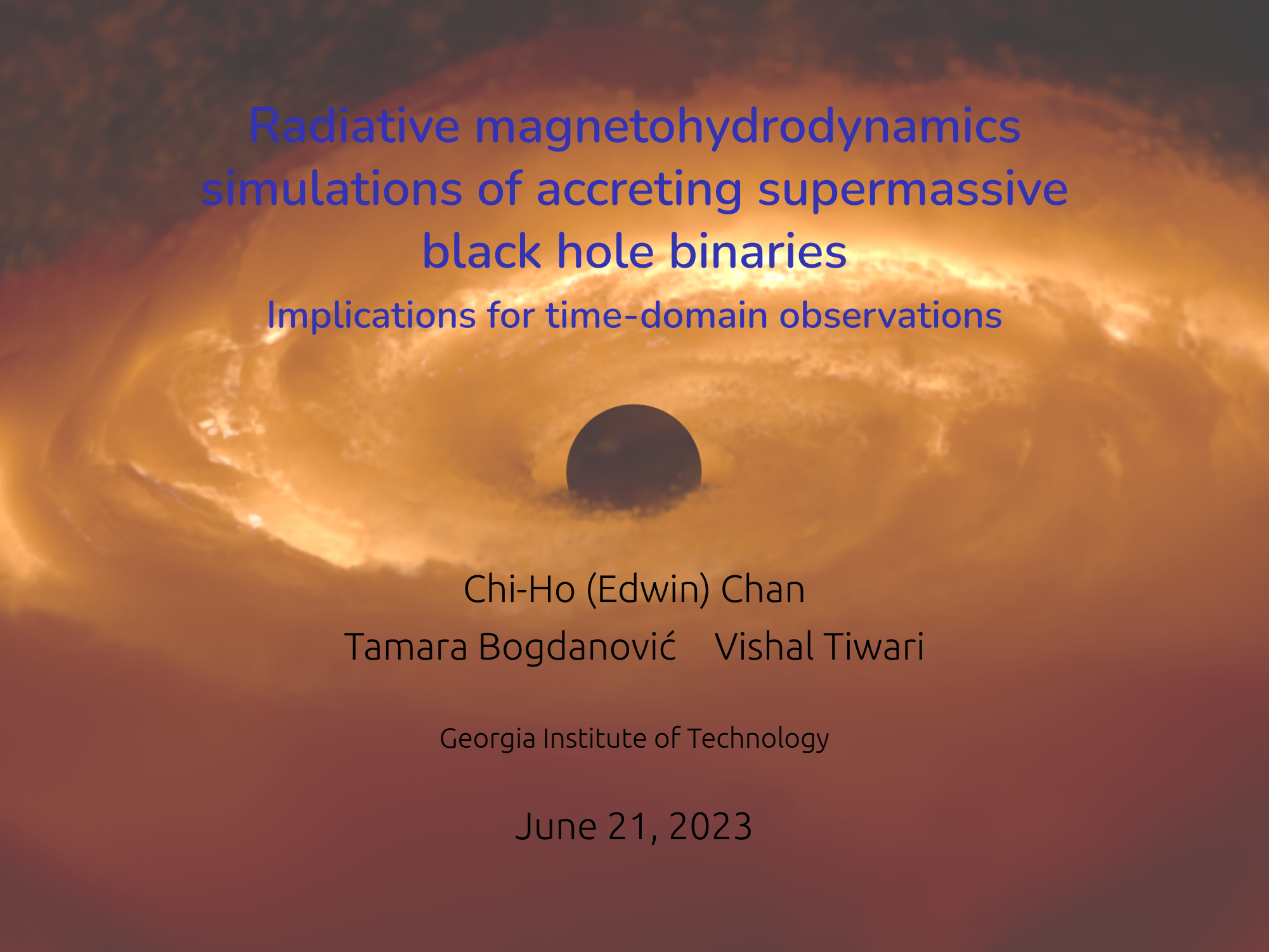
Radiative magnetohydrodynamics simulations of accreting supermassive black hole binaries

Implications for time-domain observations



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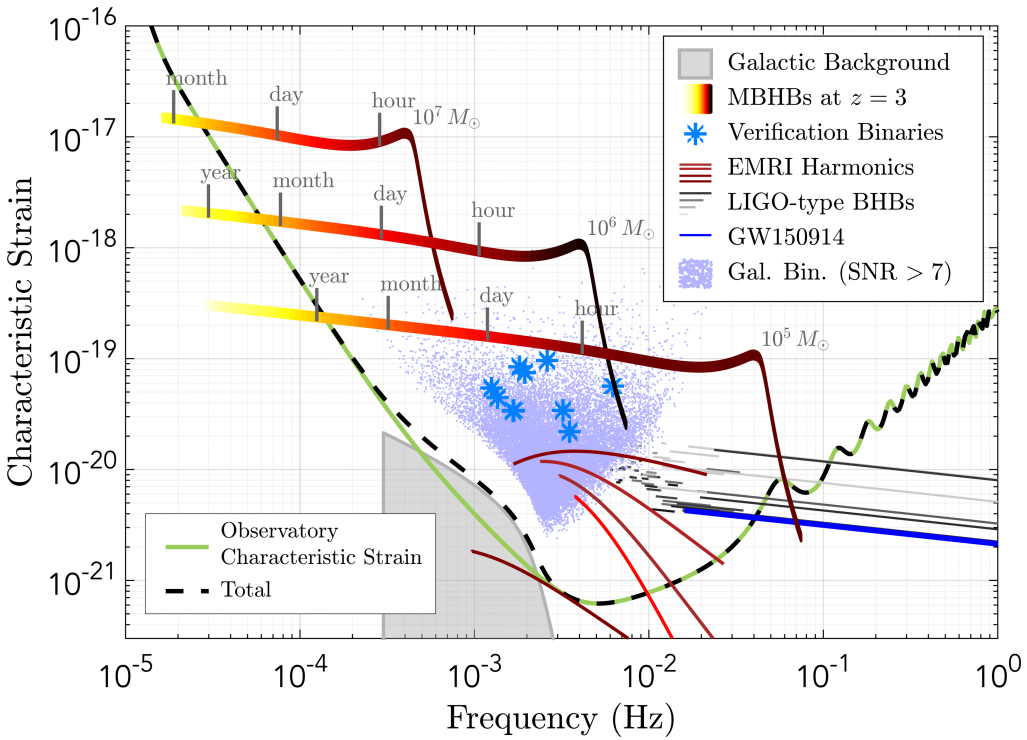
June 21, 2023

