PLASMA DYNAMICS AROUND ECCENTRIC BINARY BLACK HOLES

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INTRODUCTION

- Supermassive binary black holes (BBHs) form during galaxy merging.
- Orbits are stable and long-lasting.
- New NanoGrav results might predict a background of Supermassive BBHs.
- We can only detect signals from the disk, not the BHs.
- Understanding how the disk evolves helps multi-messenger observations.
- There have not been many simulations on BBHs with eccentric orbits.

OBJECTIVE

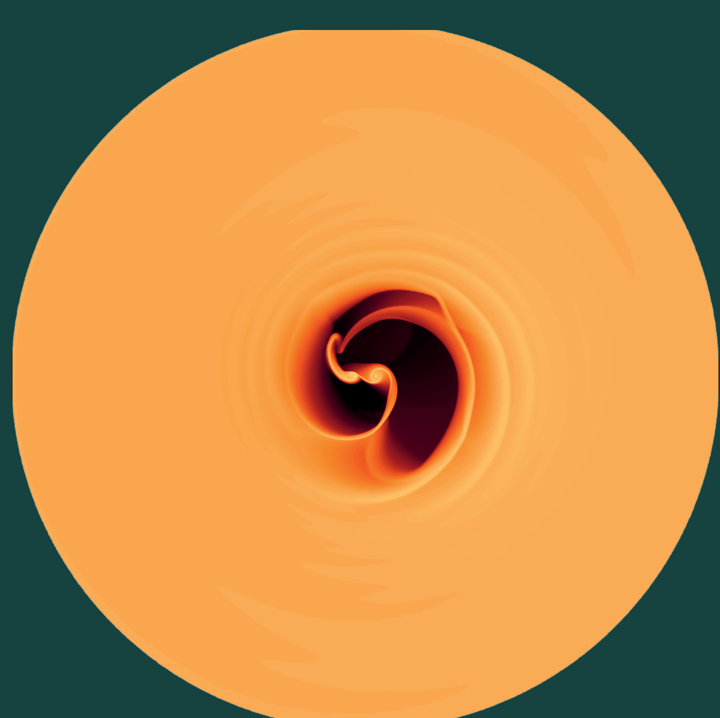
To explore how eccentric orbits affect gas around binary black holes (BBHs). We performed Python analysis mainly to answer these two questions:

1. Does a stable eccentricity point exist?
2. How to determine the radius of a minidisk and would its total mass reach a certain stable value?

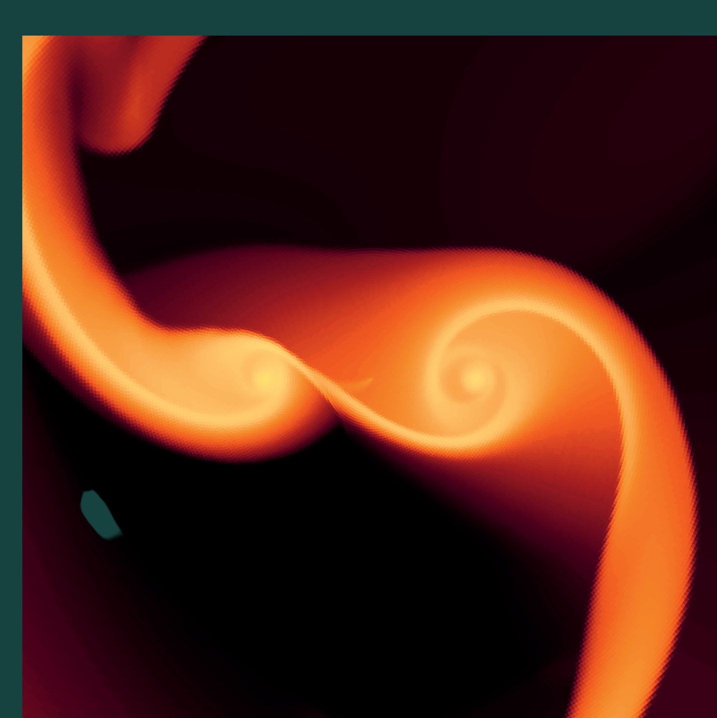
DISCO HYDRODYNAMIC CODE

A 3D Moving-Mesh Magnetohydrodynamics Code Designed for the Study of Astrophysical Disks.

