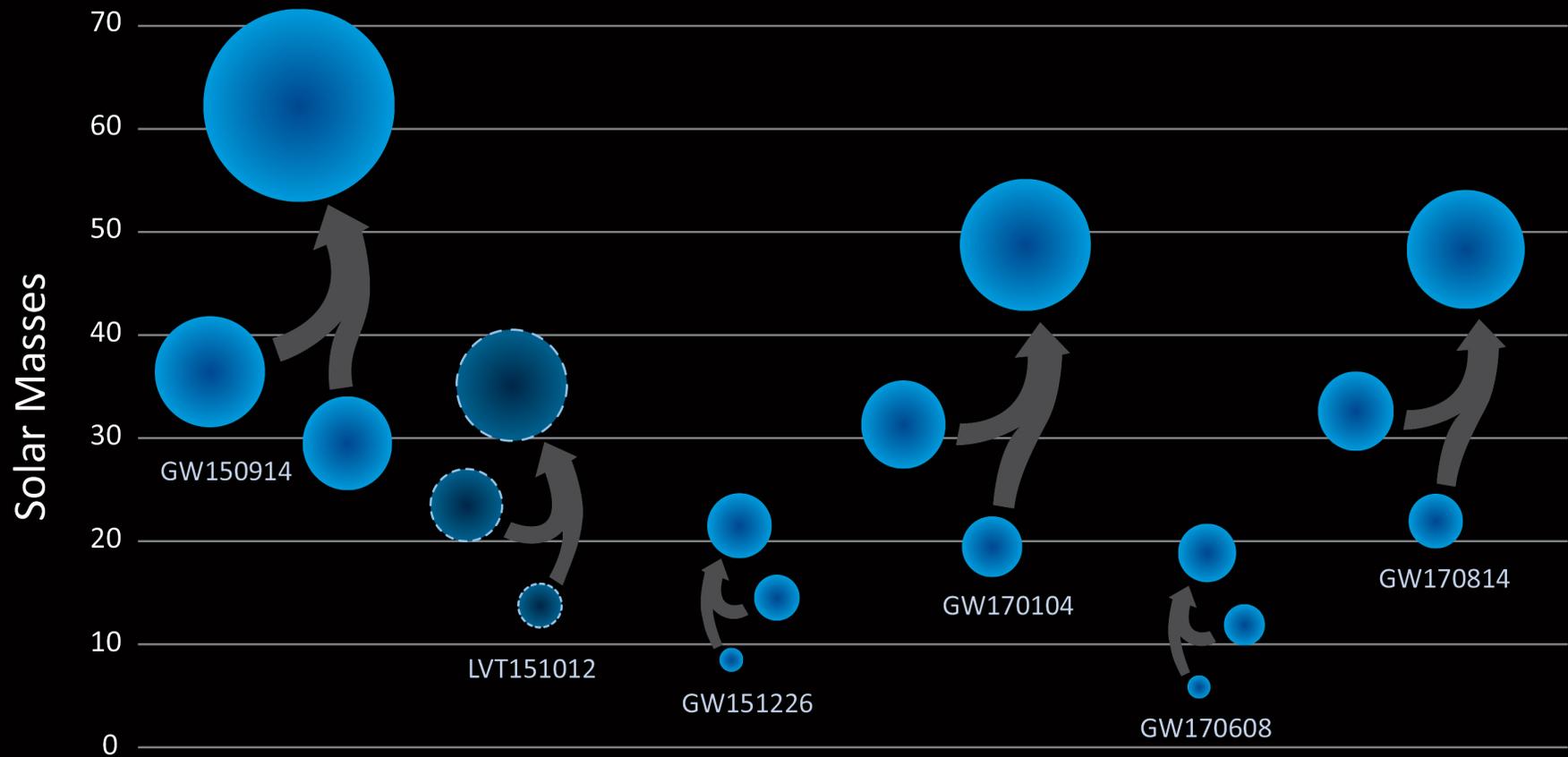


BH mergers induced by tidal encounters with a galactic centre MBH

Shiho Kobayashi & Joseph John Fernandez



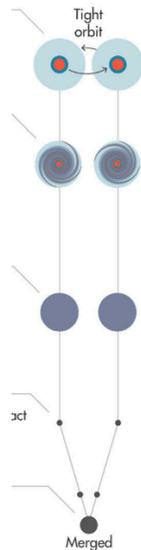
Known BH Mergers



Formation Models

- Isolated stellar field binaries

- Common-envelope
- Chemically homogeneous evolution

