Radiative model of magnetically-arrested flows and its application to M87*

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MHD solutions

3D GRMHD, single-fluid simulations performed with HARM_COOL (Sapountzis & Janiuk 2019, Janiuk & James 2022)

resolution: 288 × 256 × 256 (R-θ-ϕ)

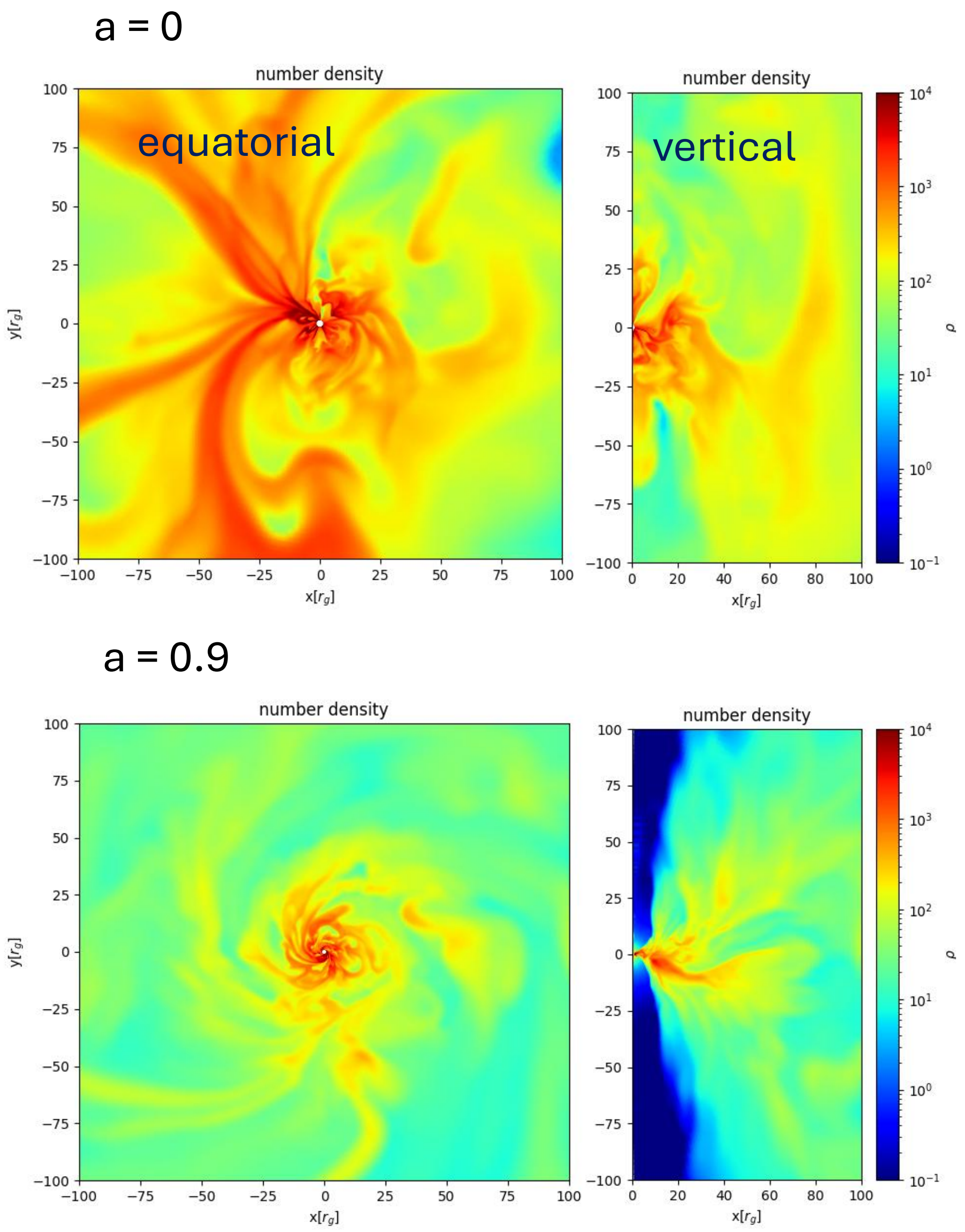
time: 50000 GM/c^3

all solutions in the MAD state, ϕ_{BH} ~ 20 (MAD-ness parameter)

