The Kinematical Signature of Massive Black Hole Binaries

Yohai Meiron & Ari Laor

Department of Physics
Technion – Israel Institute of Technology

Stars and Singularities Workshop, Weizmann Institute of Science

December 8, 2009

Introduction

Binary Black Holes (BBHs) form when galaxies merge.

Do they actually *coalesce*?

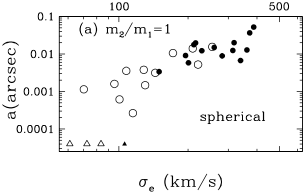
Theory

No, the binary reaches a stalling radius.

Yes, due to triaxiality, massive perturbers, gas. . .

Expected BBH stalling radii $\lesssim 0.''1$ even in nearby galaxies.

Yu (2002)



Can BBHs be detected even when *not resolved* directly?

Introduction

BBHs produce a *kinematic* signature on scales 5–10 stalling radii. This may be observed when the BBH is *unresolved*.

Method

Map the stellar kinematics near a BBH through scattering experiments (3-body simulations).

The "reverse" approach of previous studies.

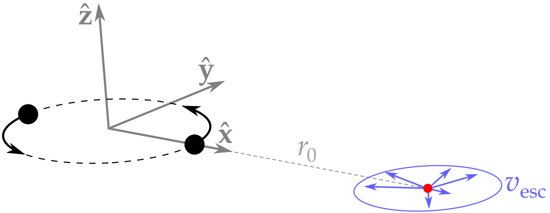
Assumption

The BBH is in a fixed circular orbit, embedded in a static *bulge potential*.

Stability Maps

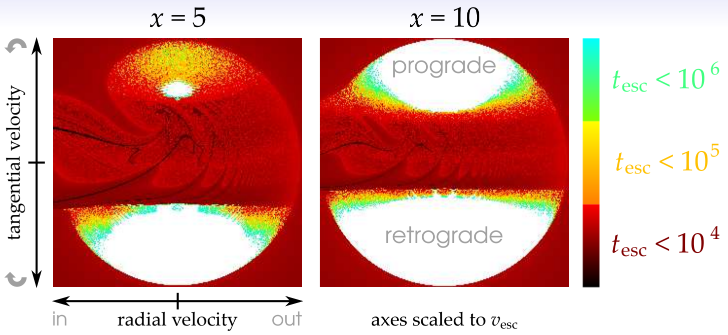
Cuts in phase space to probe regions of stability.

Similar concept in Wiegert & Holman (1997).



all possible velocity vectors at $\mathbf{r}_0$

Stability Maps



With decreasing r

- Tangential retrograde orbits are preferred.
- Volume of stable orbits shrinks.

independent of the initial conditions for phase space population.

Observed Kinematic Signature

Calculate the projected stellar velocity distribution for a binary at the *hard binary separation*:

$$a_h = \frac{q}{1+q}\frac{GM_\bullet}{4\sigma^2}$$

embedded in an *isothermal sphere*:

$$\rho(r) = \frac{\sigma^2}{2\pi G r^2}$$

where σ is determined from the *M-σ relation*.

Observed Kinematic Signature

Calculate the projected stellar velocity distribution for a binary at the *hard binary separation*:

$$a_h = \frac{q}{1+q}\frac{GM_\bullet}{4\sigma^2}$$

embedded in an *isothermal sphere*:

$$\rho(r) = \frac{\sigma^2}{2\pi G r^2}$$

where σ is determined from the *M-σ relation*.

Observed Kinematic Signature

Calculate the projected stellar velocity distribution for a binary at the *hard binary separation*:

$$a_h = \frac{q}{1+q}\frac{GM_\bullet}{4\sigma^2} \xrightarrow{q=1} \sim 1.6\ \text{pc}, \quad \xrightarrow{q=0.1} \sim 0.3\ \text{pc}$$

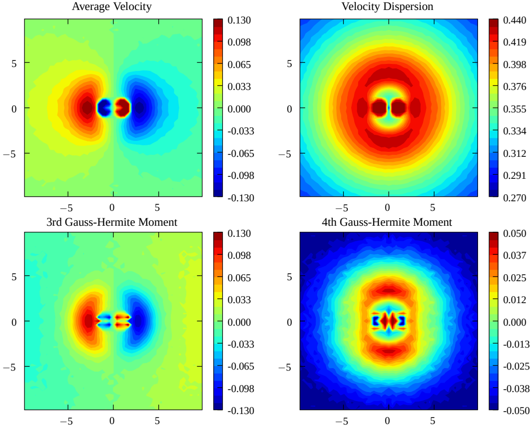
embedded in an *isothermal sphere*:

$$\rho(r) = \frac{\sigma^2}{2\pi G r^2}$$

where σ is determined from the *M-σ relation*.

