# A new type of EMRIs produced by tidal capture of binary black holes

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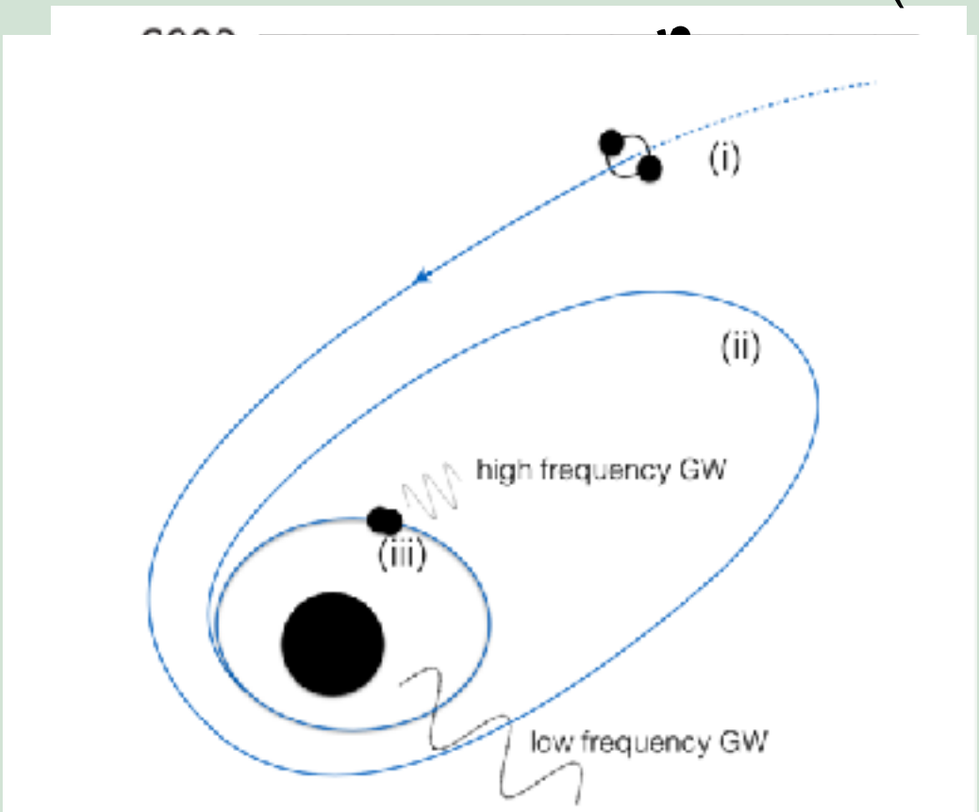
# How to place a binary around a SMBH?

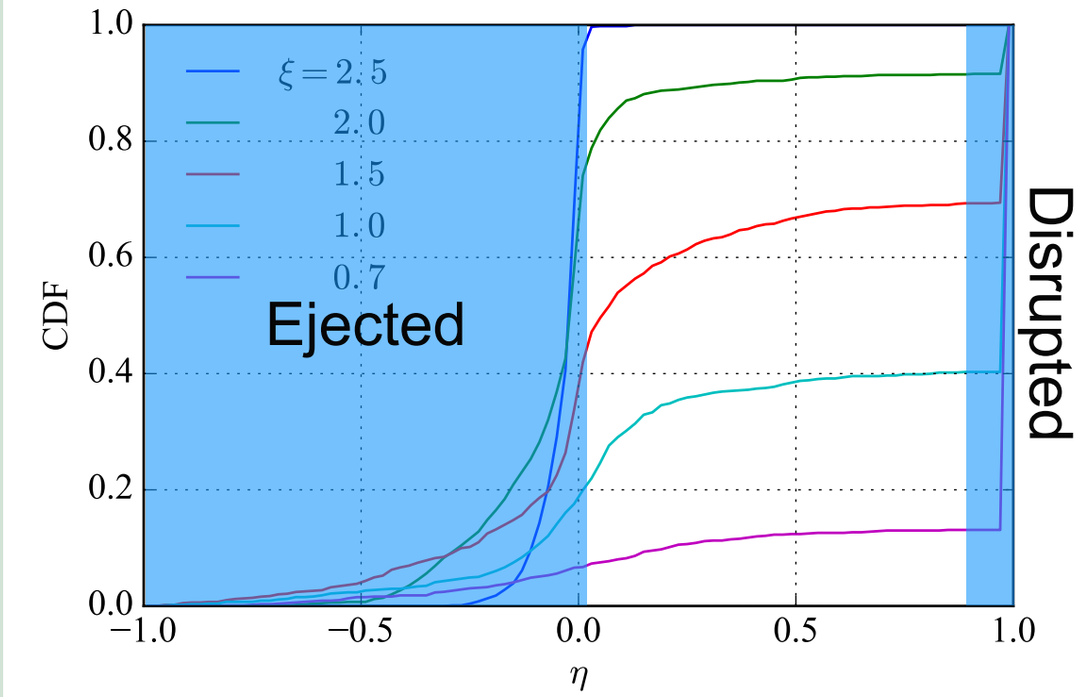
(XC & Han 2018 CommsPhy)




- Extreme-mass-ratio inspiral (EMRI)
  - Form at tidal radius, GW mHz, LISA source
- Tidal capture of BBHs:
  - according to Hills 91, Addison, Laguna, Larson 2015

$$R_p \lesssim 21\, R_g \left(\frac{T_{\rm rlx}}{10^9\,{\rm yr}}\right)^{1/4} \frac{q^{3/8}}{(1+q)^{1/4}} \times \left(\frac{\eta}{0.1}\right)^{3/8} \left(\frac{m_1}{10\,M_\odot}\right)^{1/2} \left(\frac{M_3}{10^6\,M_\odot}\right)^{-3/4}.$$

  - but not hyperbolic orbit, not long-term evolution, no GWs




- Results:

$$0.7 < R_p/R_t < 2.5$$

$${\rm About}(10-30)\%$$

$$1 - e_3 = \frac{R_p}{R} \simeq 9.3\times10^{-5} \frac{q}{(1+q)^{4/3}} \left(\frac{\xi}{2}\right) \times \left(\frac{\eta}{0.1}\right) \left(\frac{m_1}{10\,M_\odot}\right)^{2/3} \left(\frac{M_3}{10^6\,M_\odot}\right)^{-2/3}.$$

e=0.9999

# Long-term evolution of b-EMRIs

(XC & Han 2018 CommsPhy)

