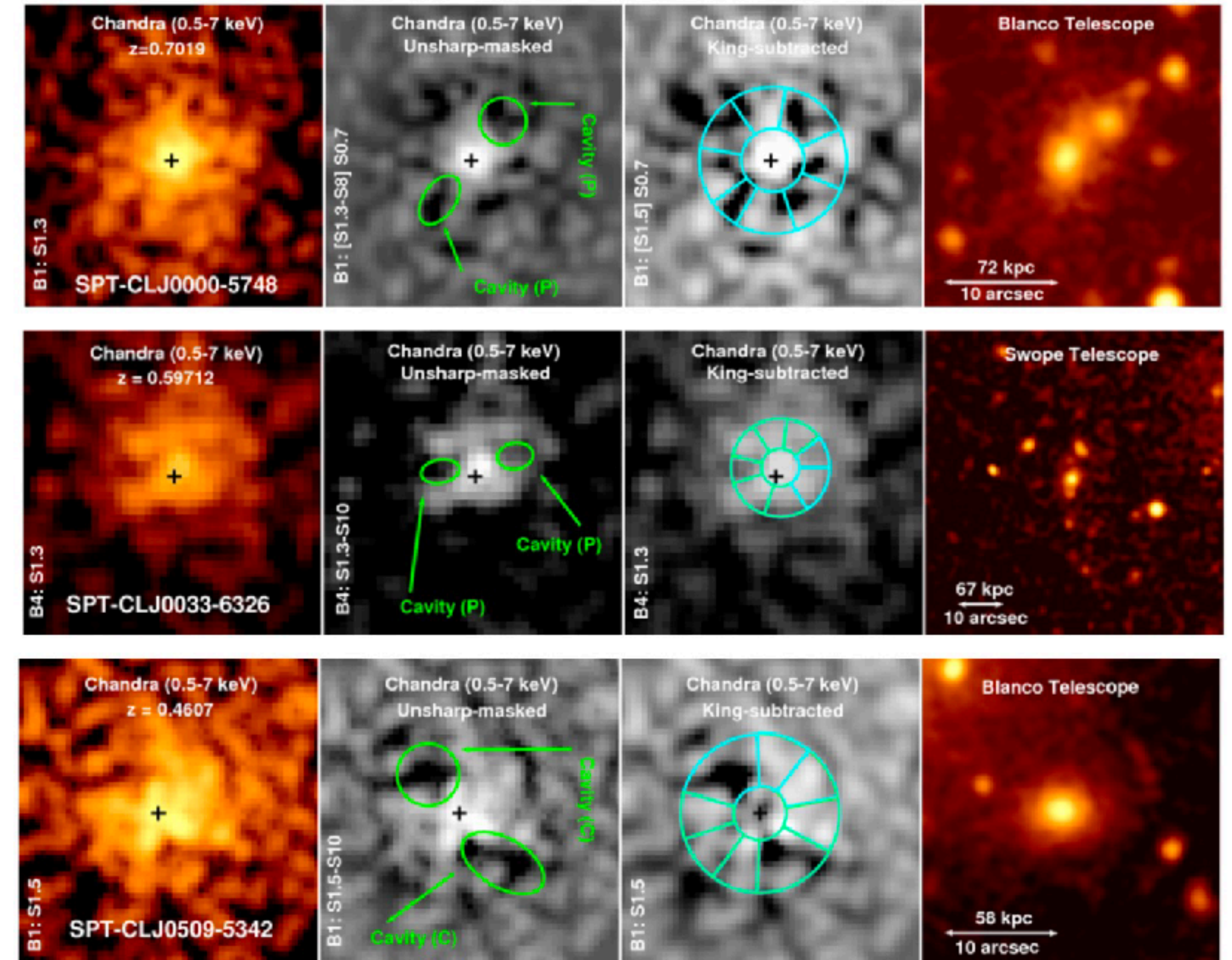
Radio lobes



Composite visible and radio image of Hercules A. The radio emission, in red, traces the jet.