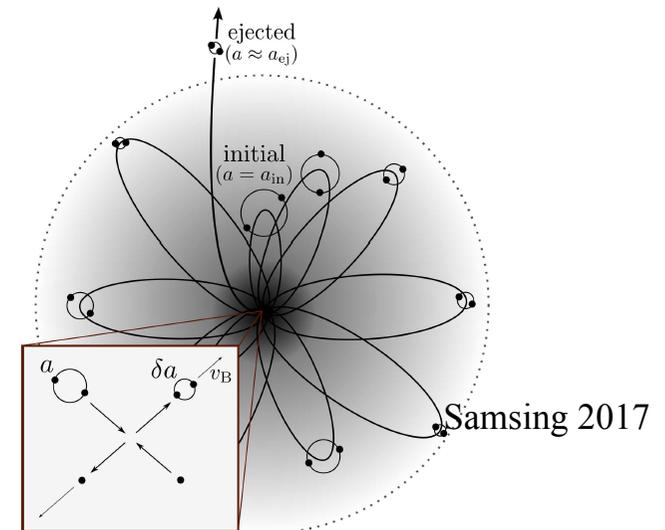


Phinney 1991; Belczynski et al. 2016
Mandel & de Mink 2016; Marchant et al. 2016

- Dynamical formation

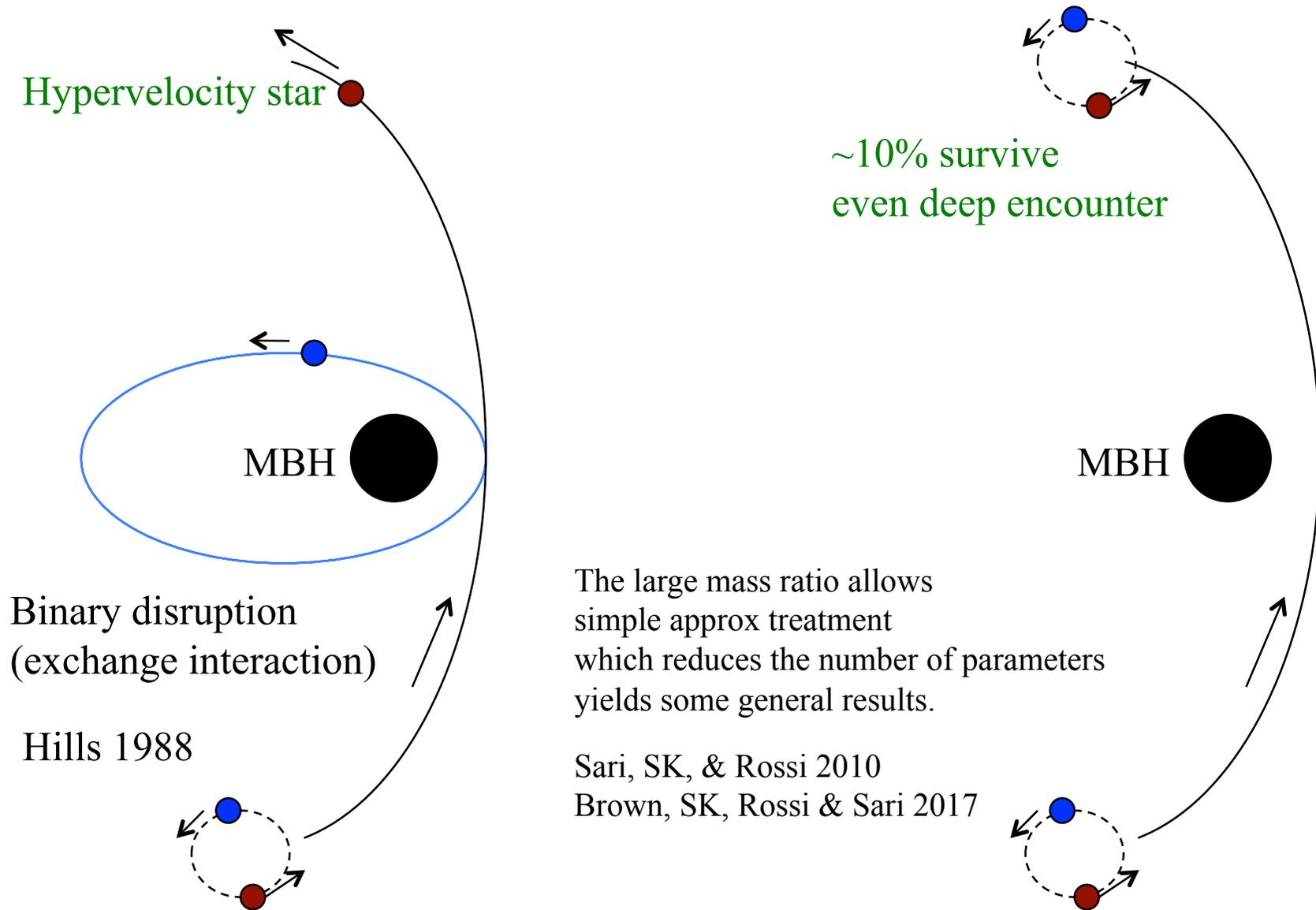
- Binary-single encounters in globular clusters/galactic nuclei
- Kozai-Lidov mechanism
- Fly-by