scaled to M = 6.5 × 10^9 Msun

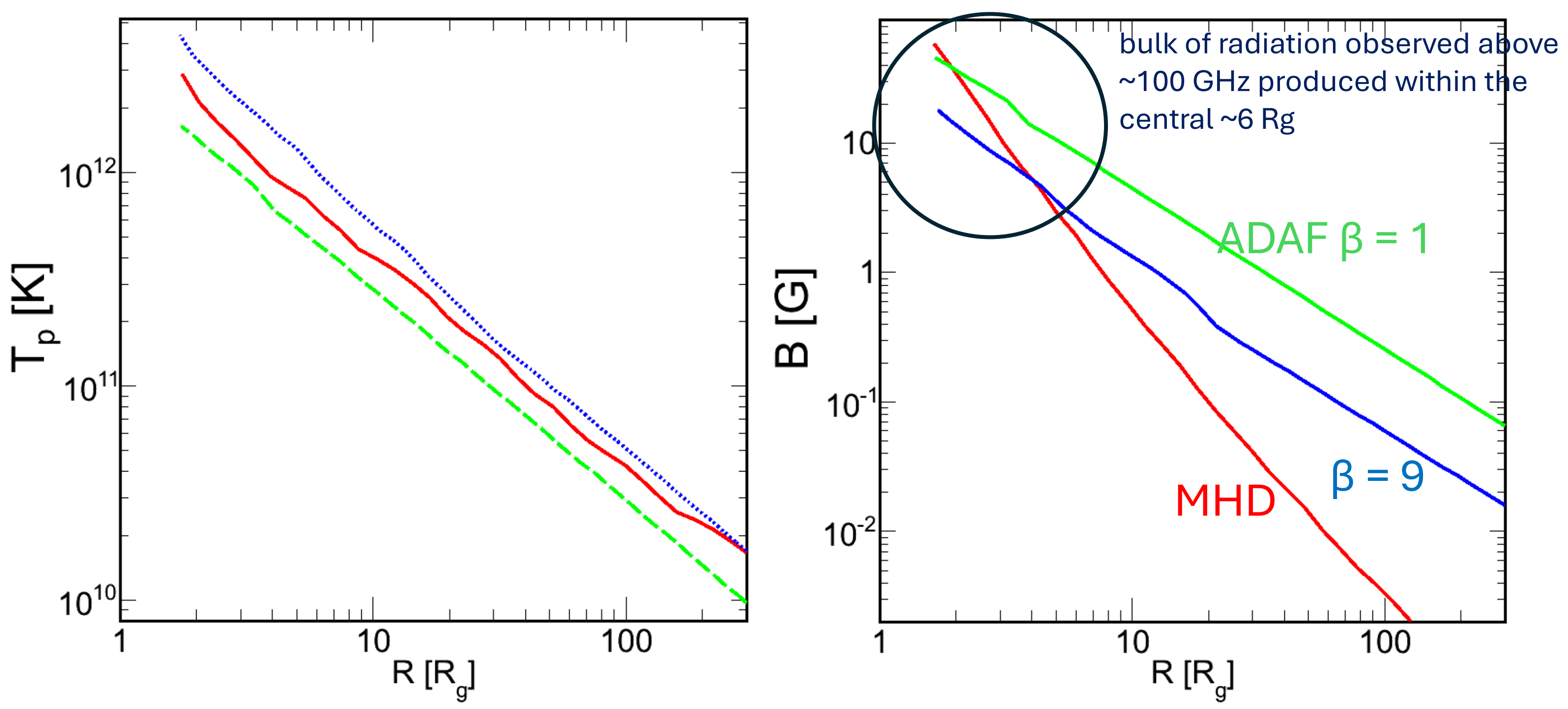
for a=0.9 strong jets (with a power ~3 × 10^{43} erg s^{-1} for the fitted accre. rate ~ 0.01 Msun yr^{-1})

for a=0 no jets, also quasi-spherical structure in the central part



MHD solutions vs ADAF theory

Radial profiles – very similar in both models for all parameters except for B, much flatter in analytic models – due to assumption of constant β=Pgas/Pmag



