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Comparison of T_i/T_e prescription: two-temperature GRMHD simulations

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Introduction

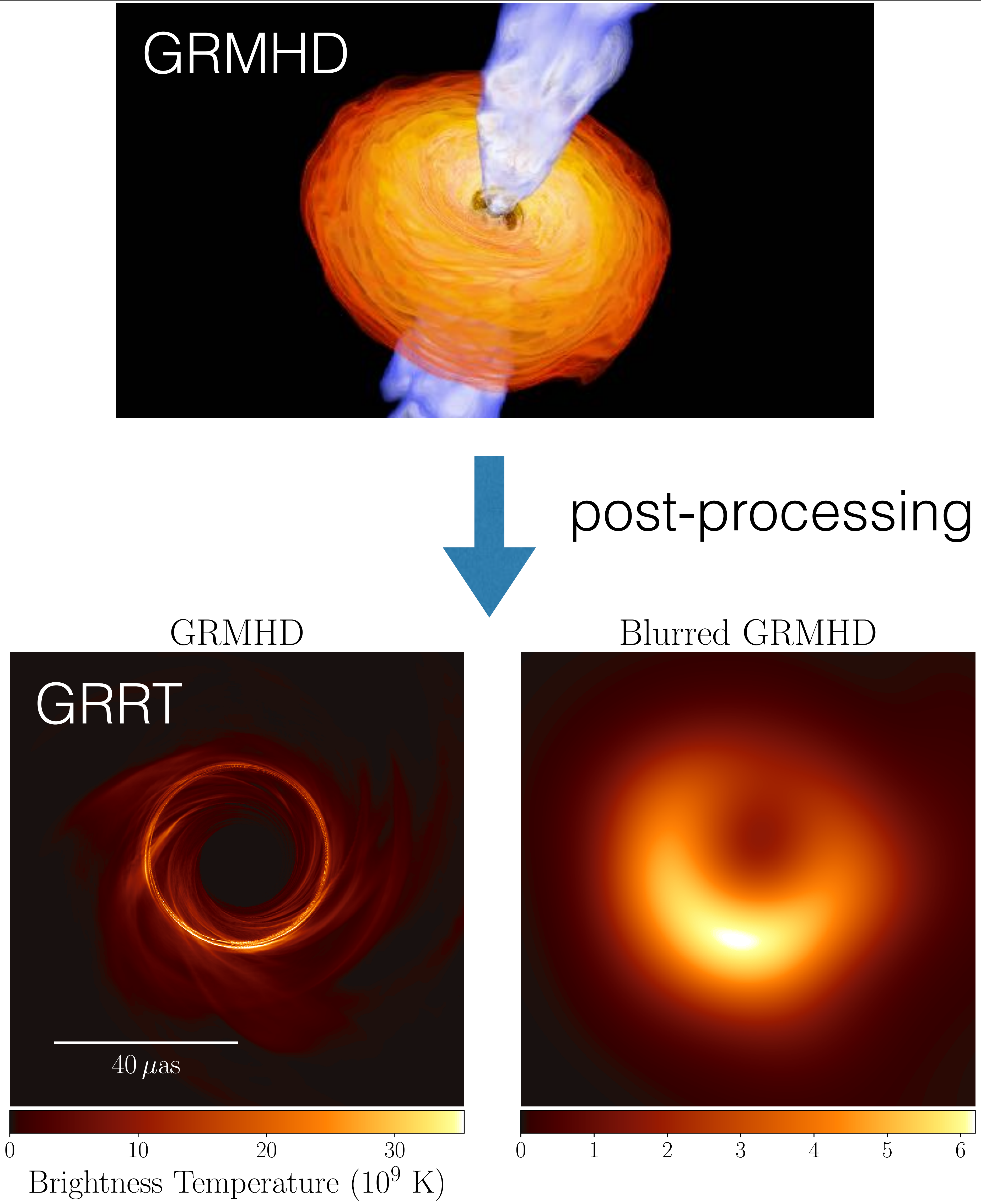
- For imaging shadow and jets in M87, synchrotron emission from thermal electrons is calculated from GRMHD simulations in post-processing.