- Efficient and accurate at evolving orbital fluid motion in two dimensions.
- The novelty of moving and evolving grids.
- Compatible with arbitrary disk models.
- We can manually set thermal, orbital, and gravitational parameters.
- Parameters include mass ratio, eccentricity, viscosity, cooling term (e. g. isothermal), sink rate, sink size, etc.



Circumbinary disk



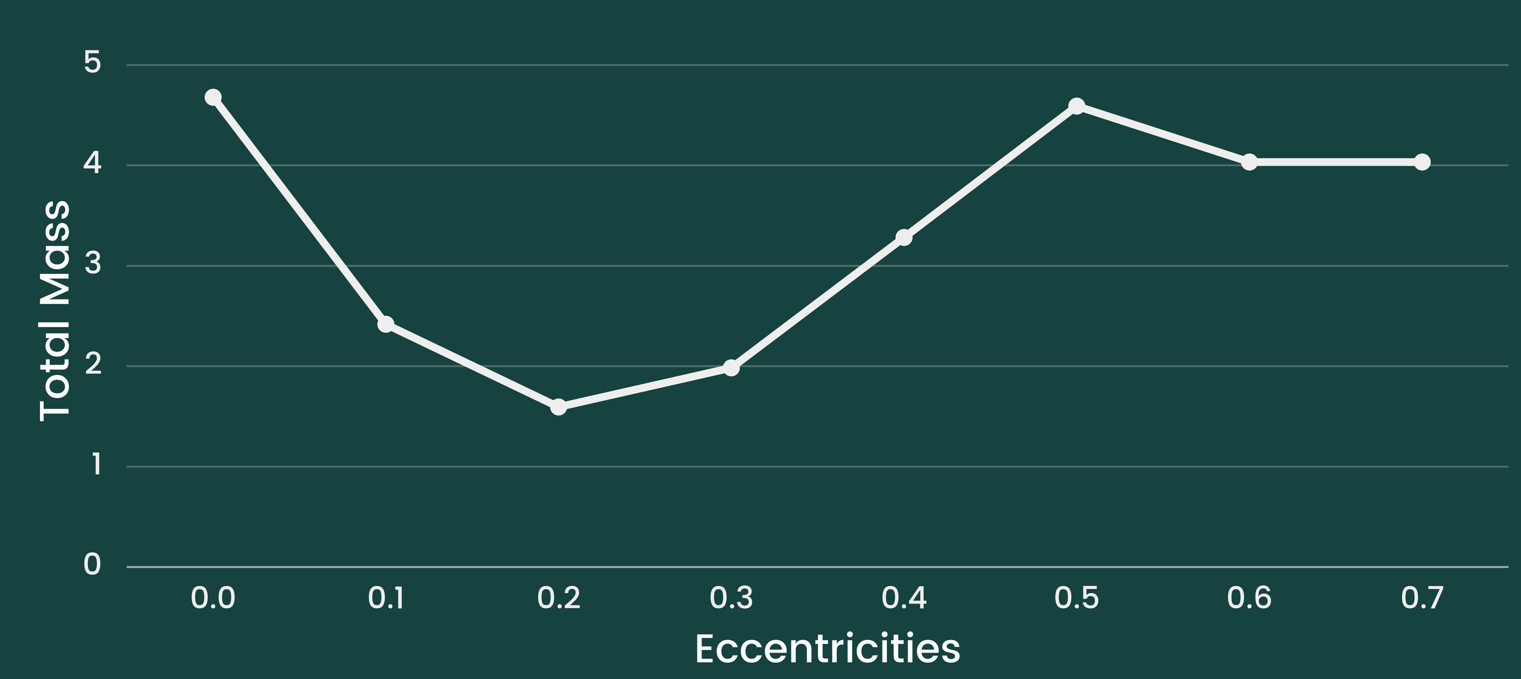
Minidisk streams

2D density plot of 0.4 eccentric run at 927th/1000 orbit in log scale.