Red: angle-averaged radial profiles in the GRMHD solutions

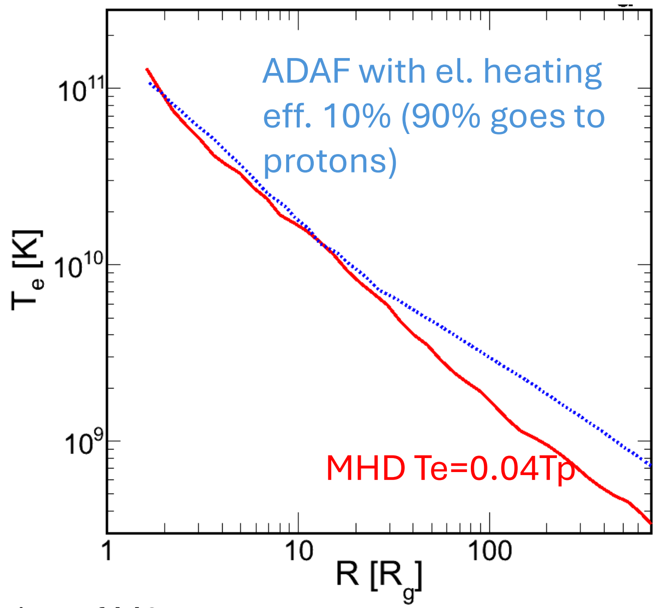
Blue and green: ADAF (two-temperature flow) model of Shapiro et al. (1976), in the GR form Abramowicz et al. (1996) Gammie & Popham (1998), Manmoto (2000)

Both MHD and ADAF models for the same a=0.9, accr. rate = 0.1 Msun/year, M = 6.5 × 10^9 Msun

