GRAVITATIONAL WAVE SIGNAL FROM TRANSIENT ASTRONOMICAL EVENTS

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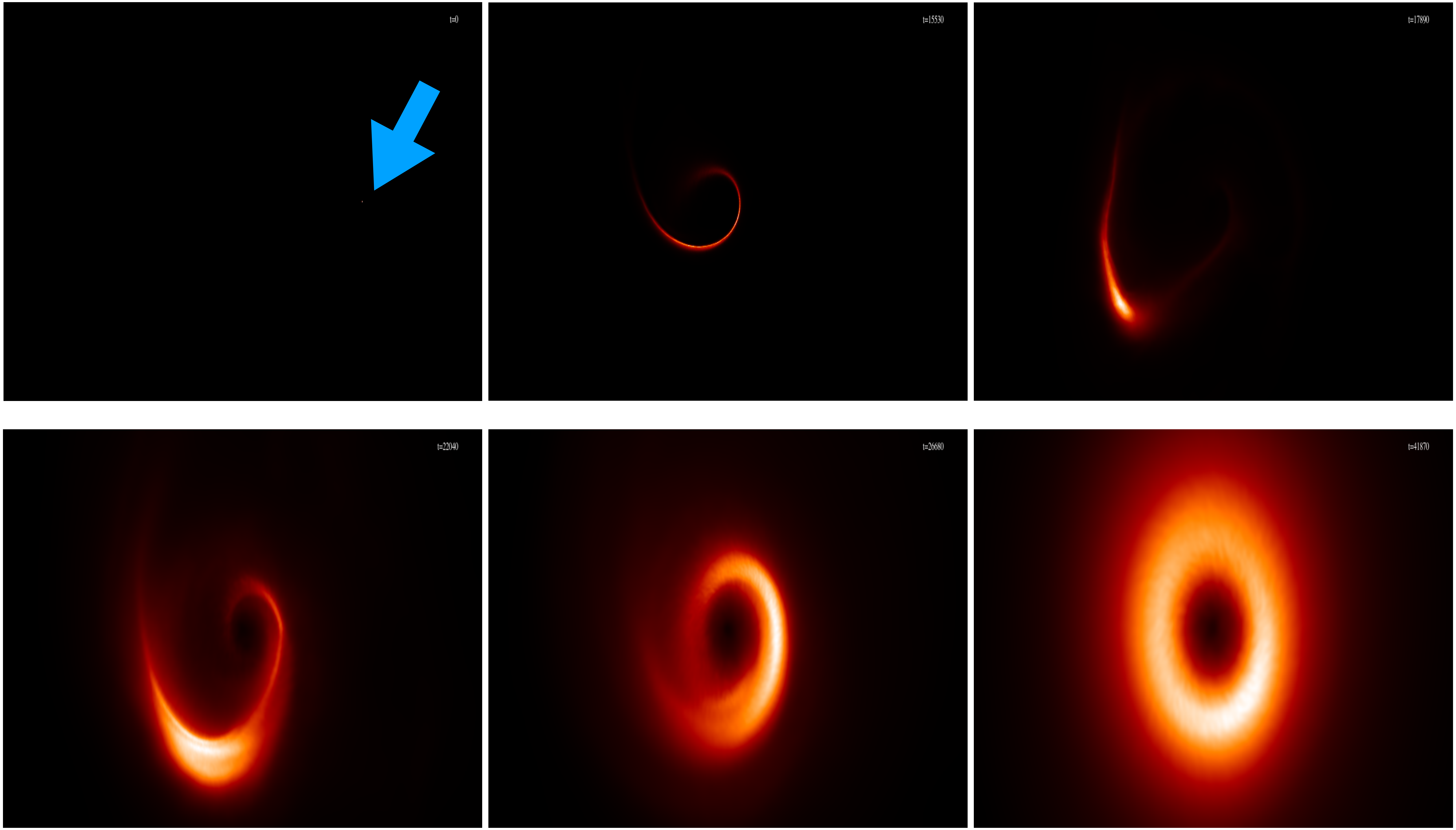
In collaboration with: G. Lodato, D.J. Price, E.M. Rossi, R. Nealon, D. Liptai