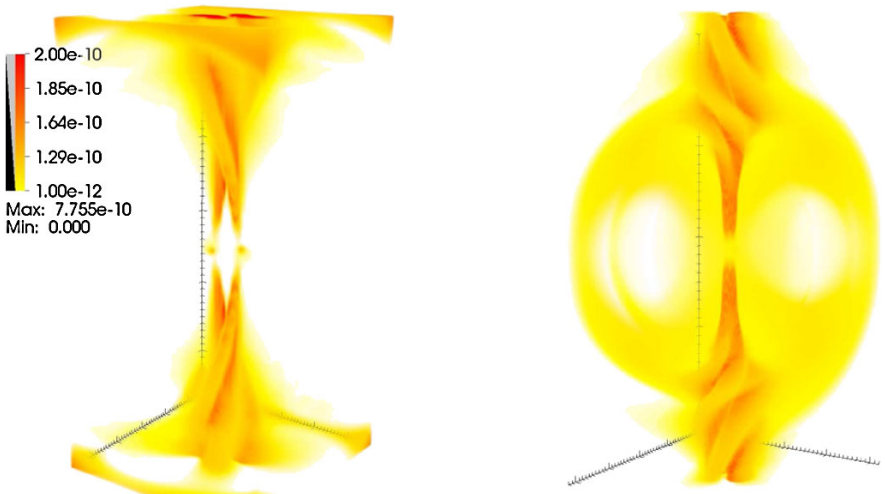
LISA and SMBH binaries

- LISA will fly mid-2030s
  - final design phase now; mission adoption in early 2024
- SMBHs may be in gas-rich environments
  - EM signal helps localize and characterize sources

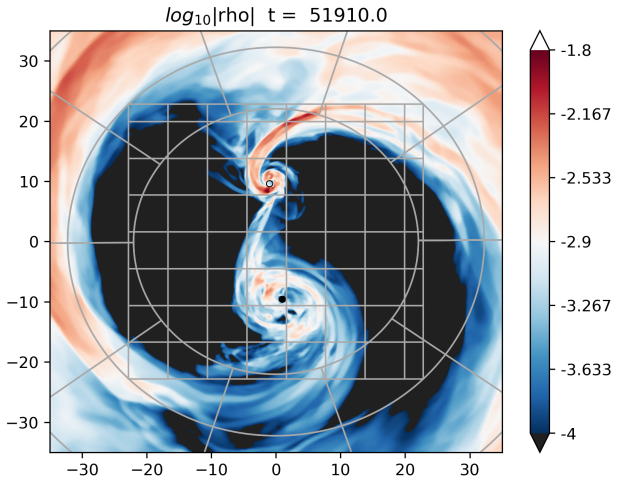


(Amaro-Seoane et al. 2017)

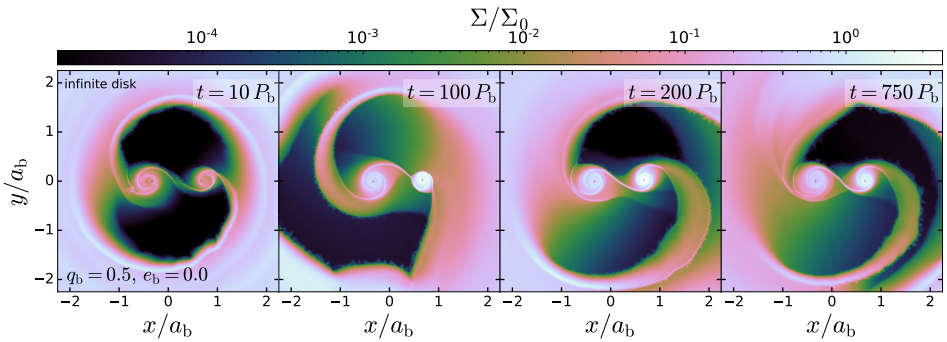
SMBH binary simulations: Progress and challenges



(electrovacuum: Palenzuela et al. 2010)



(3D GRMHD: Avara et al. 2023)



(2D HD: Muñoz et al. 2020)