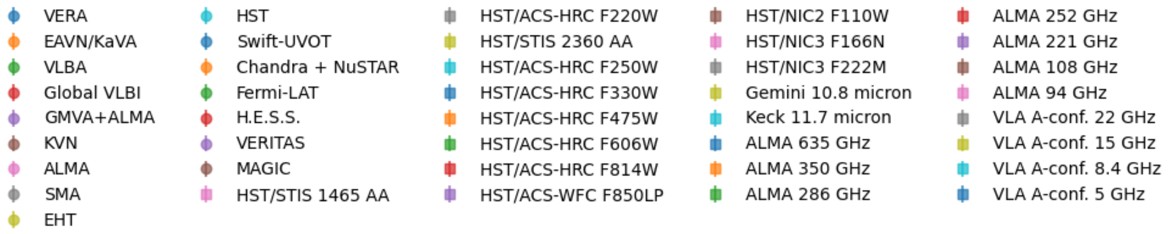
Thermal synchrotron spectra

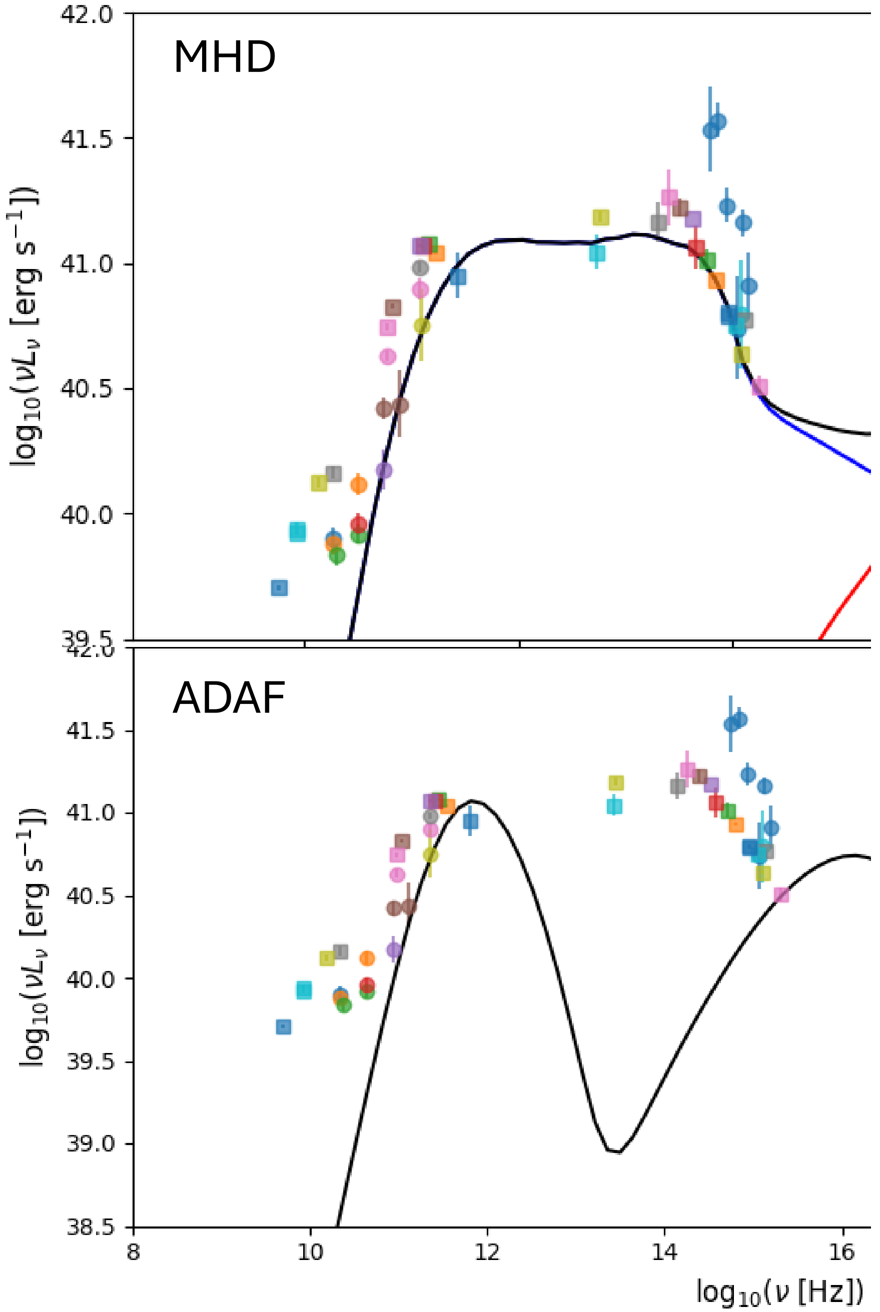
For MHD and ADAF spectra computed with the same GR Monte Carlo code

For the MHD model we assumed Te=0.04Tp, for which the average Te is very similar to ADAF at this accr. rate (also very similar to radiative GRMHD simulation of Chael et al. 2019)



