Likelihood of tidal disruption events as second generation mergers of binary black holes

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Abstract

Our goal is to understand the likelihood of tidal disruption events (TDEs) occurring as a result of second generation binary black hole (BBHs) mergers. By examining this evolution pathway, we hope to uncover the methodology behind unidentified transients and optical counterparts to BBH LIGO alerts.

Tidal Disruption Events

TDEs occur when a star is within a tidal radius of a black hole (BH) and is ripped apart, leading to a bright transient and the remnants of the star being accreted onto the BH. Typically, these events are observed in the center of galaxies around massive and supermassive BHs at rates estimated to be between 10^{-5} to 10^{-4} annually. [arxiv:2104.14580] TDEs, outside of being used to study quiescent BHs, are also sources for very high energy neutrinos (arXiv:2005.05340) and are a ripe area for study of physical phenomena.

In this project, we are examining solar mass BHs, with estimated timescales for TDEs being on the order of magnitude of a week, and so with LIGO and Vera Rubin observations, we can examine new transients on short time scales.

Equations and Figures

The equations are adapted from arXiv:2009.10082, and utilize a reduced mass system in the figuring for the mergers. The figure below is a depiction of the system, with the inspiraling BBHs and the star at the center at orbital phase ψ.

$$r = \frac{a(1-e^2)}{1+ecos\psi}$$

$$v = \sqrt{G(M+m)(2/r-1/a)}$$

$$\mathcal{E} = -G(M+m)/2a$$

$$\ell^2 = G(M+m)a(1-e^2)$$

$$sin\alpha = \frac{\ell}{vr} = \frac{1+ecos\psi}{\sqrt{1+2ecos\psi+e^2}}$$

$r'_p(a, e, \theta, \phi, \alpha, y) < r_T$ where $r'_p = a'(1-e')$
conditions $\alpha \not\approx \pi$ and $\theta \approx \pi$ otherwise a merger does not occur.

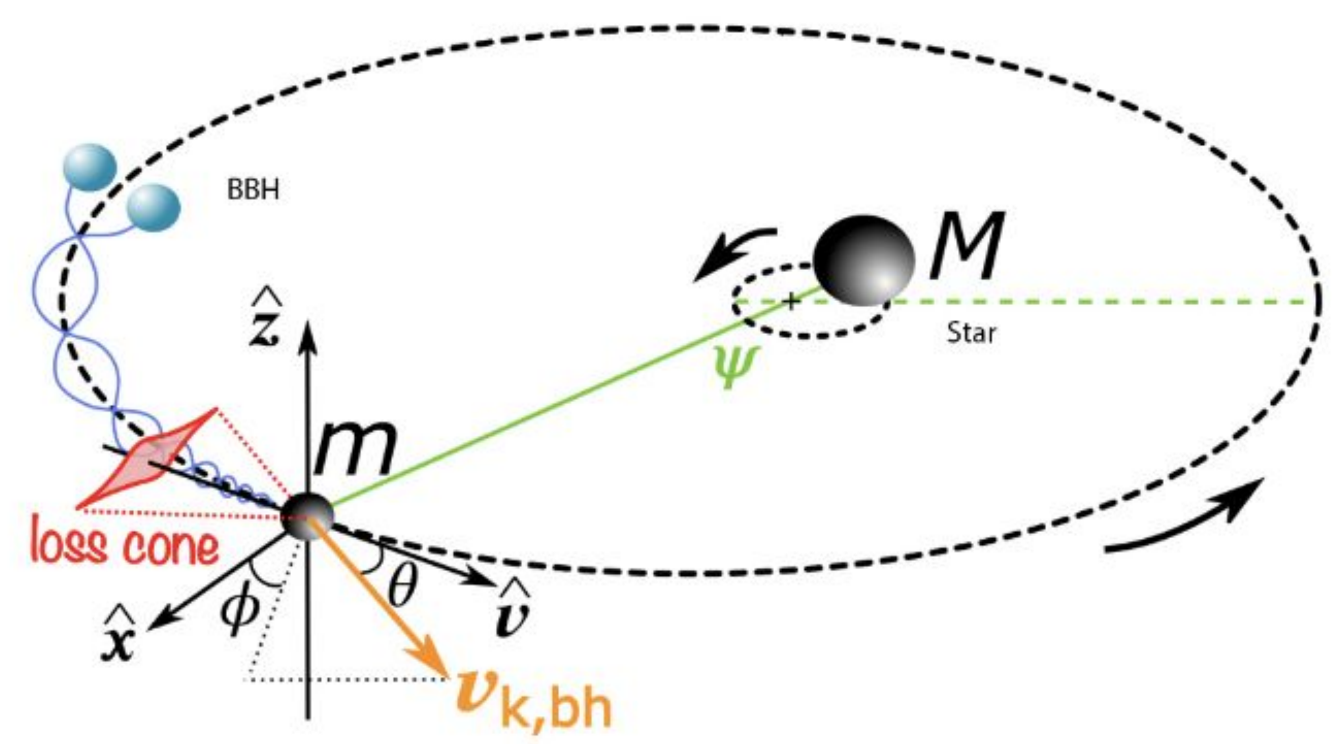
$$\mathcal{E} = \frac{1}{2}(\mathbf{v}+\mathbf{v}_k)^2 - \frac{G(M+m)}{r} = \mathcal{E} = 1/2v_k^2 + vv_k cos\theta$$