many simulations
with different physics,
none with radiation

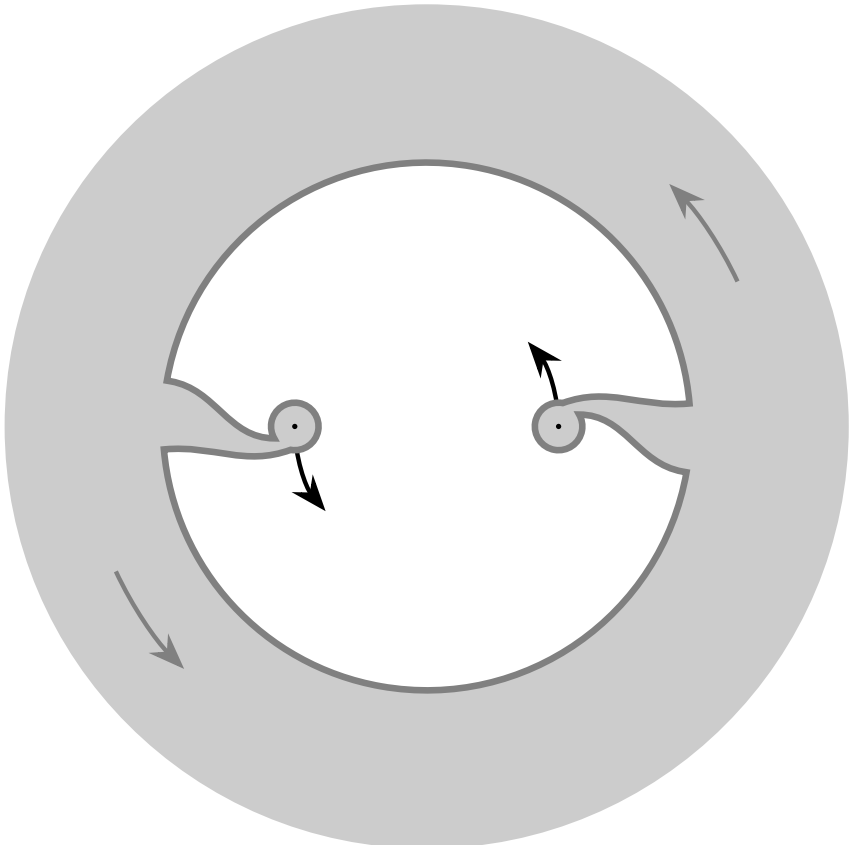
Properties of SMBH binary studied

$q = 1 \quad M_{\mathrm{tot}} = 2 \times 10^7\, M_\odot$

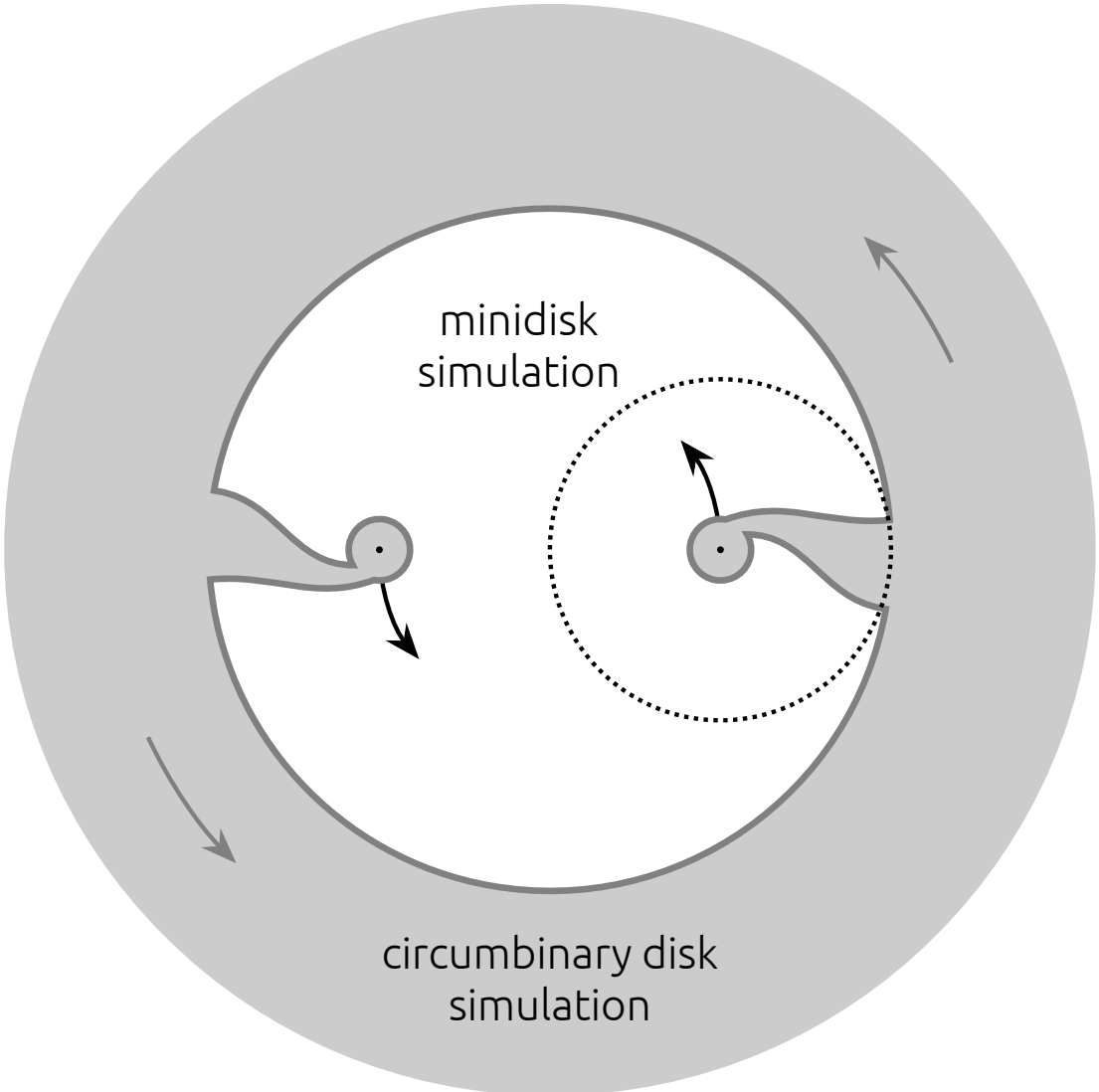
$e = 0 \quad a = 100\, GM_{\mathrm{tot}}/c^2$

$T_{\mathrm{orb}} \approx 7\,\mathrm{d} \quad T_{\mathrm{gw}} \approx 24\,\mathrm{yr}$

- as individuals:
  LISA “verification binaries”
- as a population:
  LISA “precursors”