data for 2018 multiwavelength campaign of M87

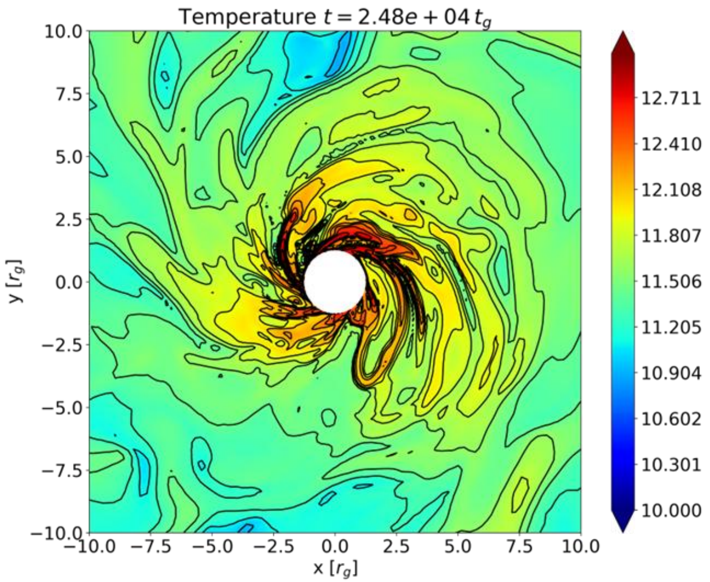


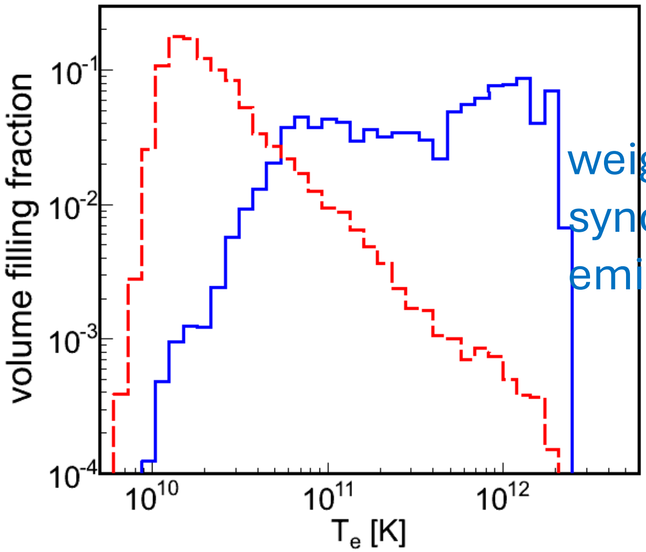


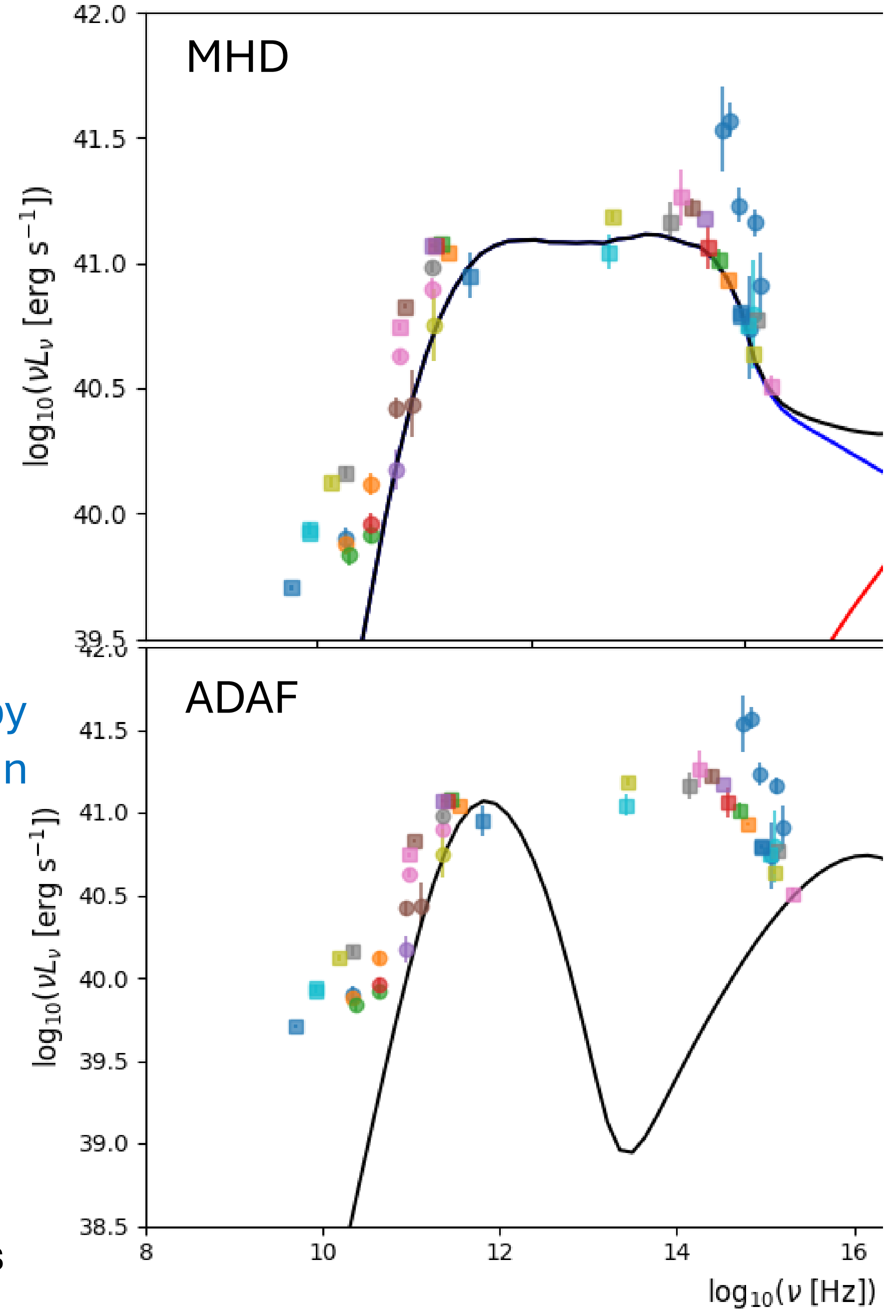
Thermal synchrotron spectra

Much broader in the (MAD) MHD model and remarkably well matches the mm to UV data of M87