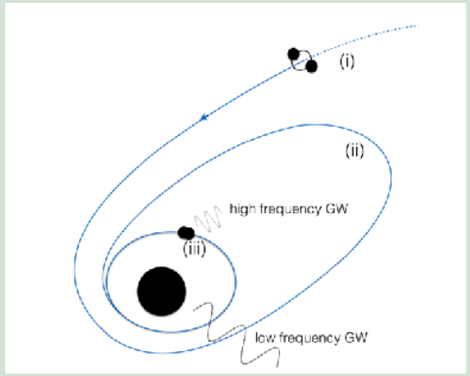
## Not all binaries count:

big a-=> big b-EMRI

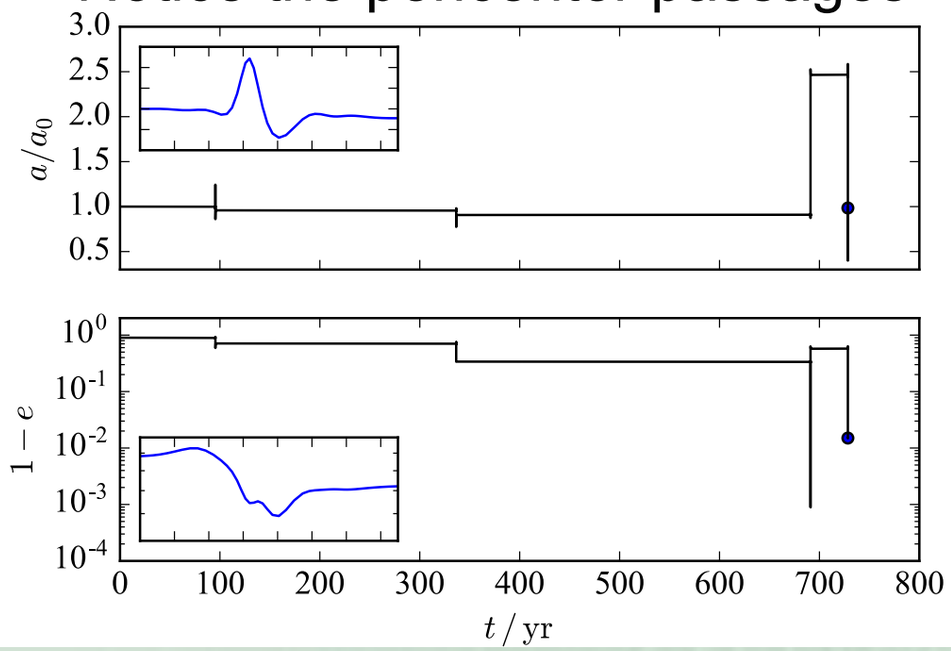
$$T_{\rm relax} \propto (1-e_3^2)$$

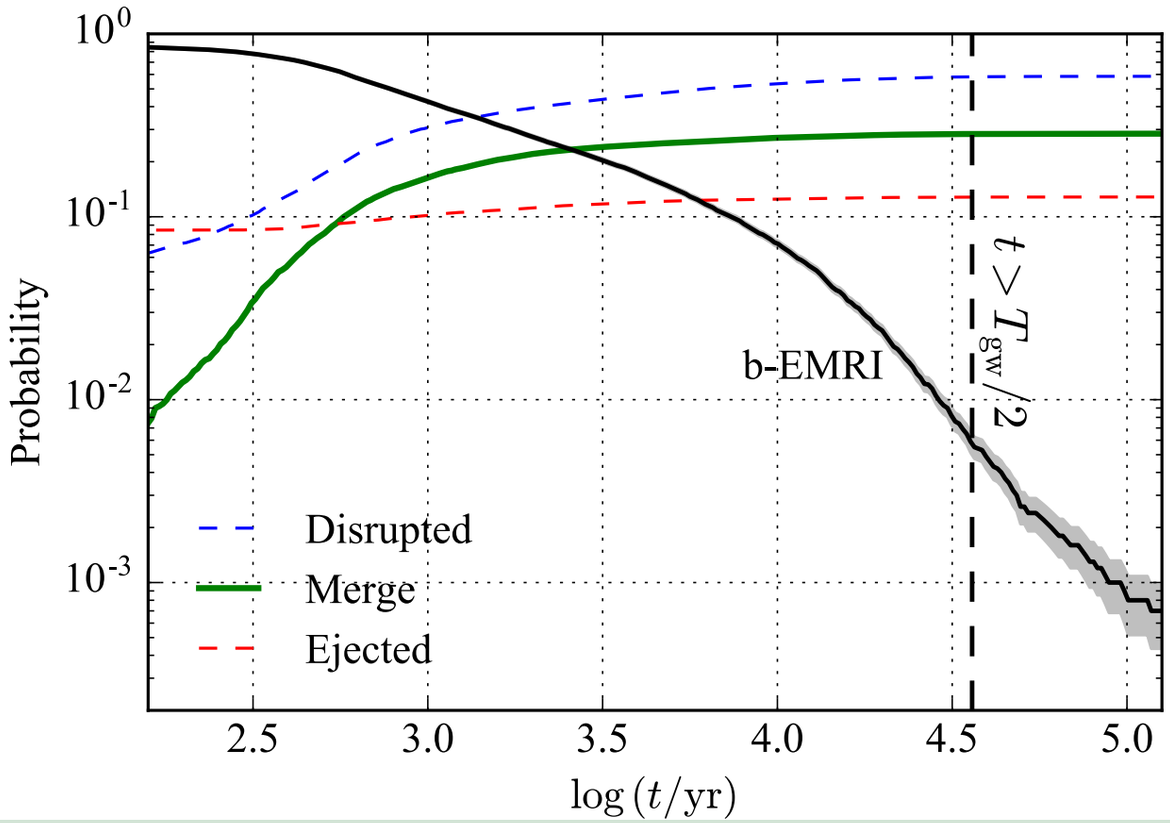
$$T_{\rm gw} \propto (1-e^2)^{7/2}$$

$$\text{Then}: a_{\rm cri} \simeq 4.2\times10^4\, r_g\, \frac{q^{3/8}}{(1+q)^{-1/12}} \left(\frac{T_{\rm rlx}}{10^9\,\text{years}}\right)^{1/4} \times \left(\frac{\xi}{2}\right)^{-5/8} \left(\frac{\eta}{0.1}\right)^{3/8} \left(\frac{m_1}{10\,M_\odot}\right)^{-1/6} \left(\frac{M_3}{10^6\,M_\odot}\right)^{-1/12} \sim 0.005\,\text{AU}$$