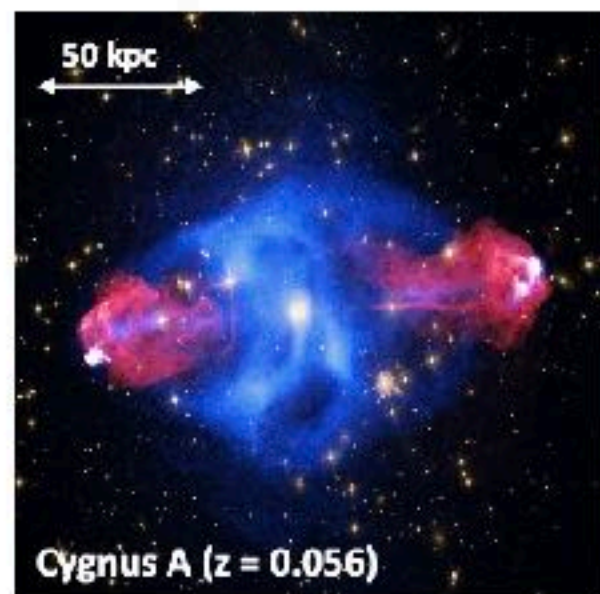
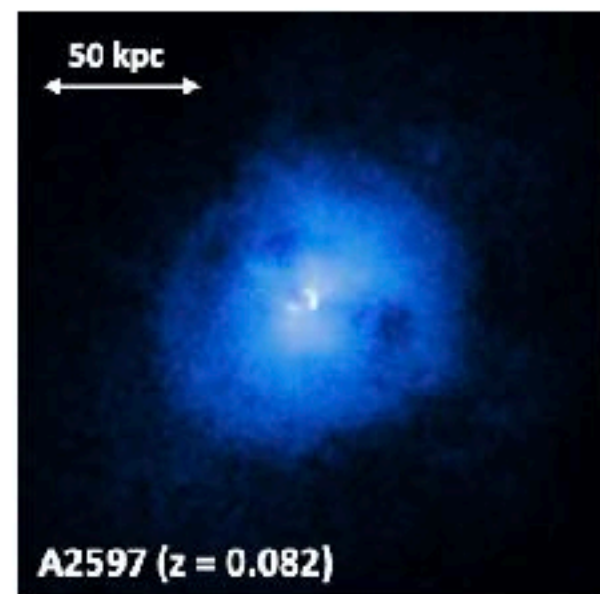
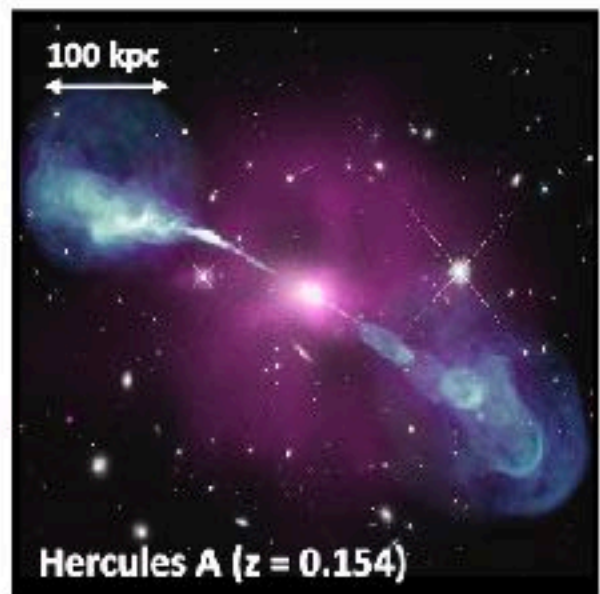
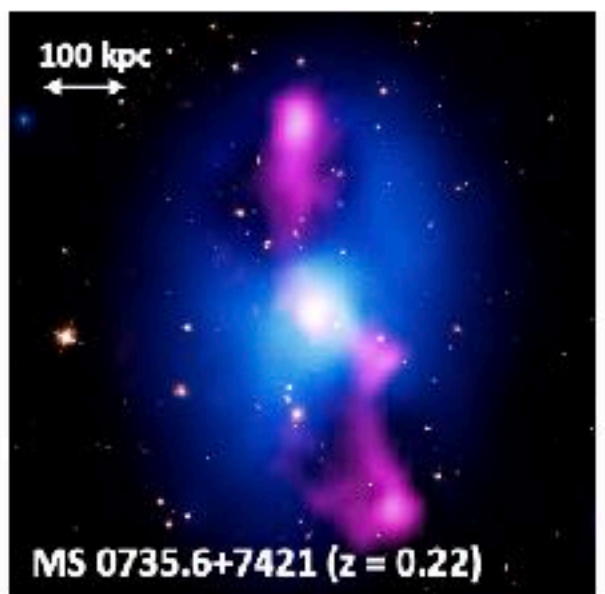
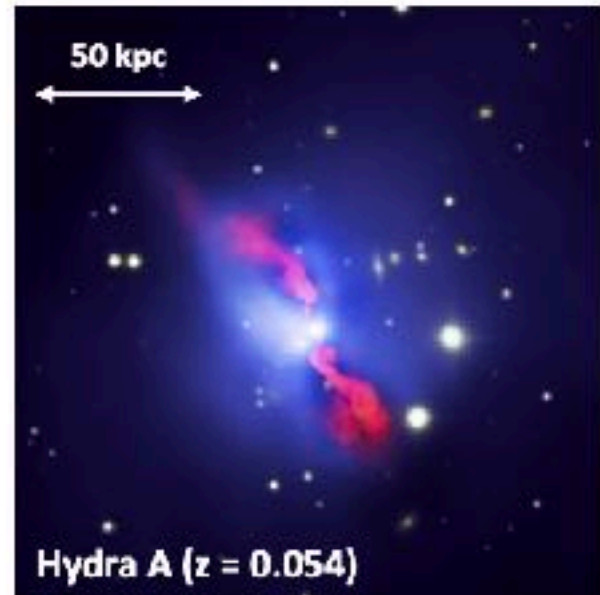
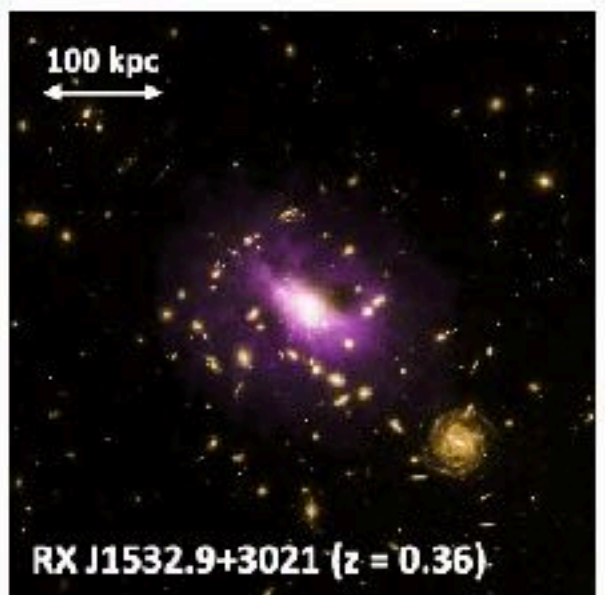
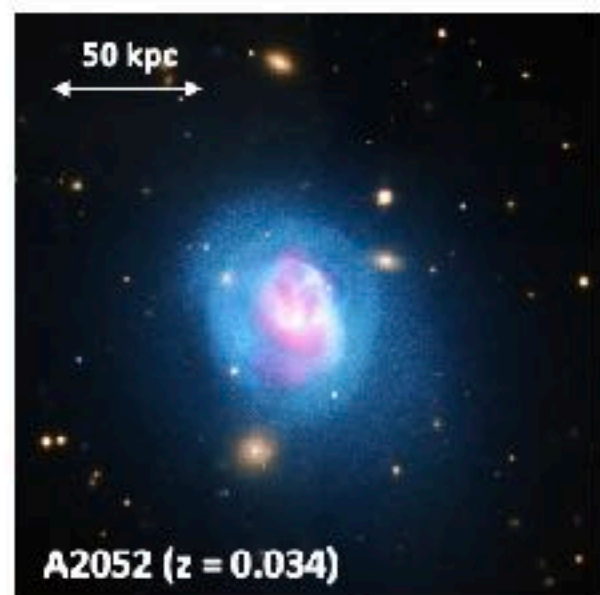
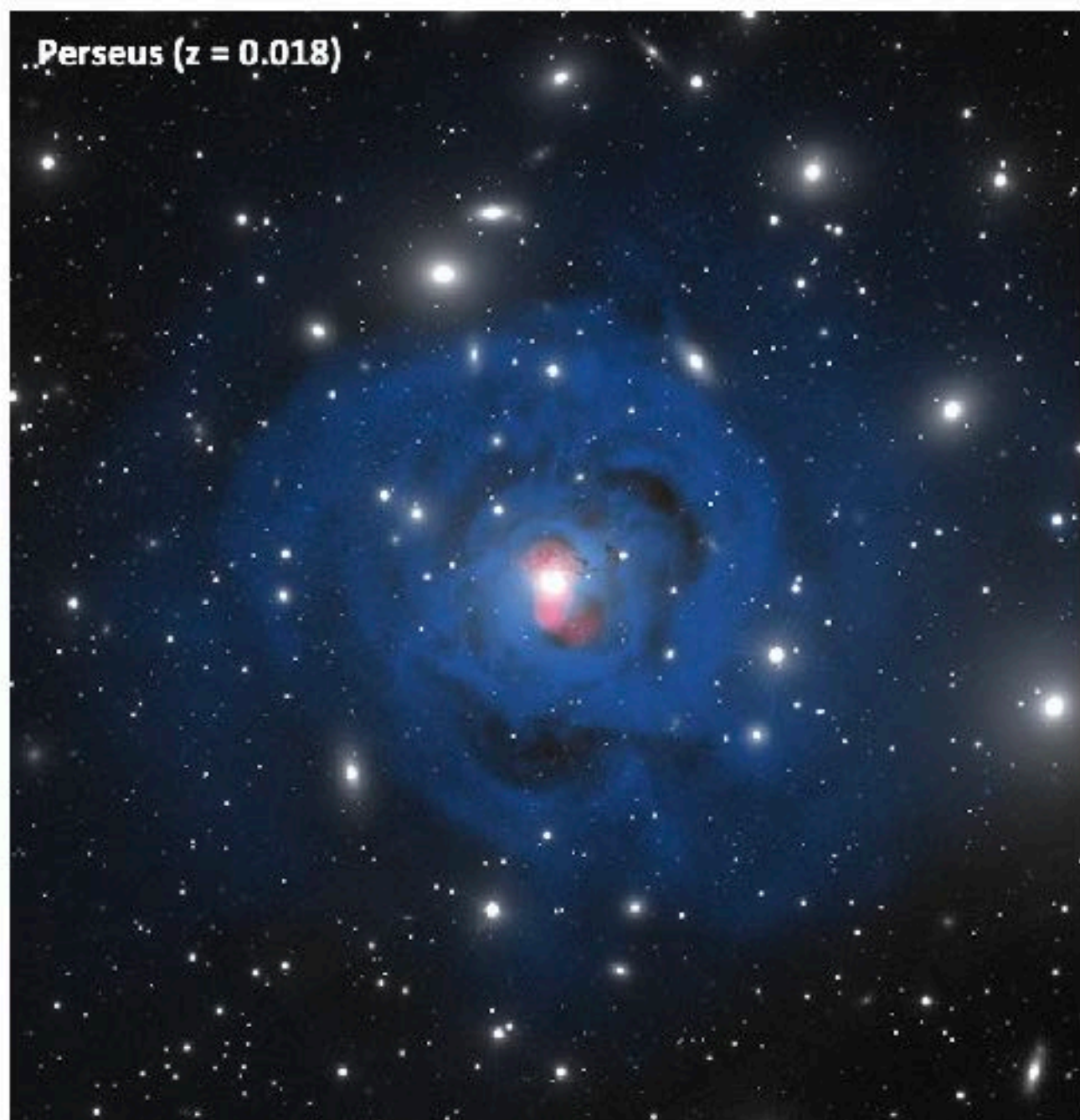
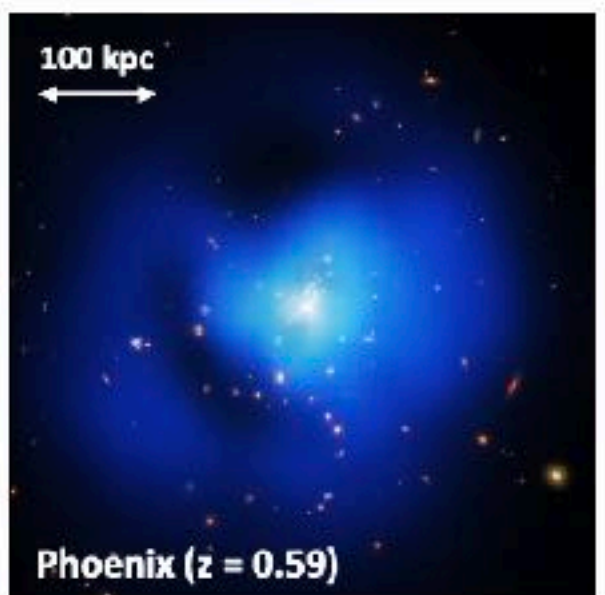
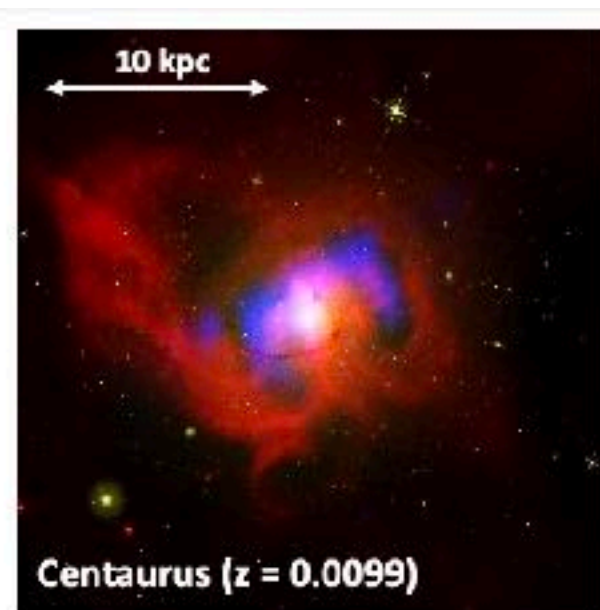
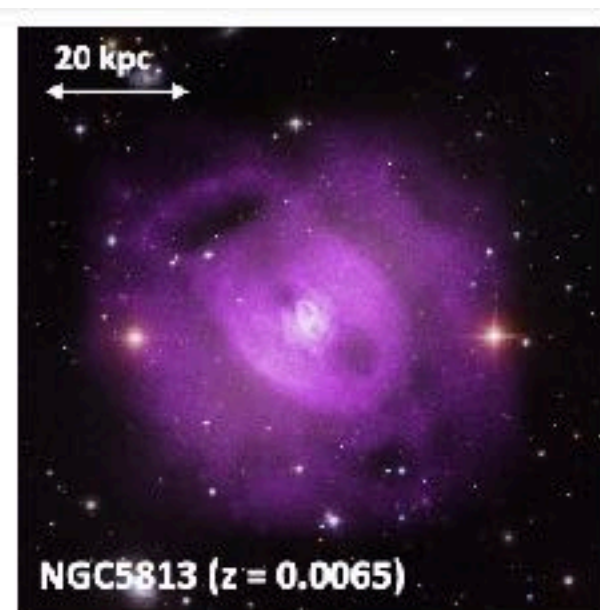
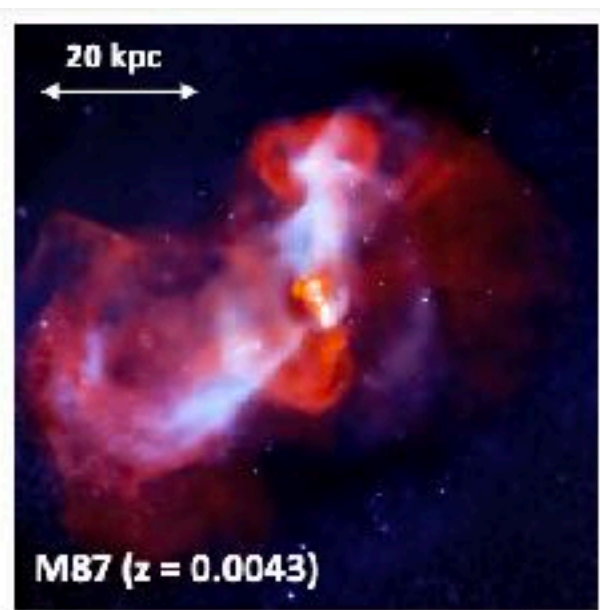
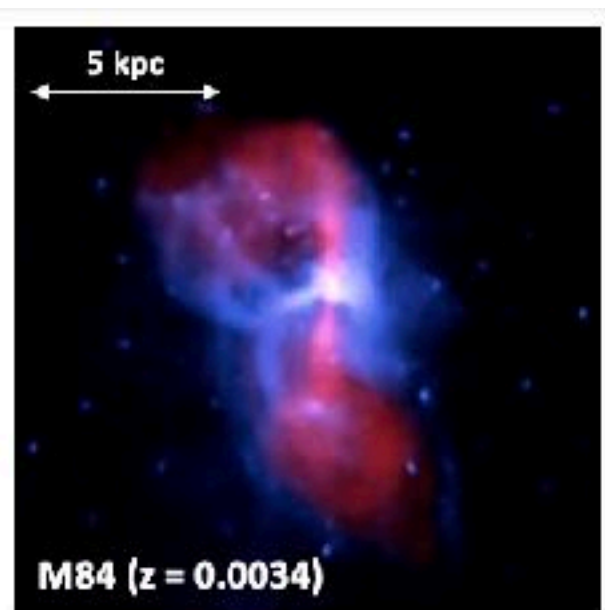
Credits: NASA, ESA, S. Baum and C. O'Dea (RIT), R. Perley and W. Cotton (NRAO/AUI/NSF), and the Hubble Heritage Team (STScI/AURA)

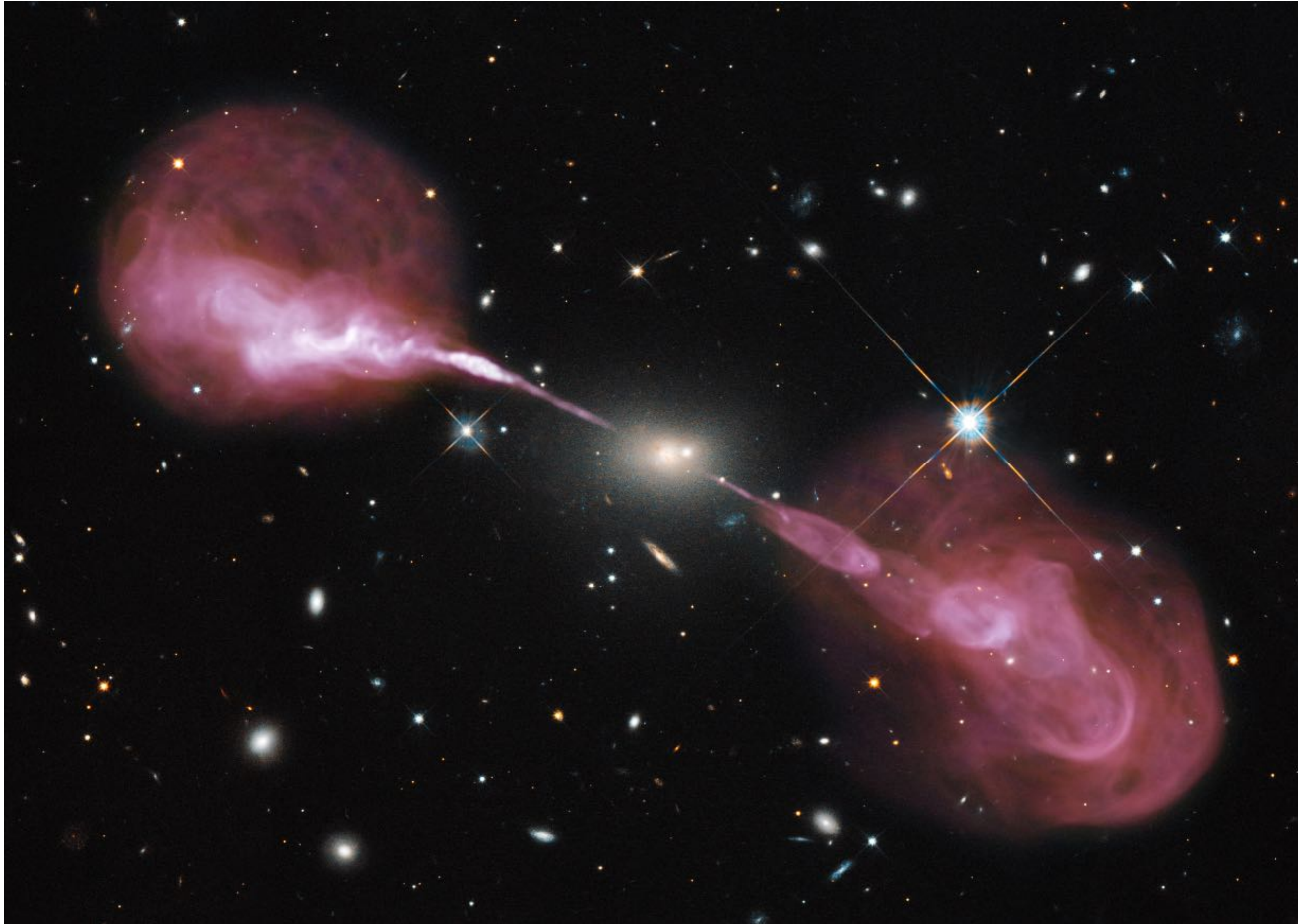
X-ray cavities



Images of a sample of clusters observed with the South Pole Telescope with candidate X-ray cavities

