Gravitational Waves From Nearly Maximally Spinning Supermassive Black Holes

Kwinten Fransen

Based on [1712.07130]
with G. Compère, T. Hertog, J. Long

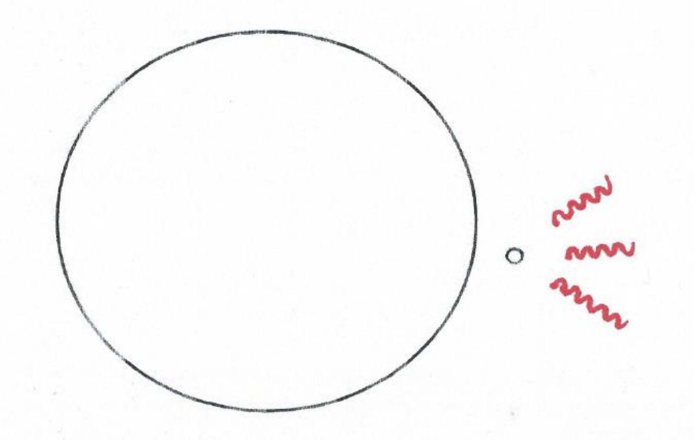
7th Belgian-Dutch Gravitational Waves Meeting

Setup

- Extreme Mass Ratio Inspiral (EMRI):

Supermassive central black hole | small orbiting compact object

$$M \gg \mu$$



Setup

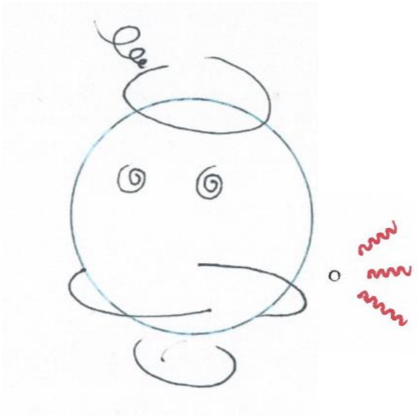
- Supermassive black hole is nearly maximally spinning

$$\frac{J}{M^2} \lesssim 1 \qquad \text{or} \qquad \lambda = \sqrt{1 - \left({}^{J}/_{M^2}\right)^2} \ll 1$$

Angular momentum J

$G = 1$

$c = 1$



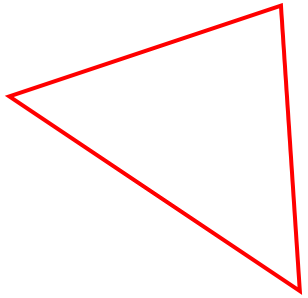
Setup

- Neglect internal structure small compact object
- Corotating, Equatorial orbit
- Final stage of the EMRI, ‘plunge’

See [1603.01221] (S. Gralla et al.) for earlier inspiral stage

Motivation

- EMRIs LISA target
- Nearly maximally spinning black holes?



Motivation

- EMRIs LISA target
- Nearly maximally spinning black holes?
- Analytic tools

$$\text{static} \rightarrow \text{general rotating black holes} \overset{?}{\leftarrow} \text{nearly-extremal}$$

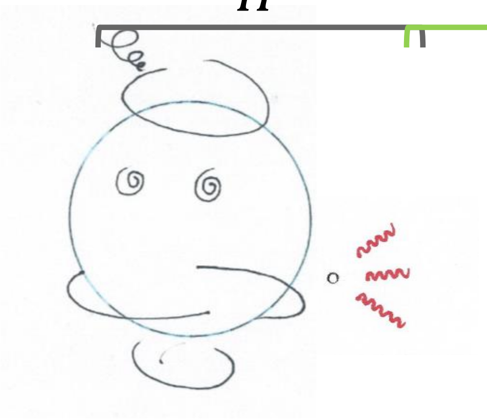
Approach

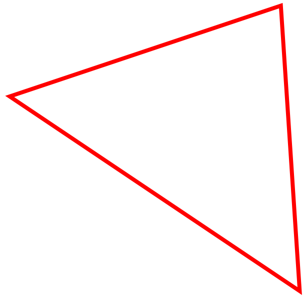
- Black hole perturbation theory $\mu \ll M$