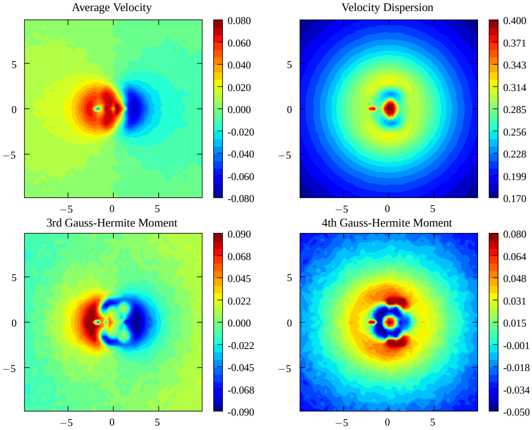
Kinematical Maps

Equal Masses



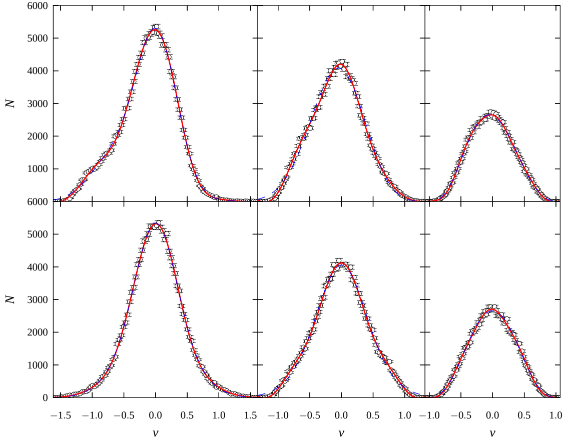
Kinematical Maps

1:10 Mass Ratio

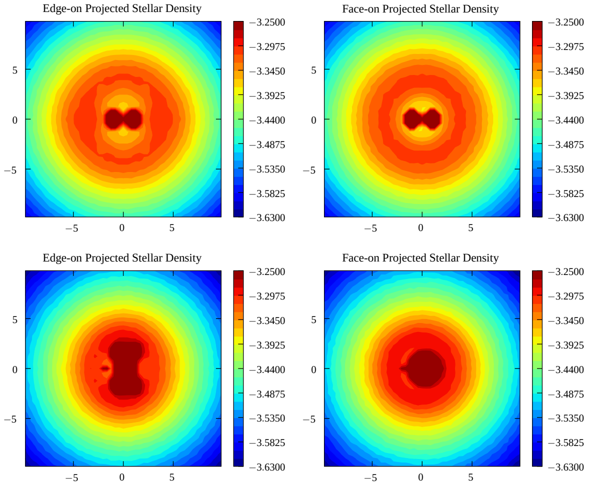


Example Line Profiles

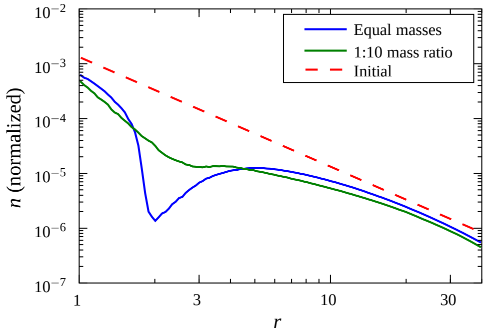
Equal Masses



Projected Density



Density Profile



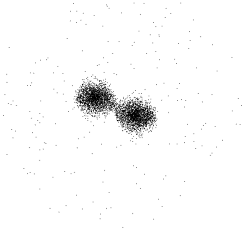
Ratio	N_i	Divergent	Crashing	M_{def}/M_{12}
1	6.8×10^7	.26	.013	1.01
0.1	8.2×10^7	.34	.026	0.45

Merritt (2006) found $M_{def}/M_{12} \approx 0.5$

Summary

The predicted BBH signature

- A counter-rotating torus.
- A dip in σ.



Observable?