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Binary black holes surrounding massive black hole

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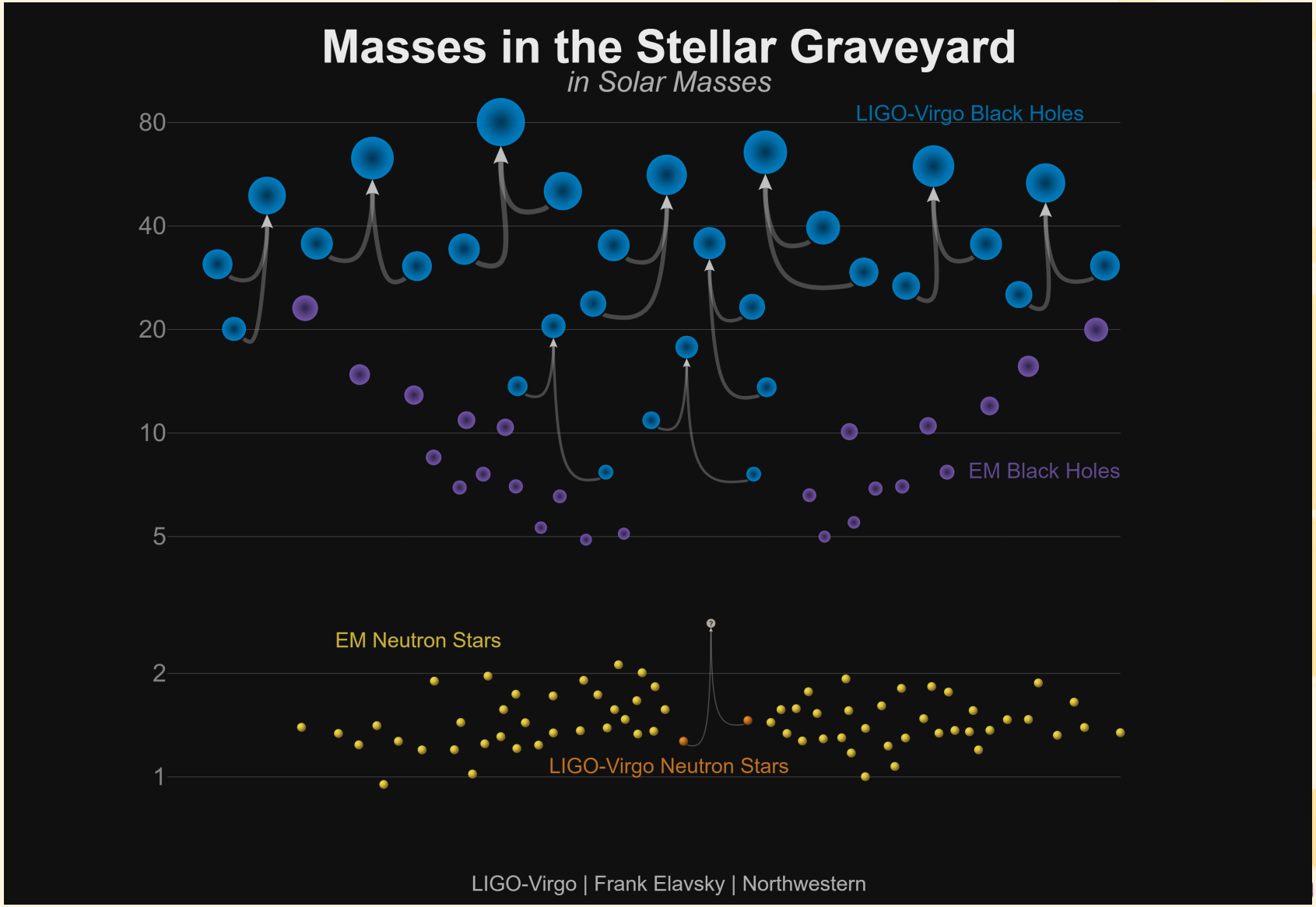
LIGO-Virgo detections