MINIDISKS

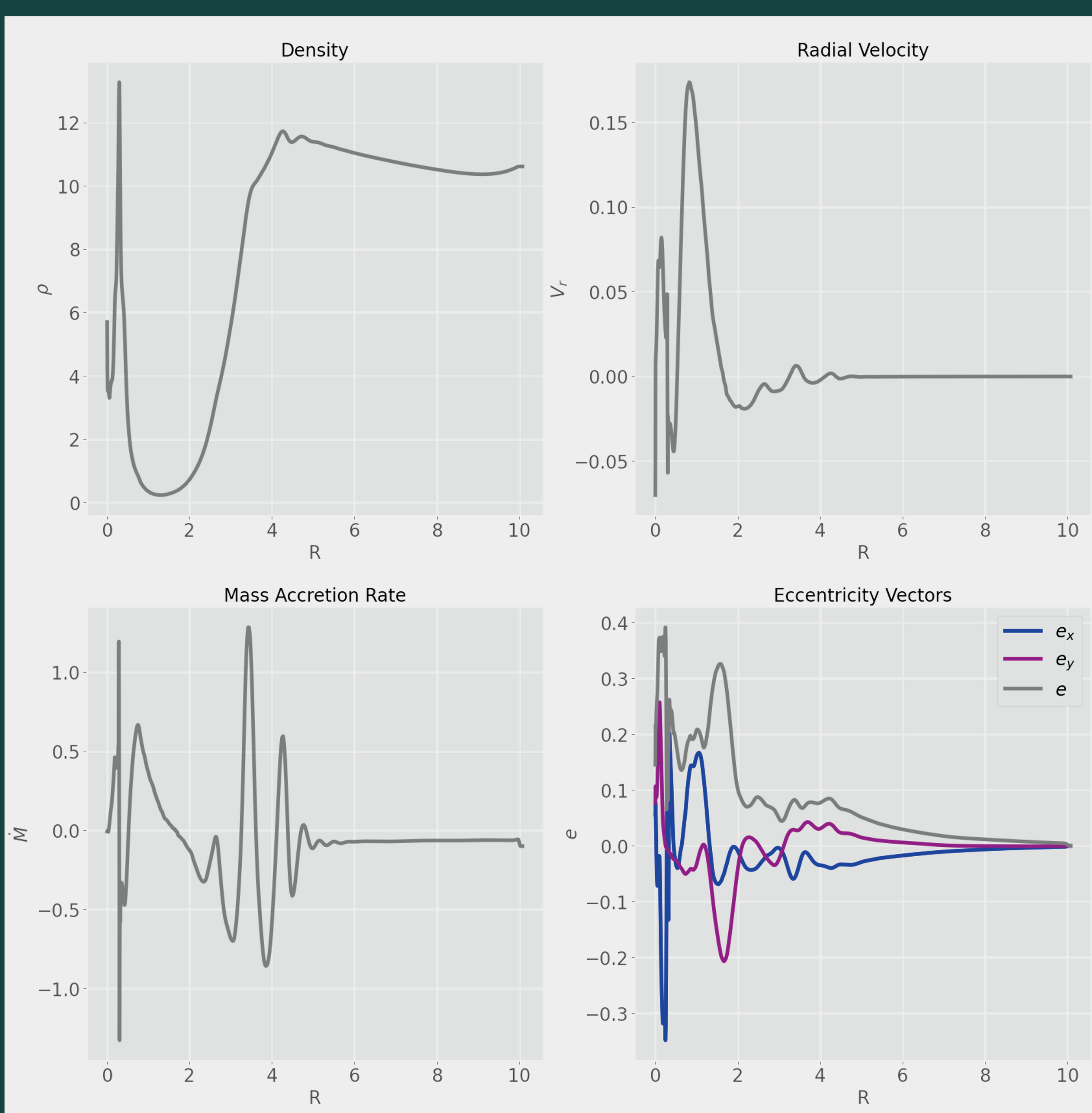
Minidisks contain the amount of gas gravitationally bound to only one black hole in a binary system. The exact radius of a minidisk can be difficult to determine. In this work, we use the minimal mean density as the cutoff.

The plot below shows the total mass of one of the minidisks in different eccentric runs averaged every 100 orbits and then averaged into one value. It only plots values in the range of 400th ~ 500th orbits. Resonating with the results below (white box), the total mass at 0.2 eccentricity is smaller than other eccentricities at this time step, potentially due to a large time derivative of eccentricity. This indicates that we need to increase the total time for each run so that they can reach steady state before stablizing the total mass.