The era of collaborative multi-wavelength and multi-messenger astronomy: science and technology. 22nd-24th October 2019, Firenze



simulation by Martina Toscani made with GR PHANTOM

So far around 40 events of this type have been detected

- ✱ very luminous EM sources (X rays, γ rays, optical, IR)
- ✱ lightcurve that goes as $t^{-5/3}$
- ✱ they can present Super Eddington luminosities
- ✱ GW burst corresponding to the phase of disruption of the star

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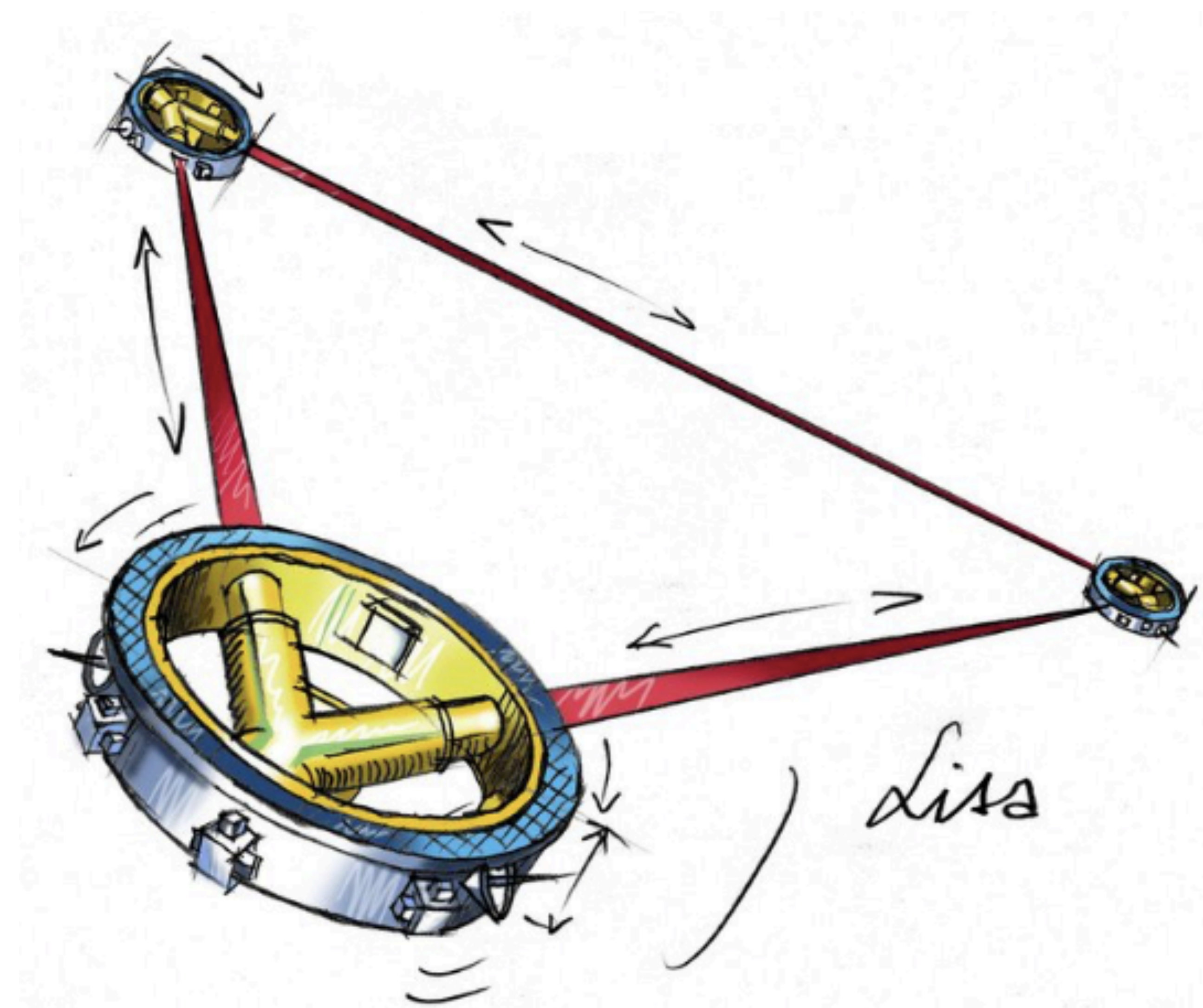