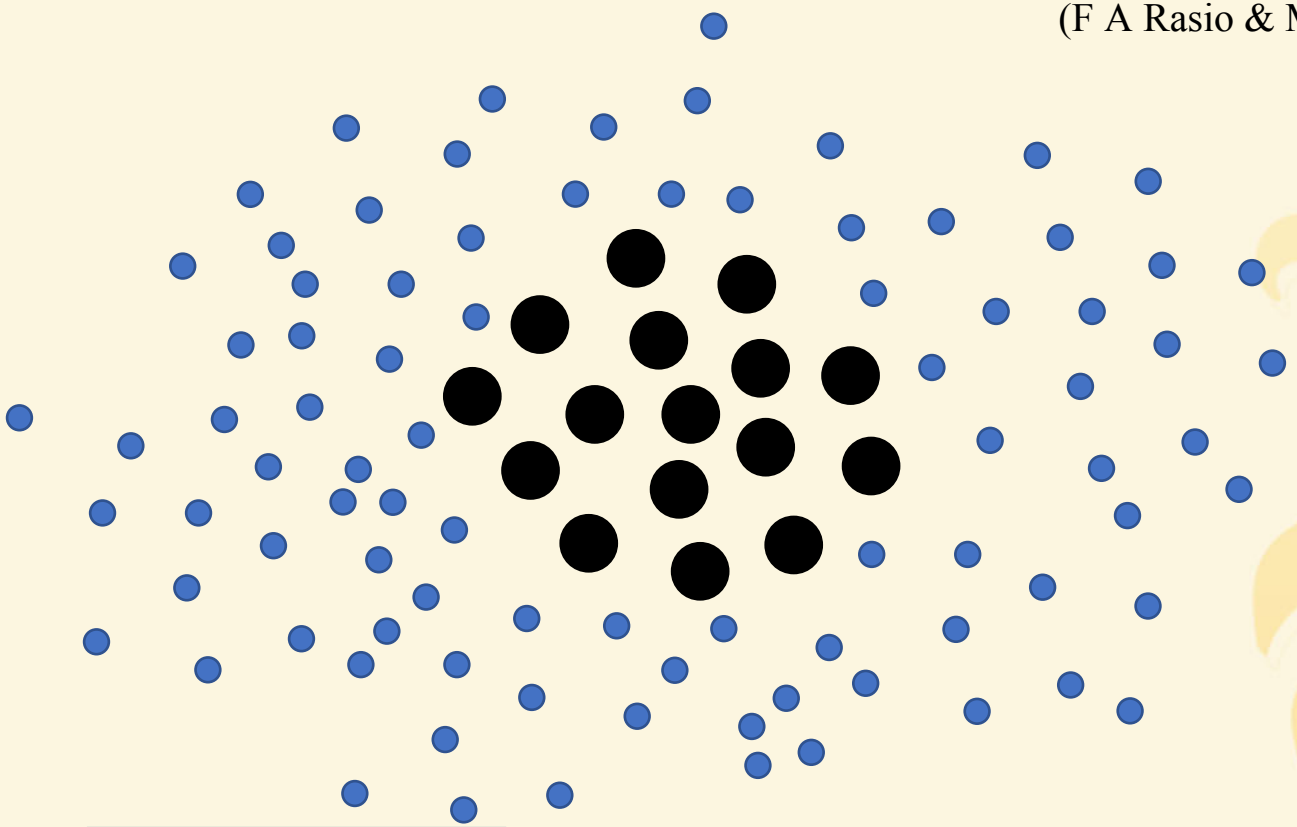
Formation Channel of binary black hole

- Primordial black hole (e.g. M Sasaki, 2016)
- Common-envelope (e.g. M Dominik, K Belczynski, etc 2012)
- Dynamical formation (e.g. C. L. Rodriguez 2016, M Zevin & J Samsing 2019)

Globular clusters!

Fate of young clusters

(F A Rasio & M Freitag 2004)