Bence Kocsis's talk

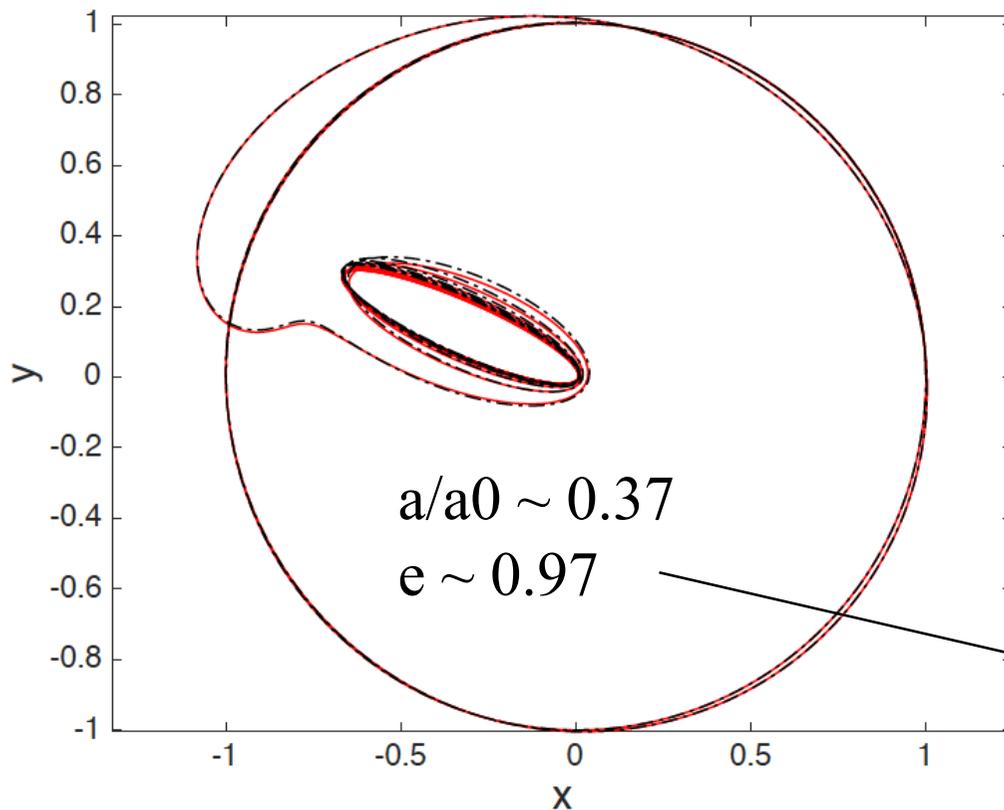


Wen 2003; Thompson 2011; Antonini et al. 2014;
Breivik et al. 2016; Rodriguez et al. 2016; Antonini & Perets 2012
vanLandingham et al. 2016; Silsbee&Tremaine 2107.

Another Dynamical Model



Orbit of the secondary in the primary comoving frame



GW merger timescale (Peters 1964)

$$T_{GW} = \frac{3}{85} \left(\frac{c^5 a_0^4}{G^3 m_1 m_2 m} \right) (1 - e_0^2)^{7/2}$$
$$= 1.2 \times 10^{14} \text{ yrs} \left(\frac{m}{20 M_{sun}} \right)^{-3} \left(\frac{a_0}{1 \text{ AU}} \right)^4 (1 - e_0^2)^{7/2}$$

The merger time becomes smaller by a factor of $\sim 10^6$.