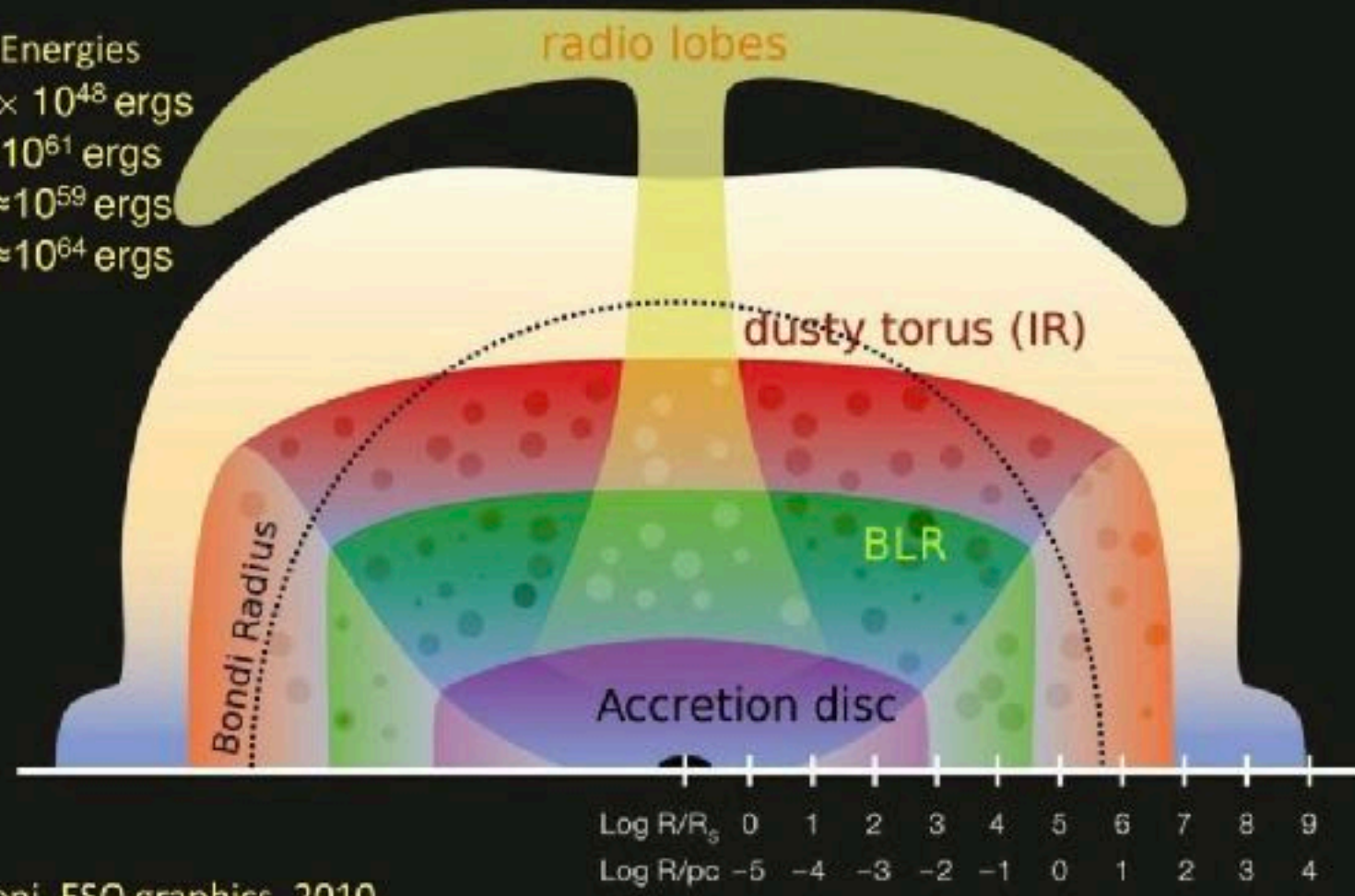
Credits: Hlavacek-Larrondo+2014



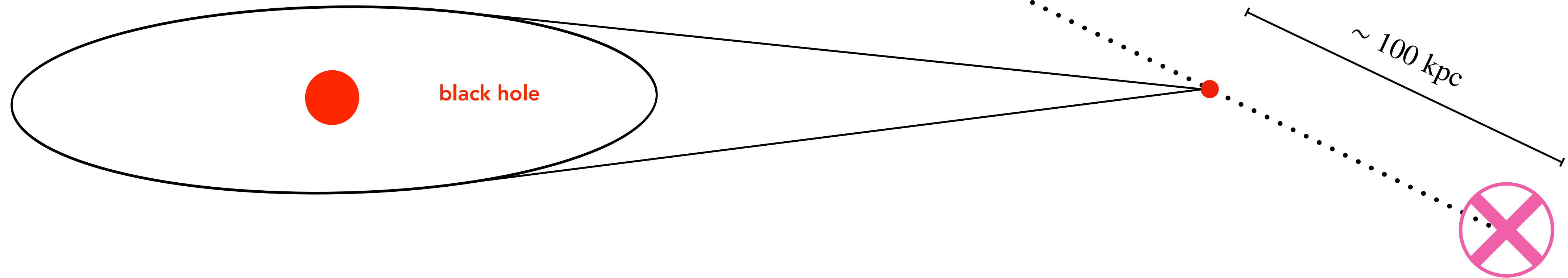


A logarithmic view of the AGN-galaxy connection

Binding Energies
 $E_{b,\odot} \approx 4 \times 10^{48}$ ergs
 $E_{b,BH,B} \approx 10^{61}$ ergs
 $E_{b,gal,11} \approx 10^{59}$ ergs
 $E_{b,Coma} \approx 10^{64}$ ergs



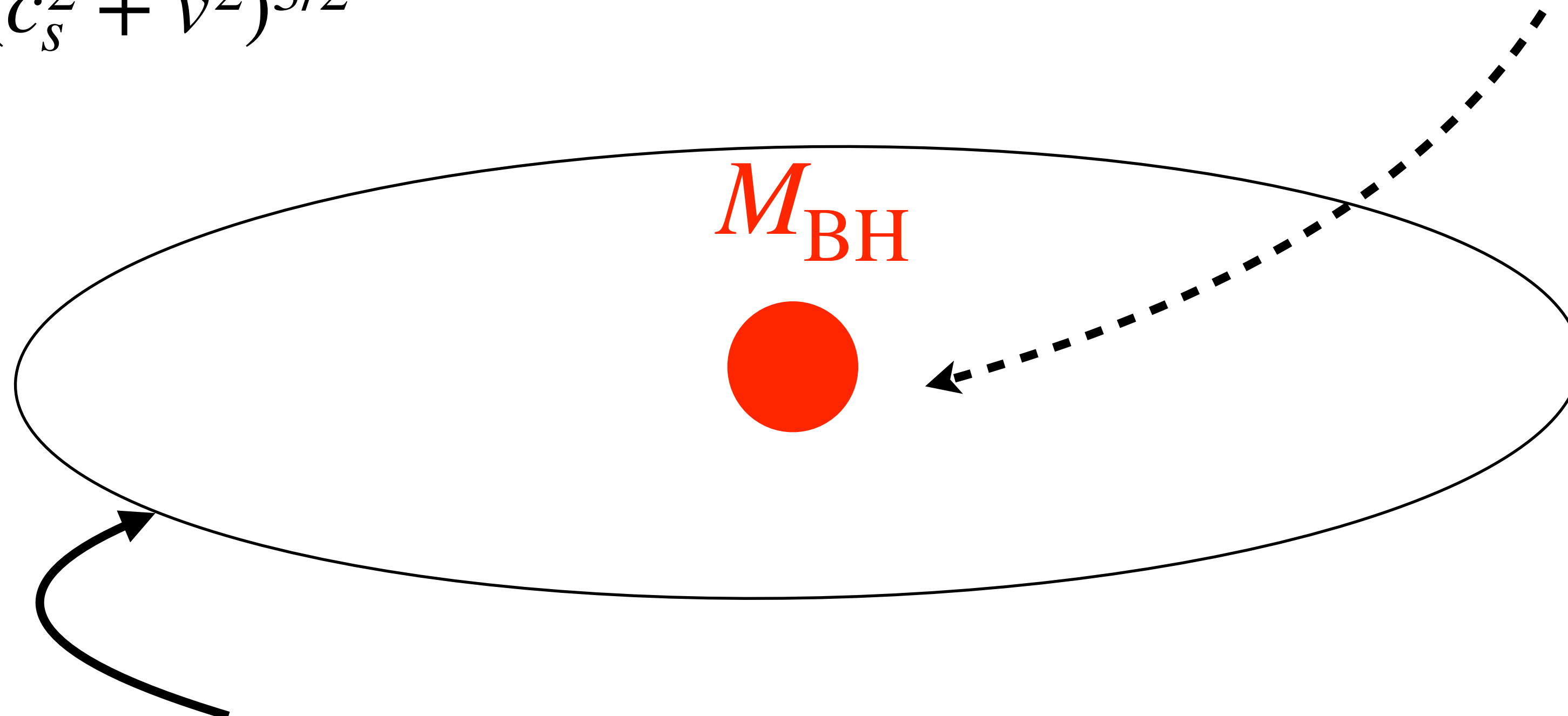
A. Merloni, ESO graphics, 2010



$$r_g = \frac{2GM_{BH}}{c^2} = 10^{-5} \left(\frac{M_{BH}}{10^8 M_{\odot}} \right) \text{ pc}$$

$$\dot{M}_{\text{in}} = \frac{4\pi\alpha G^2 M_{\text{BH}}^2 \rho}{(c_s^2 + v^2)^{3/2}}$$

Accretion rate \dot{M}_{BH}
Bondi-Hoyle-Lyttleton parametrisation



ρ c_s v_{rel}

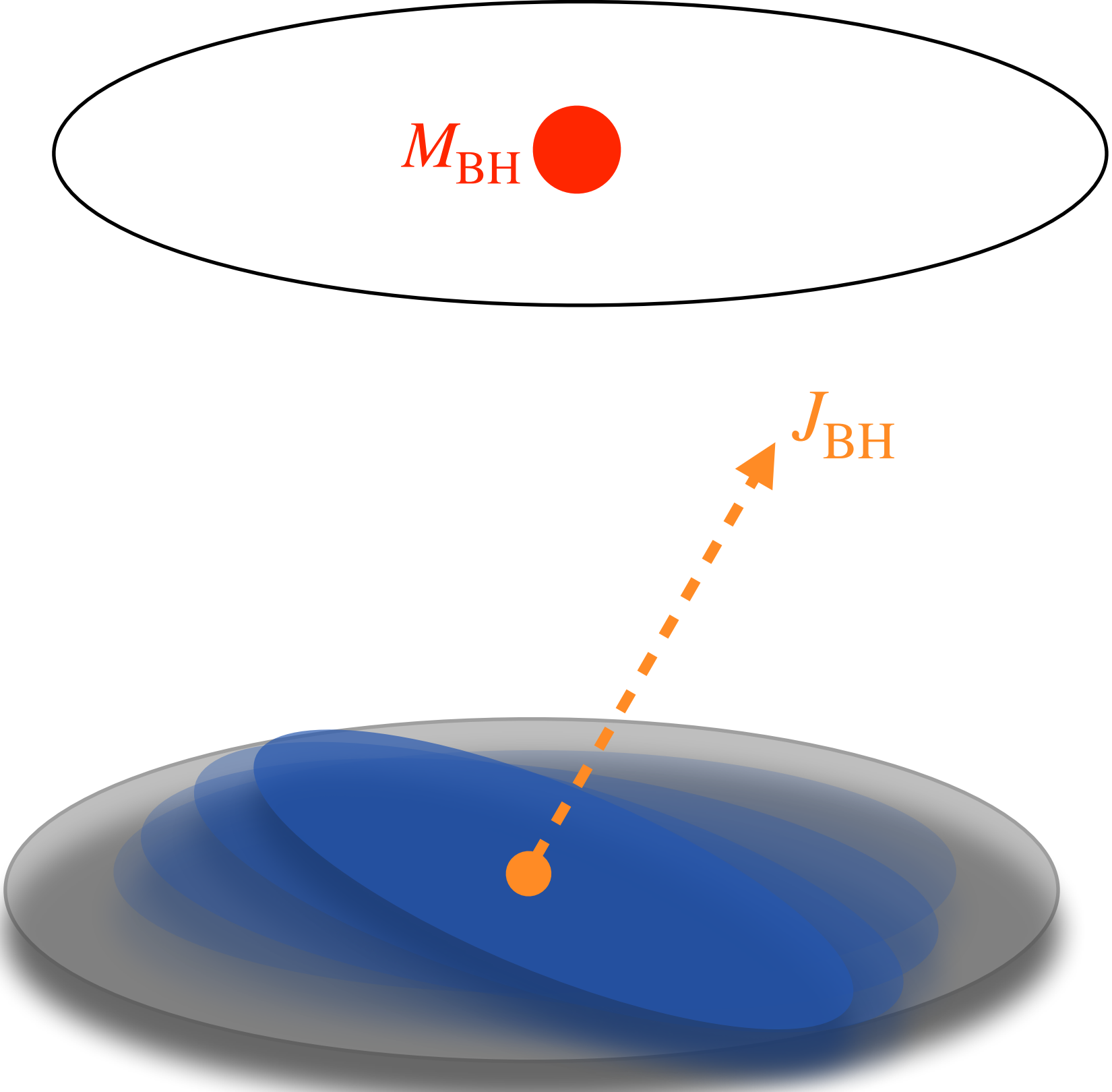
α

Hot

Cold

BH particle accretion length
("resolved scale")

