

Bringing LISA's Massive BH Binaries to Light: From RMHD Simulations to Observations

Tamara Bogdanović

Center for Relativistic Astrophysics Georgia Institute of Technology

Edwin Chan (GT)

Shane Davis (UVA)



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Yan-Fei Jiang (CCA)

Vishal Tiwari (GT)

Tamara Bogdanović

Center for Relativistic Astrophysics Georgia Institute of Technology



What will we learn from multi-messenger detections of MBHBs?

MBH formation and growth

Co-evolution of MBHs with their host galaxies





But close and merging MBHBs have not yet been definitively detected

Tests of cosmology and fundamental physics



The landscape of simulations

2D/3D Hydro ~10³-10⁴ orbits

3D MHD



Tiede et al. 20 (Talk by Haiman)



Most & Wang 24

More computationally expensive per binary orbit

Avara et al. 24 (Talks by Campanelli, Noble)

This talk



Simulating LISA precursors with RMHD

Use radiation MHD code Athena++ (Stone+ 20, Jiang+ 21)

$$q = 1$$
 $M_{tot} = 2 \times 10^7 M_{\odot}$
 $e = 0$ $a = 100 GM_{tot}/c^2$

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

- Non-spinning MBHs accreting at about $0.1 \, \dot{M}_{\rm Edd}$
- Simulate the circumbinary disk and mini-disk separately •





Structure of the circumbinary disk

- RMHD disk is thinner, denser, and more filamentary
- Inner-edge overdensity is less conspicuous among filaments

Tiwari, Chan, TB et al. 25 (arXiv:2502.18584)

Circumbinary disk: Light curve

• Light curve shows periodicity due to the binary and overdensity

Tiwari et al. 25

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• Light curve shows periodicities due to the binary and overdensity

Circumbinary disk: Radiation temperature

- Flung-out streams deposit energy at the inner edge producing radiation
- T_{rad} ~ 2x10⁴ K at the photosphere

Tiwari et al. 25

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Structure of the mini-disk

- RMHD mini-disk is thinner, denser and non-axisymmetric

Structure of the mini-disk

Chan, Tiwari, TB et al., in prep.

Mini-disk: Shape of the photosphere

• The non-axisymmetry in shape and temperature of the photosphere results in anisotropic emission of radiation

Mini-disk: Anisotropic emission

Mini-disk: Anisotropic emission

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• Anisotropic emission implies light curve periodicity even in the absence of relativistic Doppler boosting and lensing

Summary and the look ahead

- Produced the first RMHD simulations of MBHB accretion disks for a LISA precursor binary.
- They show some unique properties compared to those in MHD and hydrodynamic simulations.
- Preliminary analysis indicates that EM periodicities related to MBHB orbital period are present.
- What next? Explore more binary configurations. Provide more detailed predictions for the EM spectra and photometric light curves.
- In 10 years to LISA: Build a parametrized bank of the EM signatures (similar to the GW templates) that depend only on the input accretion rate + MBHB parameters needed for description of GWs.

Questions are welcome!

Tamara Bogdanović <u>tamarab@gatech.edu</u>

Circumbinary disk: Thermal spectrum

- Flung-out streams deposit energy at the inner edge producing radiation
- T_{rad} ~ 2x10⁴ K at the photosphere

Tiwari et al. 25

 $T_{\rm rad} = (E_{\rm r}/a_{\rm SB})^{1/4}$

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• $T_{rad} \sim 10^5 \text{ K}$ at the photosphere

 $\sqrt{1}$

Stream-disk collision shock hidden by optically thick gas