GWs from TIDAL DISRUPTIONs

After the disruption about half of the star circularizes around the BH and forms an accretion disc

If we assume

1. very weak magnetic field
2. shallow specific angular momentum profile
3. inner and outer boundaries well defined

PAPALOIZOU PRINGLE INSTABILITY

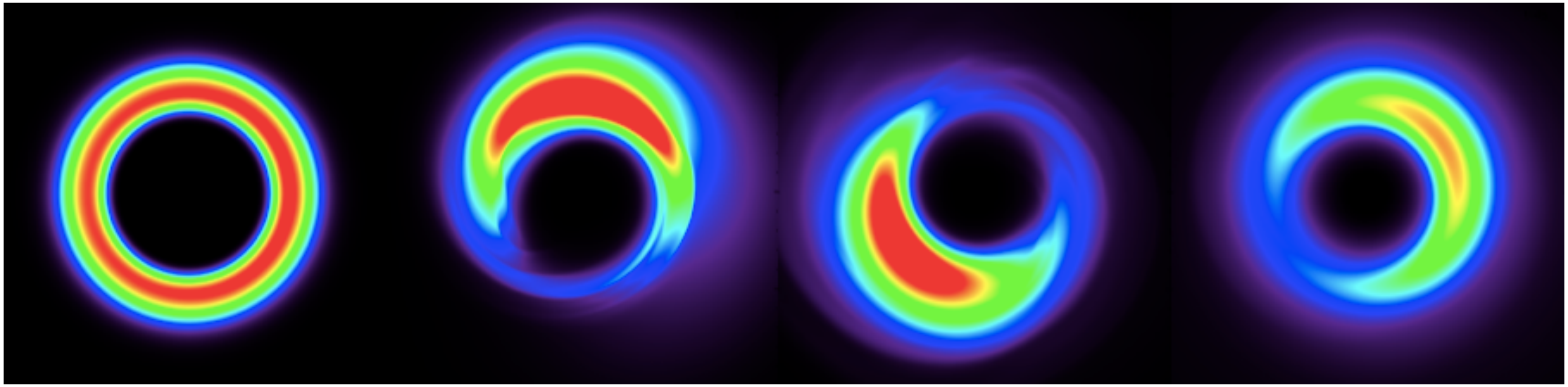
Global hydrodynamical instability non-axisymmetric
Clump of matter that travels around the torus

- with a mass $\approx 1M_\odot$
- Keplerian frequency
- radius of maximum density twice the stellar pericenter
- it lasts for around 20 orbits

initial condition motivated by Bonnerot et al 2016, Nealon et al 2018, Bugli et al 2018

Time varying mass quadrupole

GRAVITATIONAL WAVE EMISSION



hydro simulation in Toscani et al 2019a, MNRAS

IDEA: aproximate the clump of matter as a $1M_\odot$ **point particle** on a Keplerian orbit at $2r_\mathrm{p}$