ECCENTRICITY

BBHs with eccentric orbits have not been studied extensively. The time evolution of the orbits and minidisks is chaotic and creates overdensity regions that theoretical models do not predict. We have launched multiple eccentric runs on the Symmetry cluster with Python analysis to see if there is a stable eccentricity point, at which the eccentricity of the orbit stays in the same shape across a long time steps (~ 1000 orbits). However, it is worth pointing out that for all eccentricities, the cavities (dark low-density regions) around the binary precess and eventually become eccentric.



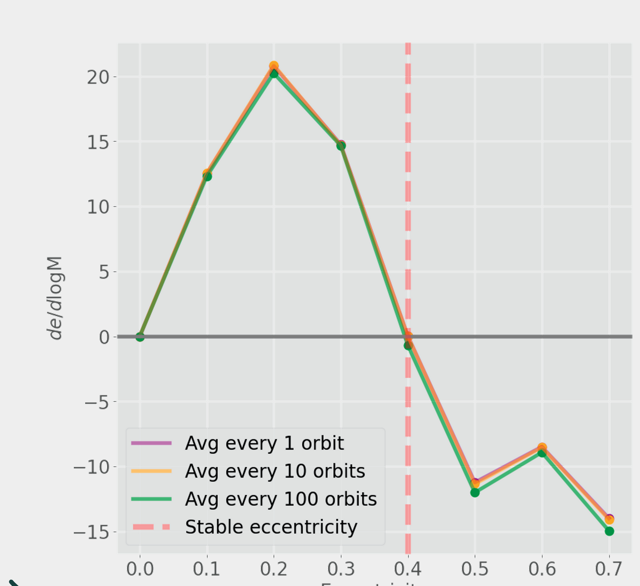
ORBITAL STABILITIES

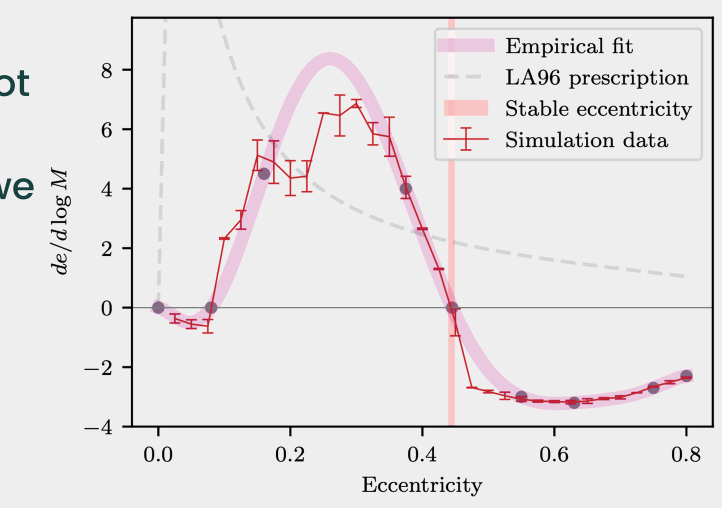
The left panel shows the quantities averaged for each time, as a function of the radius of the circumbinary disk for the last 300 orbits. As the density smooths out toward the outer edge, radial velocity and eccentricities vectors converge to 0, and the accretion rate reaches a steady state.

STABLE ECCENTRICITY POINT

The right panel shows the moving average of the time derivatives of eccentricities in the log scale. The top plot shows our result of 8 simulations of eccentricities 0 to 0.7. Compared to the published result on the bottom, we also obtained a stable eccentricity point where e ~ 0.4.

Simulation parameters (1000 orbits)
Eccentricity: 0.4
Viscosity: 0.001
Mass ratio: 1
Isothermal





Zrake, J., et al., (2021).

REFERENCES

1. Zrake, J., et al., (2021). Equilibrium Eccentricity of Accreting Binaries. The Astrophysical Journal.
2. Duffell, P. C. (2016). DISCO: A 3D MOVING-MESH MAGNETOHYDRODYNAMICS CODE DESIGNED FOR THE STUDY OF ASTROPHYSICAL DISKS.

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Scan QR code for a detailed animation of disk evolution.