Sub-grid accretion disk

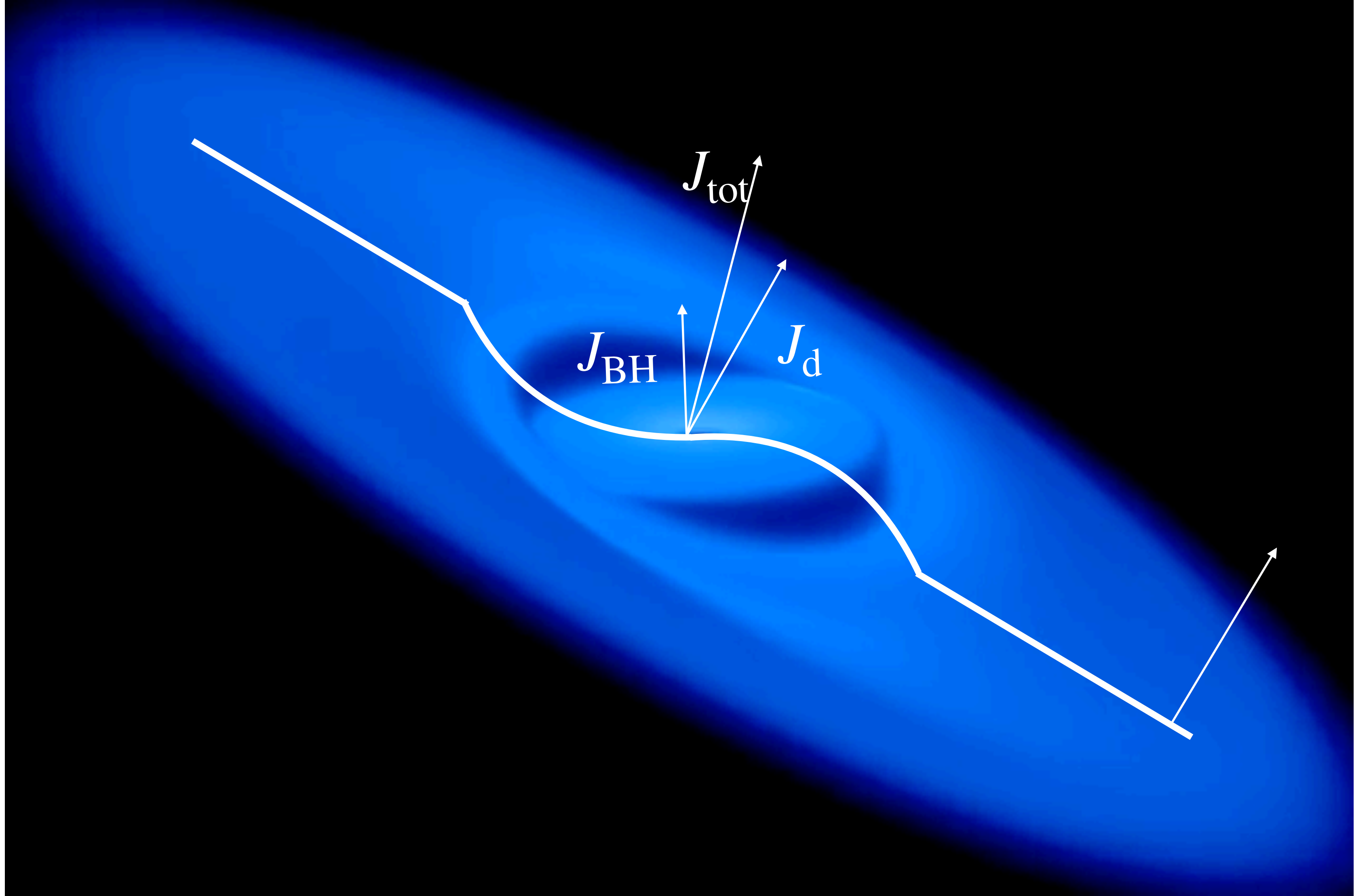


Intermediate step in mass transfer



BH spin evolution

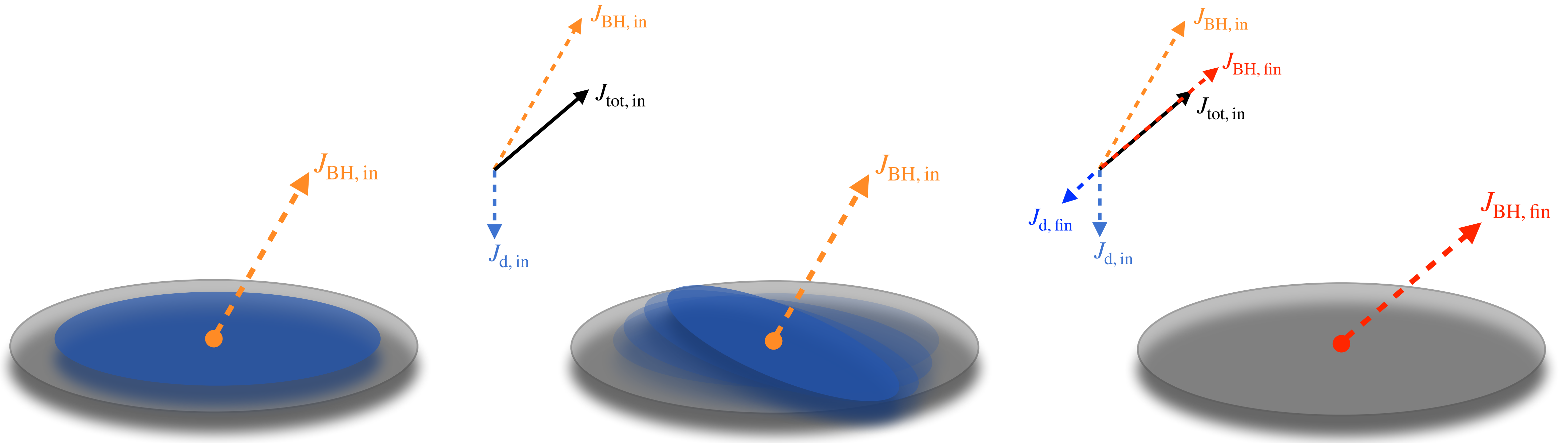




Spin evolution gas accretion

Dubois+14,20

Bustamante & Springel 19



- Thin disk structure
- Viscosity (ν_1, ν_2)
 \implies Timescales and disk properties (size, mass etc.)

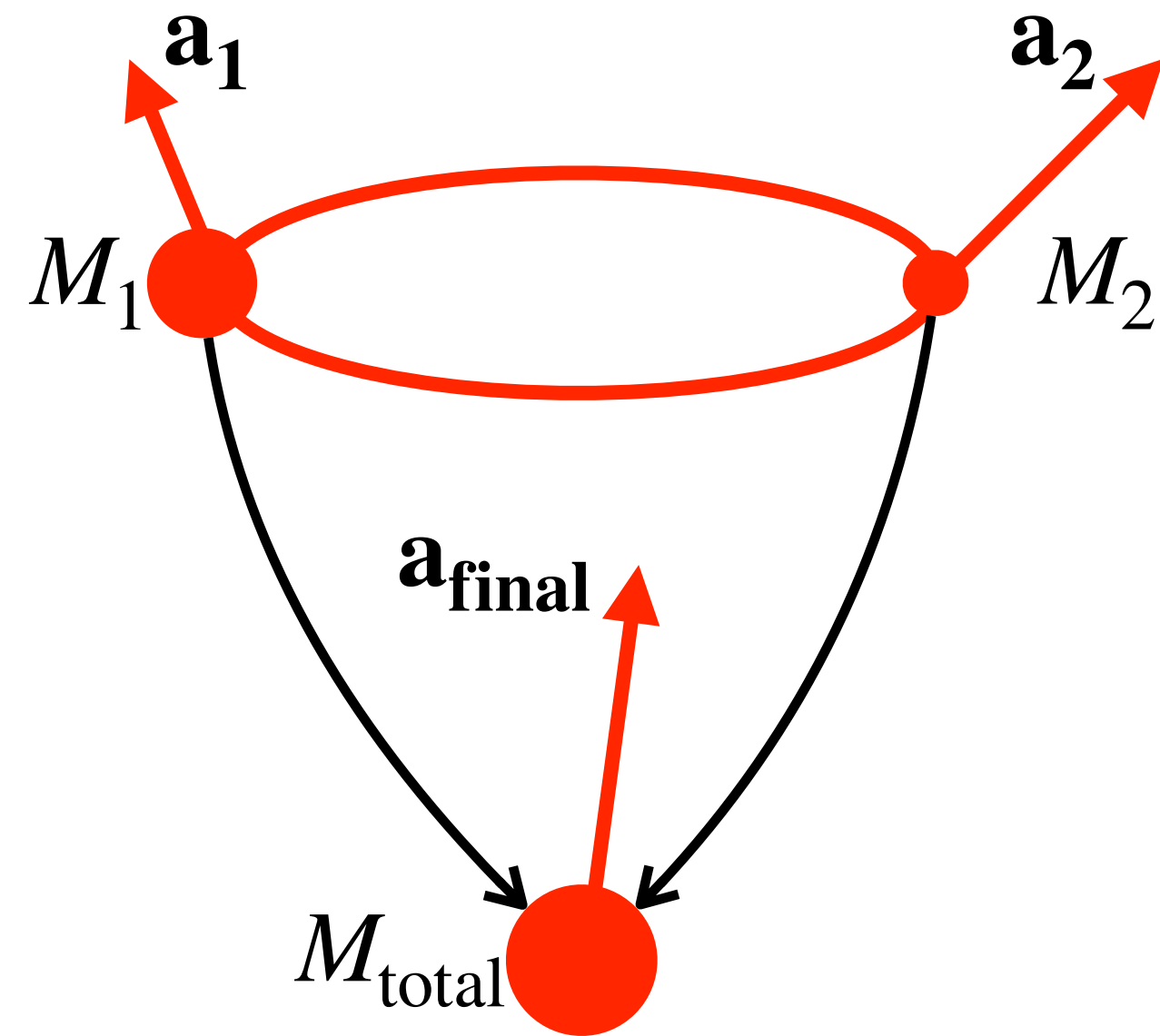
- Bardeen-Petterson (1975) effect
- disc innermost region rotates in the BH equatorial plane
- torque on BH due to warped distribution

- Inner region co-/counter-align (King+2005)
- BH spin magnitude a increase/decrease
- BH final direction along J_{tot}

Spin evolution gas accretion

- **BH growth** - disk mass M_d
- N accretion episodes in dt — mass rate is \dot{M}_{BH}
- **BH spin magnitude** — ISCO angular momentum
- **BH direction** — total angular momentum (conserved)