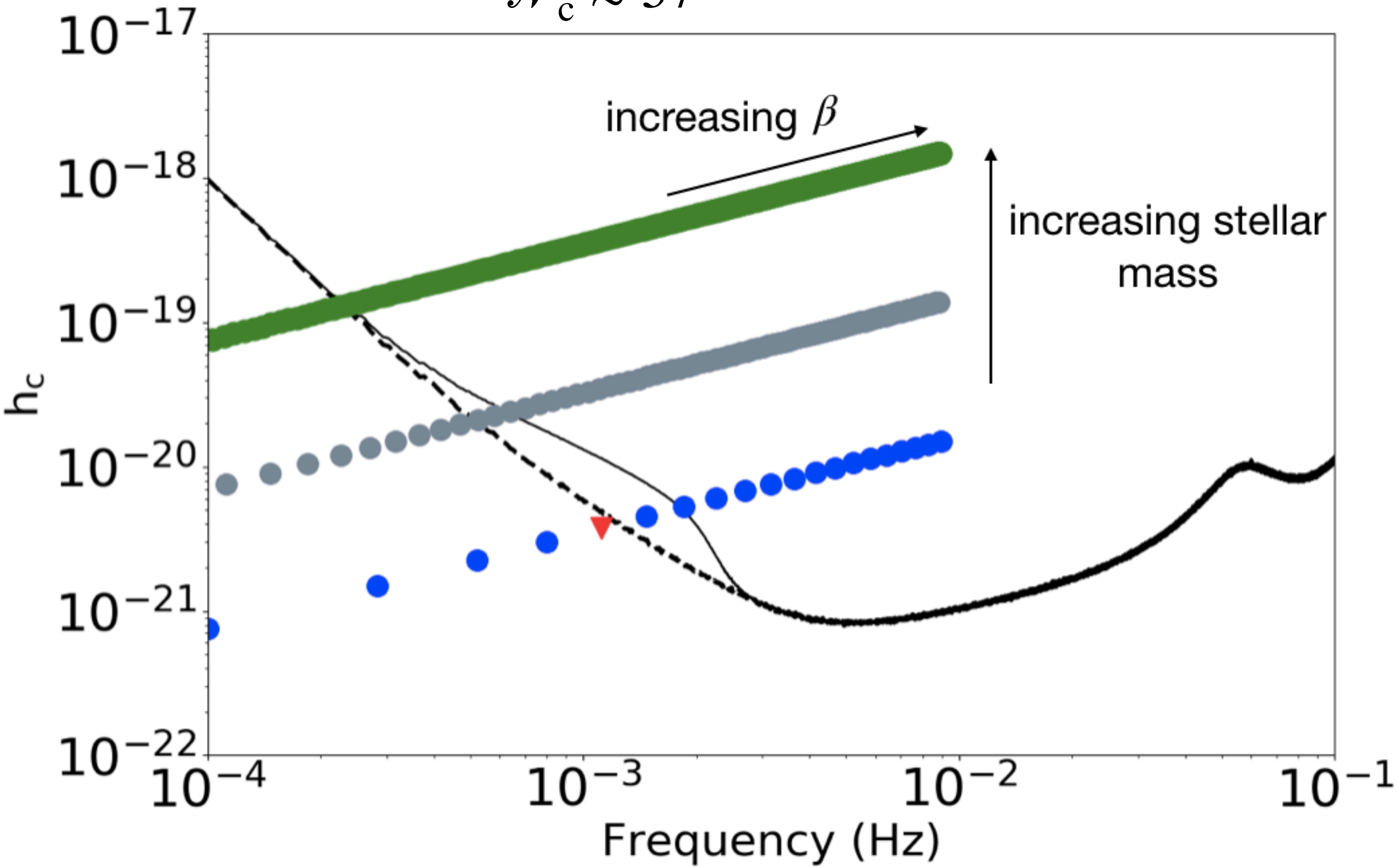
This is a **BEST-CASE SCENARIO** estimate since