Stellar evolution First

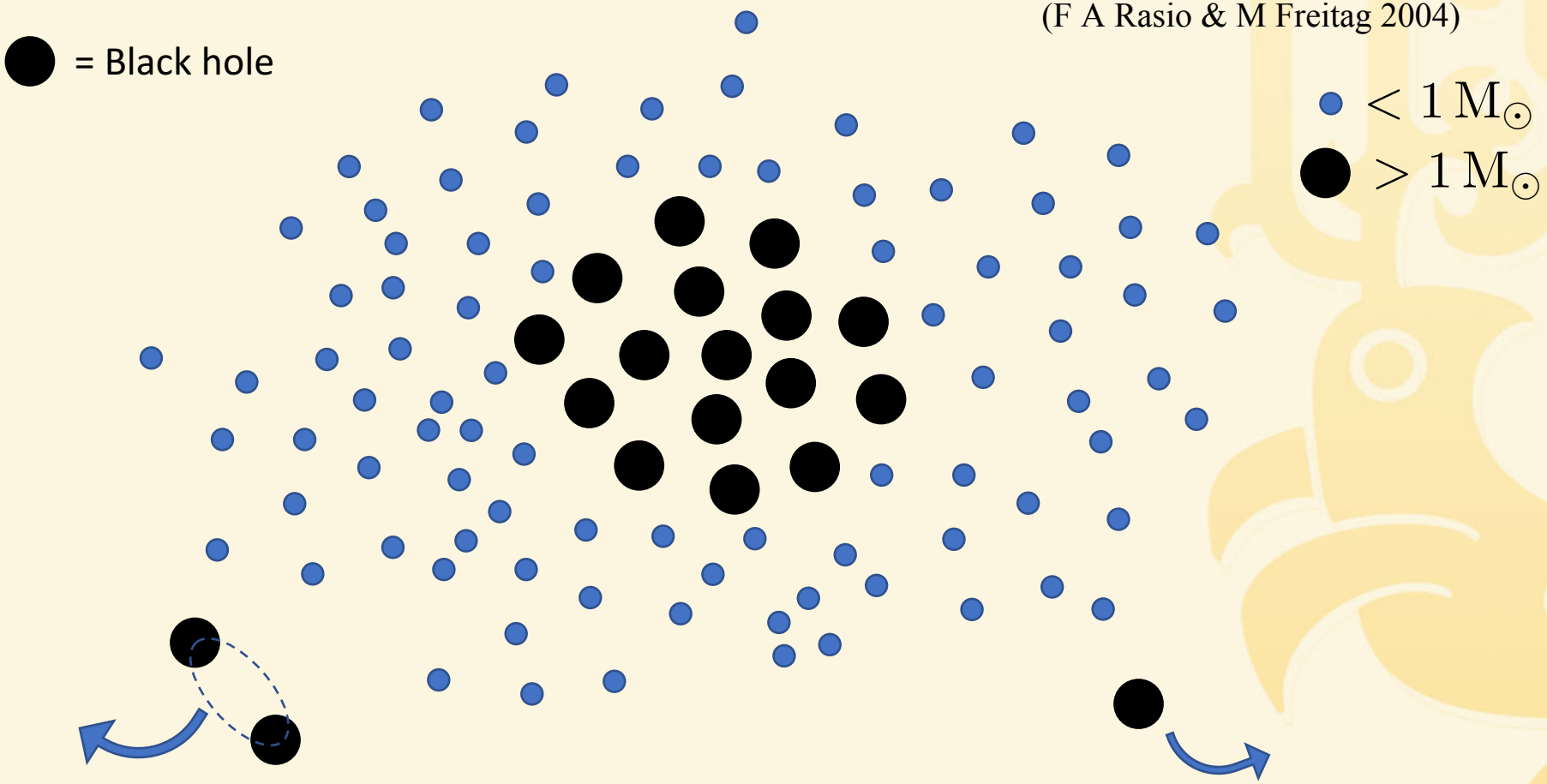
= Black hole

Mass segregation First

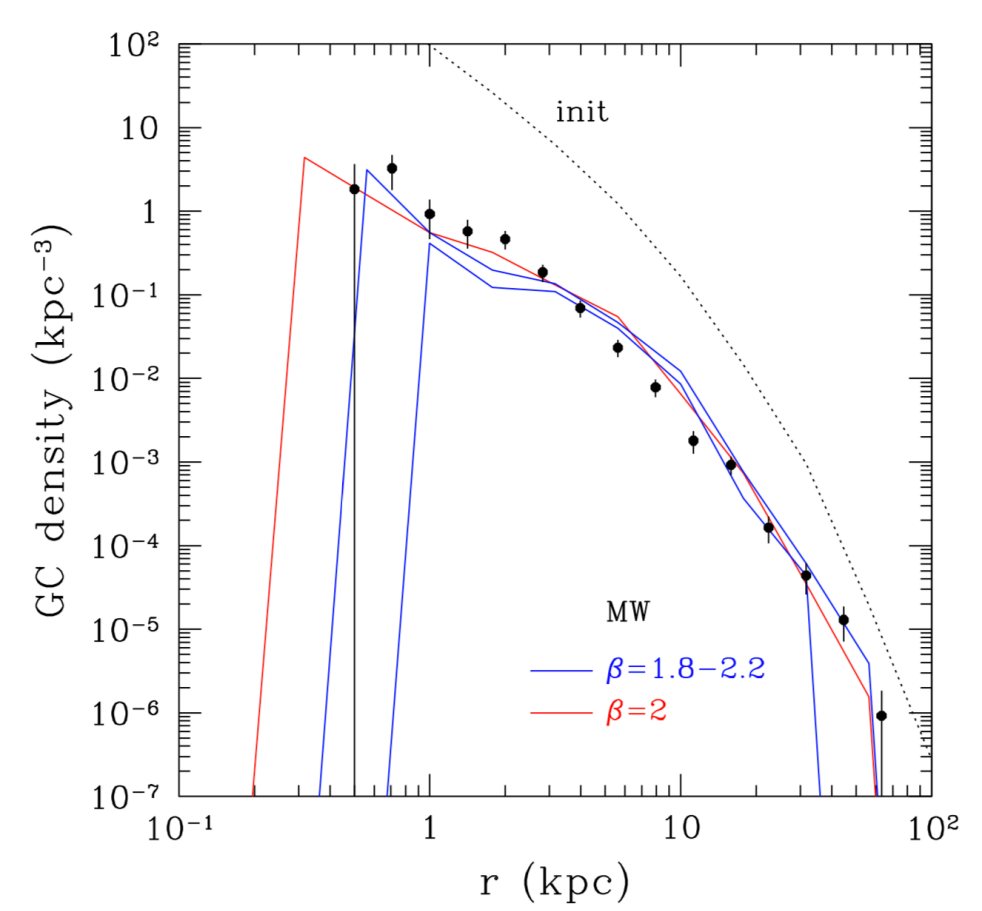
= Main Sequence

Spitzer instability

(F A Rasio & M Freitag 2004)



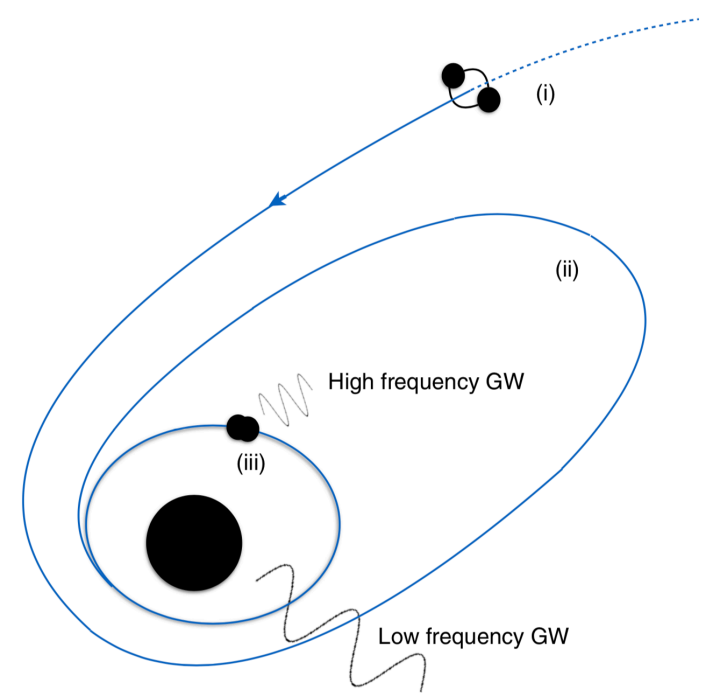
Disruption of clusters near galactic center

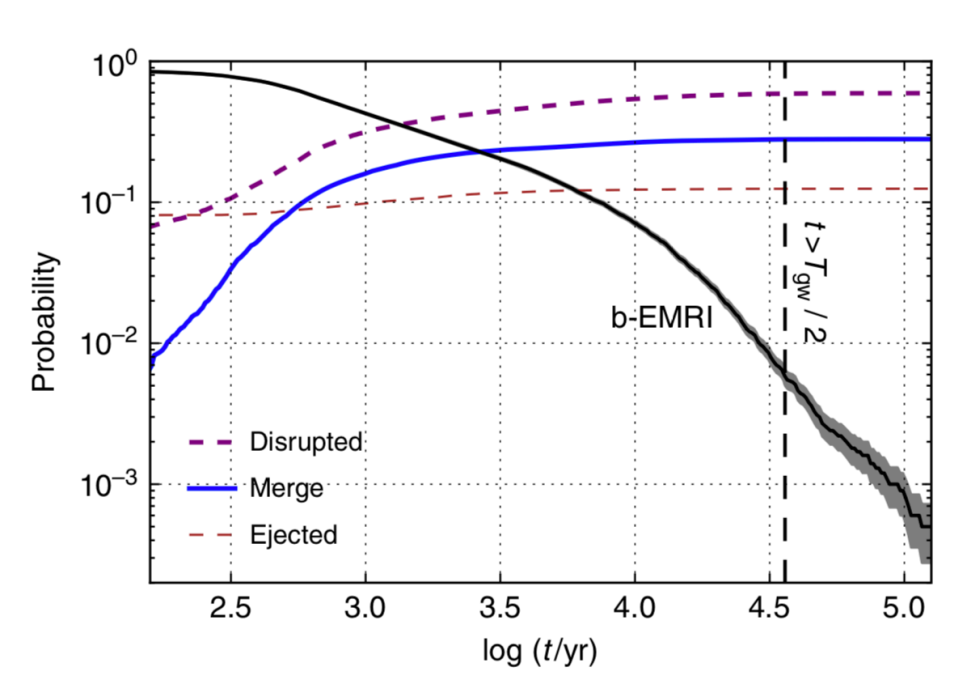


$$\mathrm{d}N/\mathrm{d}M \propto M^{-\beta}$$

(O Y. Gnedin, J P. Ostriker, and S Tremaine, 2014)