- In hot and low-density accretion flows such as RIAFs, Coulomb coupling between electrons and ions are inefficient => no thermal equilibrium.

- In single fluid MHD, ion temperature dominates, electron temperature can not be determined.

- The commonly used parameterised T_i/T_e prescription: so-called R-β model (Moscibrodzka et al. 2016)

$$\boxed{\frac{T_{\rm i}}{T_{\rm e}} = R_{\rm l}\frac{1}{1+\beta_p^2} + R_{\rm h}\frac{\beta_p^2}{1+\beta_p^2}}$$



Introduction (cont.)

- Recently new formulation of two-temperature GRMHD simulations was proposed (Ressler et al. 2015)
- This prescription provides electron temperature directly from GRMHD simulations
- In this work, direct comparison between parametrised T_i/T_e prescription and electron heating prescription obtained from two-temperature GRMHD simulations (turbulent & magnetic reconnection heating)
    - Consider: images & visibilities at 230GHz, spectrum, image size, & time variability at 230GHz

Simulation & Images

GRMHD

- 3D simulations of magnetied accretion flows onto a black hole by BHAC
  - Consider Magnetically Arrested Disk (high magnetic flux accretes)
  - BH spin: a=-0.9375, 0, 0.9375
  - run up to t=15000M
  - heating model in electron thermodynamics: turbulent & magnetic reconnection

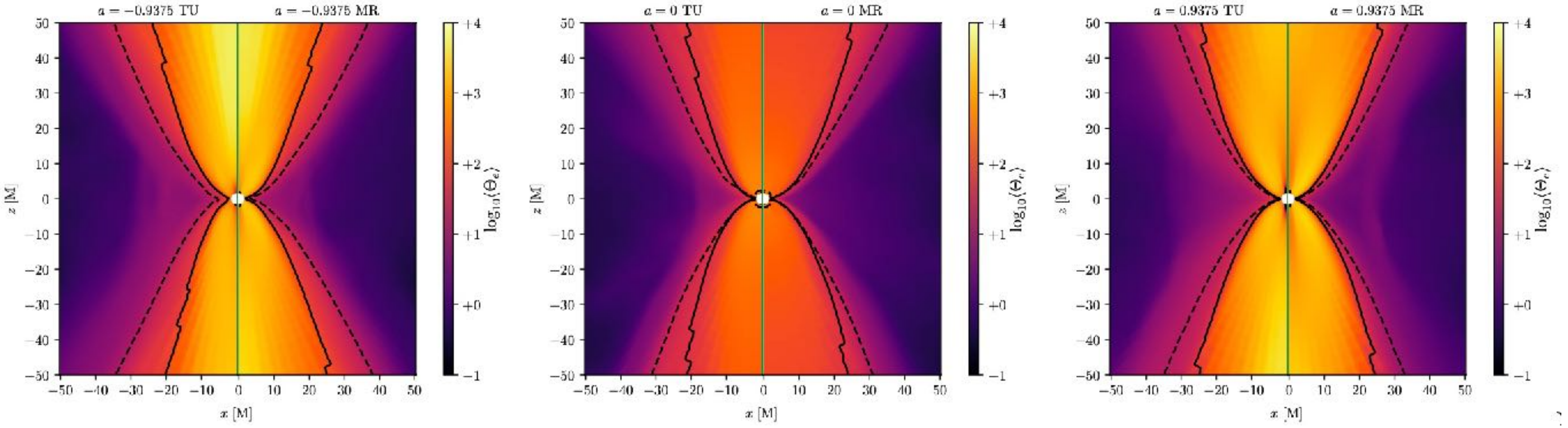
GRRT

- Calculated by BHOSS
  - 101 snapshots for each cases (t=14000 - 15000M, 10M cadence)
  - Apply M87 BH mass & distance
  - FoV: 640 x 640 μas
  - Average flux: 0.5 Jy, inclination angle: 163 deg & 60 deg
  - Electron heating prescription: Turbulent & reconnection
  - R-β prescription: R_l =1, R_h=1, 5, 10, 20, 40, 80, 160