In the MAD state the emitting region characterised by a large range of plasma parameters:







The analytic models are essentially 1D, so single value of Te at each radius

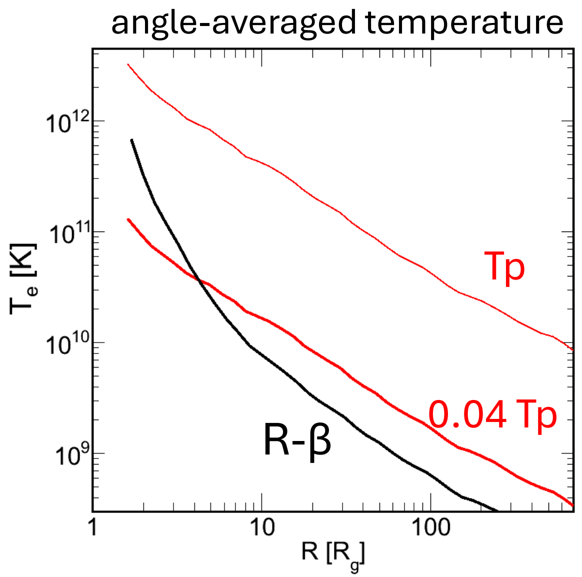
R-β prescription

$$\frac{T_i}{T_e} = \frac{1}{1+\beta^2} R_l + \frac{\beta^2}{1+\beta^2} R_h$$

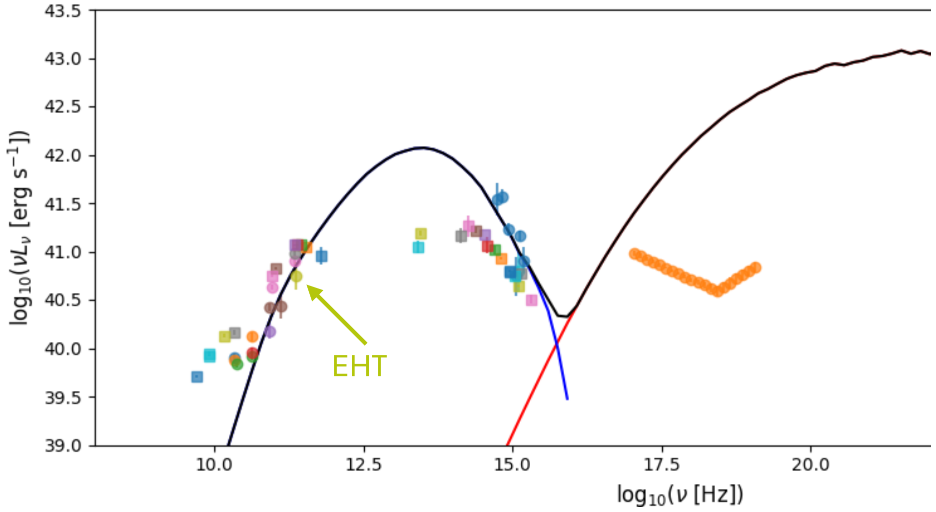
Mościbrodzka et al. (2016)