Tidal capture of stellar mass binary

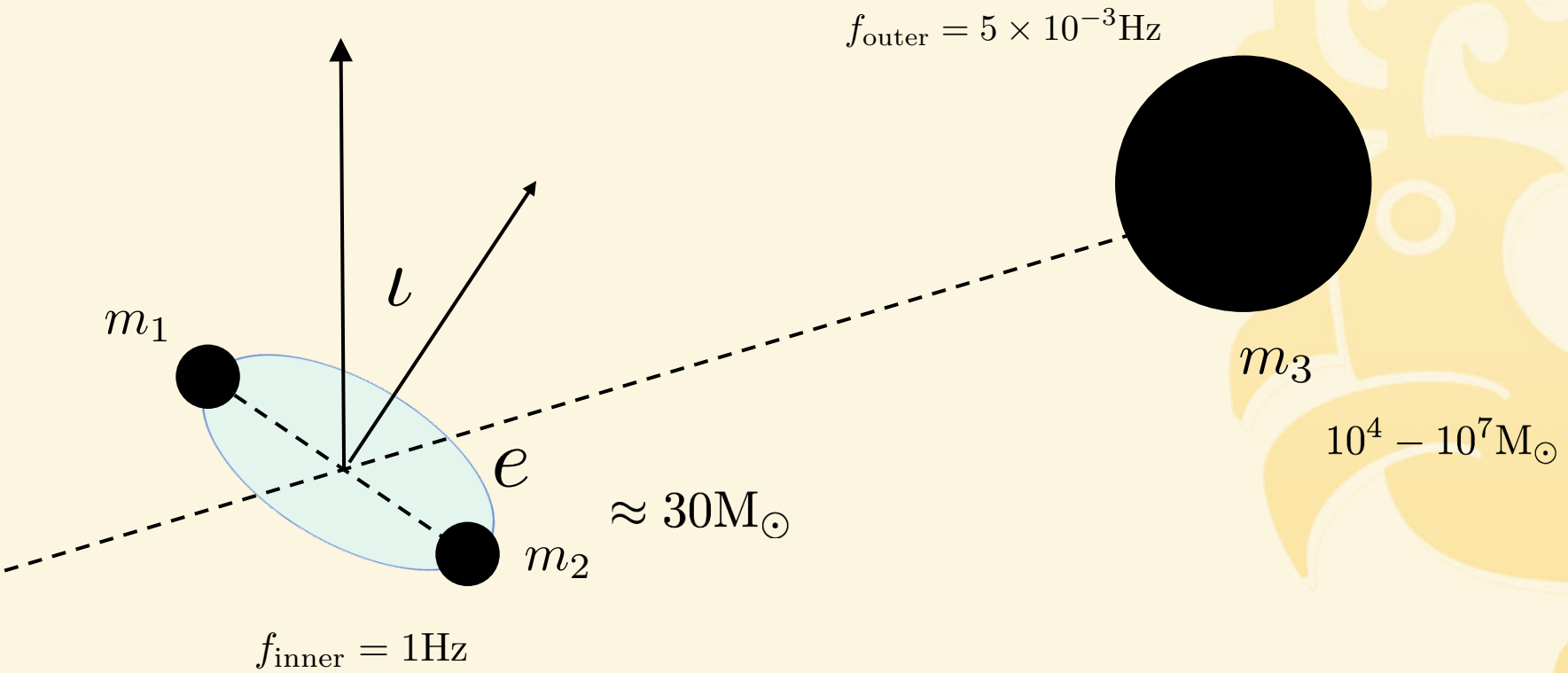




（X Chen & WB Han 2018）

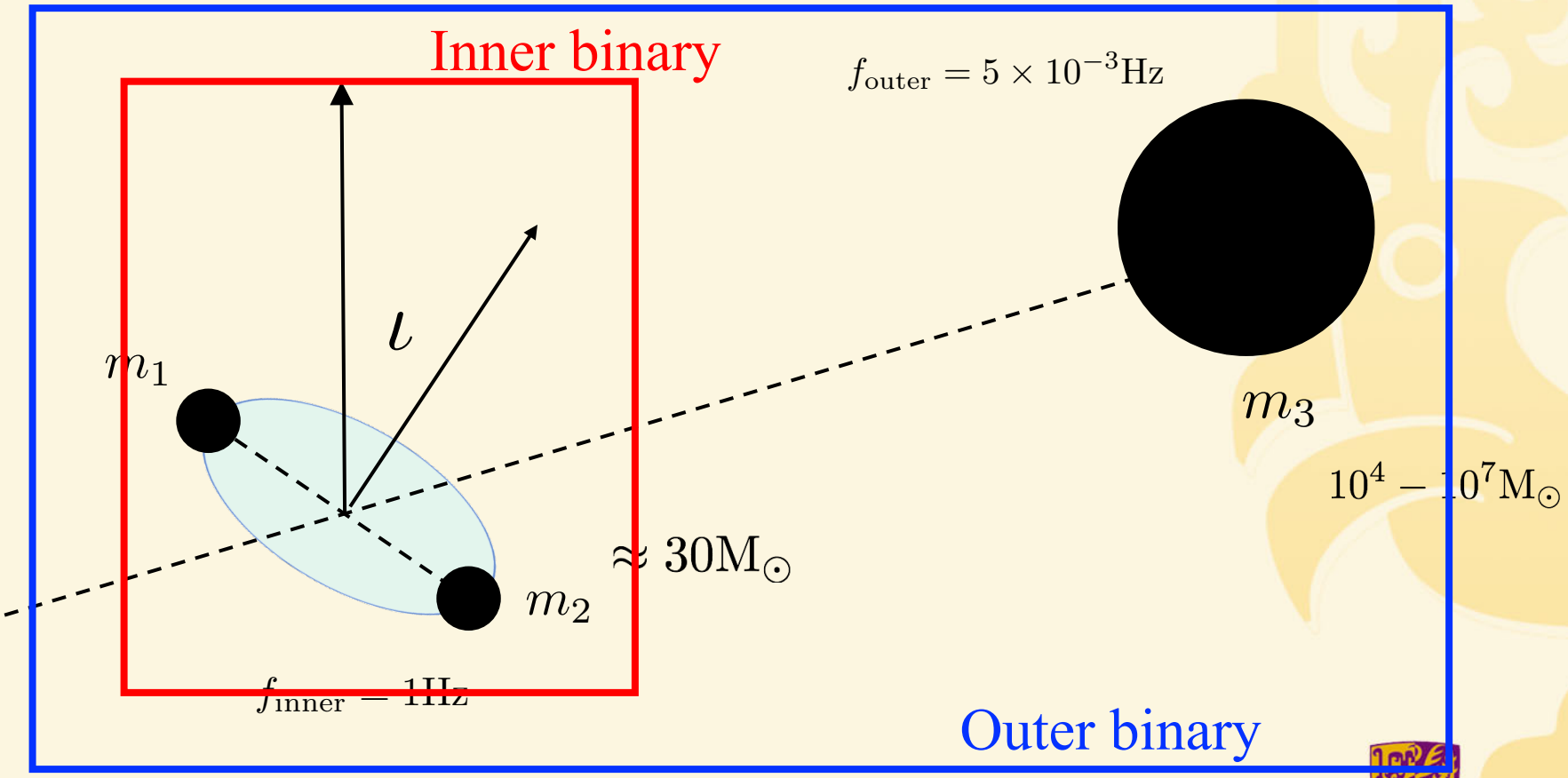
Binary-Extreme-Mass-Ratio-Inspiral

(B-EMRI)