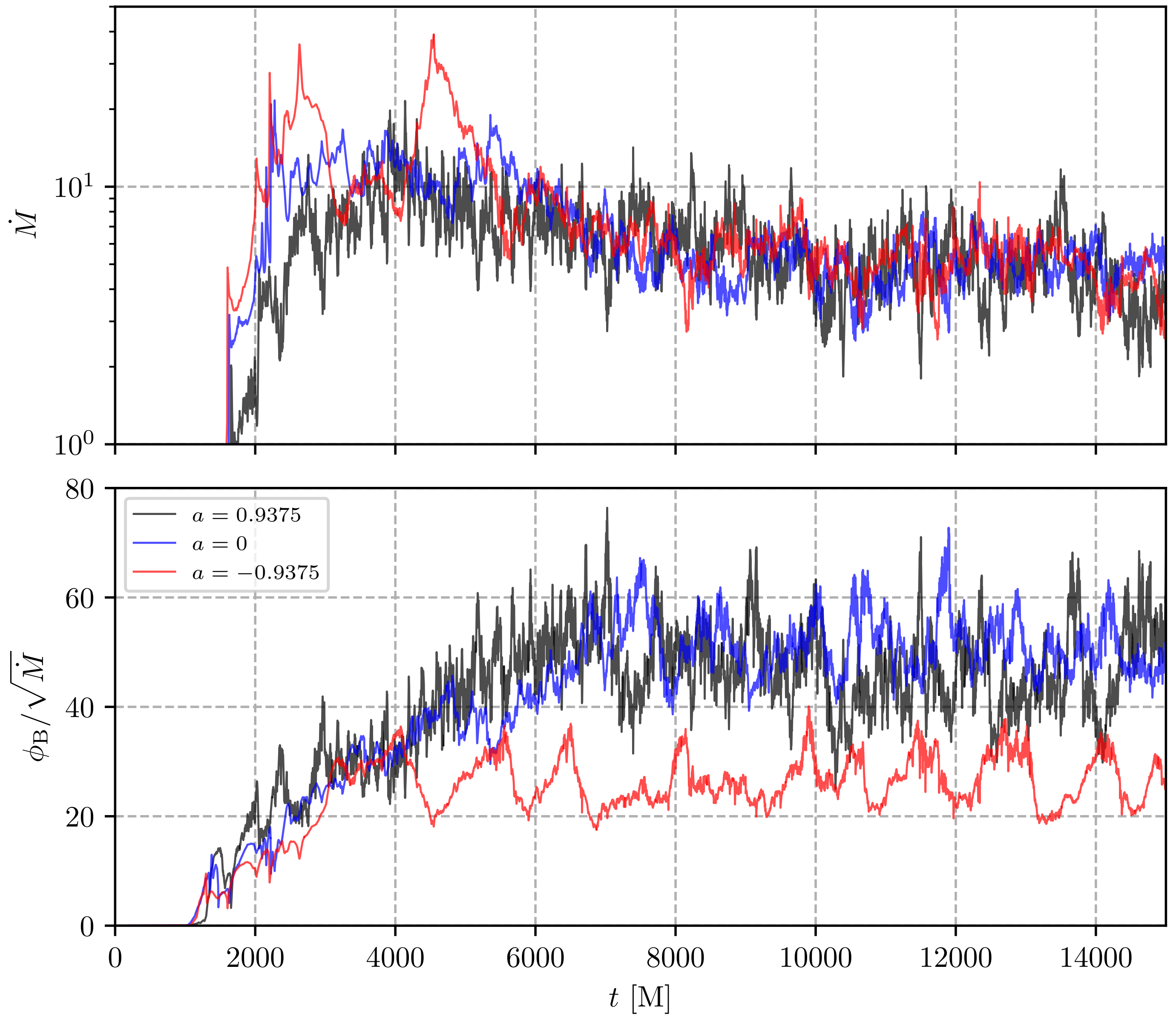
GRMHD data

Turbulent a=-0.94 Reconnection a=0 a=0.94

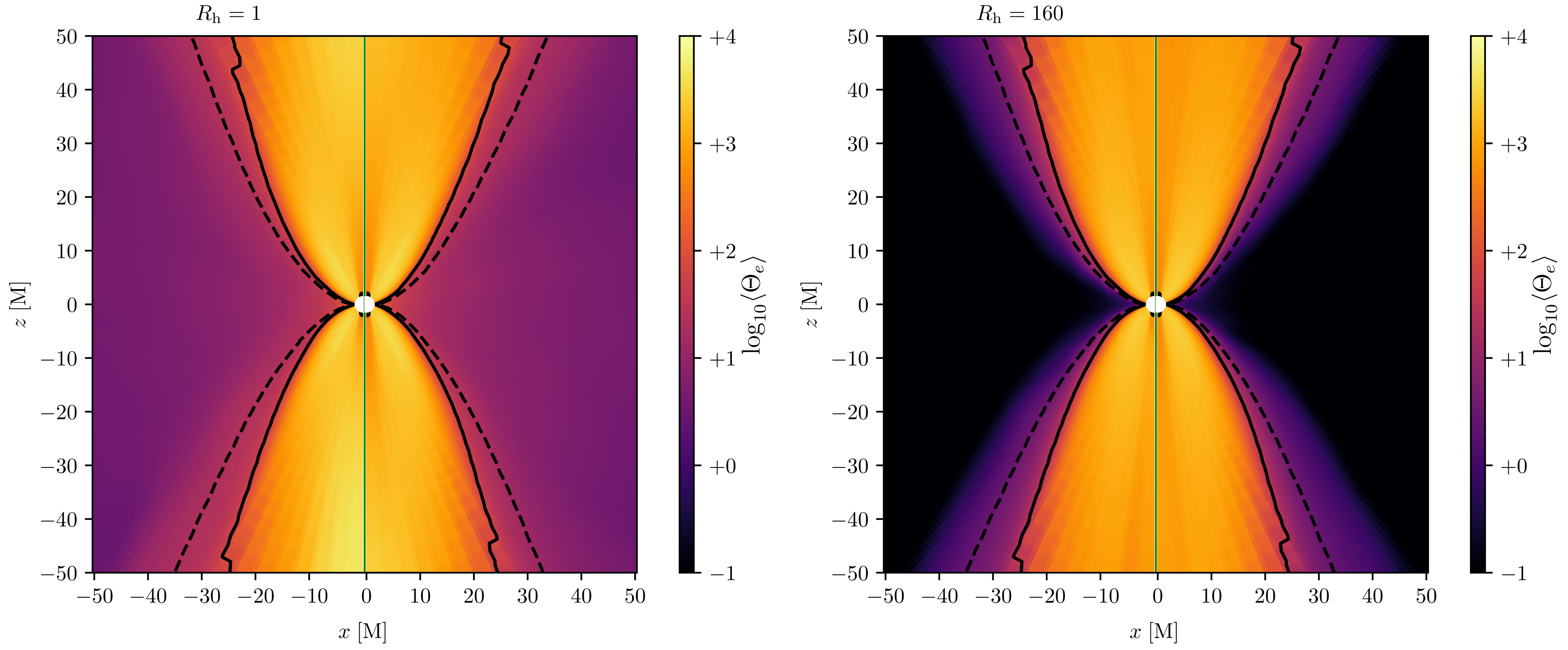
Electron temperature