Simulation strategy: Divide and conquer



MHD stage
for relaxation

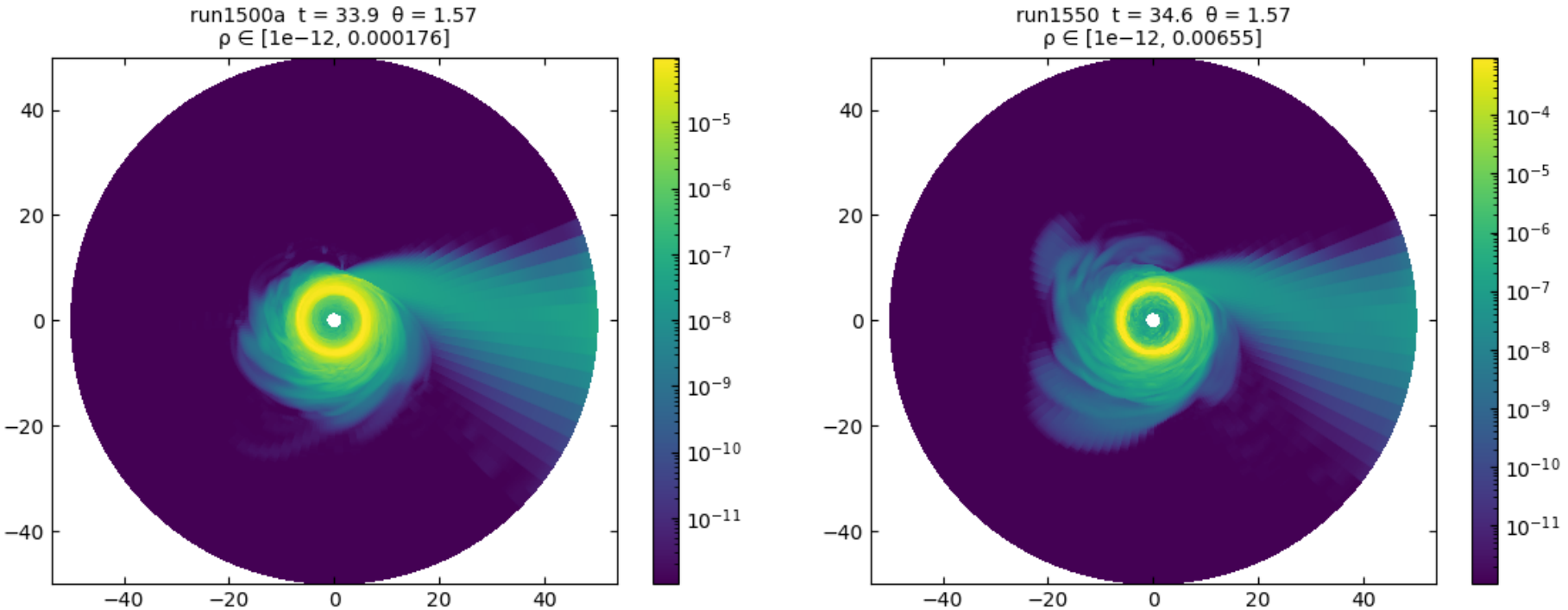
⇓

RMHD stage

MHD versus RMHD: Midplane slice

‼PRELIMINARY‼

MHD ⟹ RMHD

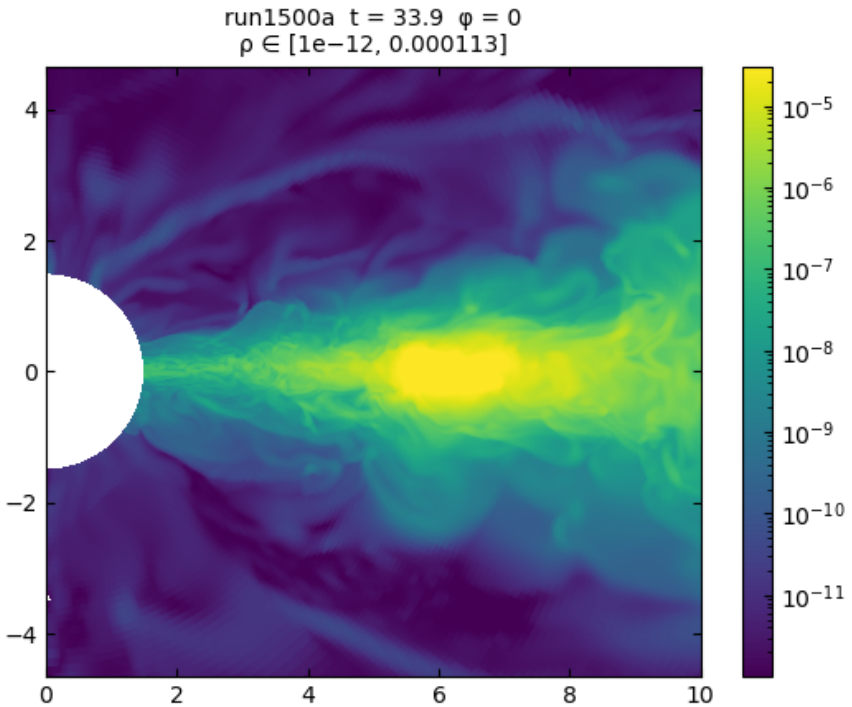


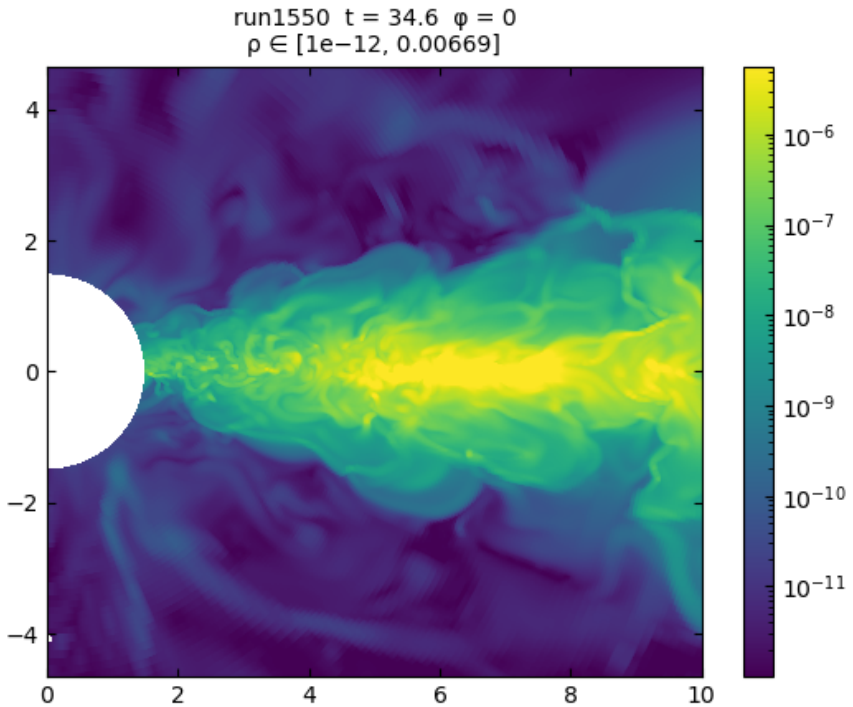
minidisk forms within ~ 1 binary orbit (~ 48 minidisk orbits)
and accumulates mass continuously