Binary-Extreme-Mass-Ratio-Inspiral

(B-EMRI)



Equation of Motion

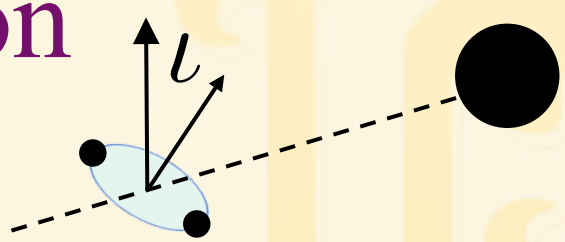
(P Galaviz, and B Brugmann, 2011)
(M Bonetti, F Haardt, A Sesana & E Barausse, 2016)

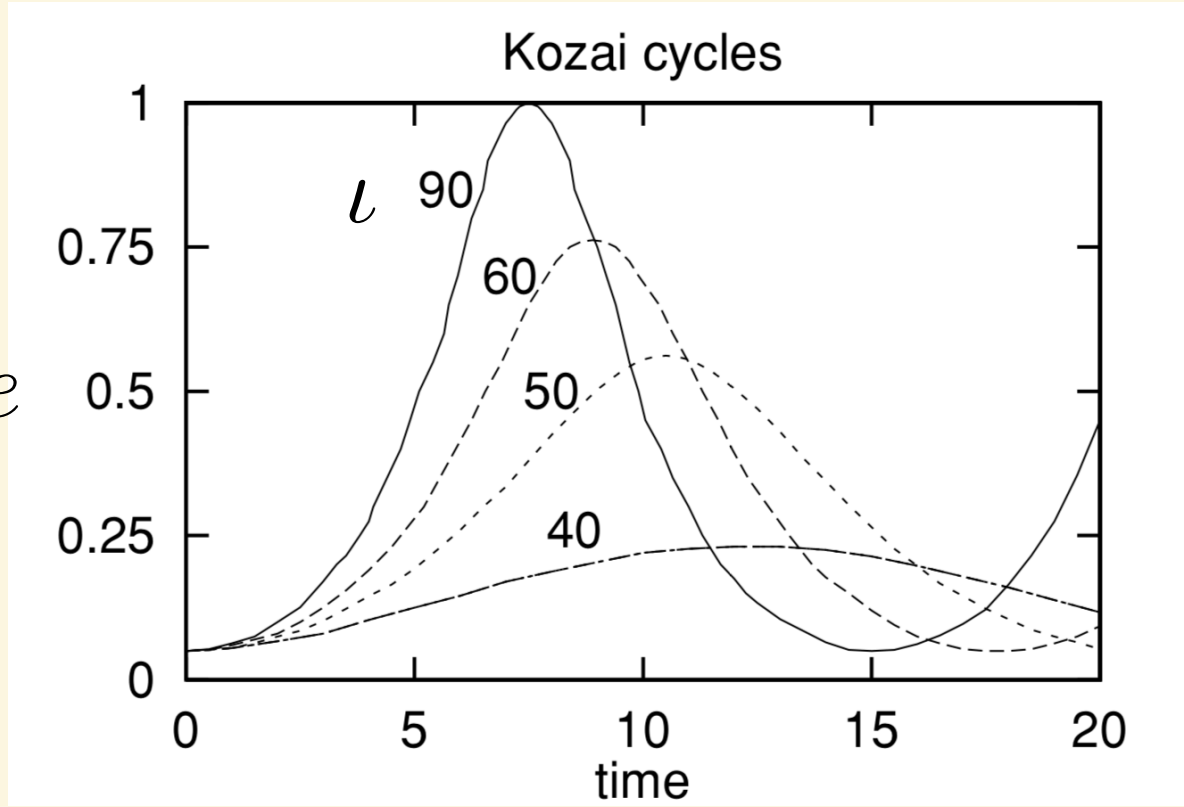
$$H_{1,\mathrm{N}} + H_{1,\mathrm{PN}} + H_{2,\mathrm{PN}} + H_{2.5,\mathrm{PN}}$$

2PN ADM Hamiltonian

Leading order dissipative

Kozai Oscillation





(credits: M Valtonen & H Karttunen 2005)