In MADs β ~ 1 in the inner flow, implying Te ~ Tp for Rlow ~ 1 (often applied in image analysis)

For Rlow = 1, Rhigh = 80:



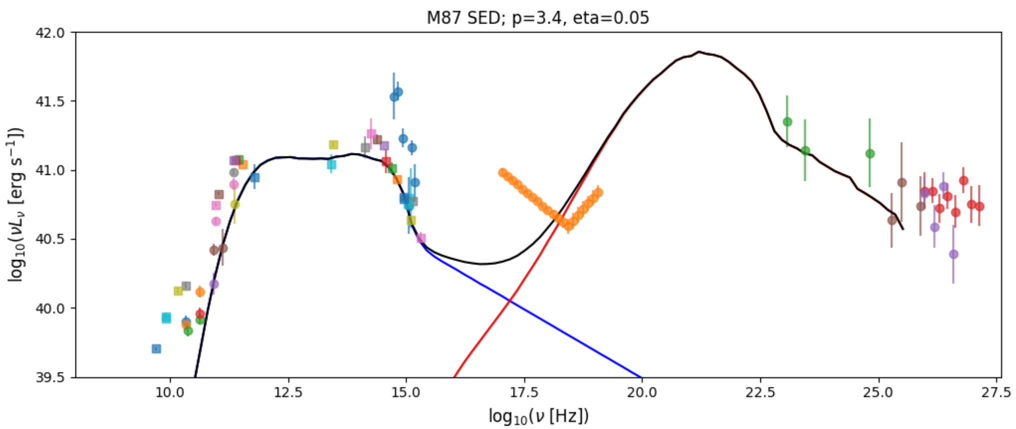
$\tau \sim 10^{-4}$, but Compton amplification = $\tau\, 16\, \Theta_e^2 > 1$