MHD versus RMHD: Poloidal slice

‼PRELIMINARY‼

MHD ⟹ RMHD

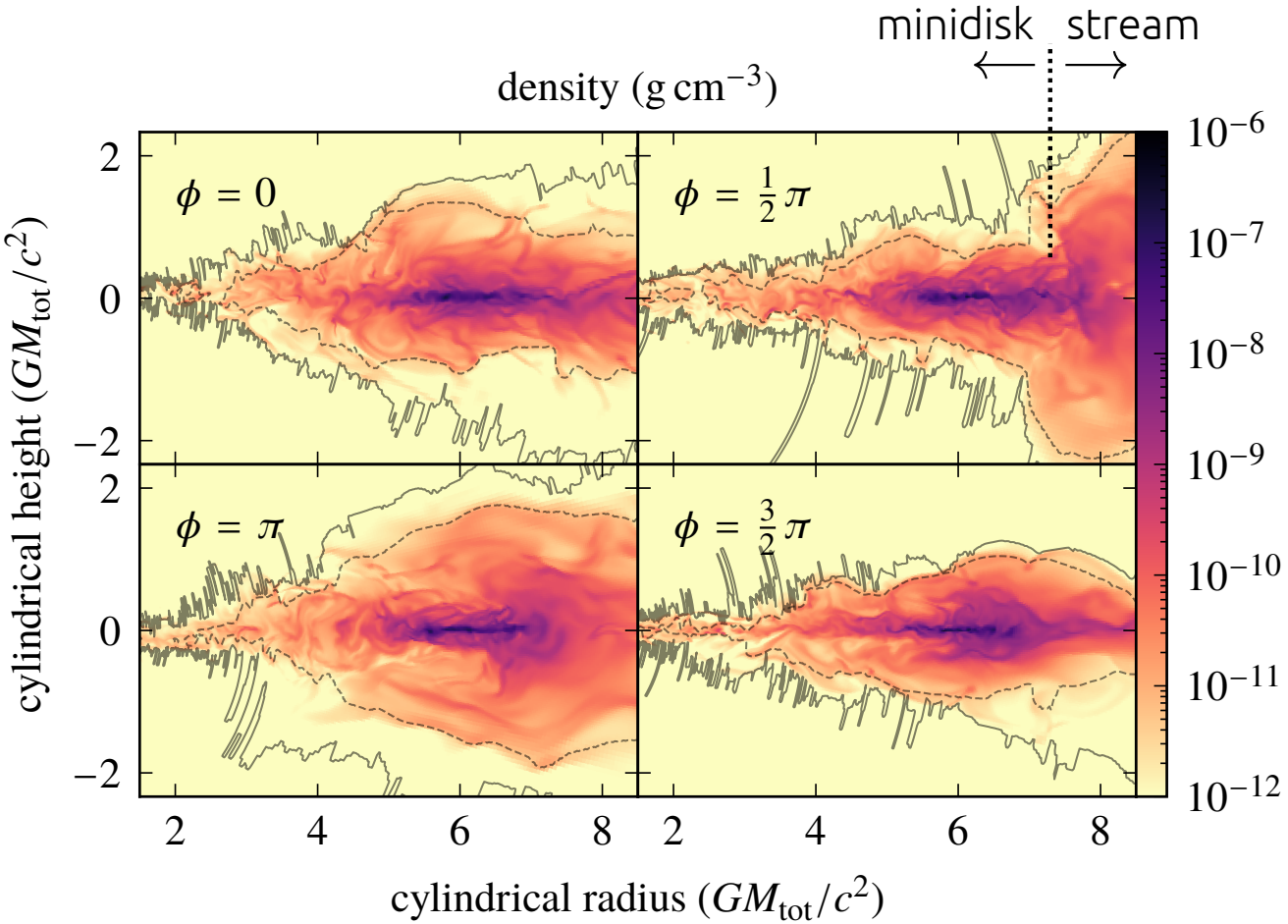




minidisk is thin and exhibits small-scale features
especially in RMHD

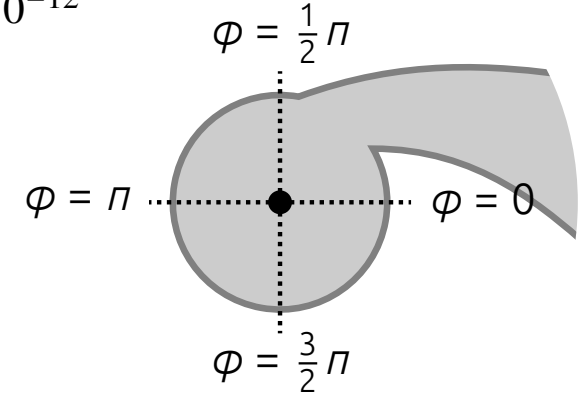
Density

!!PRELIMINARY!!