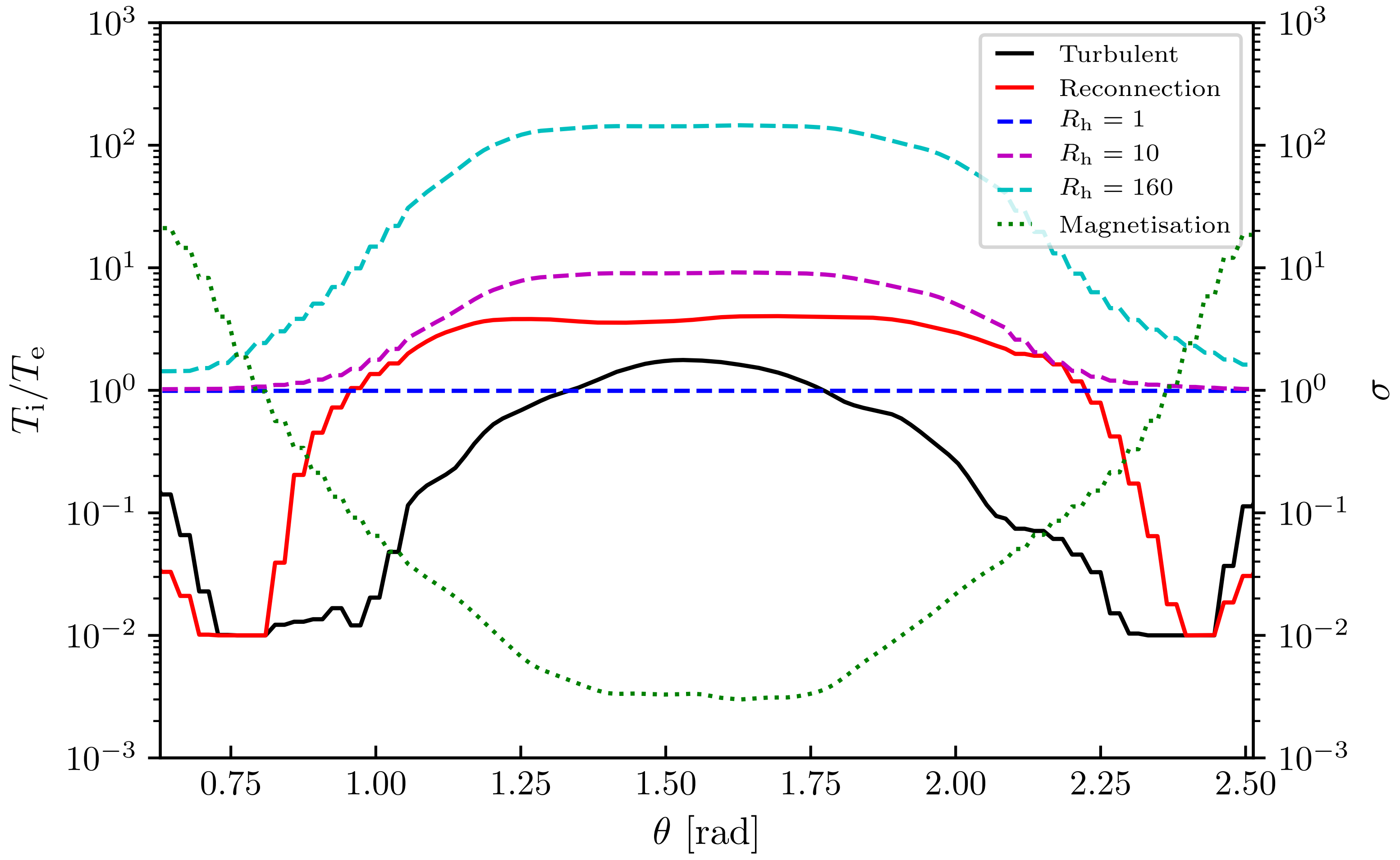
mass accretion rate & magnetic flux



Rh=1 a=0.94 Rh=160



Azimuthal profile of Ti/Te



GRRT image at 230GHz

Time-averaged (14000-15000M)
(Logarithmic scale, i=163 deg)

a=-0.94

- Is seen some difference

- Heating prescriptions have more extended diffused emission structure (in particular counter-rotating cases)