- 0^{th} order motion μ is geodesic in background M

- Matched asymptotic expansion: solutions wave equation

  for $r \to r_H$ and $r \to \infty$





Near the horizon

Near-horizon limit spacetime has an enhanced symmetry $\rightarrow$ All timelike corotating equatorial geodesics ‘look like’ circular orbits

Near the horizon

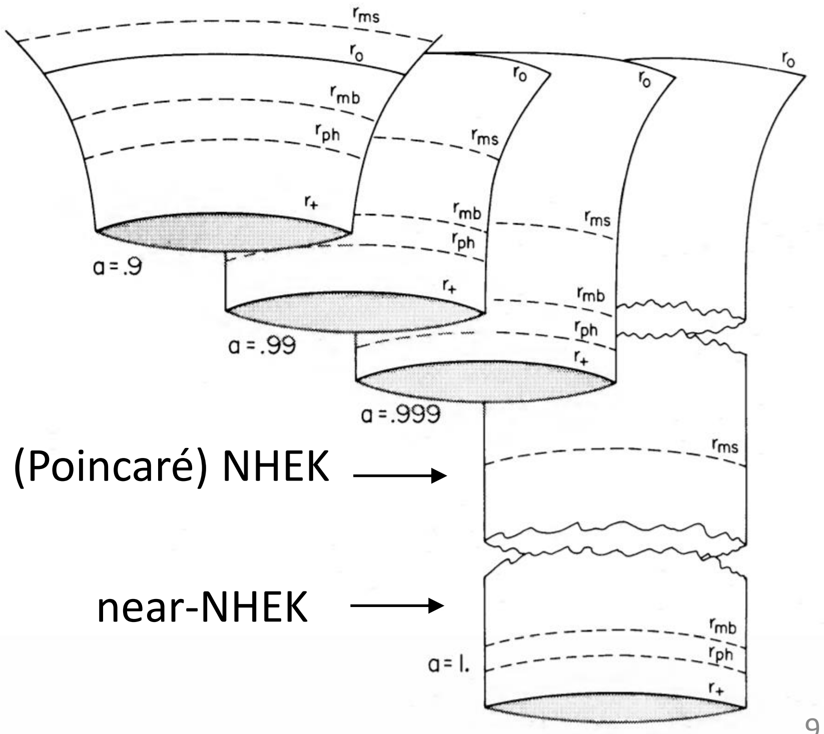
Near-horizon limit spacetime has an enhanced symmetry → All timelike corotating equatorial geodesics ‘look like’ circular orbits

2 near-horizon limits:

- Near Horizon Extremal Kerr (NHEK):

$$r - r_H \sim \lambda^{2/3}$$

- Near-NHEK: $r - r_H \sim \lambda$



Gravitational Waves

$$h_+ - ih_\times \to \mu \sum_{lm} \frac{e^{-im\Omega_H(t-r)+im\phi}}{r} S_{lm}(\theta)\lambda^{1/2} A_{lm}(\ell)\,\mathrm{f}_{lm}(t-r;e,\ell)$$

$$\Omega_H = \frac{1}{2\,M} + O(\lambda)$$

(timelike) corotating equatorial geodesics classified by (e,ℓ)

Gravitational Waves

$$h_+ - ih_\times \to \mu \sum_{lm} \frac{e^{-im\Omega_H(t-r)+im\phi}}{r} S_{lm}(\theta)\lambda^{1/2} A_{lm}(\ell)\, \mathrm{f}_{lm}(t-r; e, \ell)$$