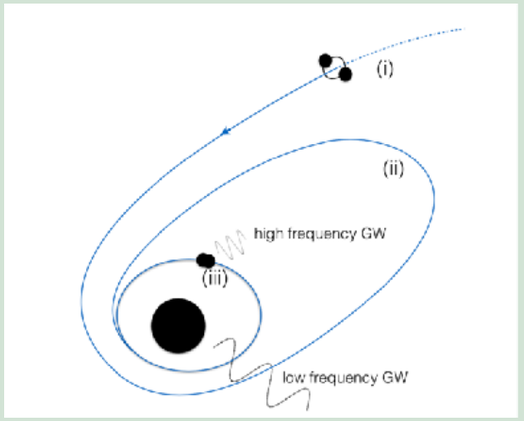

Notice the pericenter passages




- New features:
  - Not hierarchical triple
  - Eccentricity of the binary gets excited
  - Merger happens (joint LISA/LIGO observations?)
  - Merger: 30%
  - Ejected: 10%
  - Disrupted: 60%
  - Circularization: 1% (need 3-body PN terms)

# Prospect for detection

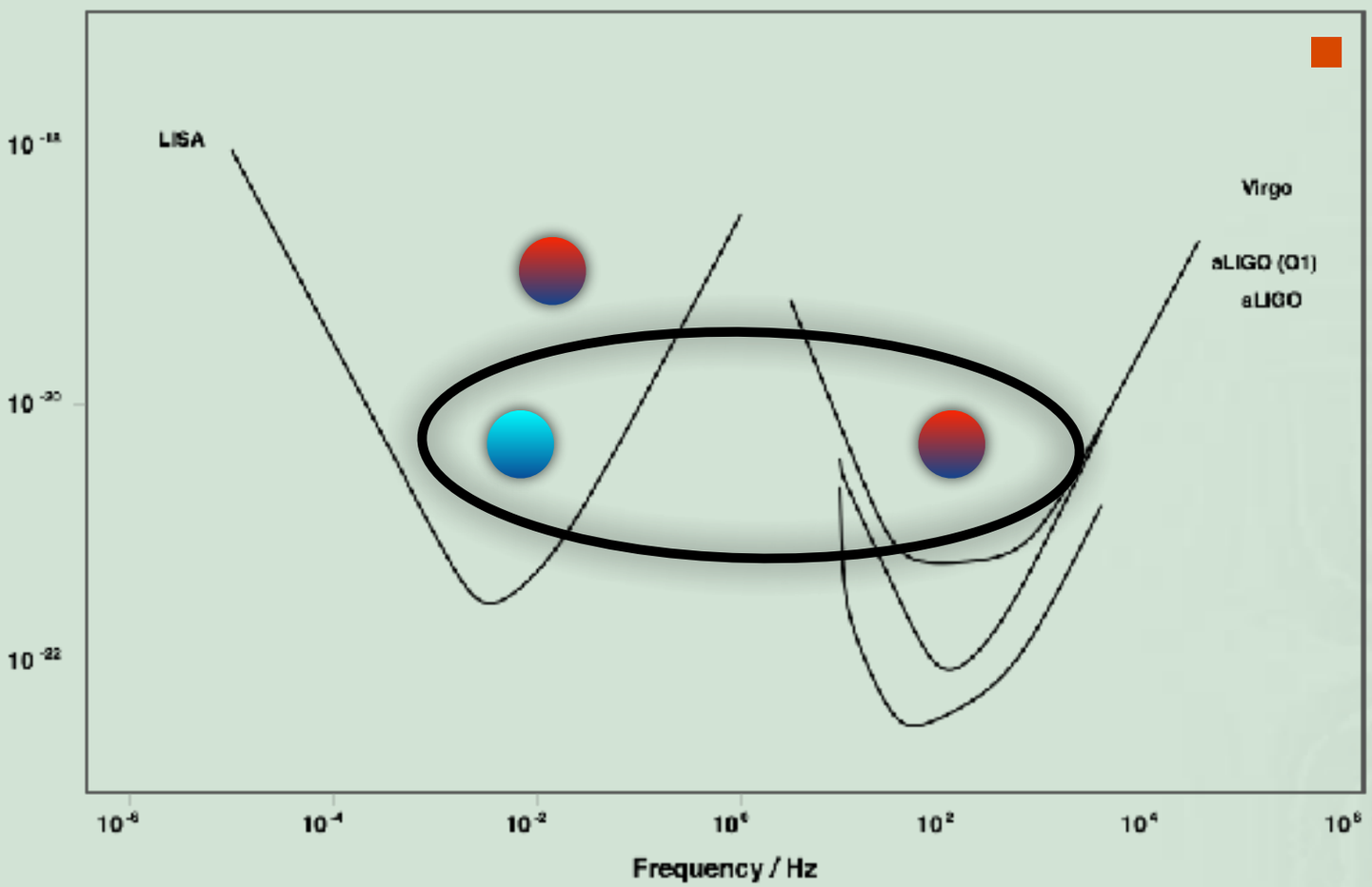



Formation rate Lifetime Number of galaxies

$$n_{\rm bemri} = (\Gamma_{\rm BHB}\, p\, f_{\rm cap})\ [t_{\rm life}\, f(t_{\rm life})]\ N_{\rm gal}$$