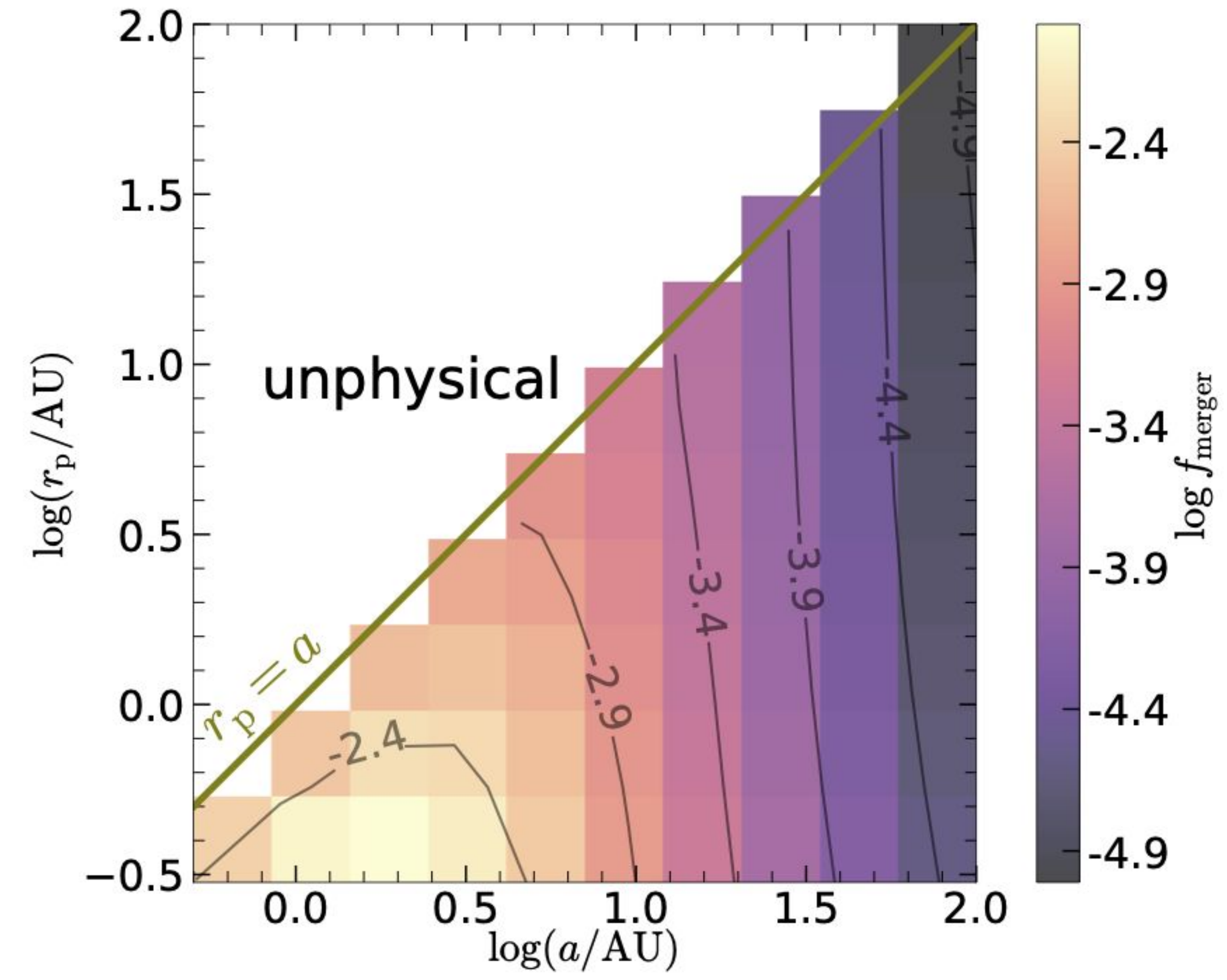
$$\frac{a}{a'} = .1 - (y^2 + 2ycos\theta)(2a/r - 1)$$

where angular momentum for a reduced mass system is $\mathbf{r} \times \mathbf{v}_k$

$$\frac{a'(1-e'^2)}{a(1-e^2)} = \frac{y^2 sin^2\theta sin^2\phi}{sin^2\alpha} + [1 + y(cos\theta - cot\alpha sin\theta cos\phi)]^2$$

$y \equiv v_k/v \;\; e' \approx 1$
$2r'_p \approx a(1-e^2)[\frac{y^2 sin^2\theta sin^2\phi}{sin^2\alpha} + [1 + y(cos\theta - cot\alpha sin\theta cos\phi)]^2] r_T$
$2r'_p \approx \frac{y^2 sin^2\theta sin^2\phi}{sin^2\alpha} + [1 + y(cos\theta - cot\alpha sin\theta cos\phi)]^2 < \frac{2r_t}{a(1-e^2)}$
where $f_c \equiv \frac{2r_t}{a(1-e^2)}$ for values of r: $r_t \sim r_\odot$





Analysis

For isotropic cases, we find that at a distance of 1 AU, there's a .003% likelihood of these events occuring. Despite these TDEs being fairly unlikely, this is the worst case scenario with kicks being distributed in isotropic ways. Additionally, with the frequency of BBH LIGO alerts, we should be able to observe these TDEs.

Future Work

We are currently working on restricting inclination angle between the star and the BBH system in order to maximize the likelihood of events occuring and research the impact on inclination angle on frequency of events.