- not all the stellar mass is involved in the PPI
- the torus is not located at a fixed position but it is spreading out

$$h_c = h\sqrt{\mathcal{N}_c} \approx h\sqrt{f\tau}$$ Colpi&Sesana, 2017

$$\mathcal{N}_c \approx 57$$

GWs from TIDAL DISRUPTIONs



Toscani et al 2019a, MNRAS

$$h^{\mathrm{PPI}} = \xi h$$

GWs from TIDAL DISRUPTIONs

$$\xi \in (0,1)$$

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GWs from TIDAL DISRUPTIONs

$$\xi \in (0,1)$$

PHANTOM: a smoothed particle hydrodynamics code for three dimensional simulations of astrophysical events

$$h^{\mathrm{TT}}(t, \mathbf{n}) \approx \ddot{M}^{\mathrm{kl}}$$

$$M^{\mathrm{kl}} = \frac{1}{c^2}\int d\mathbf{x} T_{00} x^{\mathrm{k}} x^{\mathrm{l}} \Rightarrow M^{\mathrm{kl}} = \sum_{\mathrm{a}} m_{\mathrm{a}} x^{\mathrm{k}} x^{\mathrm{l}},$$

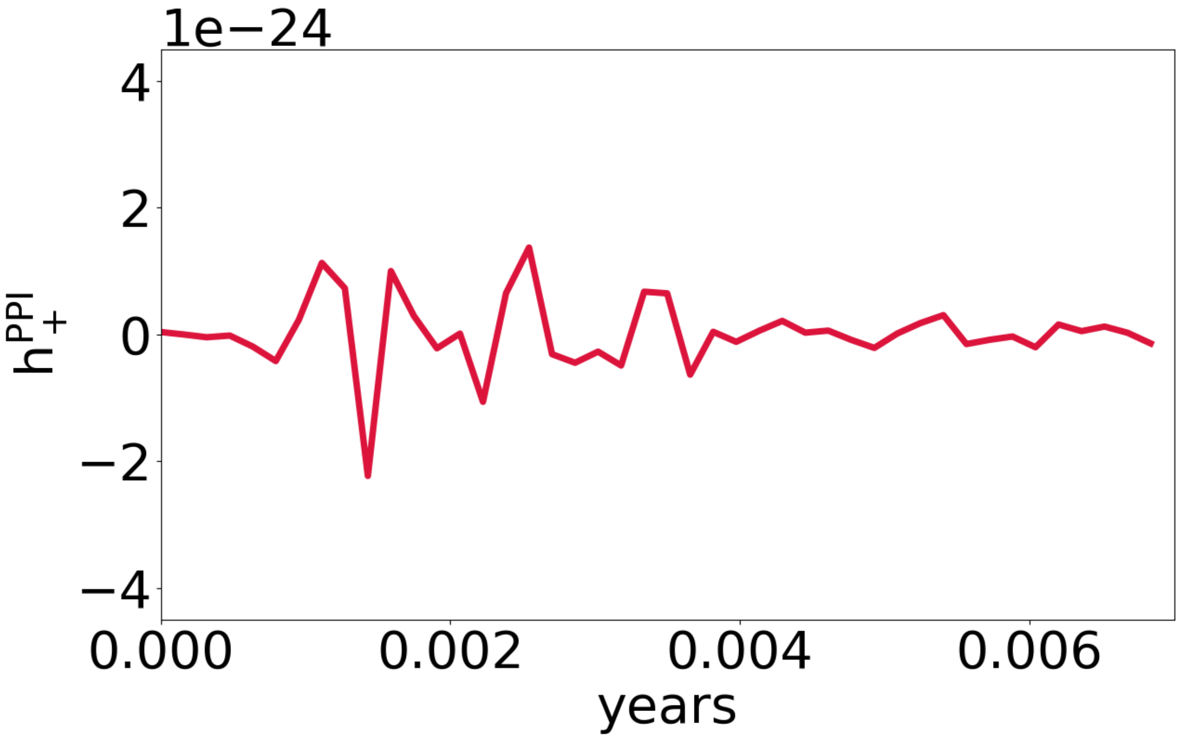
a: index that runs over the number of particles