Spin evolution BH mergers

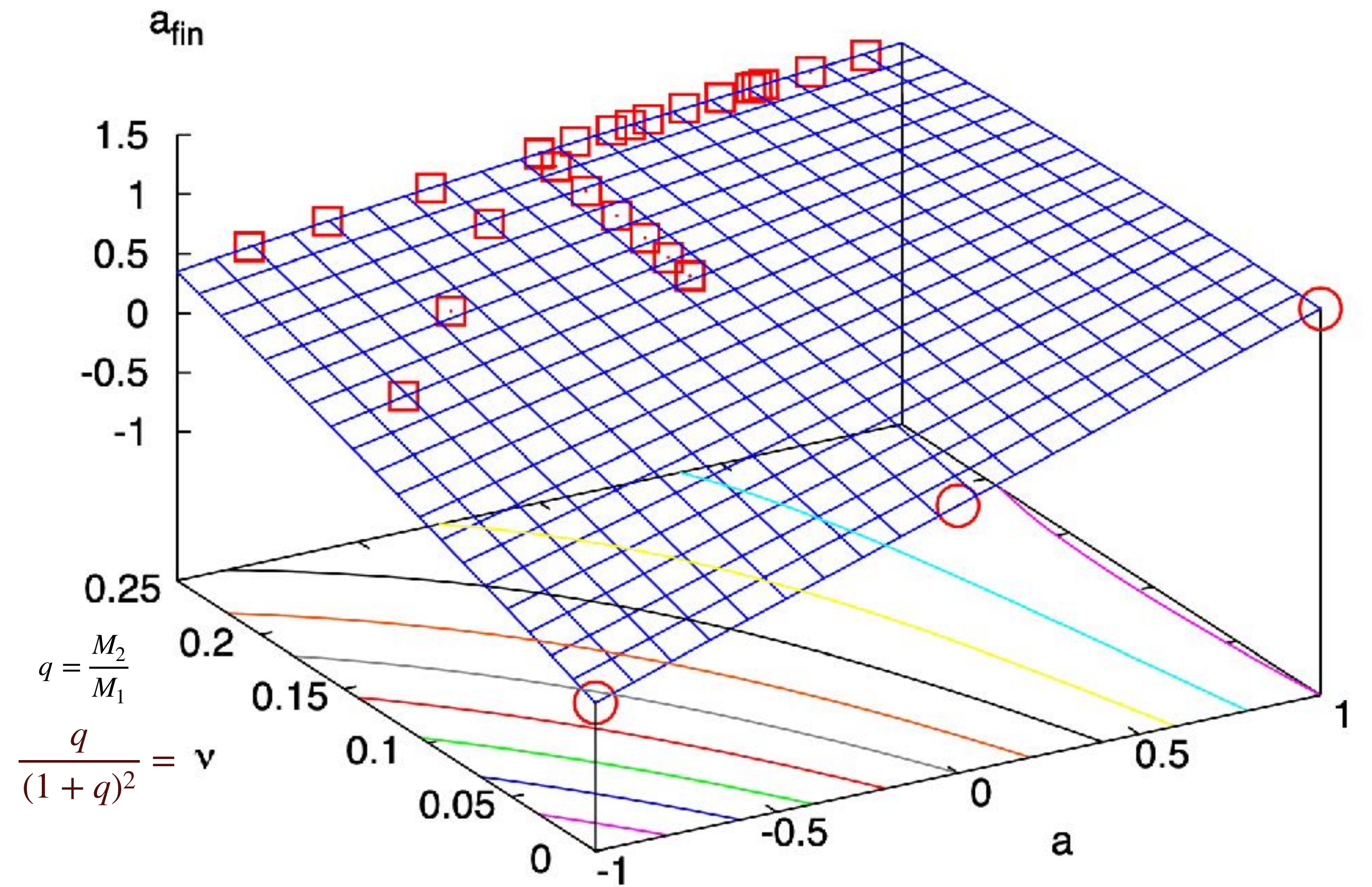


Rezzolla+08

Full numerical GR simulations

Take into account GW emission

⇒ Final spin



Feedback coupling

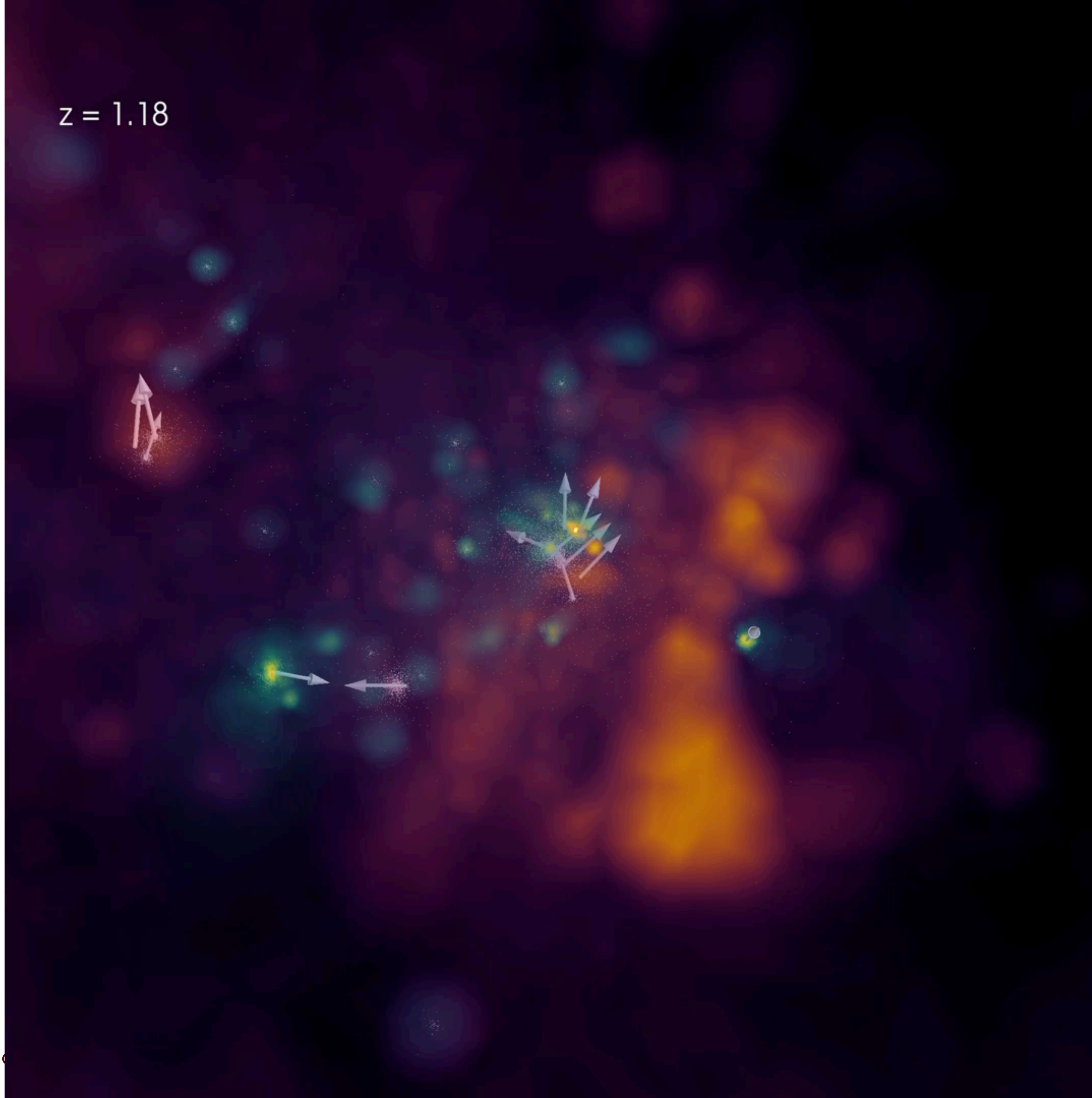
Energy injected thermally and isotropically in the BH kernel:

$$\dot{E} = \epsilon_r \epsilon_f \dot{M} c^2$$

- **Spin evolution model - ϵ_r depends on a**

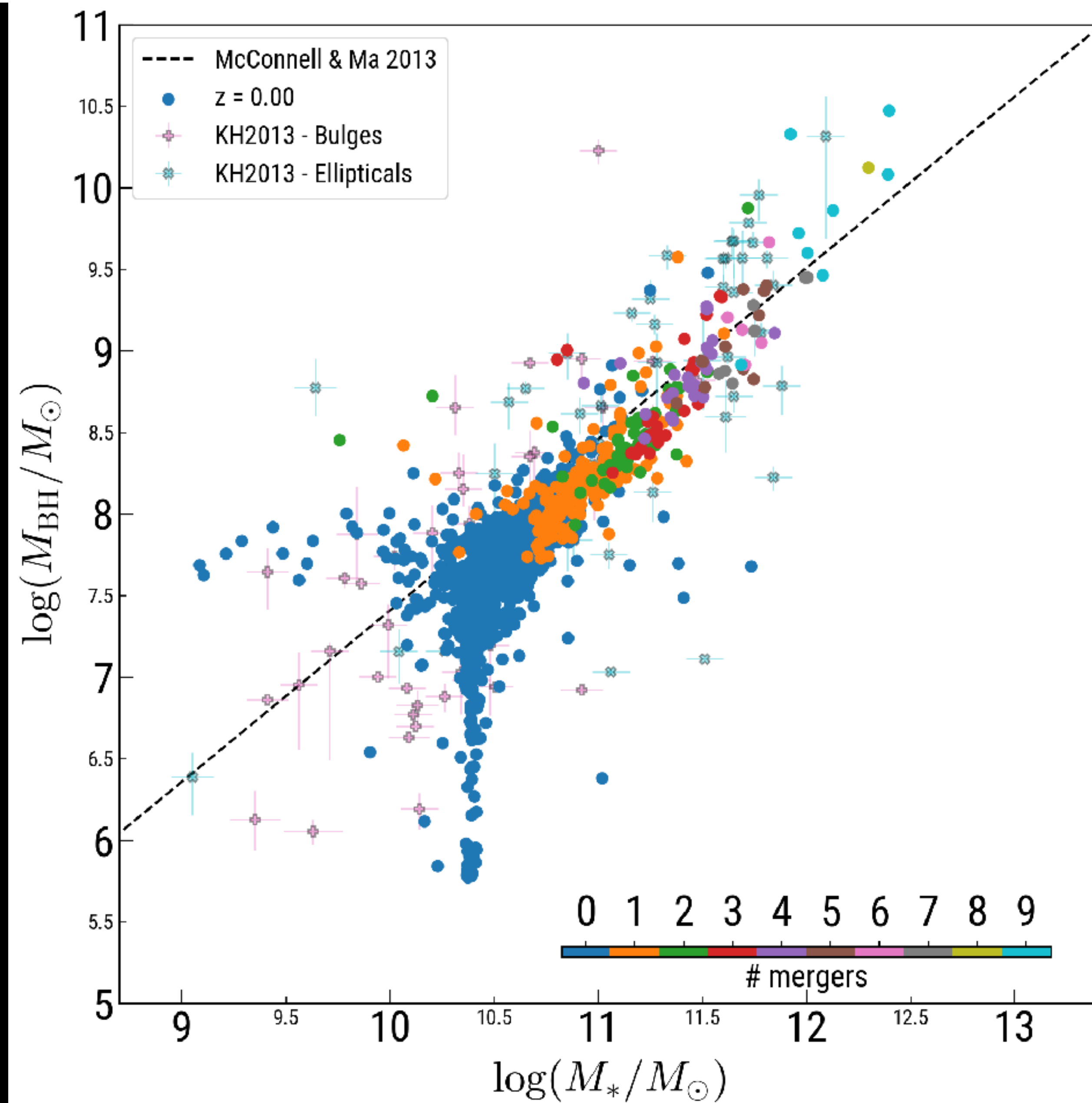
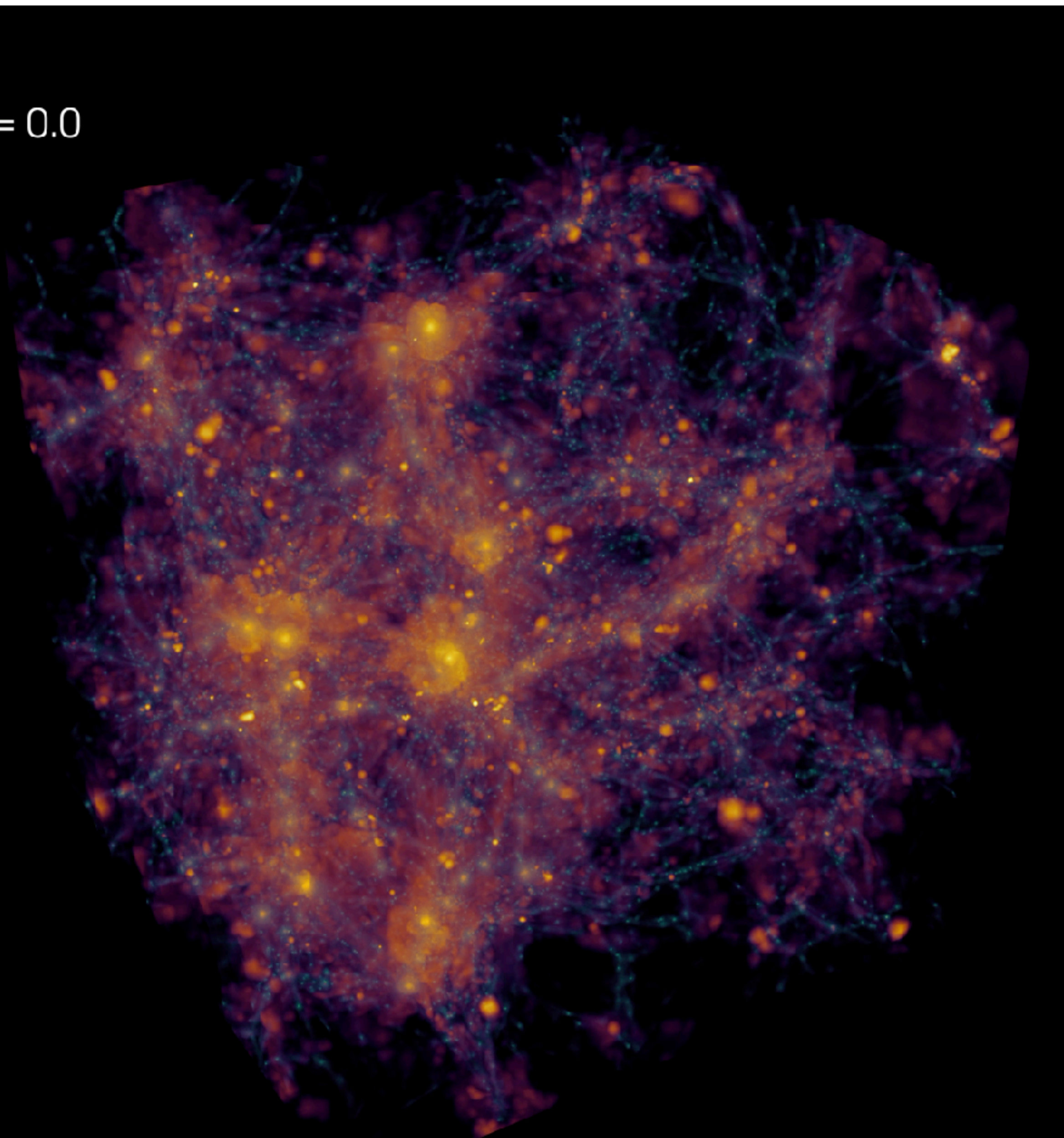
$$M_{200} \sim 10^{13} M_{\odot}$$