Fernandez & SK 2018

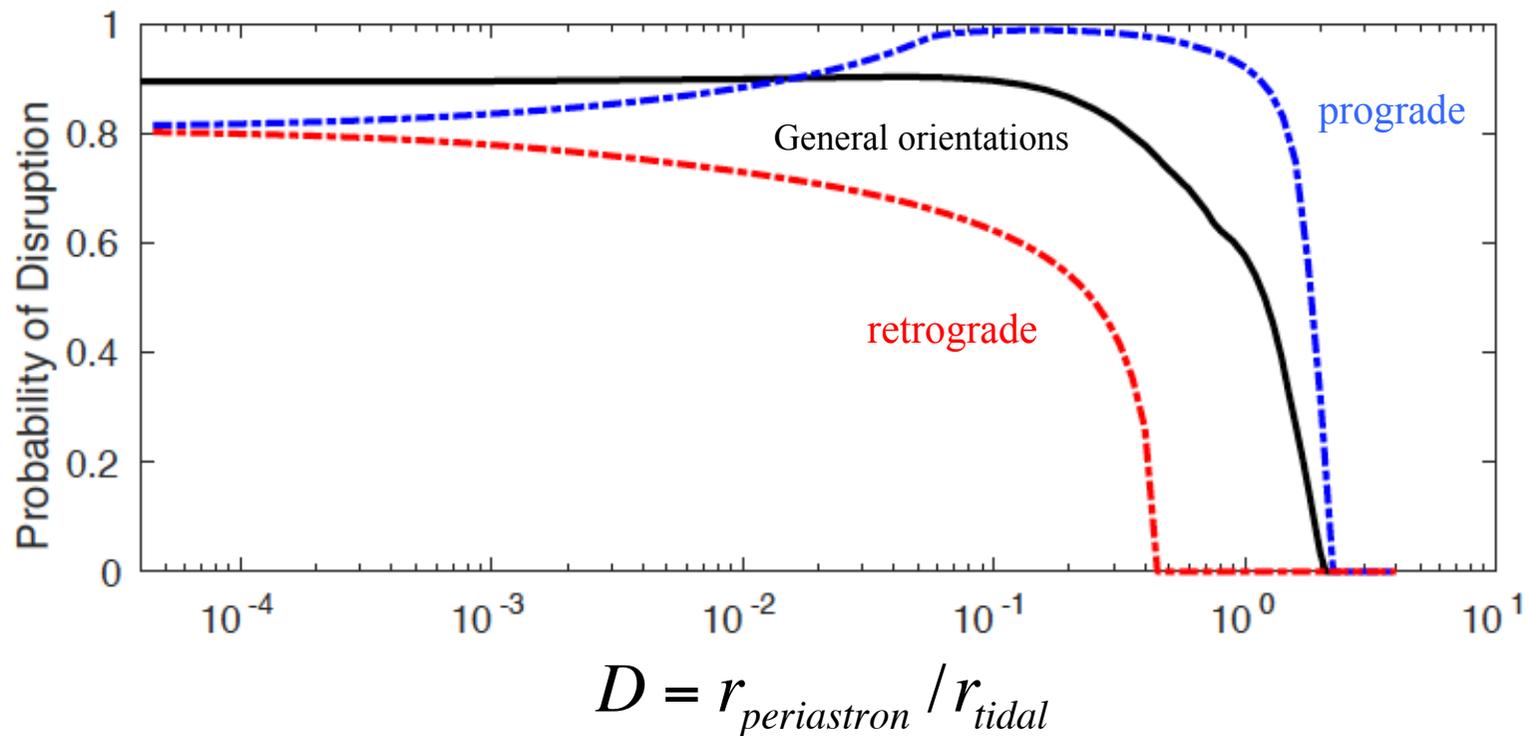
A restricted three-body problem

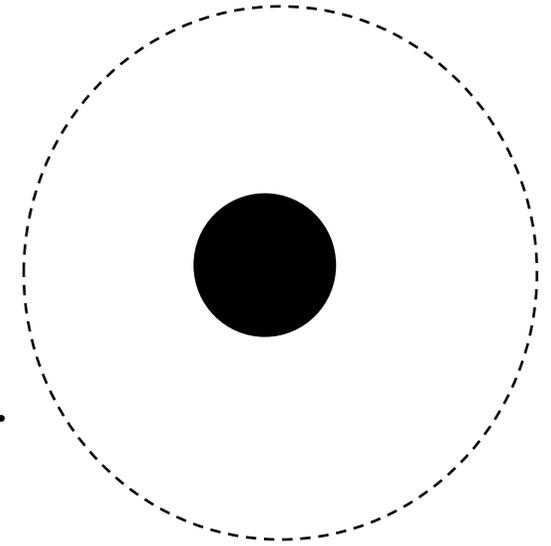
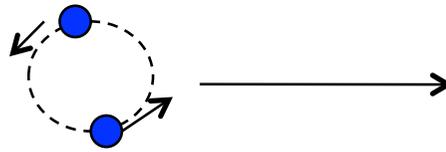
For $M/m \gg 1$, tidal encounters are characterized by just a few parameters.

Penetration factor $D \equiv R_{\text{periastron}} / R_{\text{tidal}} (= \beta^{-1})$