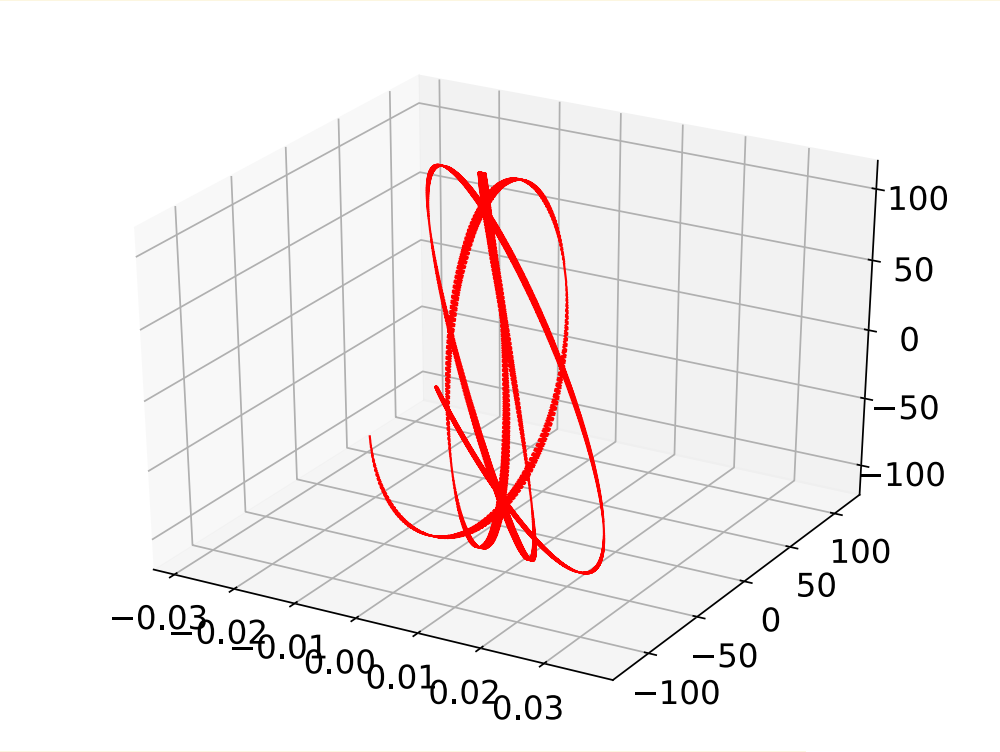
Parameter space

1 $T_{\rm GW,outer} > T_{\rm Kozai} > T_{\rm GW,inner}$

2 $T_{\rm GW,outer} > T_{\rm GW,inner} > T_{\rm Kozai}$

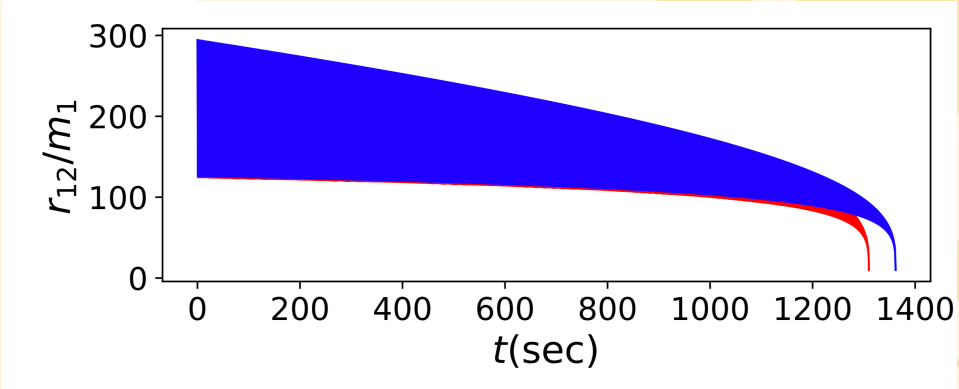
3 $T_{\rm GW,outer} > T_{\rm GW,inner} \approx T_{\rm Kozai}$