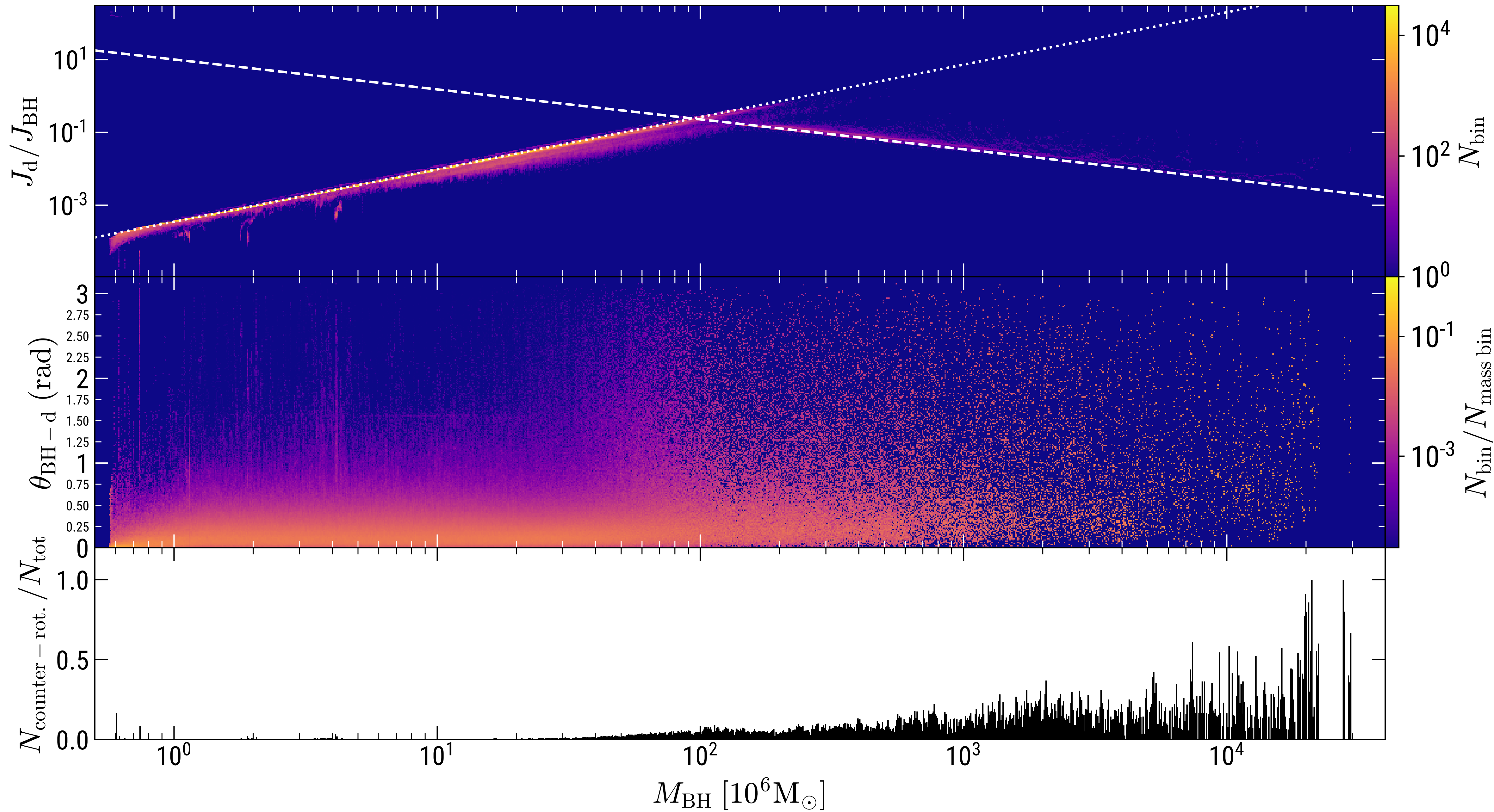
$z = 1.18$

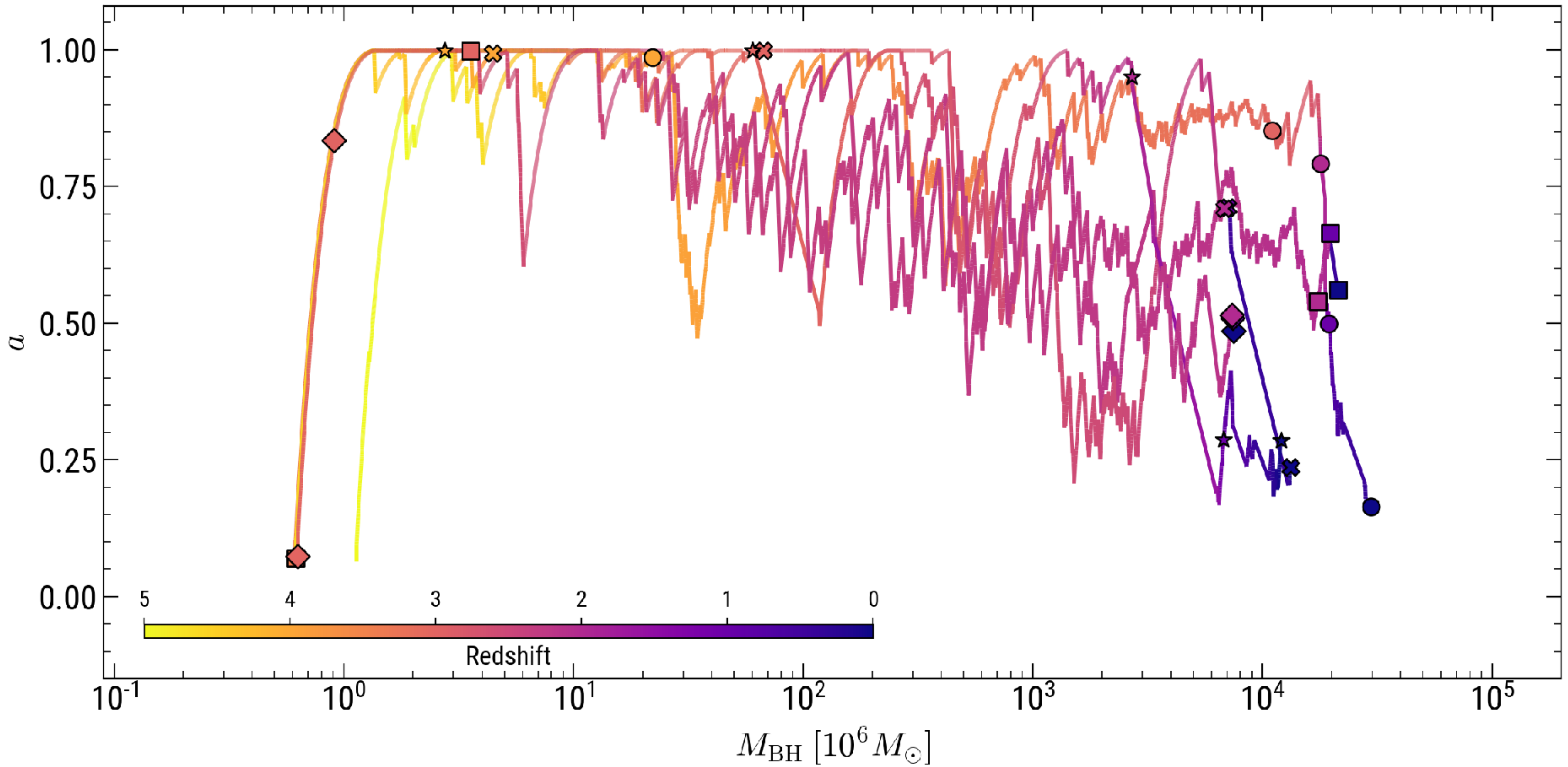


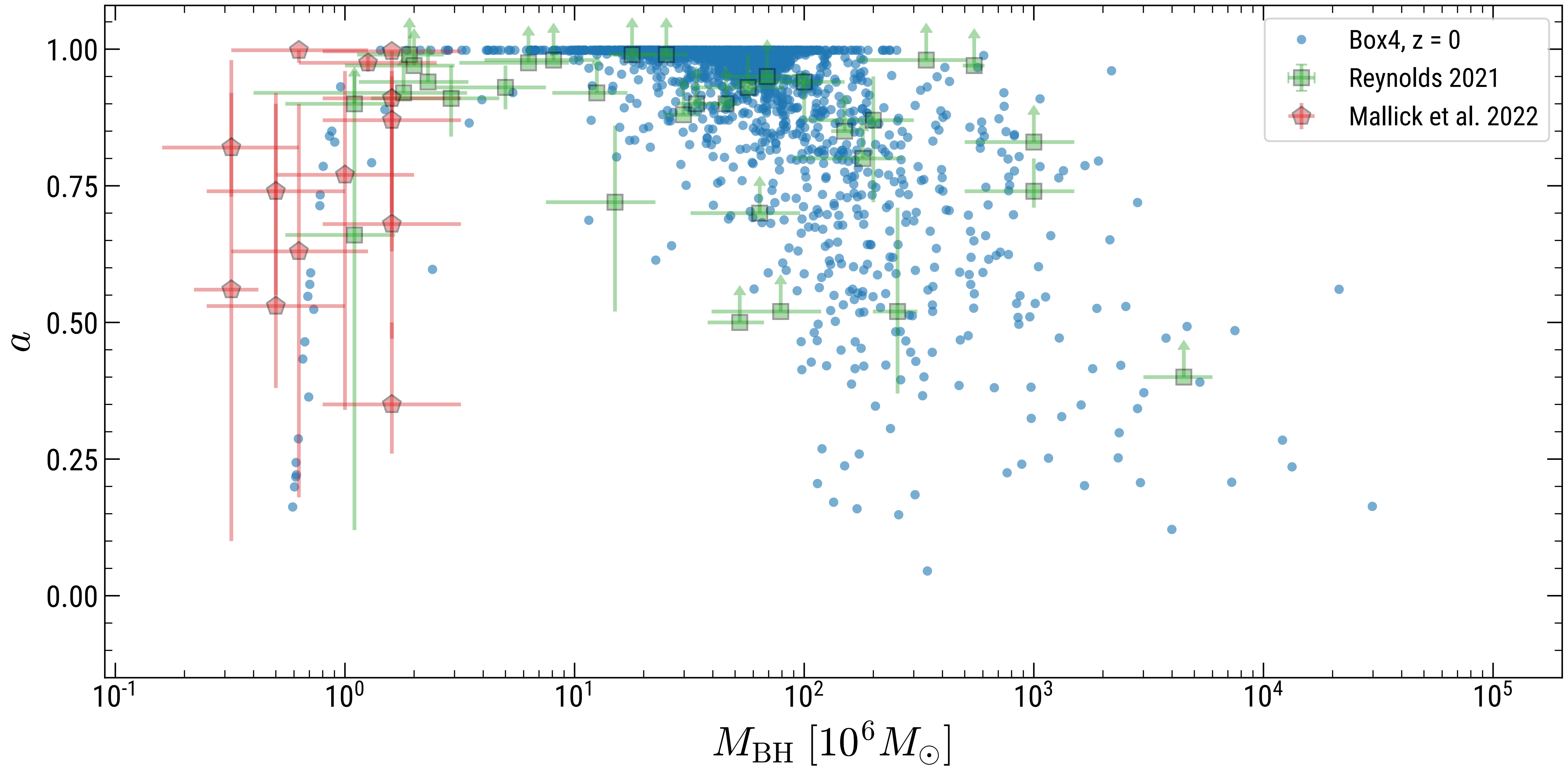
Magneticum Box4 Spin evolution: $\epsilon_f = 0.0775$