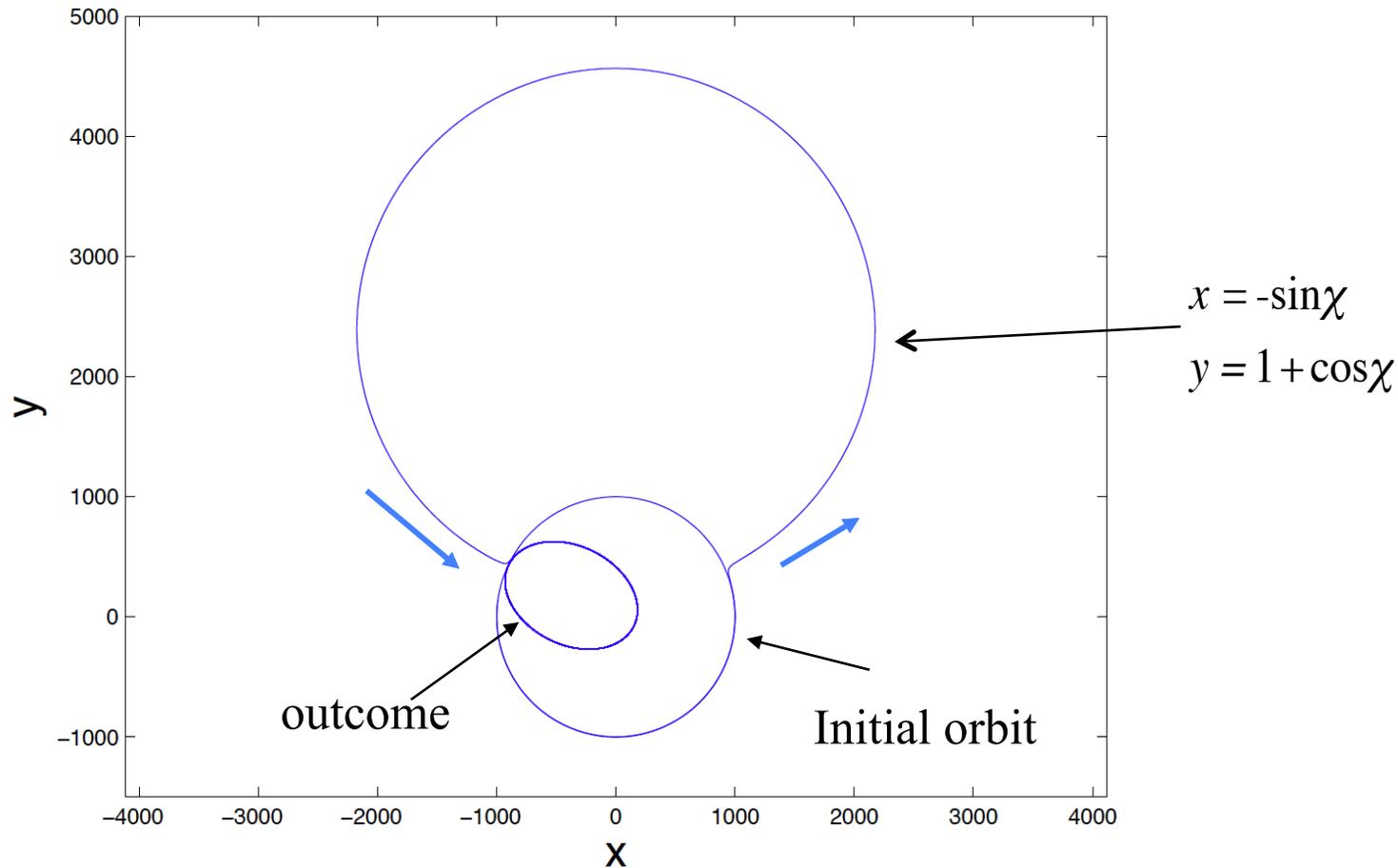
Binary orientation

Binary phase

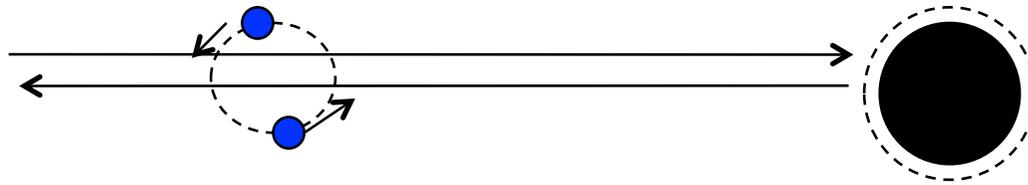




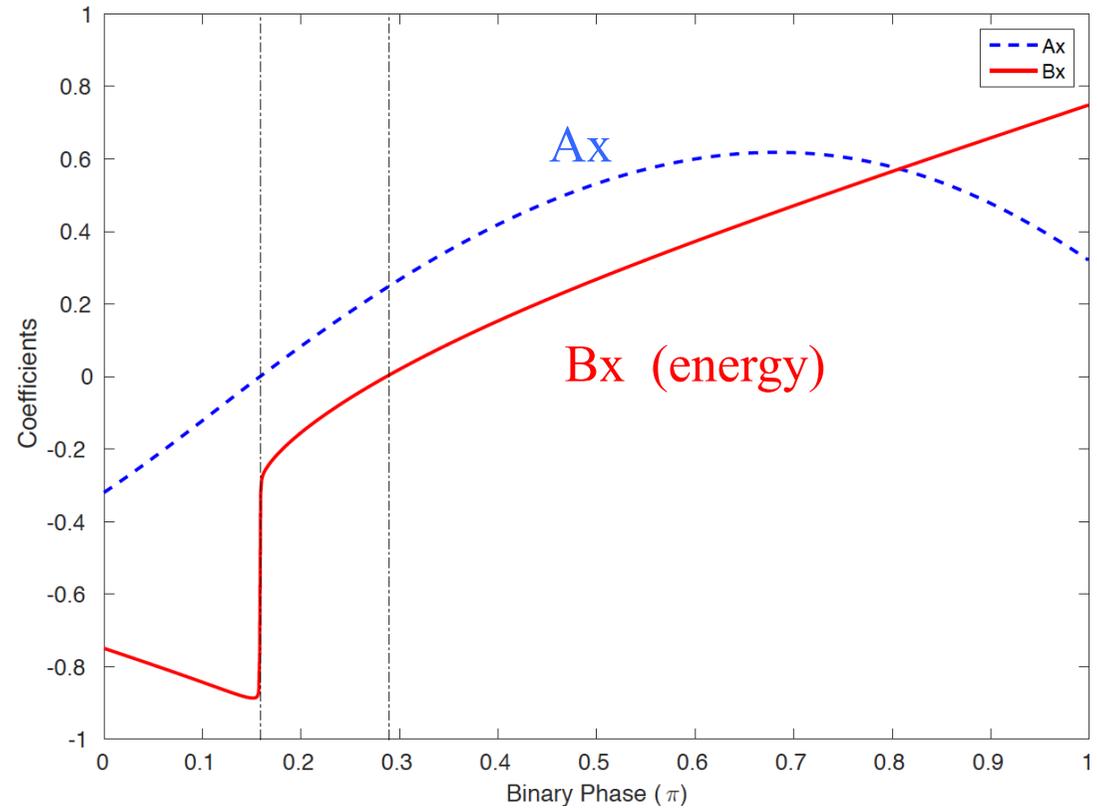
6 independent analytic solutions for $R < R_{\text{tidal}}$
 One of them dominates around the periastron passage.



Deep encounter (radial orbits)



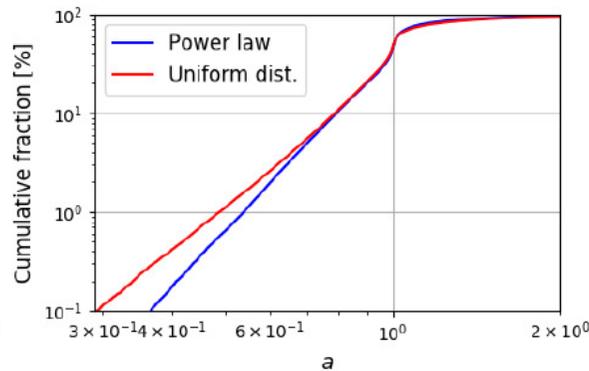
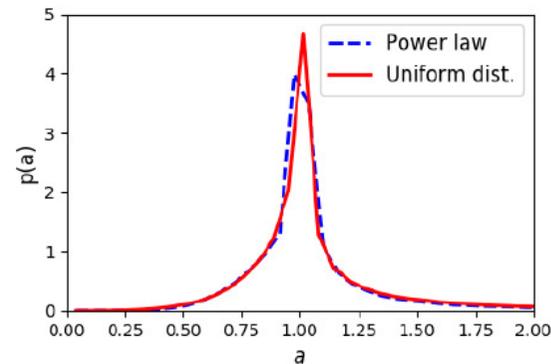
$$\begin{aligned}x(t) &= A_x |t|^{-1/3} + B_x |t|^{4/3}, \\y(t) &= A_y |t|^{1/3} + B_y |t|^{2/3}, \\z(t) &= A_z |t|^{1/3} + B_z |t|^{2/3}.\end{aligned}$$