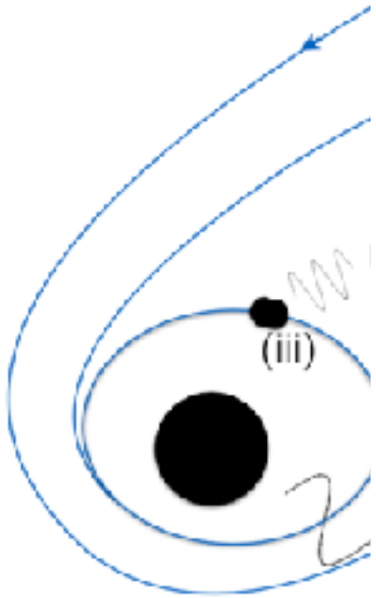
$$\sim 0.02\,{\rm Gpc}^{-3}\,({\rm two-body\ relaxation})$$

$$\sim 20\,{\rm Gpc}^{-3}\,({\rm Massive\ perturber/axisymmetric\ potential})$$




- Multi-band GW source
  - Continuous source in LISA band, a~0.005 AU
    - 0.02-20 Gpc$^{-3}$
    - Acceleration~3000 radian per year
  - Burst at pericenter
    - Every ~200 yrs per b-EMRI
    - At most 50% of catching one in five years
  - LIGO/Virgo event
    - 30% coalescence probability
    - at most 0.03 Gpc$^{-3}$ yr$^{-1}$
    - Separated from the LISA burst by 100 yrs
  - Exceptional case: both LISA and LIGO/VIrgo event
    - A small percent circularize

Easy ======> Difficult


(iii)