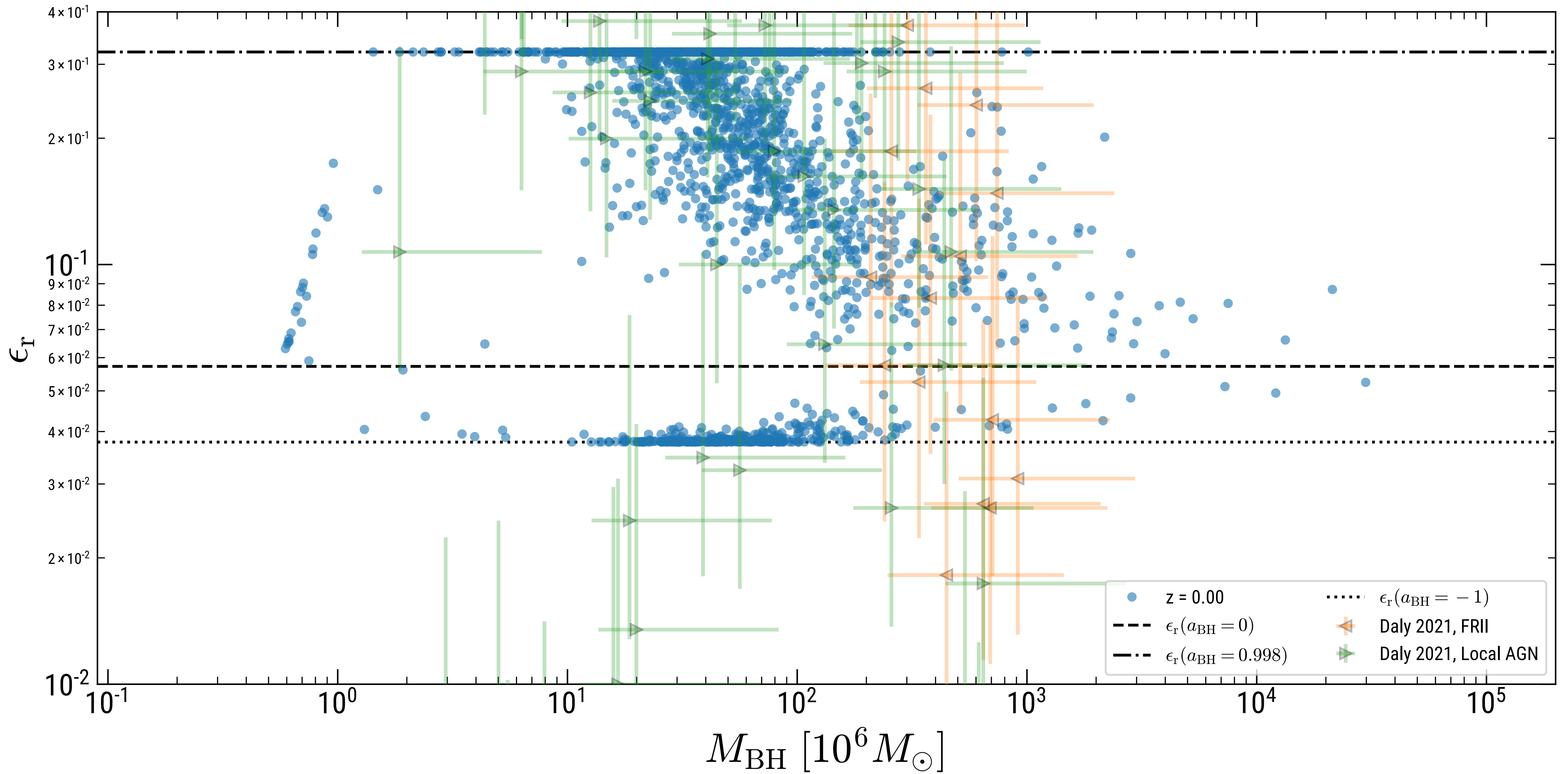
$z = 0.0$











Supermassive black hole spin evolution in cosmological simulations with **OPENGADGET3**