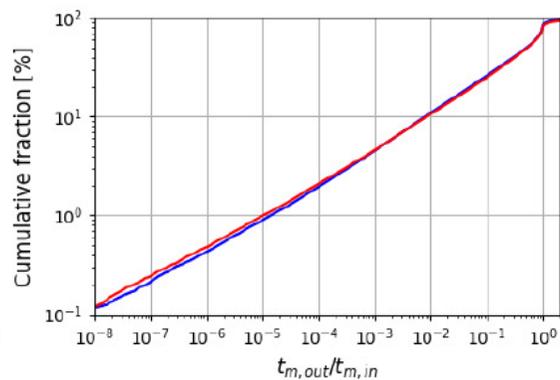
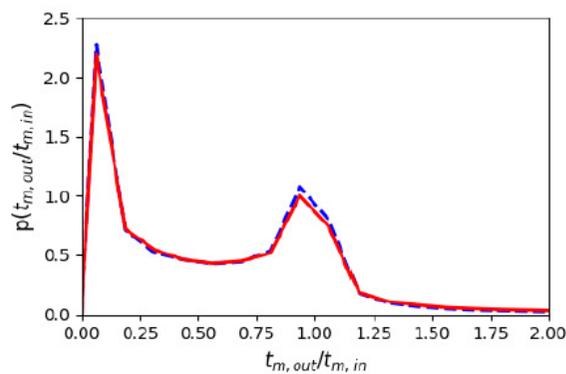
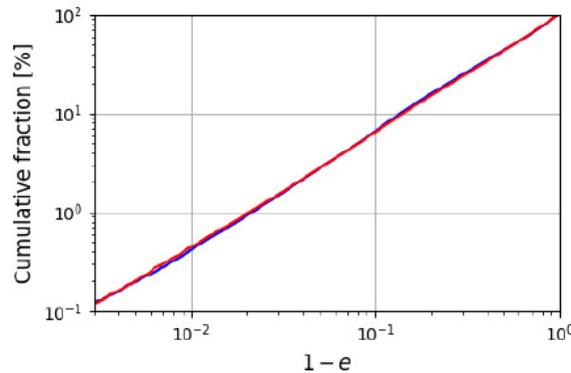
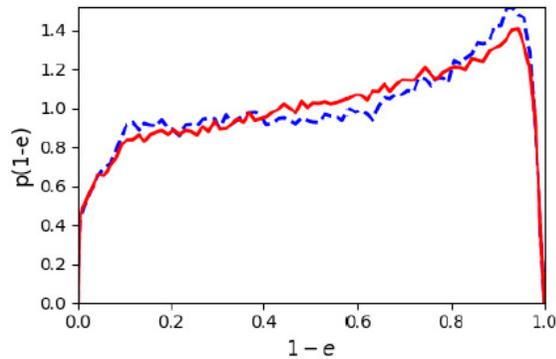
Binary phase [π]

Semi-major axis and eccentricity of survivors

Assuming a flat or a linear dependence for D distribution: $0 < D < 2$



(Weissbein & Sari 2017)



GW merger time
 10% : > 100 time shorter
 1% : $> 10^5$ time shorter

Fernandez & SK 2018

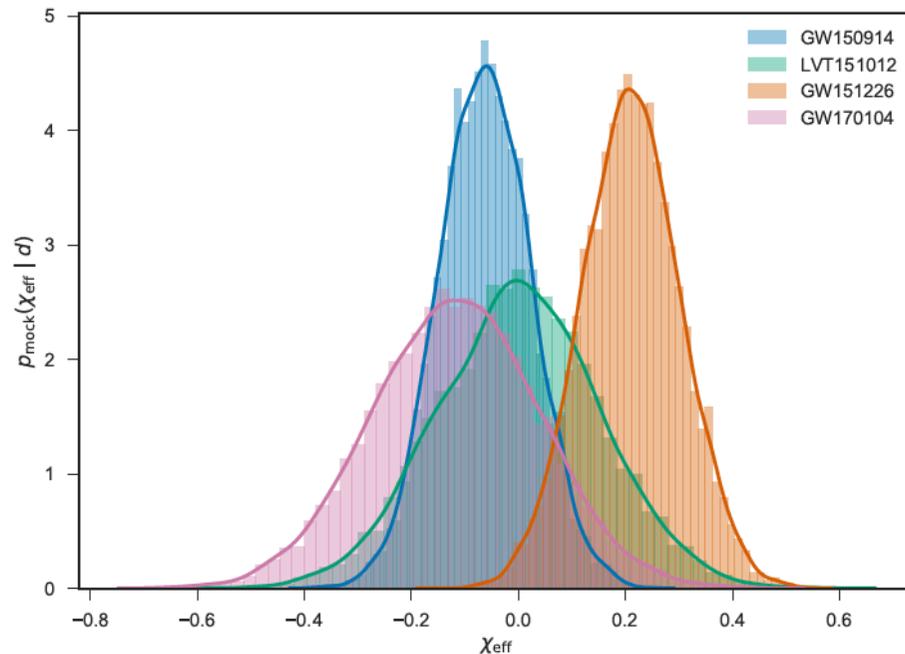
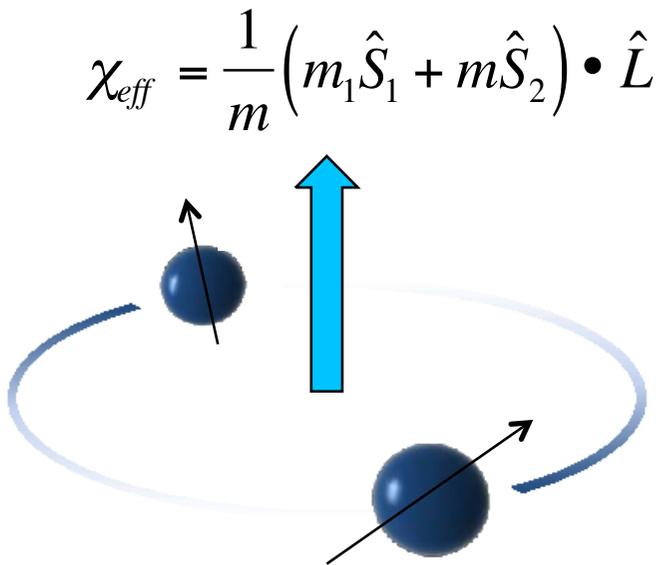
GW constraints on formation channels