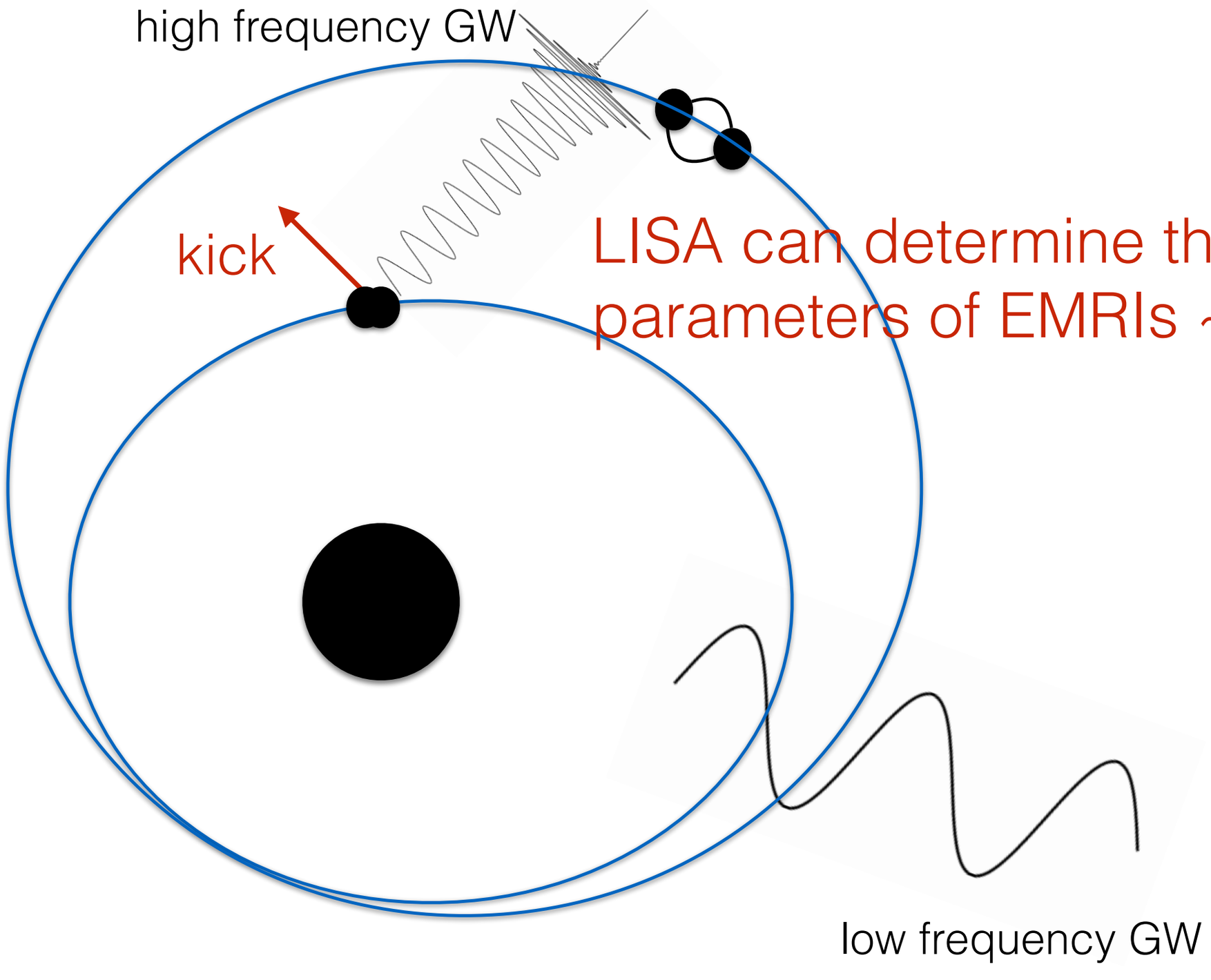

Virgo
aLIGO (O1)
aLIGO
$10^4$
$10^5$

# What stories can b-EMRI tell us?

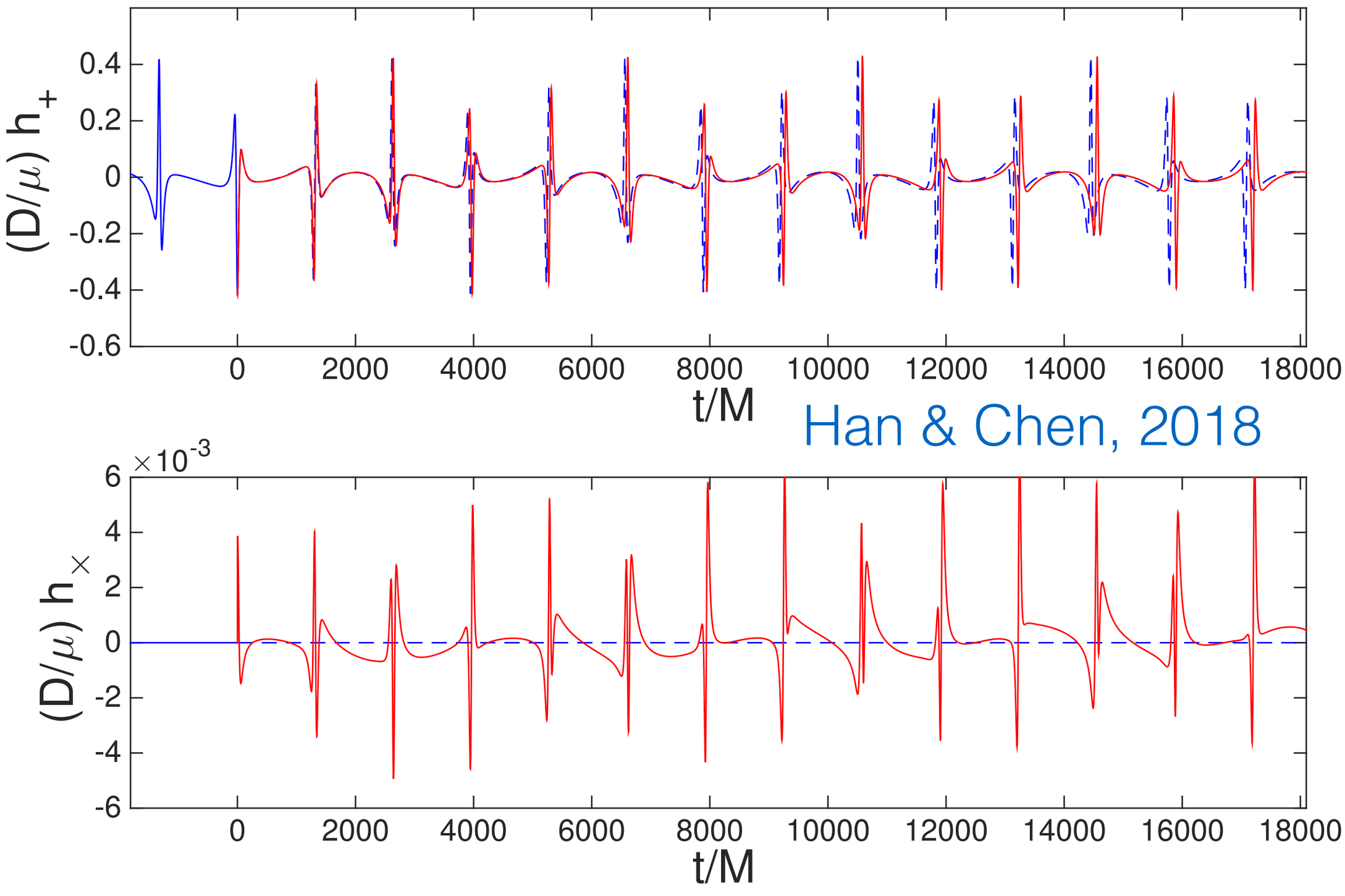
Han & Chen arXiv:1801.07060, 2018

- Providing clues for dynamical process in NSC;
- Measuring the gravitational recoil due to the merger of BBH;
- Measuring the mass loss due to the merger of binary;
- Constraining the GW dispersion in an extreme accuracy
- ……