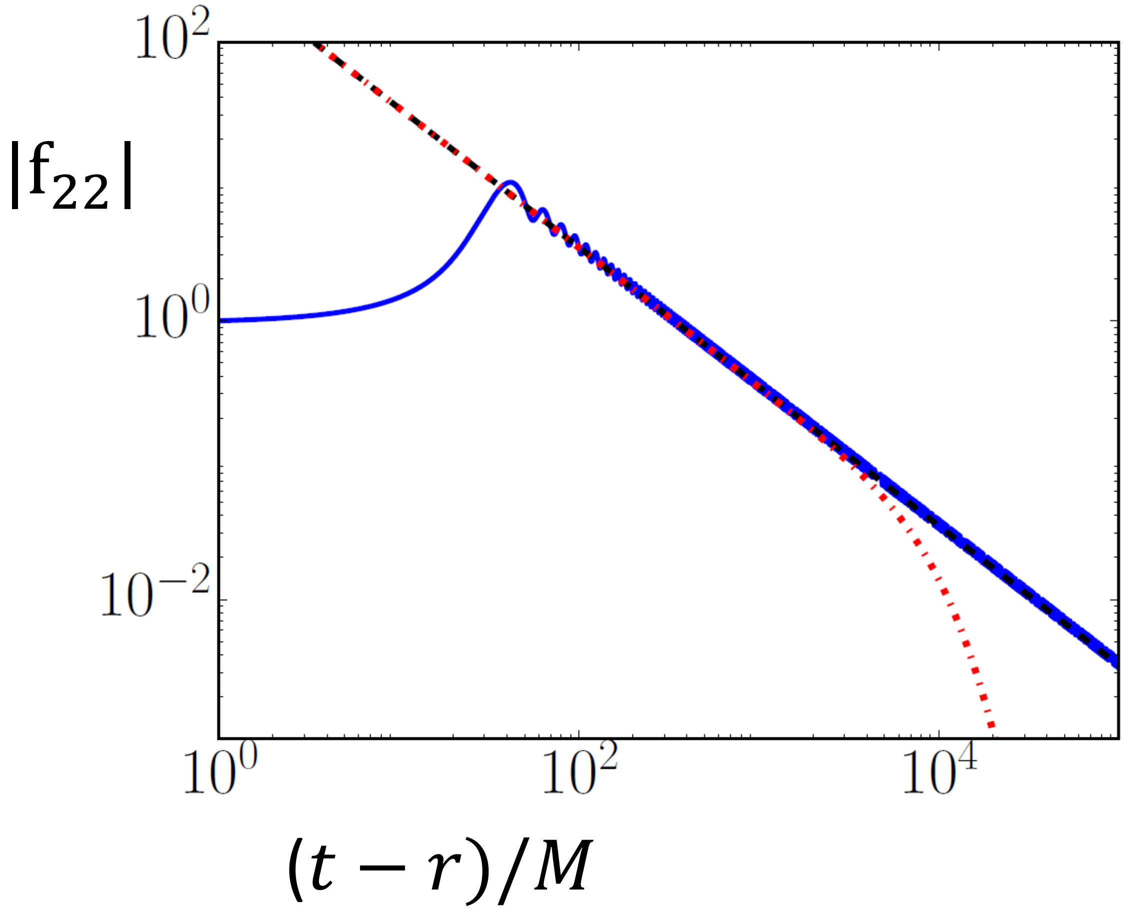
1. Frequency dominated by horizon

Gravitational Waves

$$h_+ - ih_\times \to \mu \sum_{lm} \frac{e^{-im\Omega_H(t-r)+im\phi}}{r} S_{lm}(\theta)\lambda^{1/2} A_{lm}(\ell)\, \mathrm{f}_{lm}(t-r; e, \ell)$$

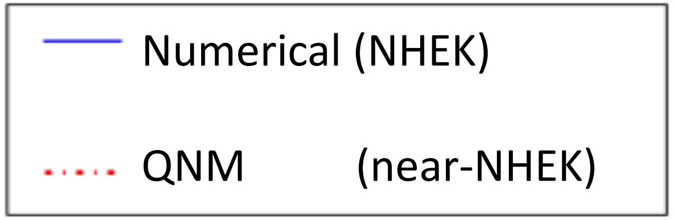
1. Frequency dominated by horizon
2. Polynomial ringdown