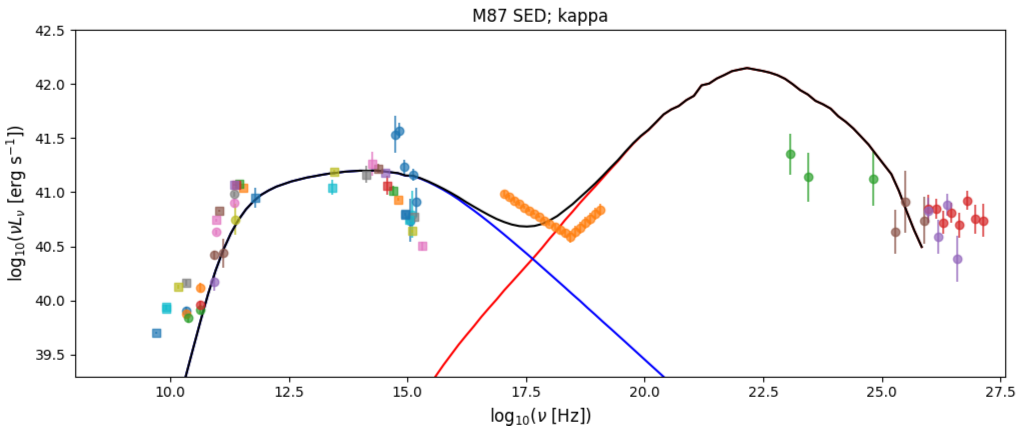


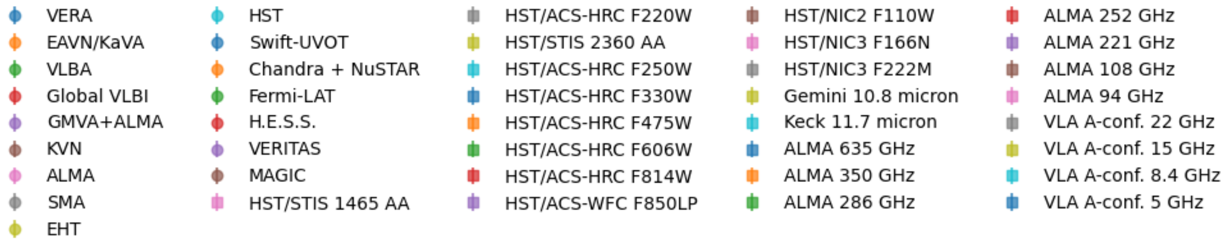
bolometric luminosity ~ Mdot c^2

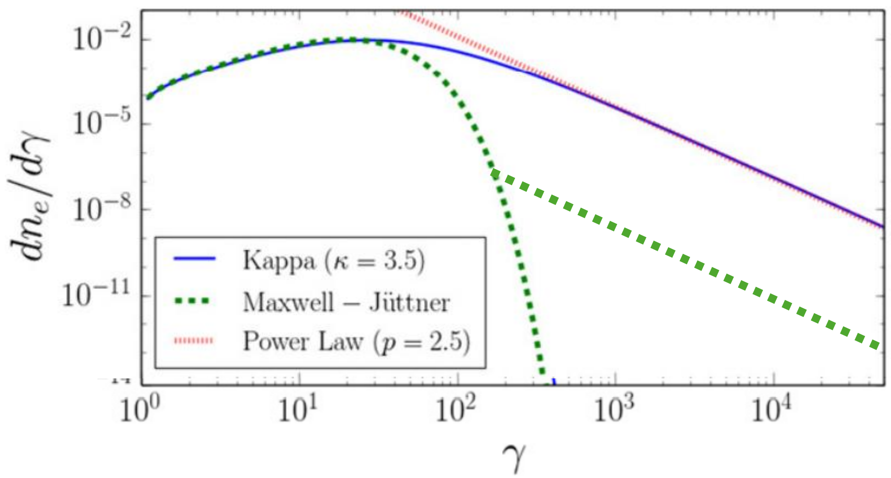
Hybrid model

A 5% energy content of nonthermal electrons allows to explain the broadband spectrum (except for soft X-rays), VHE gamma-ray underpredicted likely due to less efficient cooling of electrons in the KN regime not taken into account (yet)









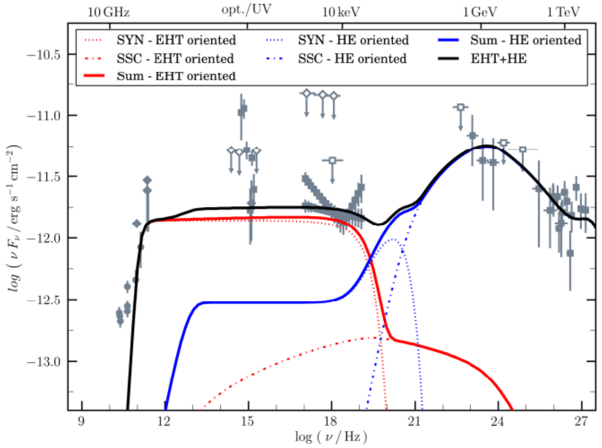
Summary

Inner parts of MAD flows characterised by a wide spread of the flow parameters, in particular Te,

resulting in a broad thermal synchrotron spectrum, notably consistent with mm-UV SED of M87

Inclusion of a weak nonthermal tail allows to a large extent to explain the broadband SED,

in a model simpler and more consistent with modeling of EHT images than multi-zone models, e.g.



EHT collab. (2025)

Work in progress, electron energy balance and polarization maps under implementation