- Binary member masses, mass ratio, orbit eccentricity

Bence Kocsis's talk

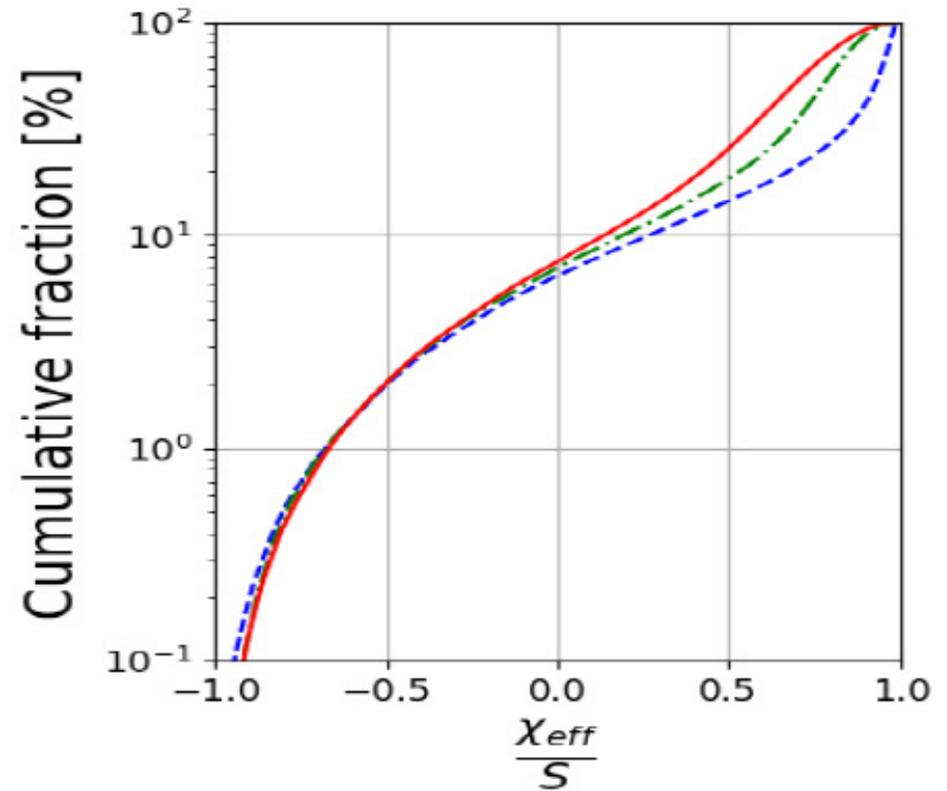
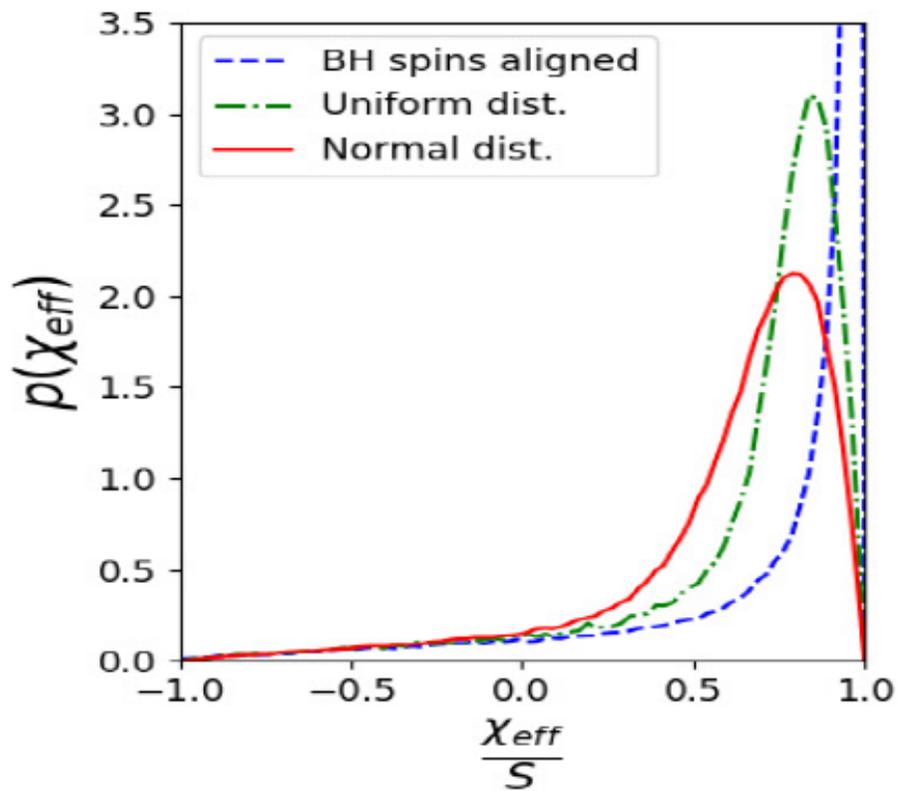
- **Spins**