Polynomial ringdown

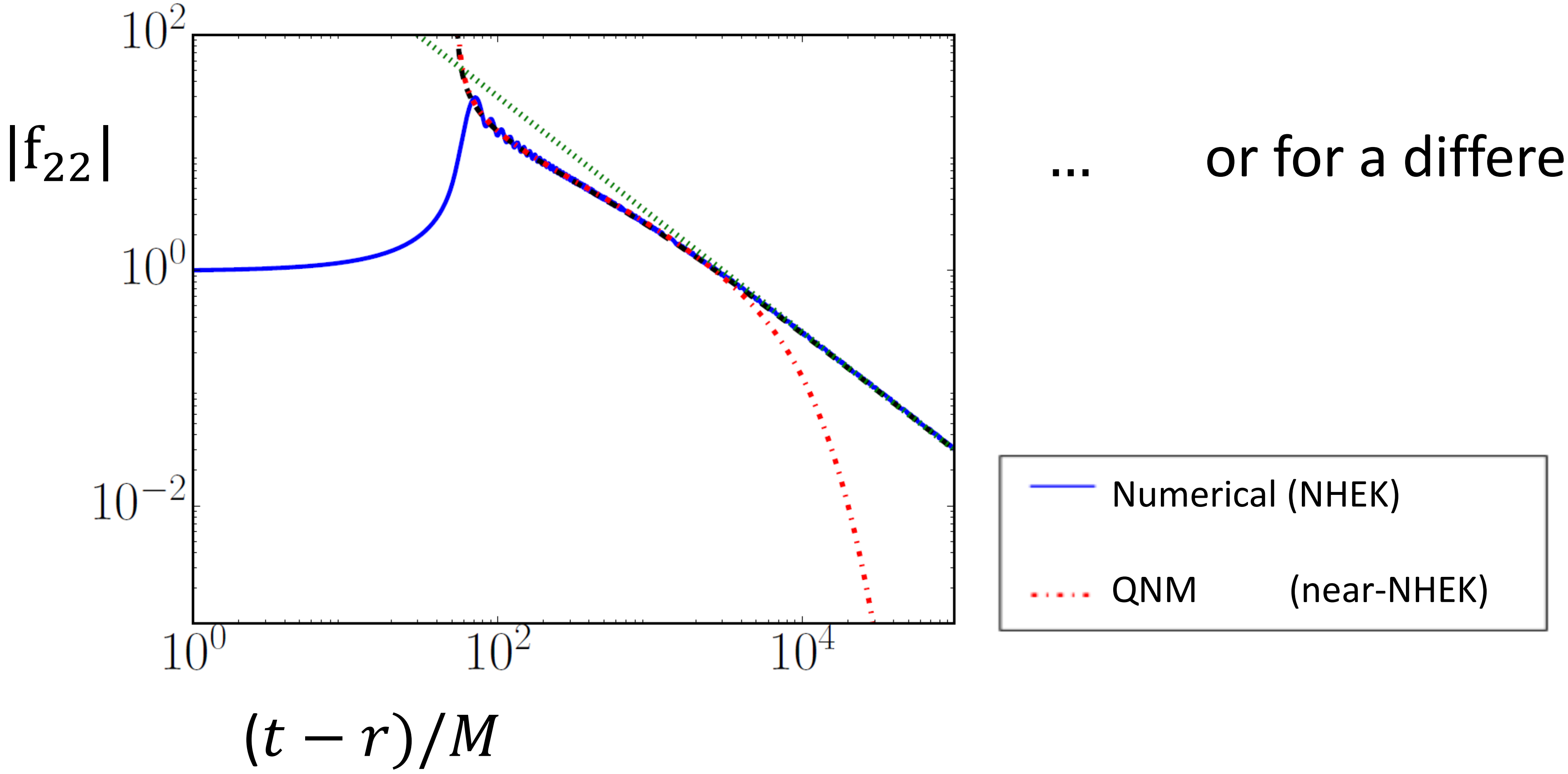


'zero-damped' Quasi-Normal Modes

$$\omega_{Nlm} \approx \frac{1}{2M}\left(m - i\lambda(N + h_{lm})\right)$$



Polynomial ringdown



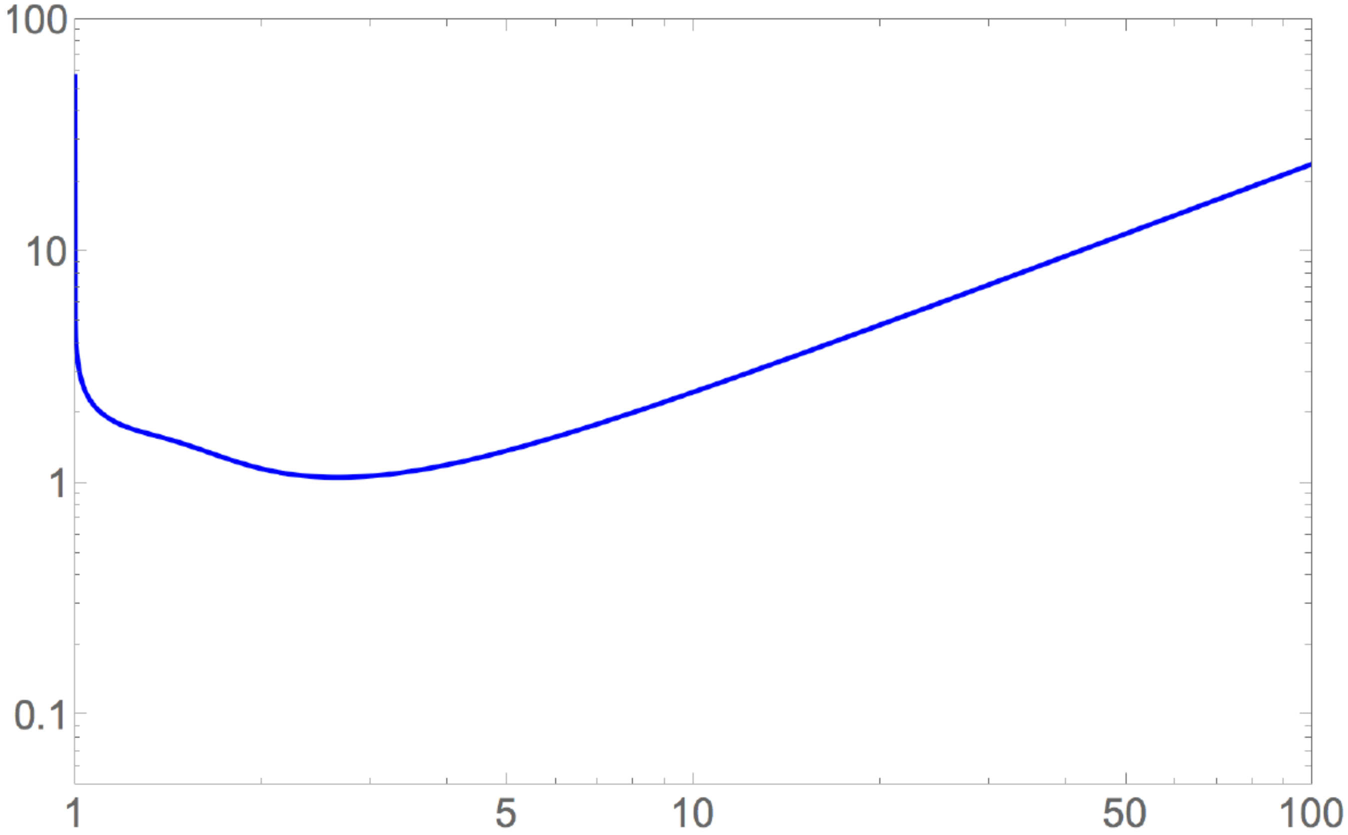
... or for a different geodesic

Gravitational Waves

$$h_+ - ih_\times \to \mu \sum_{lm} \frac{e^{-im\Omega_H(t-r)+im\phi}}{r} S_{lm}(\theta) \lambda^{1/2} A_{lm}(\ell)\, \mathrm{f}_{lm}(t-r; e, \ell)$$

1. Frequency dominated by horizon
2. Polynomial ringdown
3. Critical behavior

Critical behavior



A_{22}

$\frac{\ell}{\ell_*}$

$$A_{lm}(\ell \to \ell_*) \propto \left(\frac{\ell}{\ell_*} - 1\right)^{-1/4}$$

$$A_{lm}(\ell \to \infty) \propto \frac{\ell}{\ell_*}$$

Conclusion

$$h_+ - ih_\times \to \mu \sum_{lm} \frac{e^{-im\Omega_H(t-r)+im\phi}}{r} S_{lm}(\theta)\lambda^{1/2} A_{lm}(\ell)\, \mathrm{f}_{lm}(t-r; e, \ell)$$

$\lambda^{1/2}$ suppression $\leftrightarrow$ Slow decay $\sim$ λ^{-1}+ Critical behavior (?)

↓

Natural question: how does inspiral transition into plunge?

(i.e. which (e, ℓ) to expect?)

Thank you for your attention

You may also like

- Earlier work by S. Hadar, A. Porfyriadis, A. Strominger
- Other features of such EMRIs: [1603.01221] (S. Gralla et al.)