# 1. Accurately measure recoil velocity of binary merger and linear momentum

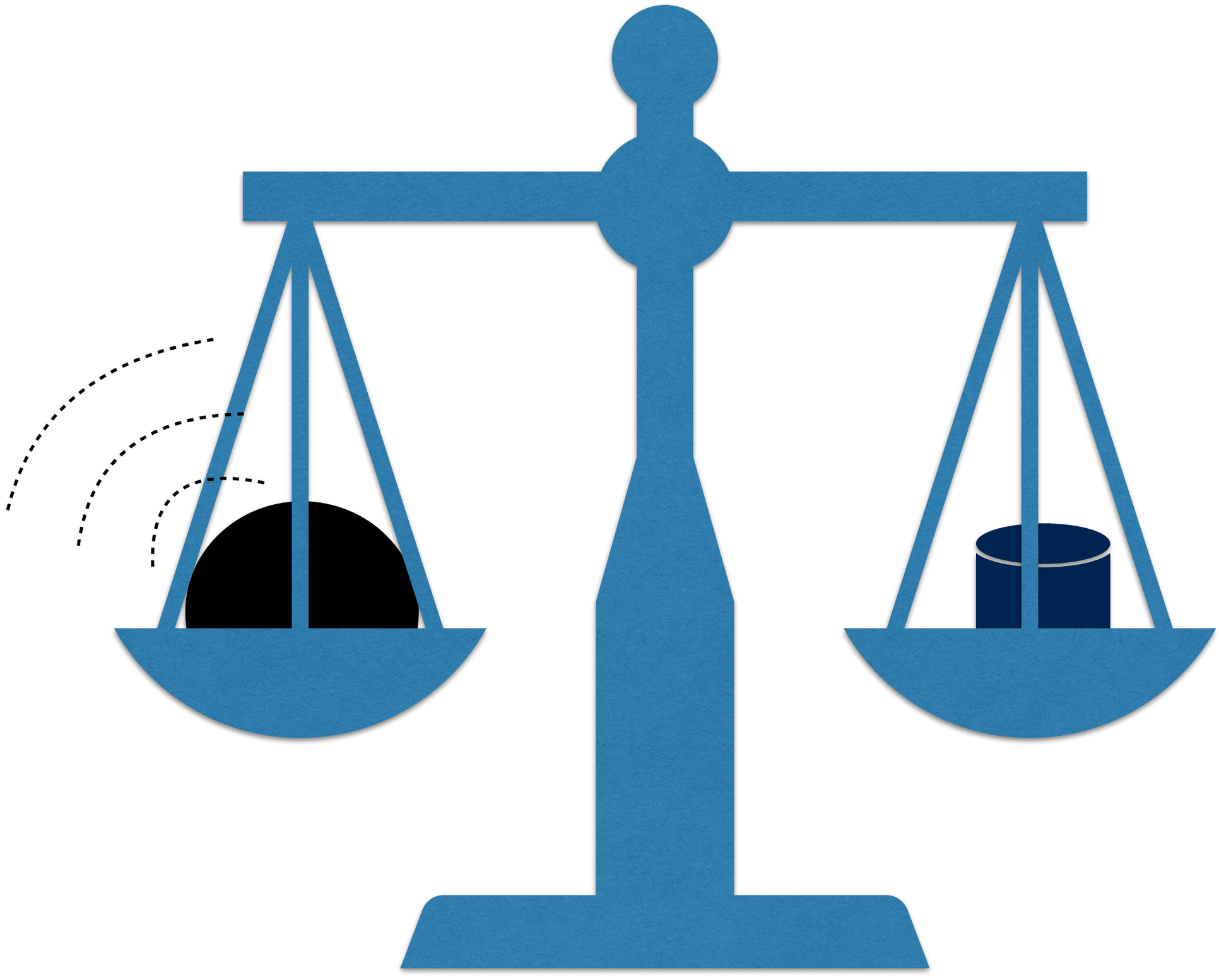


# EMRI waveforms glitch due to recoil

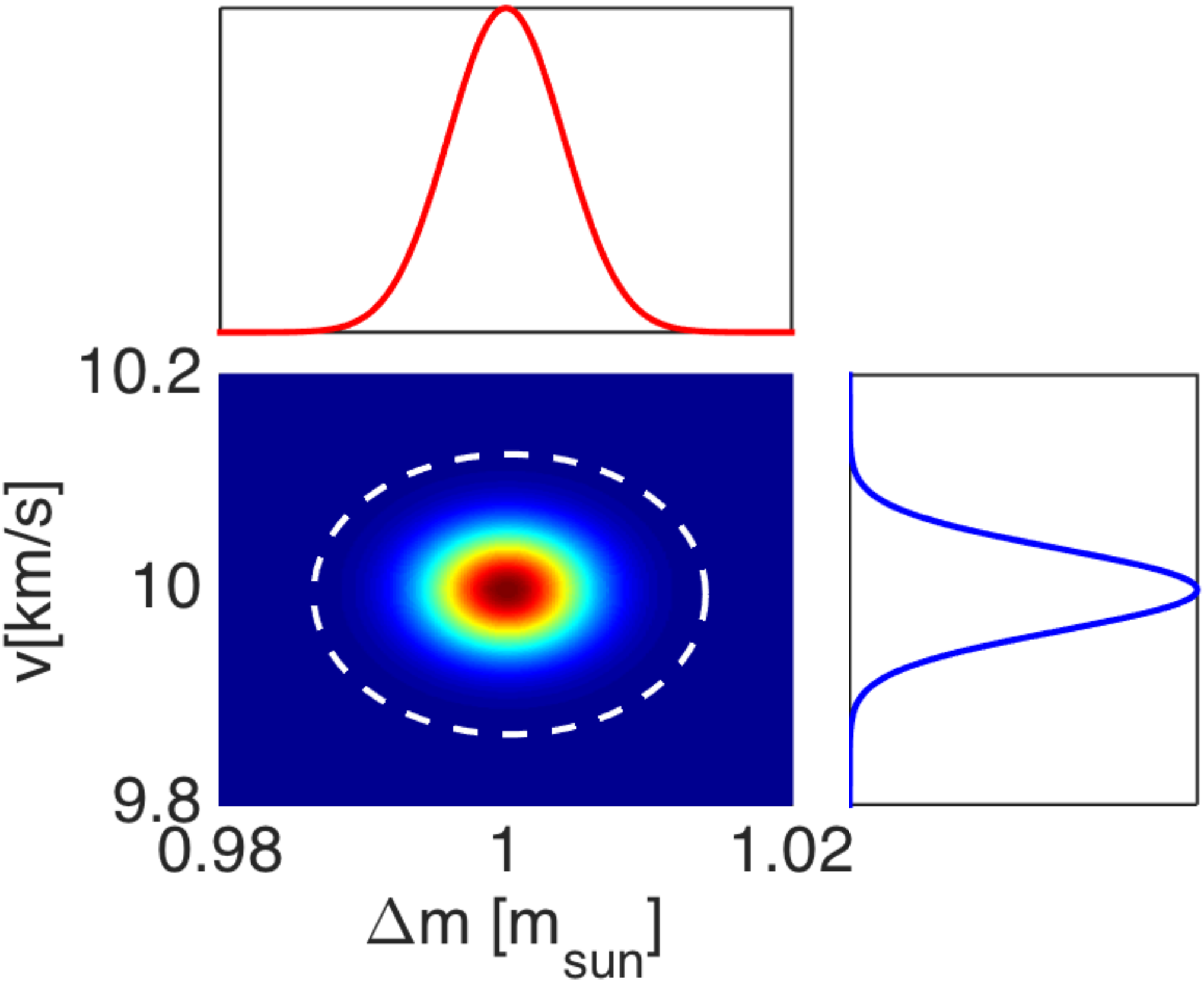


# 2. b-EMRI can accurately weighing mass loss due to binary merger

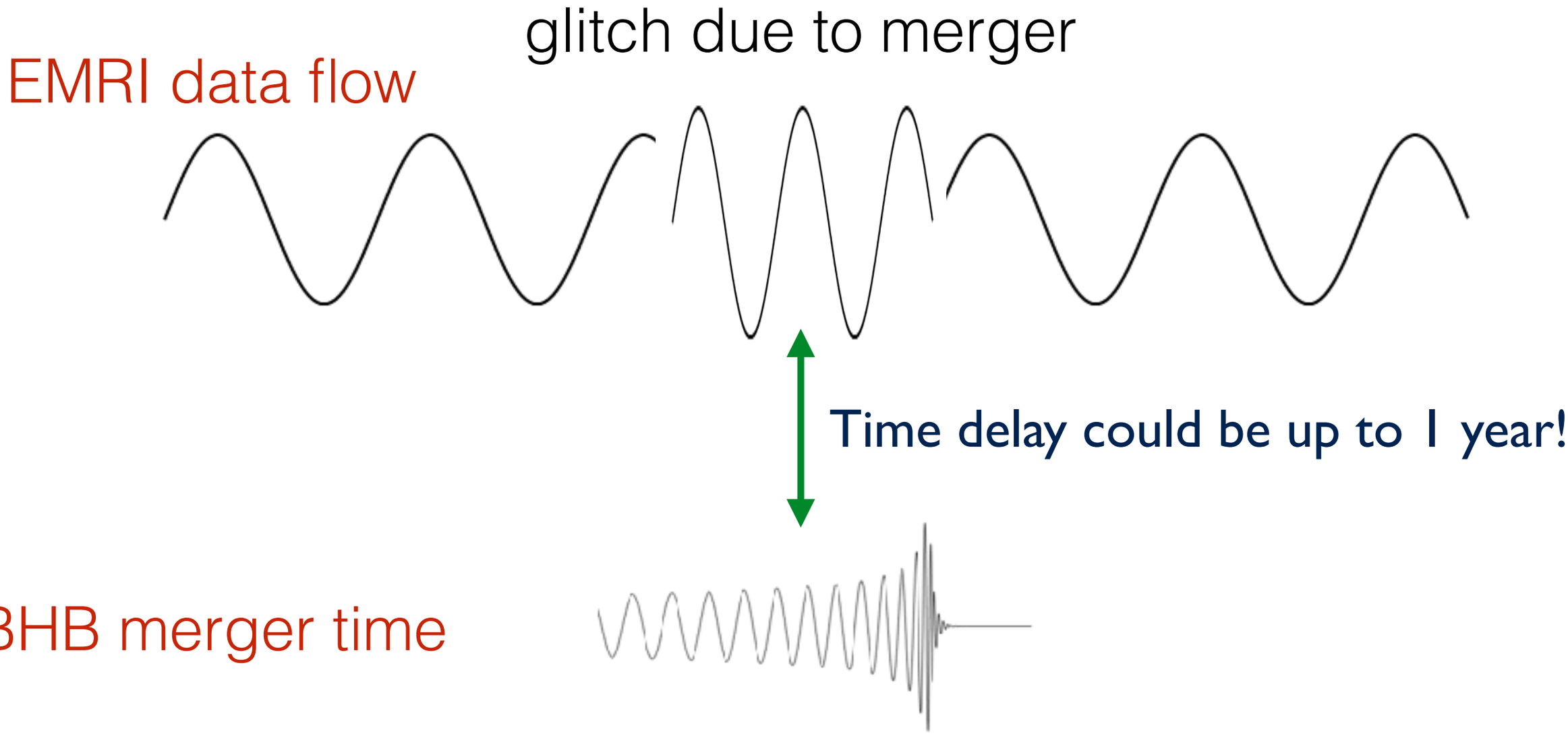
# 2. b-EMRI can accurately weighing mass loss due to binary merger Very important for binary NSs!



The accuracy of the constraint on recoil velocity and mass loss



# 3. b-EMRI can definitely confirm or rule out GW dispersion




Han & Chen arXiv:1801.07060, 2018