Case 1: GW radiation dominates



$$m_3 = 10^4\,\mathrm{M}_\odot$$

$$f_{\mathrm{outer}} = 5 \times 10^{-3}\mathrm{Hz}$$

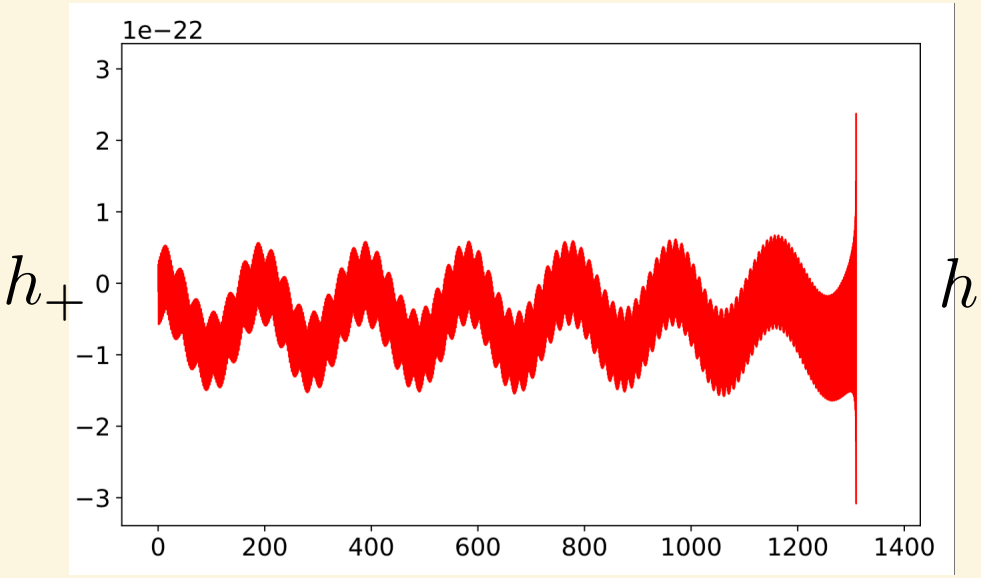


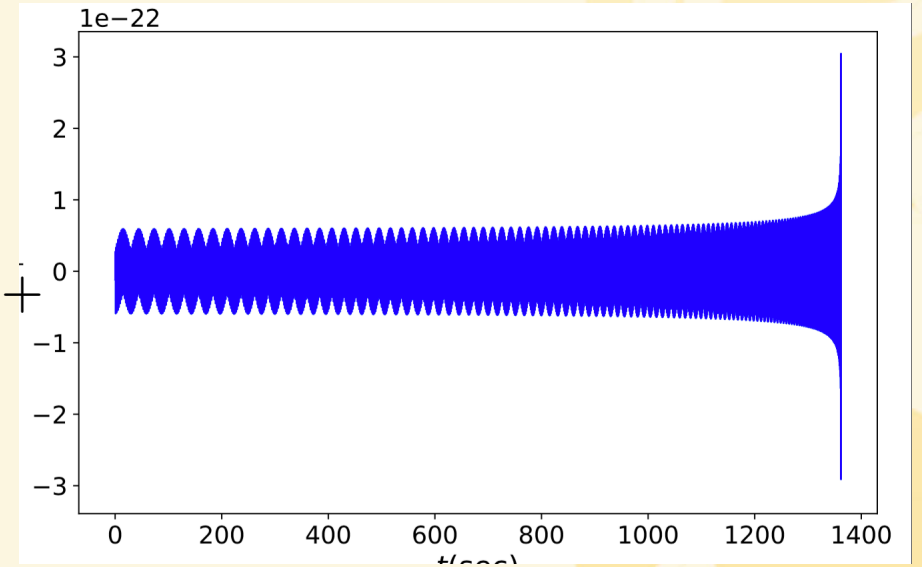
$$m_1 = m_2 = 30\,\mathrm{M}_\odot$$

$$f_{\mathrm{inner}} = 1\mathrm{Hz}$$

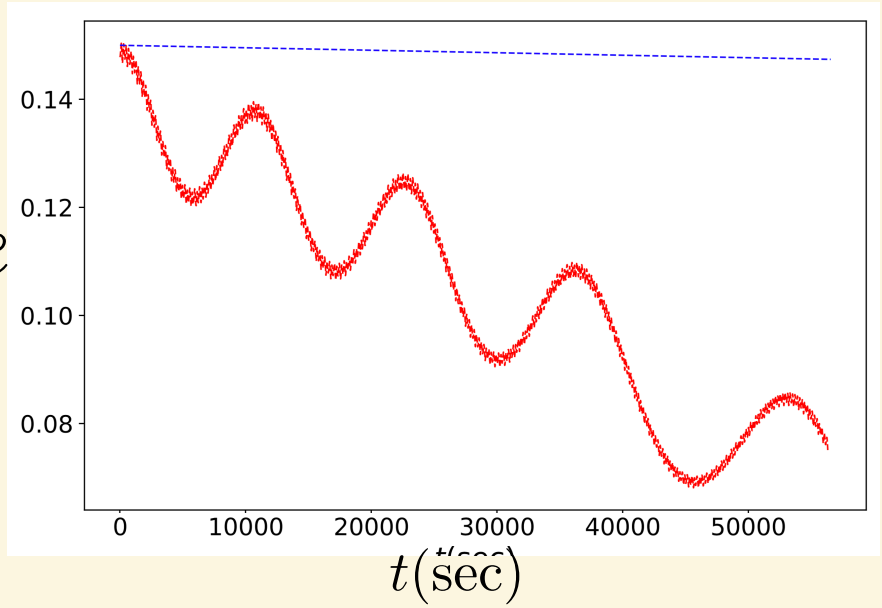
$$e_0 = 0.4$$

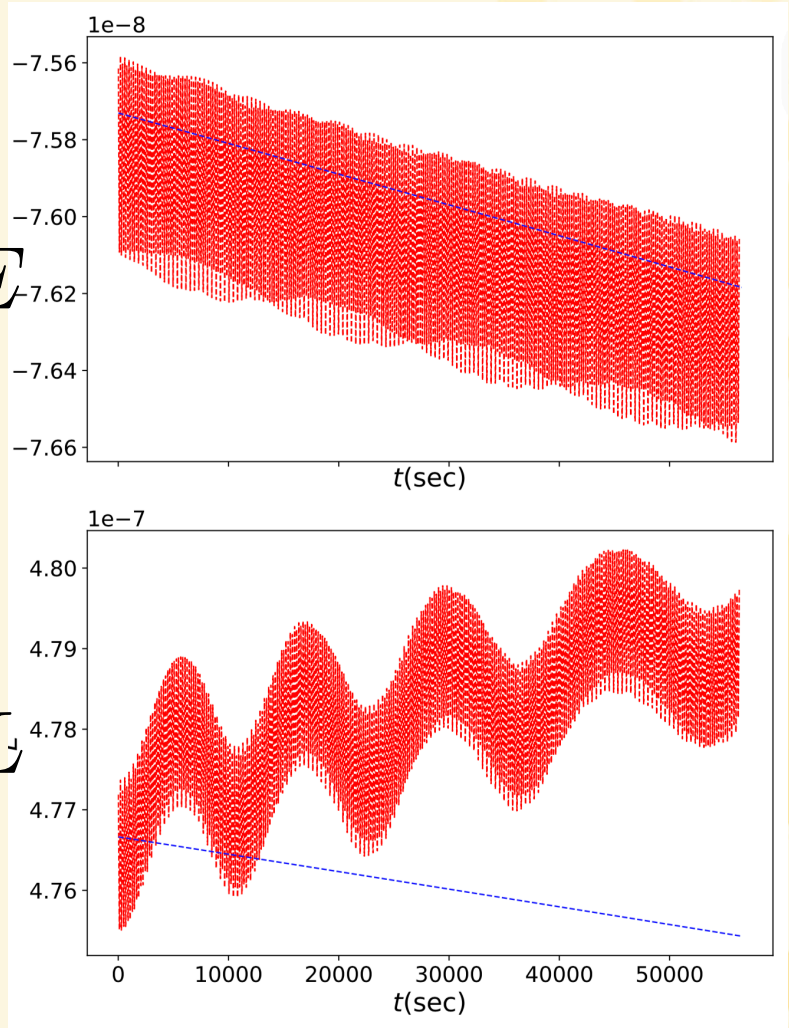
Case 1: GW radiation dominates





Case 2: restricted Kozai oscillation





$m_3 = 10^4\,\mathrm{M}_\odot$

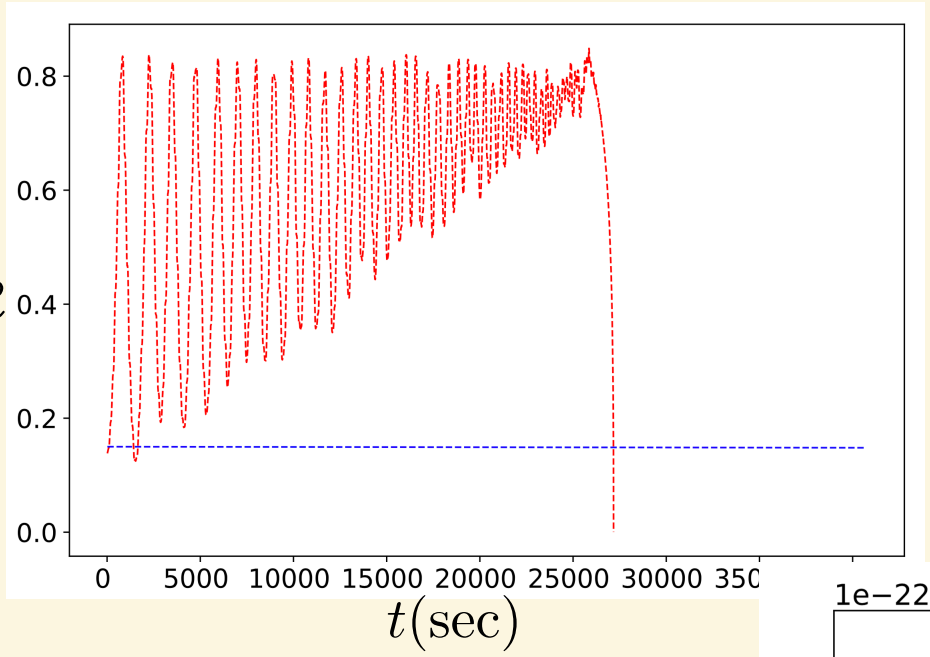
$f_{\mathrm{outer}} = 5 \times 10^{-3}\mathrm{Hz}$

$m_1 = m_2 = 30\,\mathrm{M}_\odot$

$f_{\mathrm{inner}} = 0.1\,\mathrm{Hz}$

(Agree with S Naoz 2013)