solid line:
effective photosphere

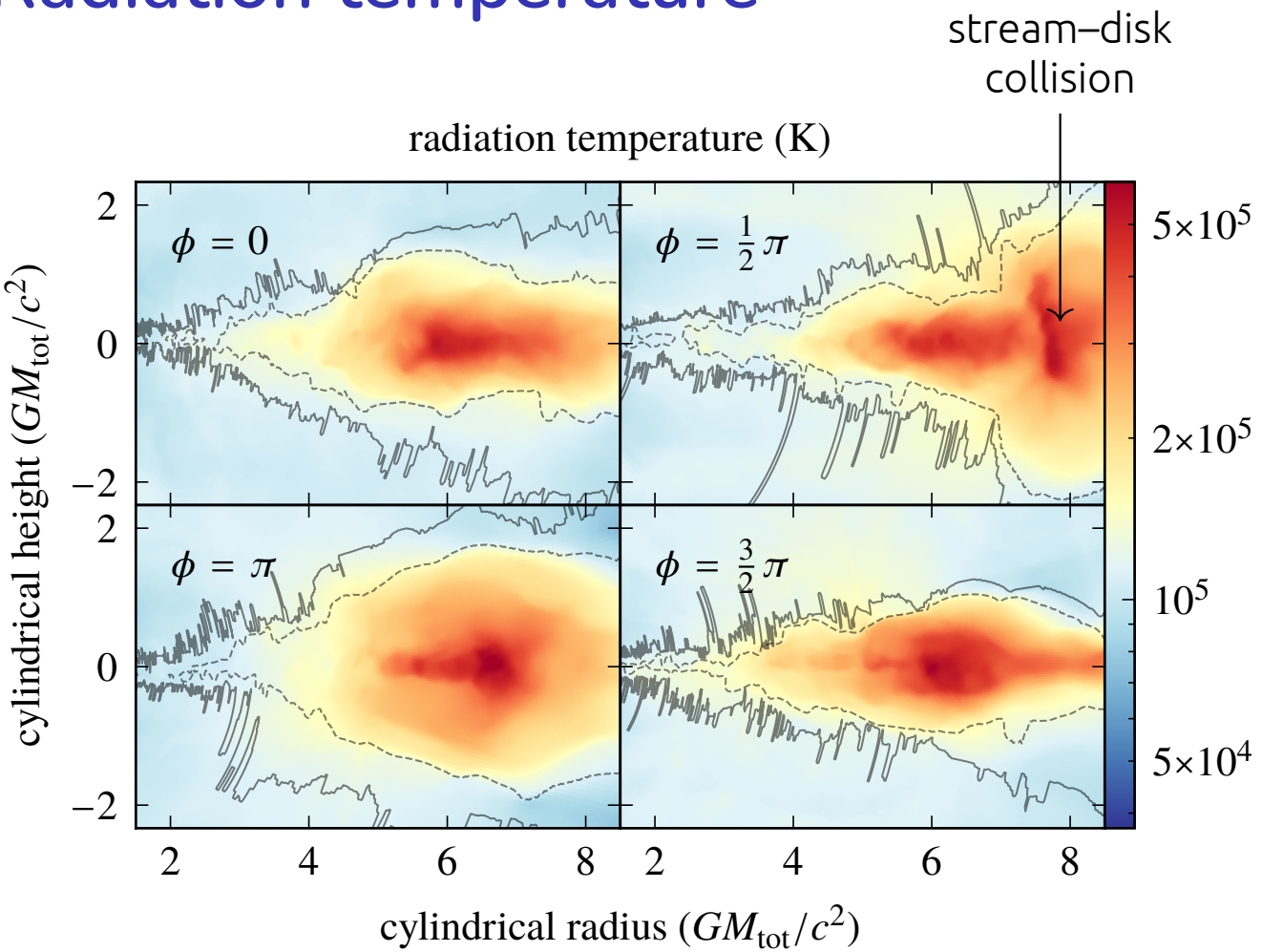
dashed line:
scattering photosphere



minidisk is dense and thin
with strong nonaxisymmetry

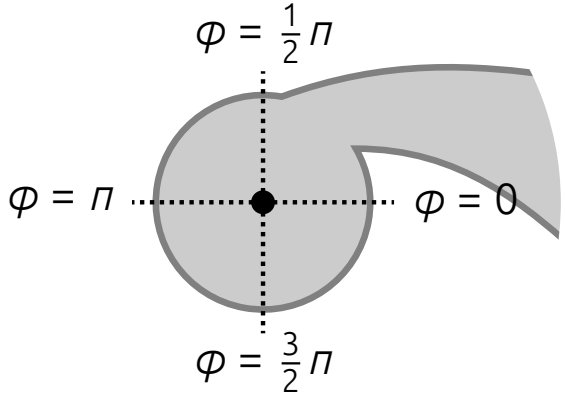
Radiation temperature

!!PRELIMINARY!!



solid line:
effective photosphere

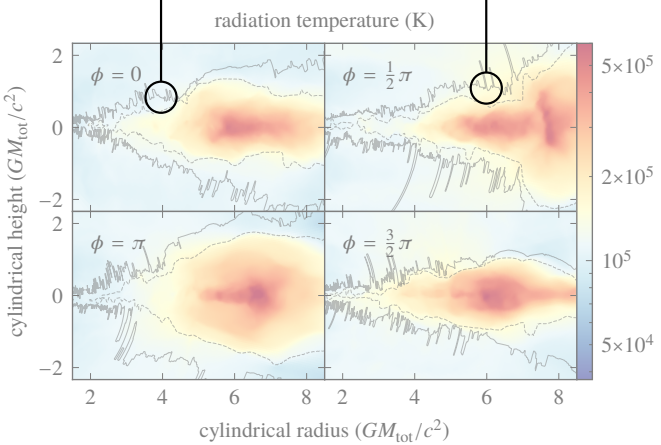
dashed line:
scattering photosphere



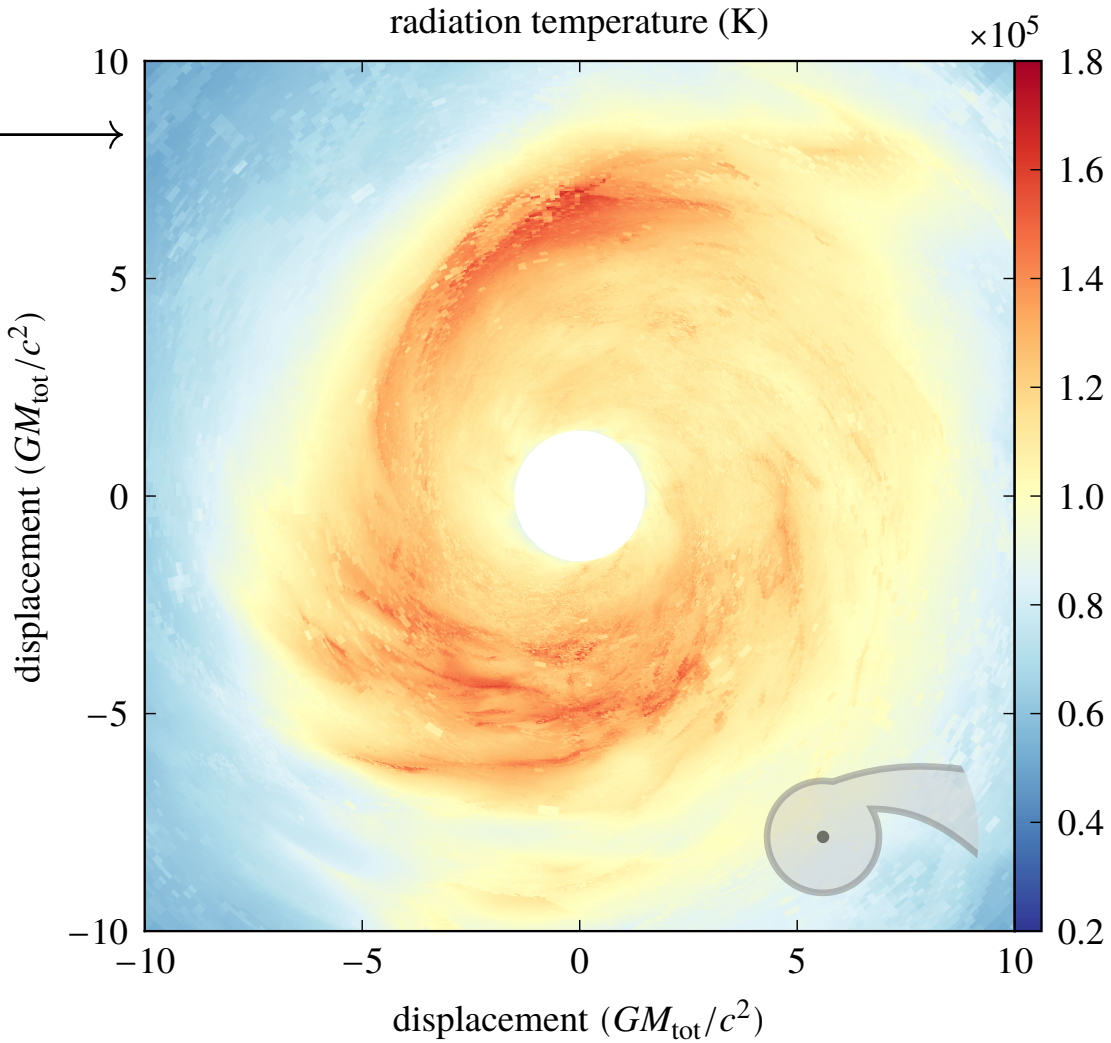
stream–disk collision generates
radiation which thermalizes

Photosphere temperature

!!PRELIMINARY!!