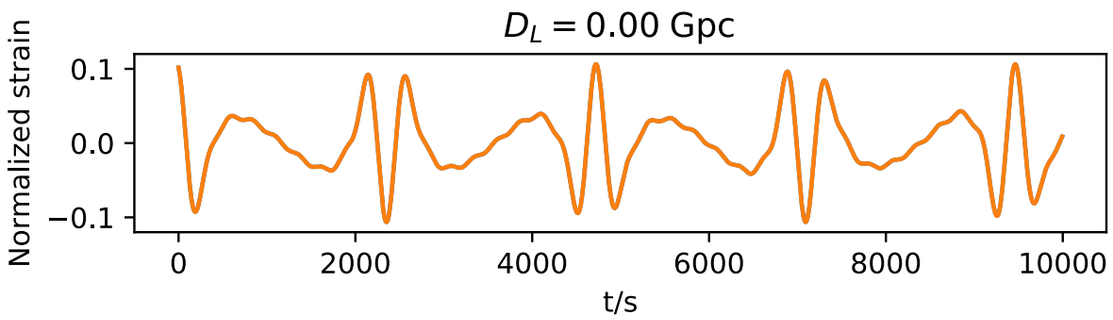
# Testing GW dispersion with highly eccentric EMRIs

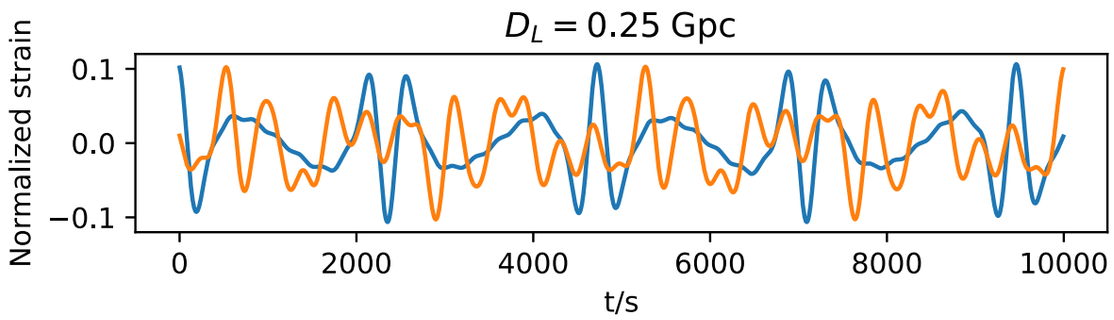
- Eccentric binary will radiates a few of modes simultaneously;

- If GWs are dispersive, the propagation velocities of different modes will be different, then induce a distortion of waveforms compared to the one predicted by GR;

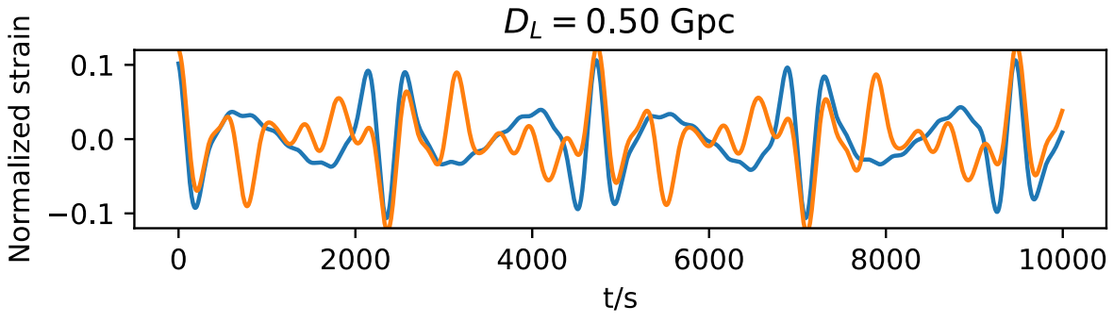
- EMRIs with 10^6 solar masses and at 1 Gpc has a capability to constrain the mass of graviton up to 3 orders better than the current result by LIGO.