- Isolated stellar field binary favor alignment (Natal kicks; Wysoncki et al.)
- Dynamical models: no preferences



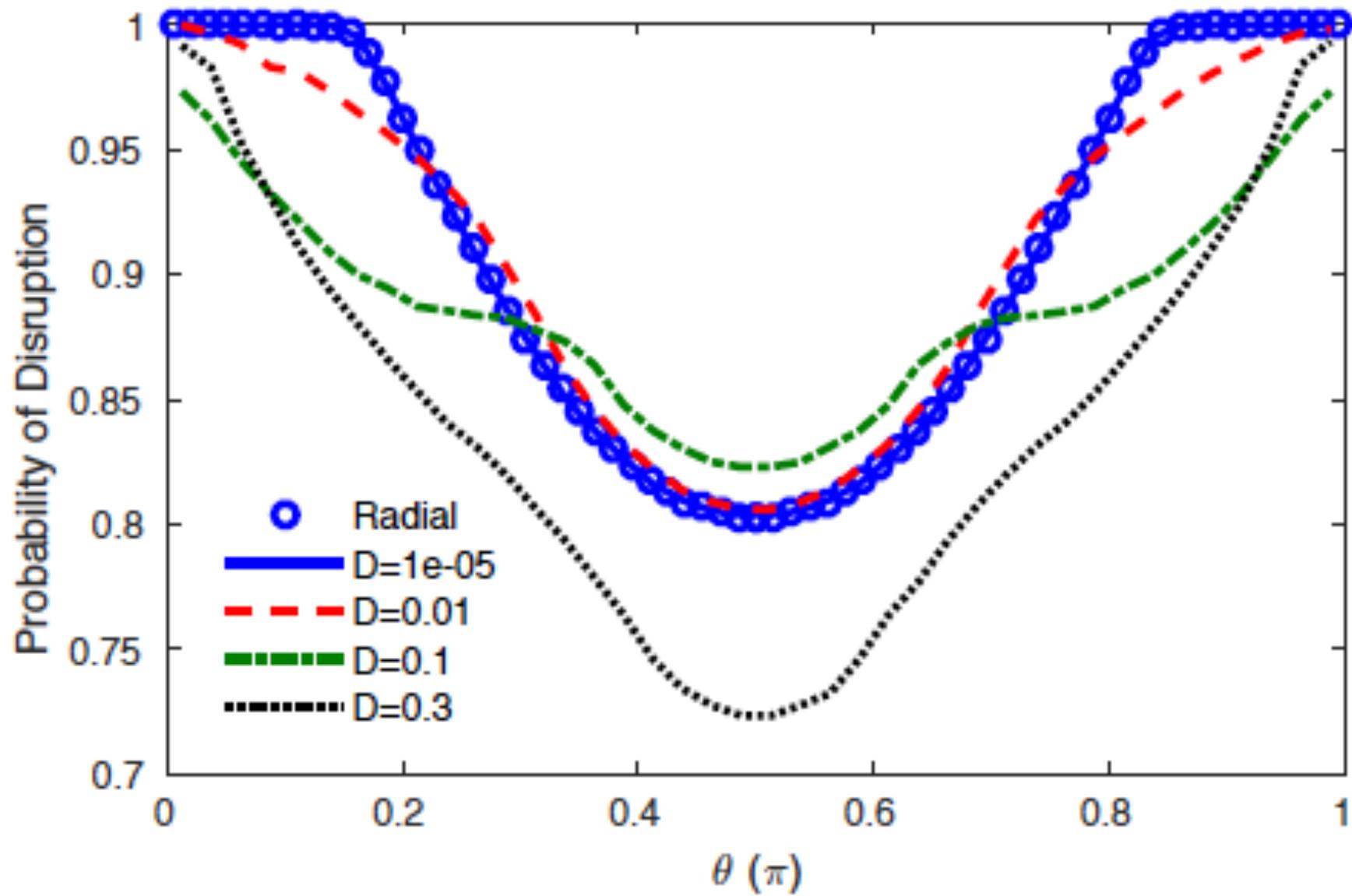
Far et al. 2017

Effective Spin Parameter



Summary

- Tidal encounter of stellar mass BH binaries with a massive BH
 - Larger mass ratio: simpler approx treatment possible, which reduces the number of system parameters, yields some general results.
- Even very deep penetration cases: $\sim 10\%$ survive
- Survivors: hard and eccentric. Much shorter GW merger time
 - 10% (1%) reduces the merger time by a factor of 100 (10^5)
 - Disrupted ones: hypervelocity BHs, EMRI
 - LIGO-Virgo BH merger rate: 10-200/Gpc³/yr; $\sim 10^7$ galaxies/Gpc³
 - Multiple encounters? Radius of BH influence \sim pc (10^4 -5 yrs)
- Effective spins
 - Tidal encounter can change the sign of the spin parameter, but only 5-10% of survivors



Semi-major axis and eccentricity of survivor orbits