a=0

a=0.94

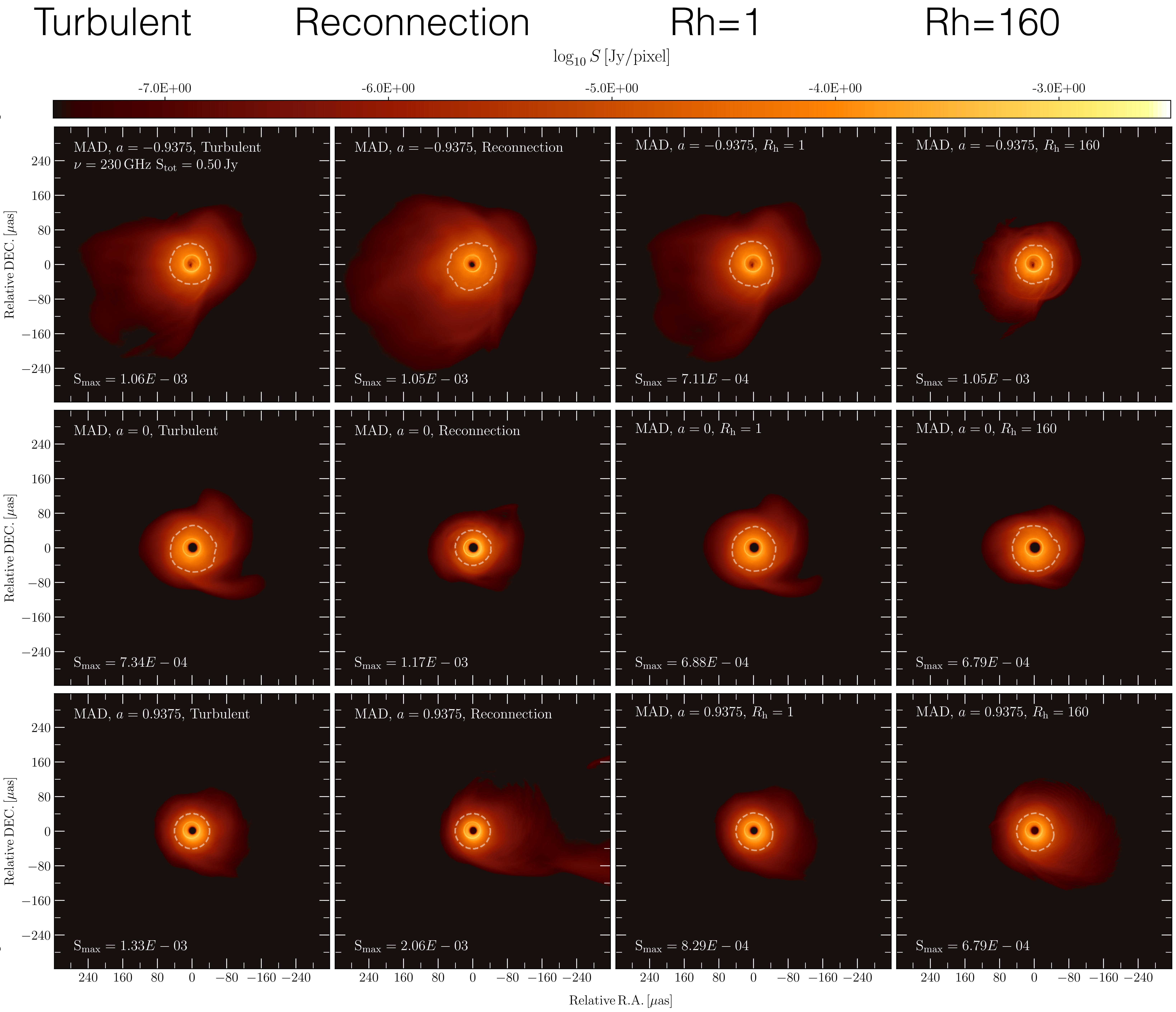
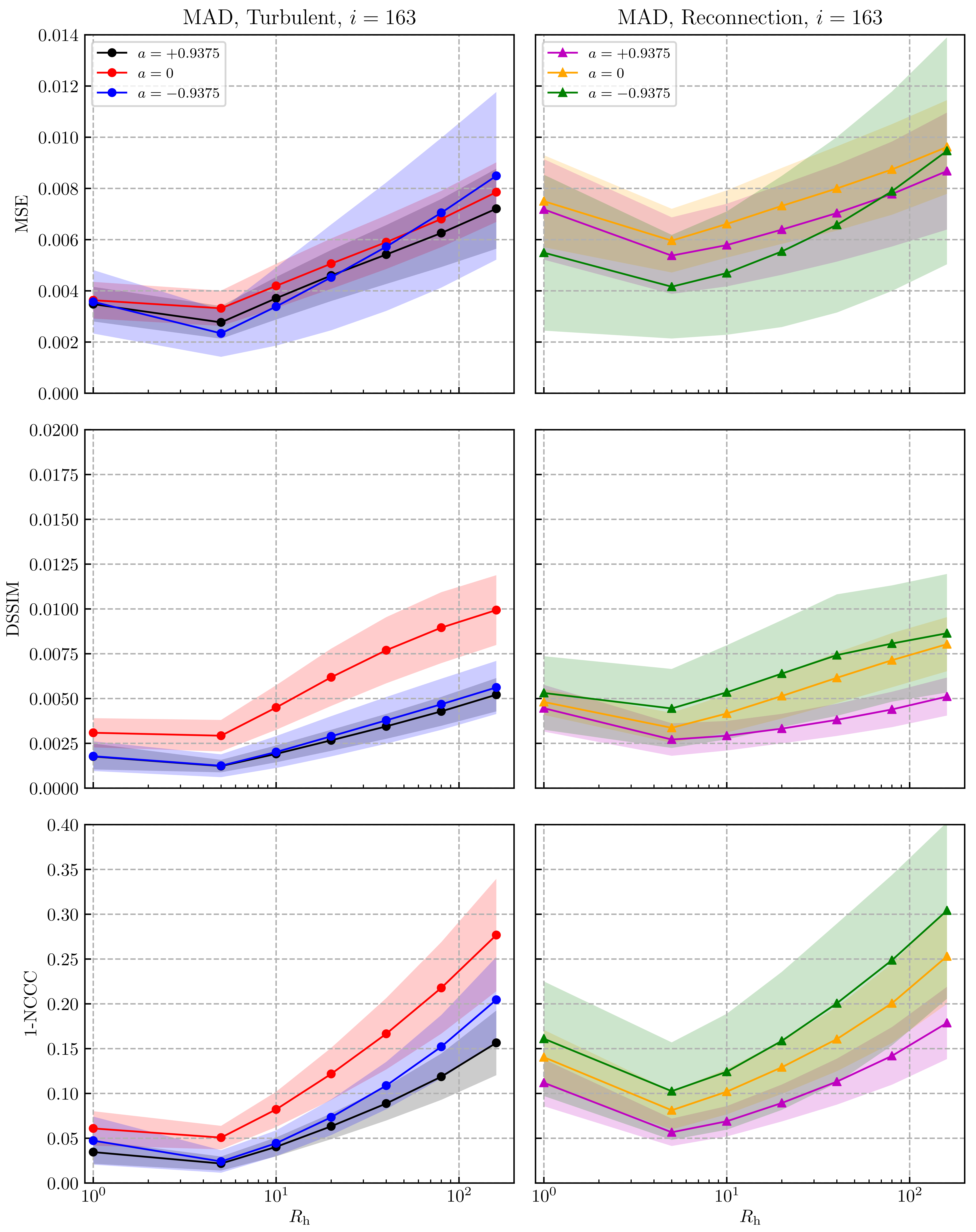


Image Comparison

- Comparison of 230 GHz snapshots (i=163 deg) between electron heating and R-β prescriptions
- Image comparison metrics: MSE, DSSIM, 1-NCCC
    - *Smaller value means better match*
- In general, R-β model well matchs both heating models
    - Turbulent model: R_h=1 & 5 have smallest values, increasing with R_h
    - Reconnection model: R_h=5 is the best matched, increasing with R_h



Summary

- We have compared T_i/T_e prescription between commonly used parameterised R-β model and electron heating prescriptions obtained from two-temperature GRMHD simulations.

- From the comparison of GRRT images, the R-β prescription is well-matched by both heating prescriptions, although images of electron heating prescriptions have a more extended and diffused emission region, in particular for counter-rotating black hole cases.

- In general, smaller R_h values yield better match to both prescriptions.

- From this comparison study, we conclude that commonly used R-β model reproduces well the T_i/T_e prescription obtained from two temperature GRMHD simulations.

- Future work: consideration of non-thermal electrons for modelling jets

For more detail: Mizuno *et al.* (2021) MNRAS, in press, arXiv:2106.09272