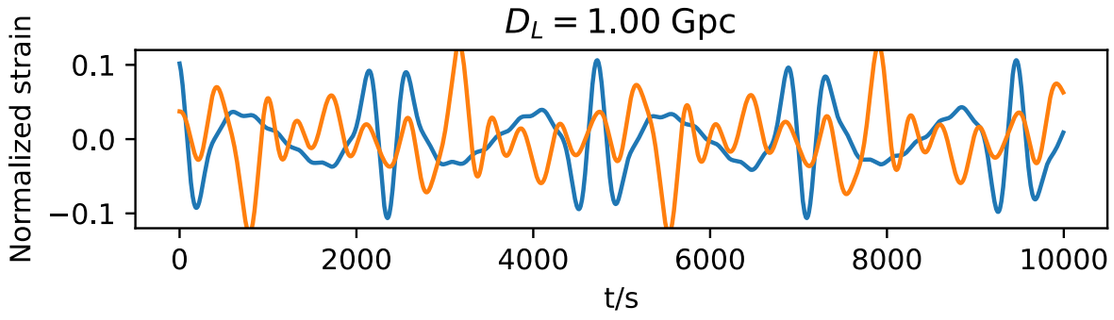
Yang, Han & Xin, arXiv:1812.04350

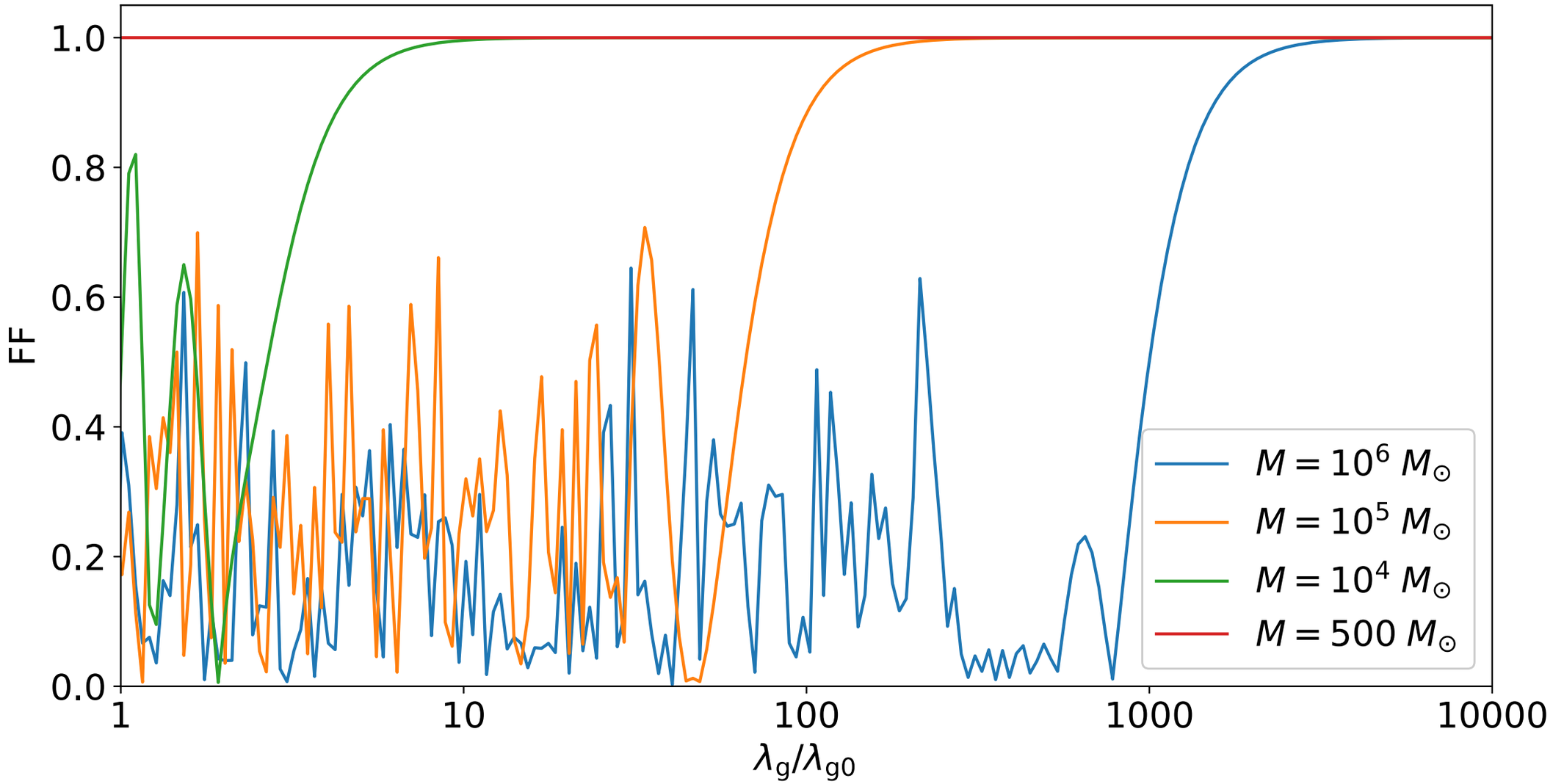



Non-dispersive GW
Dispersive GW



Thank you for your comments!