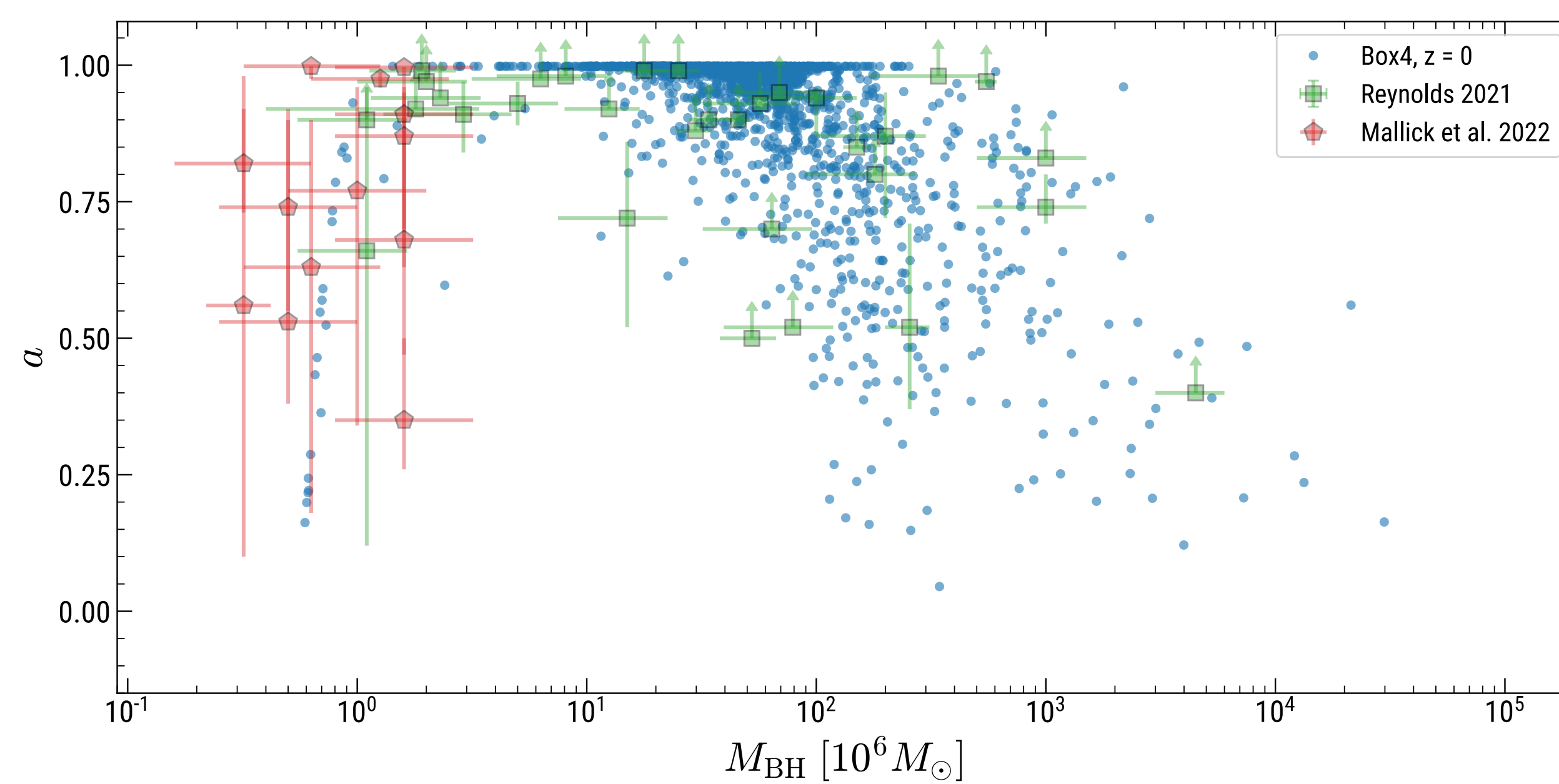
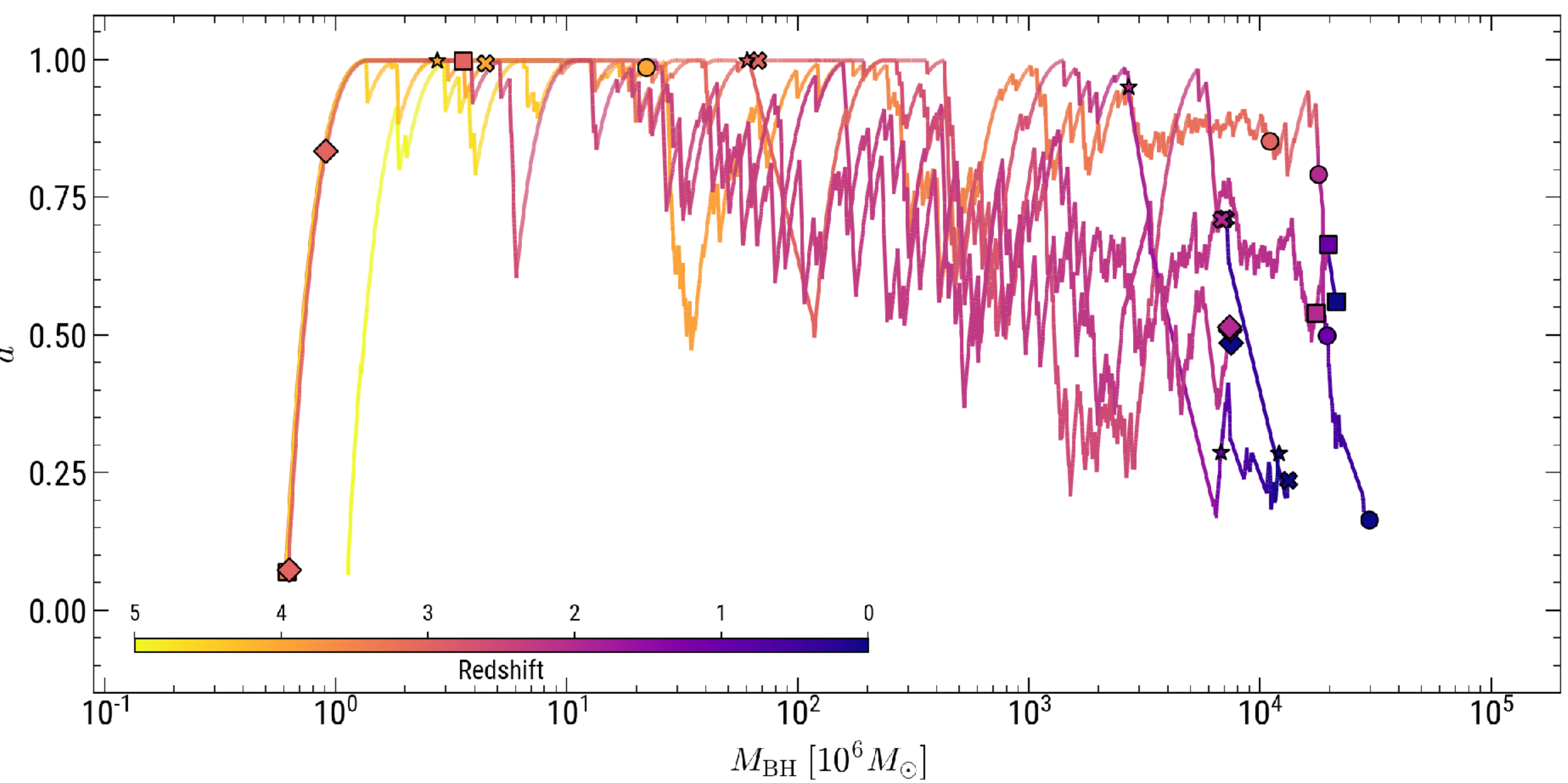
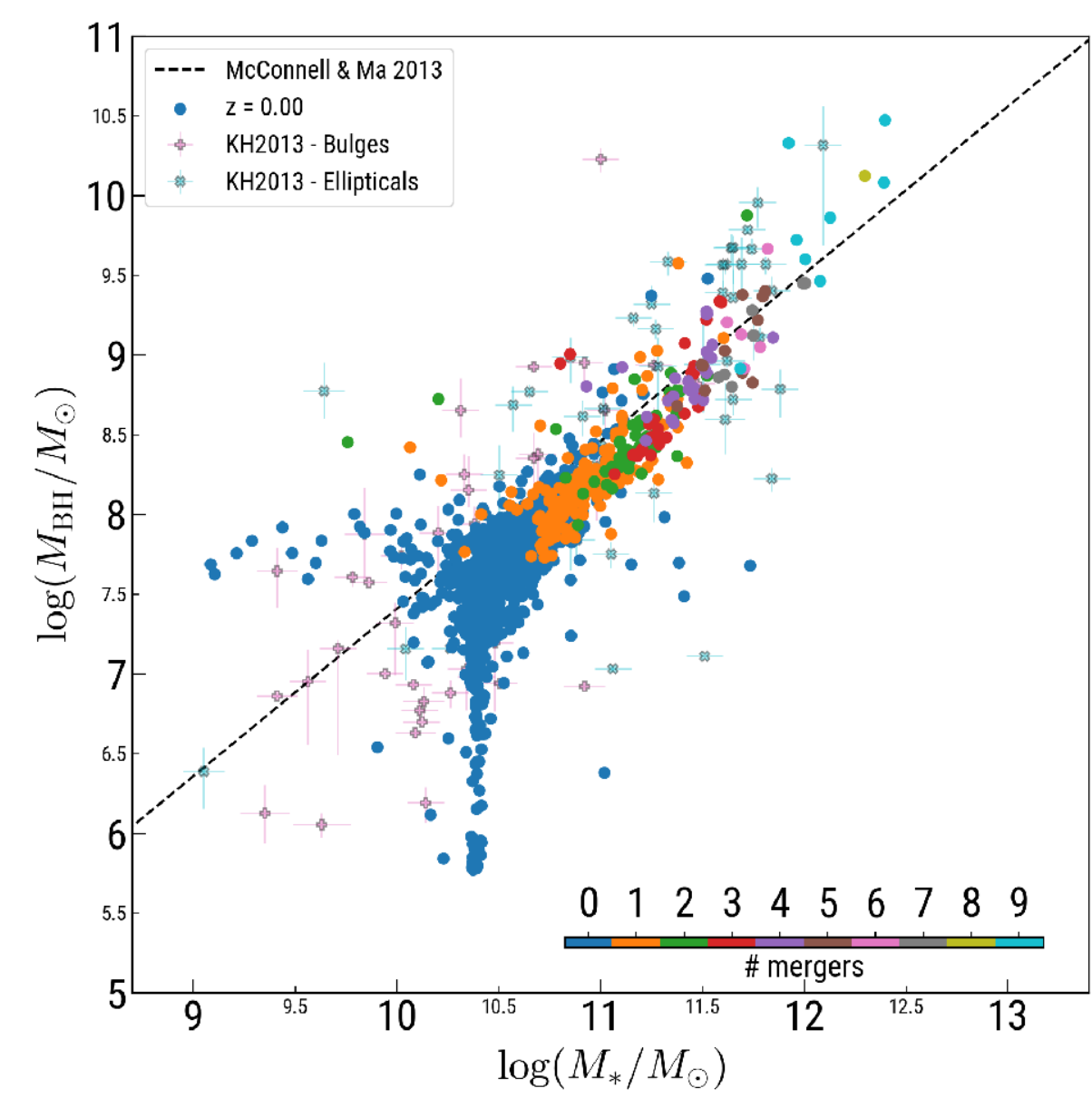
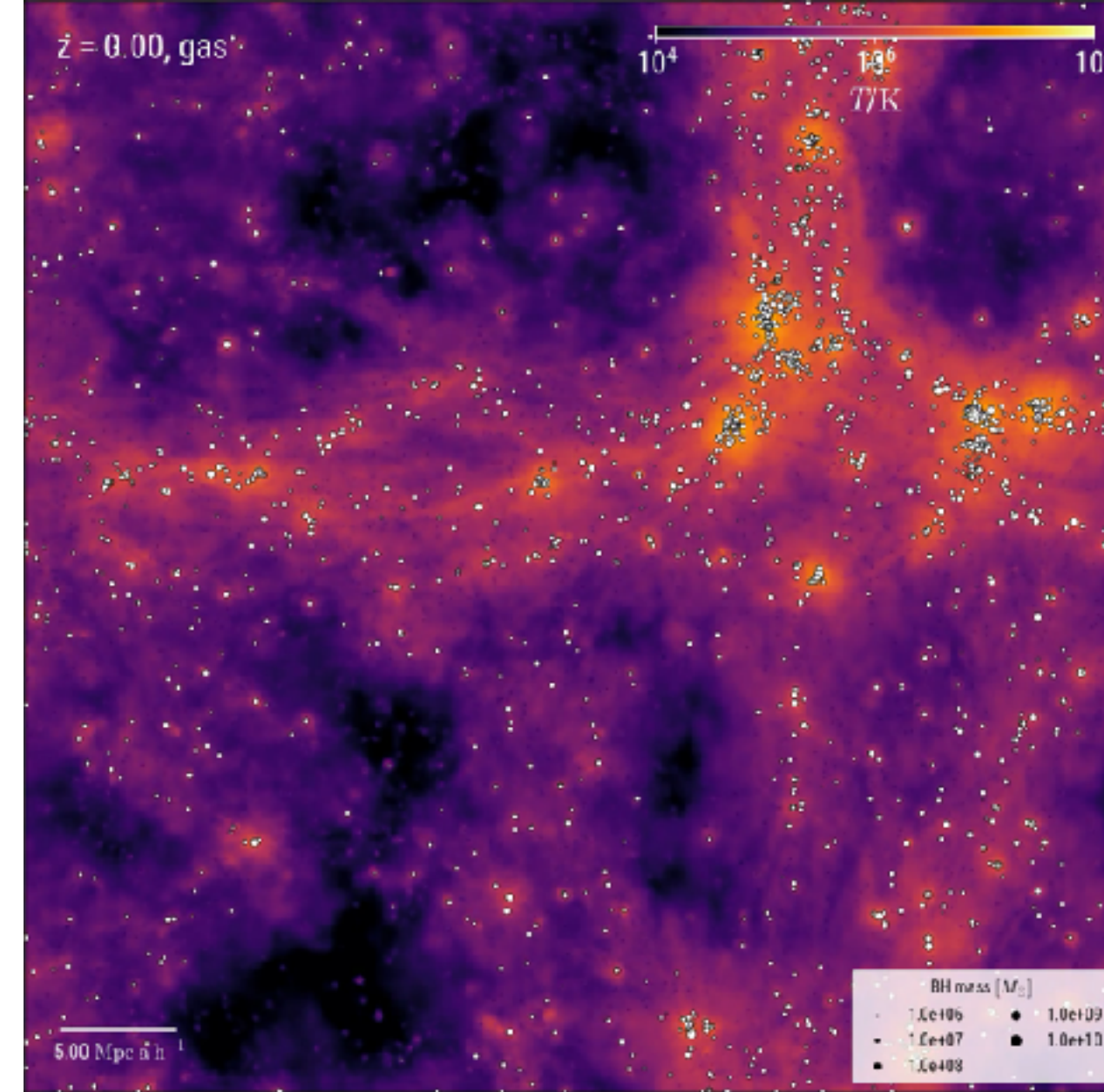
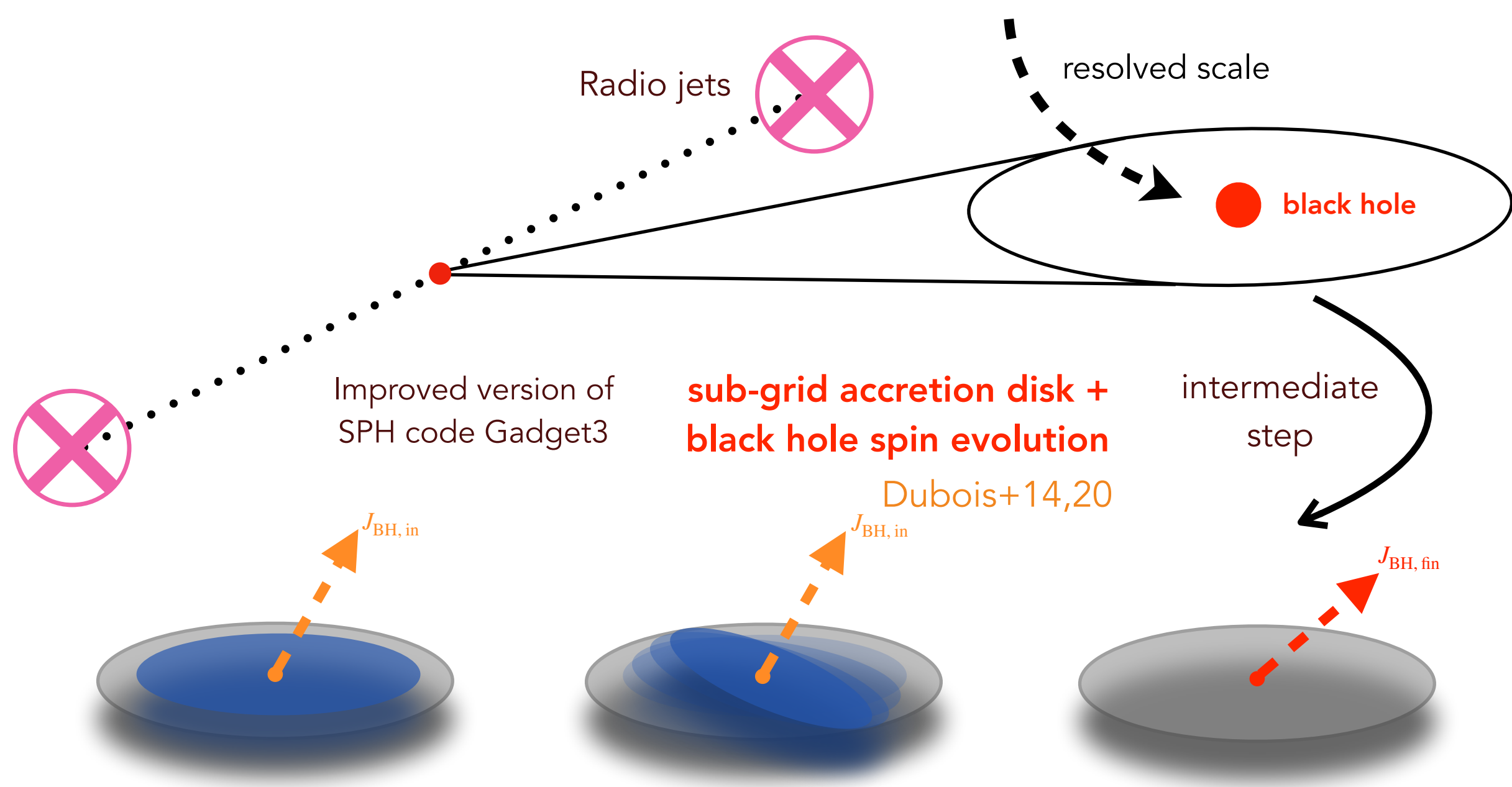
Luca Sala,¹★ Milena Valentini,^{2,3} Veronica Biffi,³ and Klaus Dolag^{1,4}

¹*Universitäts-Sternwarte, Fakultät für Physik, Ludwig-Maximilians-Universität München, Scheinerstr. 1, D-81679 München, Germany*

²*Excellence Cluster ORIGINS, Boltzmannstr. 2, D-85748 Garching, Germany*

³*INAF – Osservatorio Astronomico di Trieste, via Tiepolo 11, I-34131 Trieste, Italy*

⁴*Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Str. 1, D-85741 Garching, Germany*



<https://www.bid4best.org>

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 860744.