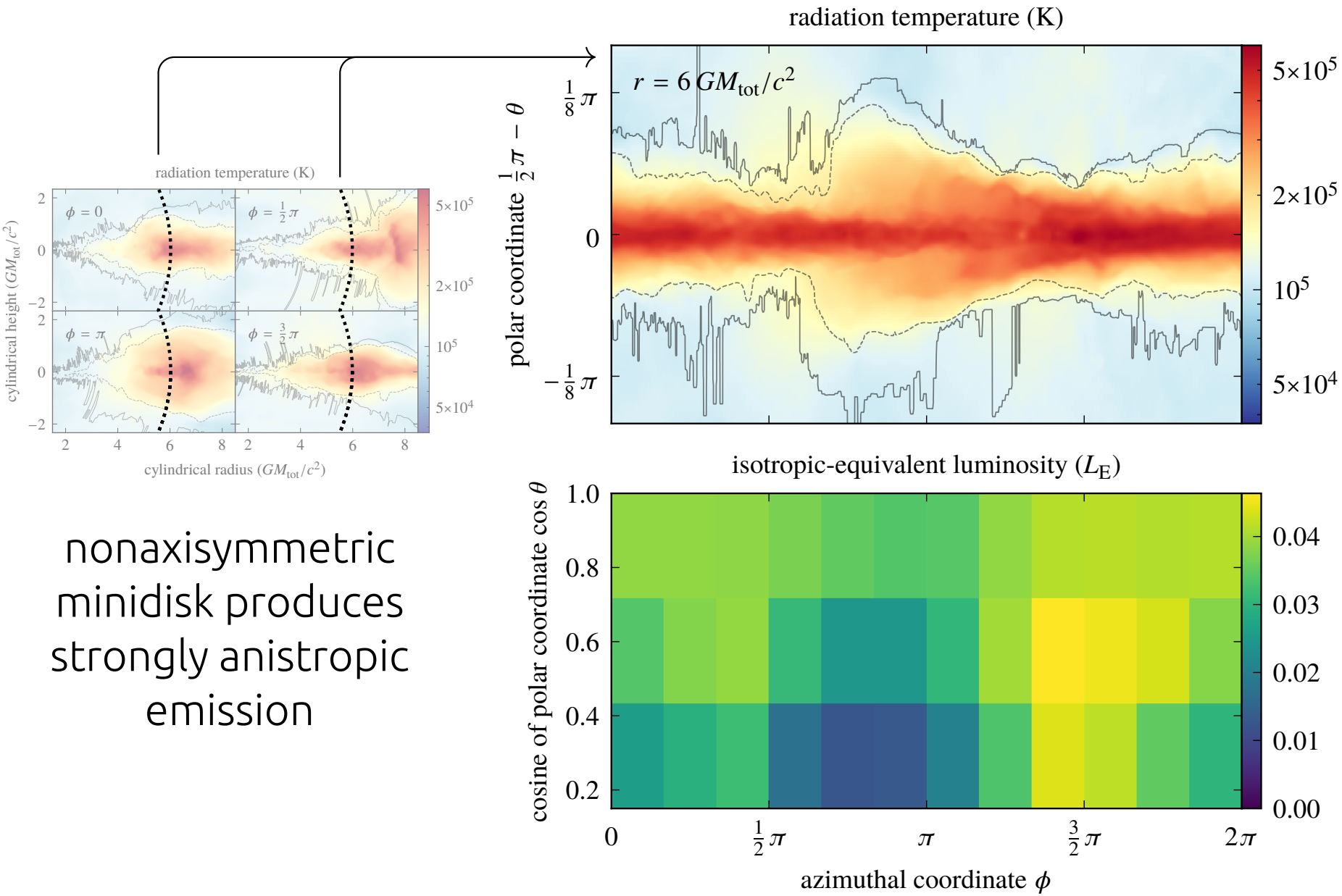


temperature on effective photosphere is ~ 1.5×10^5 K



Emission anisotropy

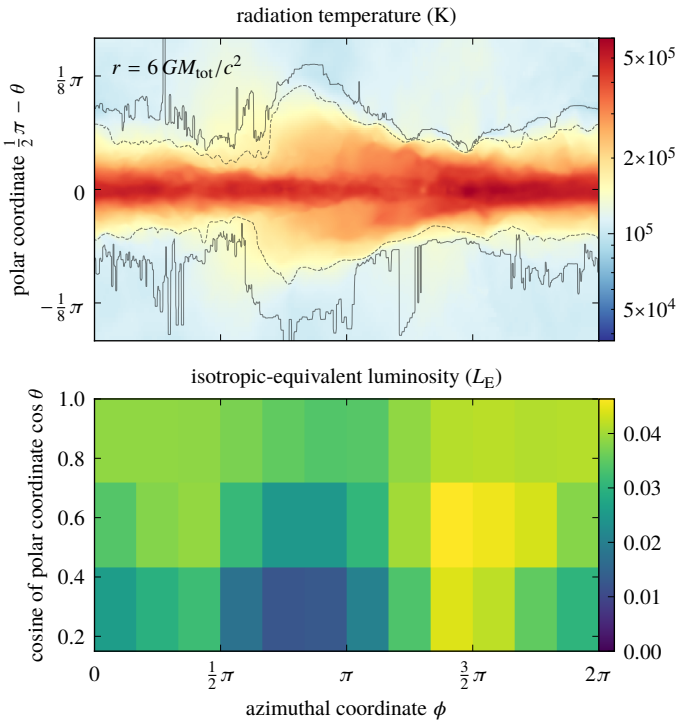
!!PRELIMINARY!!