Case 2: Third Body Induced Merger

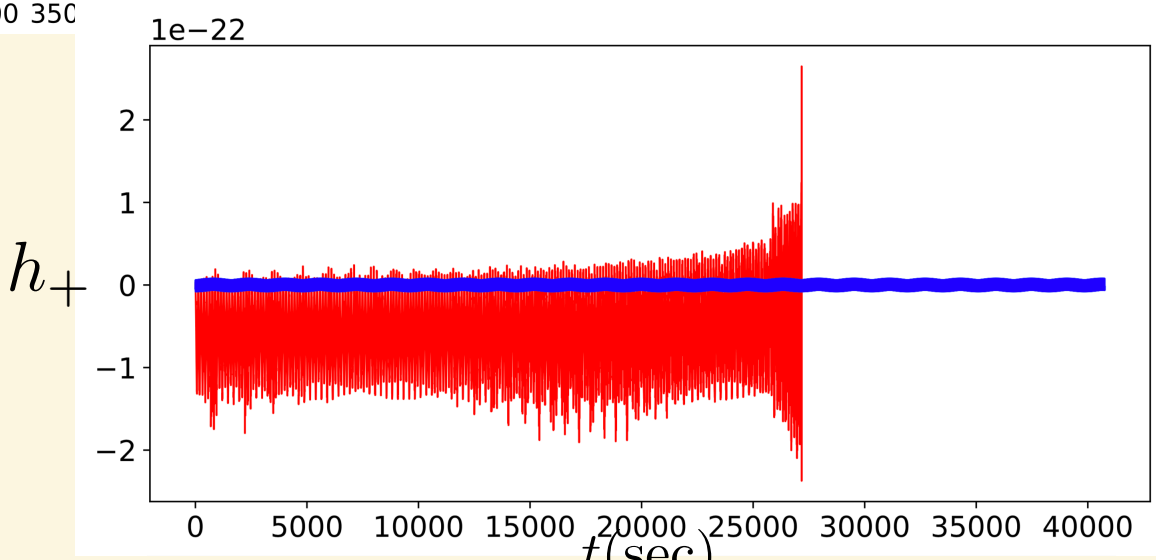


$m_3 = 10^4\,\mathrm{M}_\odot$

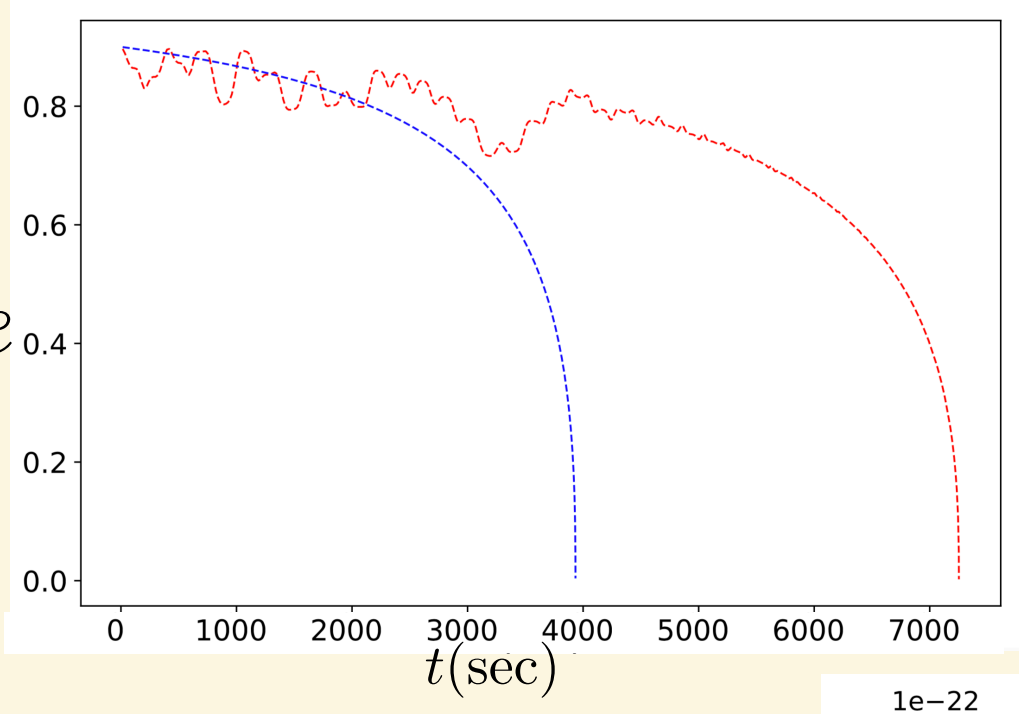
$f_{\mathrm{outer}} = 7.5 \times 10^{-3}\,\mathrm{Hz}$

$m_1 = m_2 = 30\,\mathrm{M}_\odot$

$f_{\mathrm{inner}} = 0.1\,\mathrm{Hz}$



Case 3: Delayed Merger

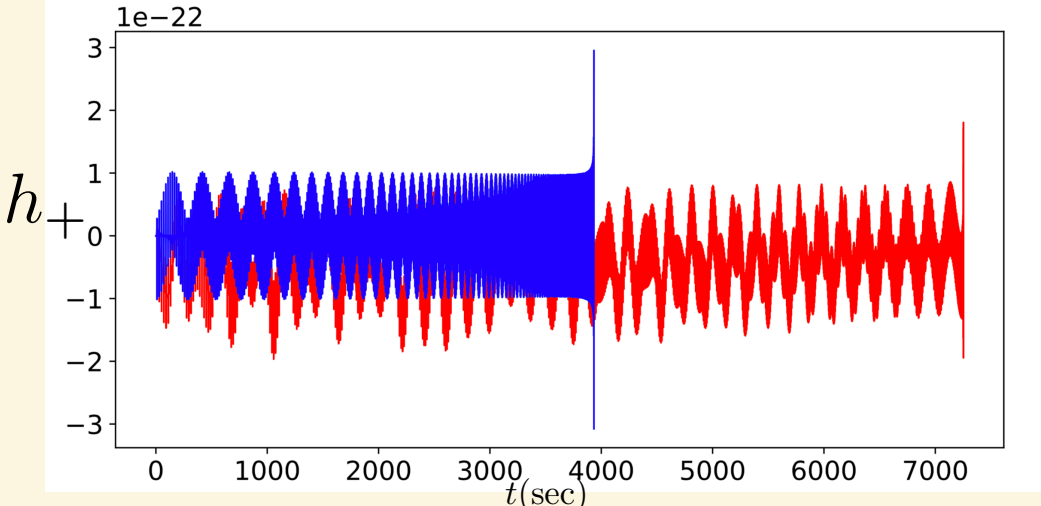


$m_3 = 10^4\,\mathrm{M}_\odot$

$f_{\mathrm{outer}} = 5 \times 10^{-3}\mathrm{Hz}$

$m_1 = m_2 = 30\,\mathrm{M}_\odot$

$f_{\mathrm{inner}} = 0.1\,\mathrm{Hz}$



Thank you!