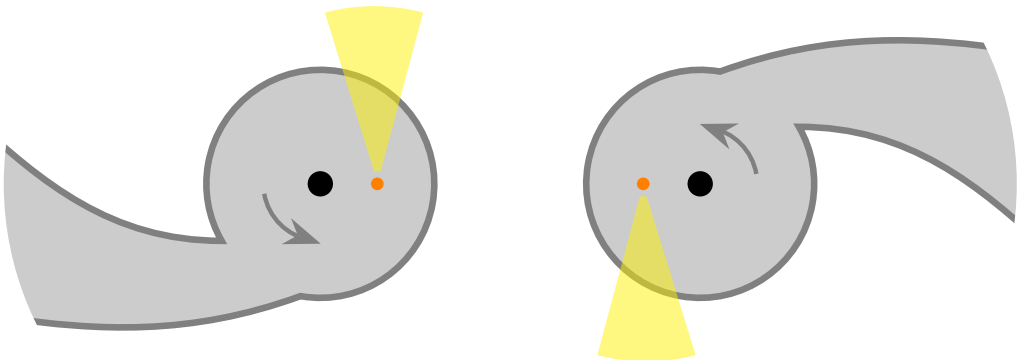
nonaxisymmetric minidisk produces strongly anistropic emission

Luminosity periodicity

!!PRELIMINARY!!



(not to scale)

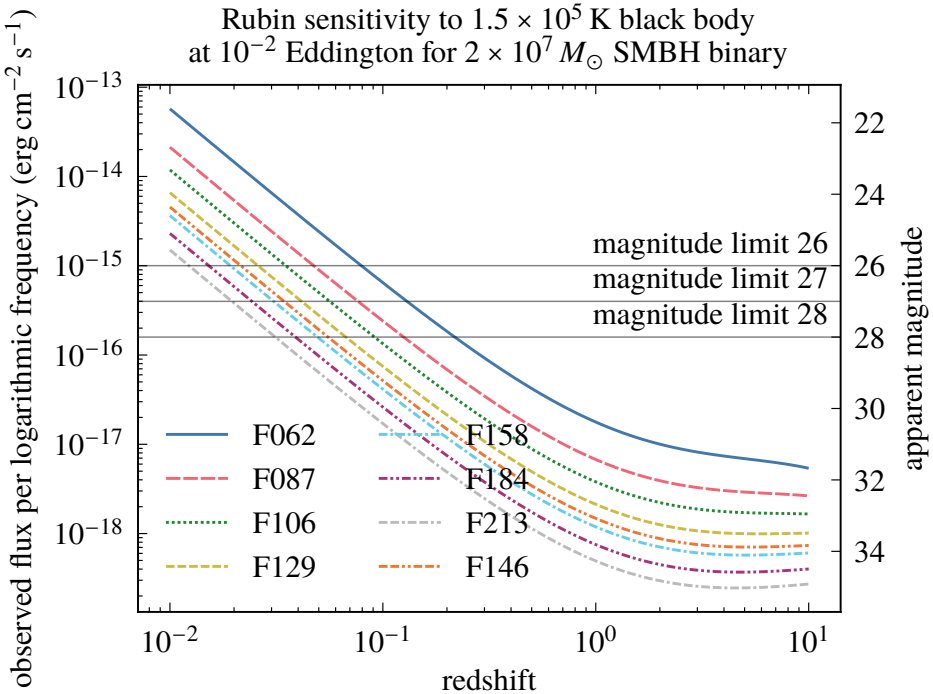


anisotropic emission leads to
luminosity periodicity
even for wide binaries

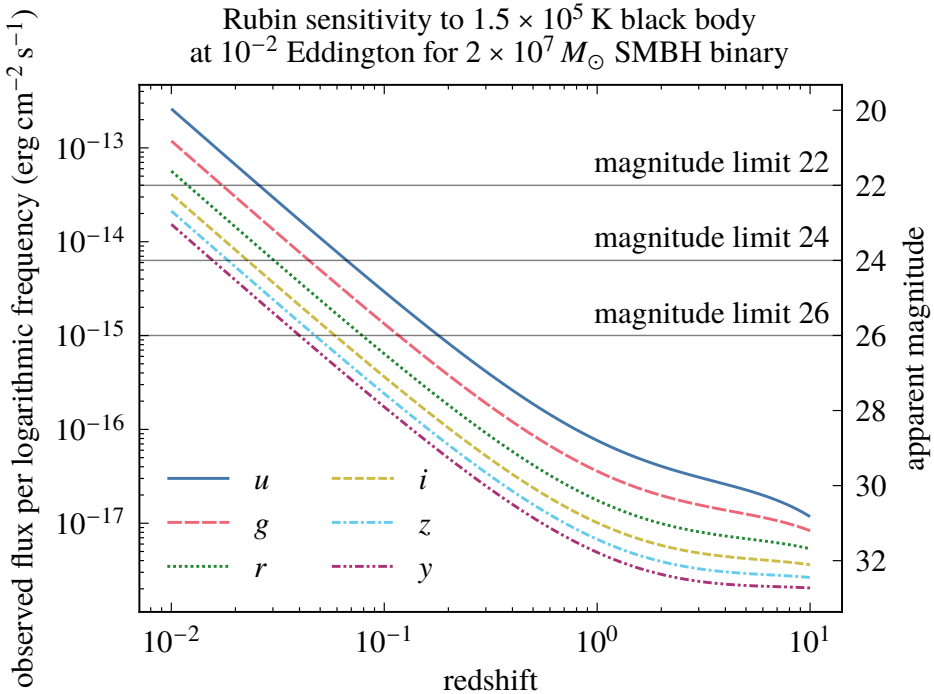
Observational prospects

‼PRELIMINARY‼

Roman HLTDS



Rubin



detectable in the local universe by transient surveys

Conclusions

studying the more numerous LISA “precursors” today
prepares us for actual LISA mergers ~ 10 years from now

EM predictions at all merger stages require
self-consistent, state-of-the-art RMHD simulations

Conclusions

!! PRELIMINARY !!

temperature

- minidisks radiate thermally at $\sim 1.5 \times 10^5$ K
- radiation from stream–minidisk collision may be thermalized, not in X-rays

periodicity

- strongly anisotropic emission may be expected even at large separations
- binary orbital motion produces lighthouse effect