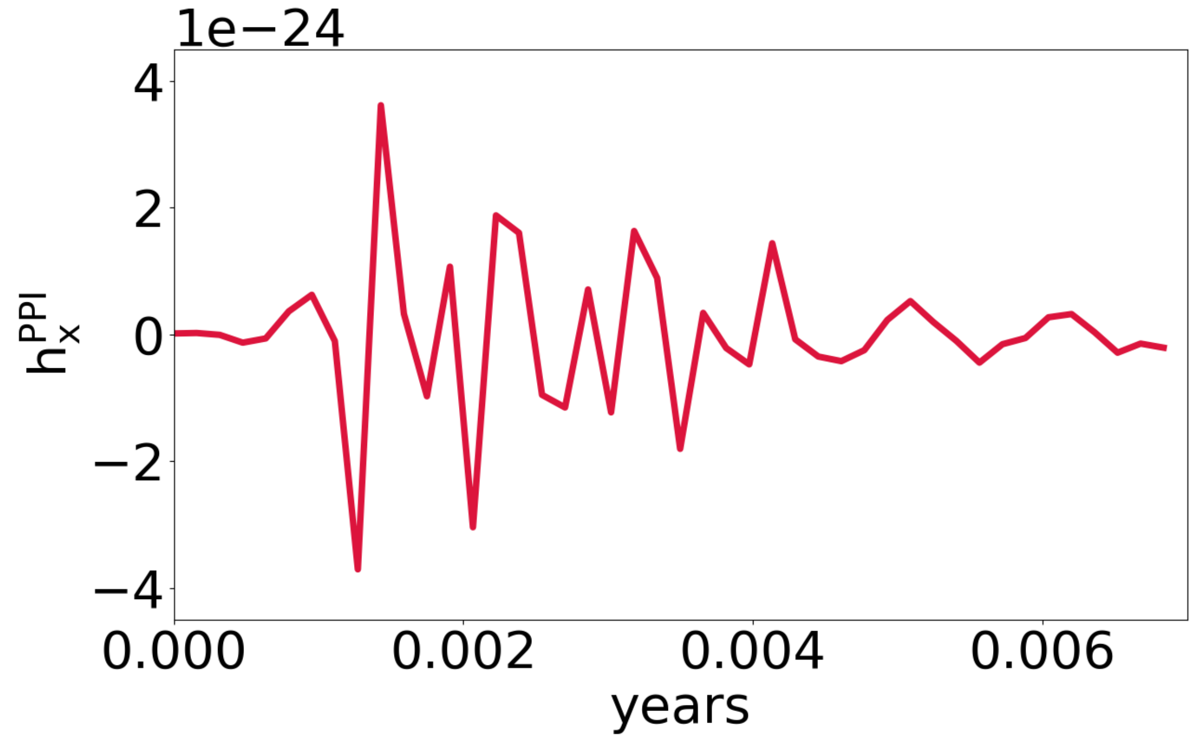
M: inertia moment of the system

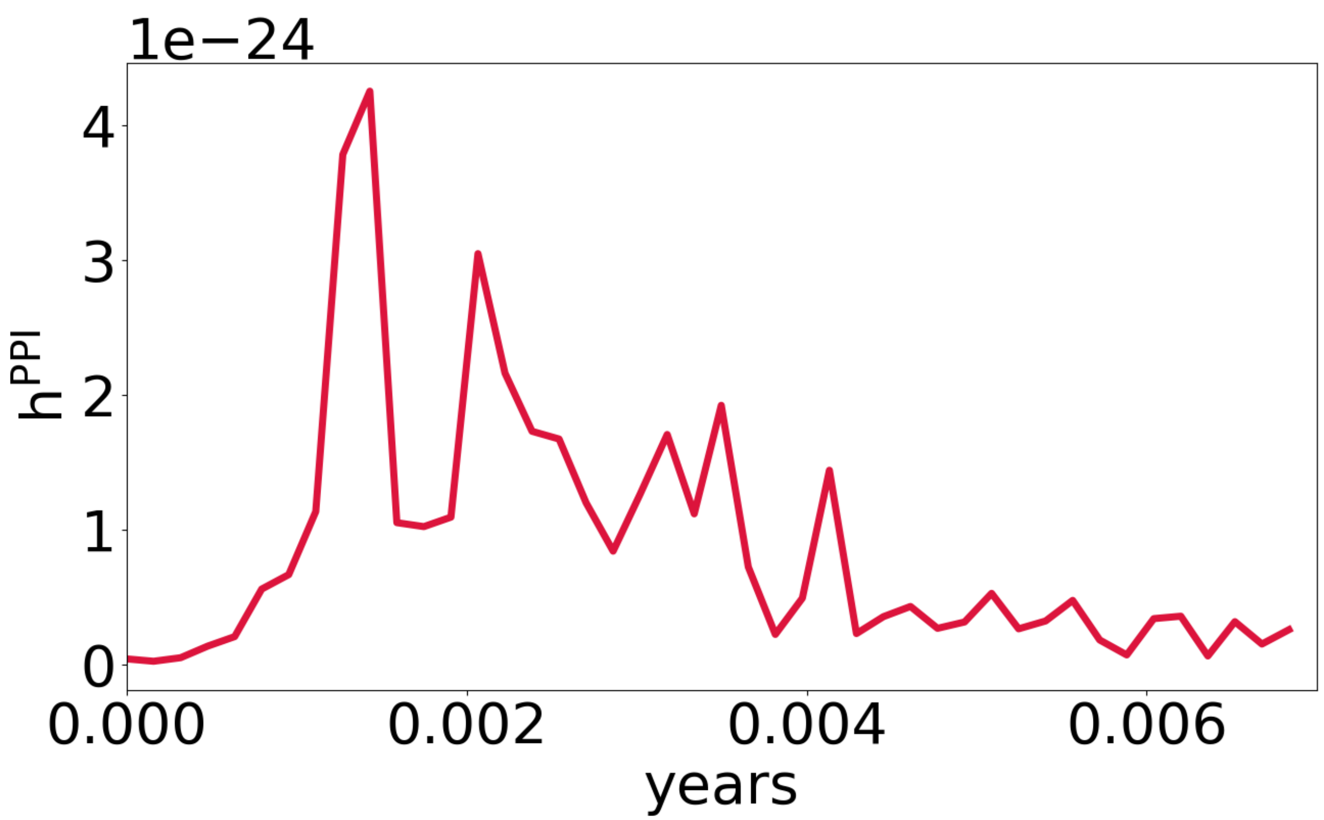
$$\ddot{M}^{\mathrm{kl}}_j = \frac{M^{\mathrm{kl}}_{\mathrm{j+1}} - 2M^{\mathrm{kl}}_{\mathrm{j}} + M^{\mathrm{kl}}_{\mathrm{j-1}}}{\Delta t^2}$$

j: index that runs over the number of dumpfiles

GWs from TIDAL DISRUPTIONs







$$\xi \approx 10^{-2}$$

Toscani et al 2019a, MNRAS

- the signal reaches the peak when the overdensity is stonger (6th orbit)
- the signal is two orders of magnitude lower than the analytical expectations
- the range of stellar masses for which the signal is above the LISA curve is 10-100 $M_{\odot}$
- if we consider a magnetic field ab initio the PPI is suppressed before

MORE INVESTIGATIONS ABOUT TDEs

- GW burst during the disruption phase (Kobayashi et al 2004, Rosswog et al 2009, Haas et al 2012, Anninos et al 2018)
- prolongated GW emission from the accretion discs thanks to the presence of global instabilities (Toscani et al 2019a)
- ...what can we say for the GW background?...

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MORE INVESTIGATIONS ABOUT TDEs

Idea: globular clusters in galaxies are the most likely environments for **INTERMEDIATE MASSIVE BLACK HOLES**

Assuming that these BHs disrupt **WHITE DWARFS**, what is the overall signal from this type of sources?

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how many GCs per galaxy?

IMBH mass range?

h_c

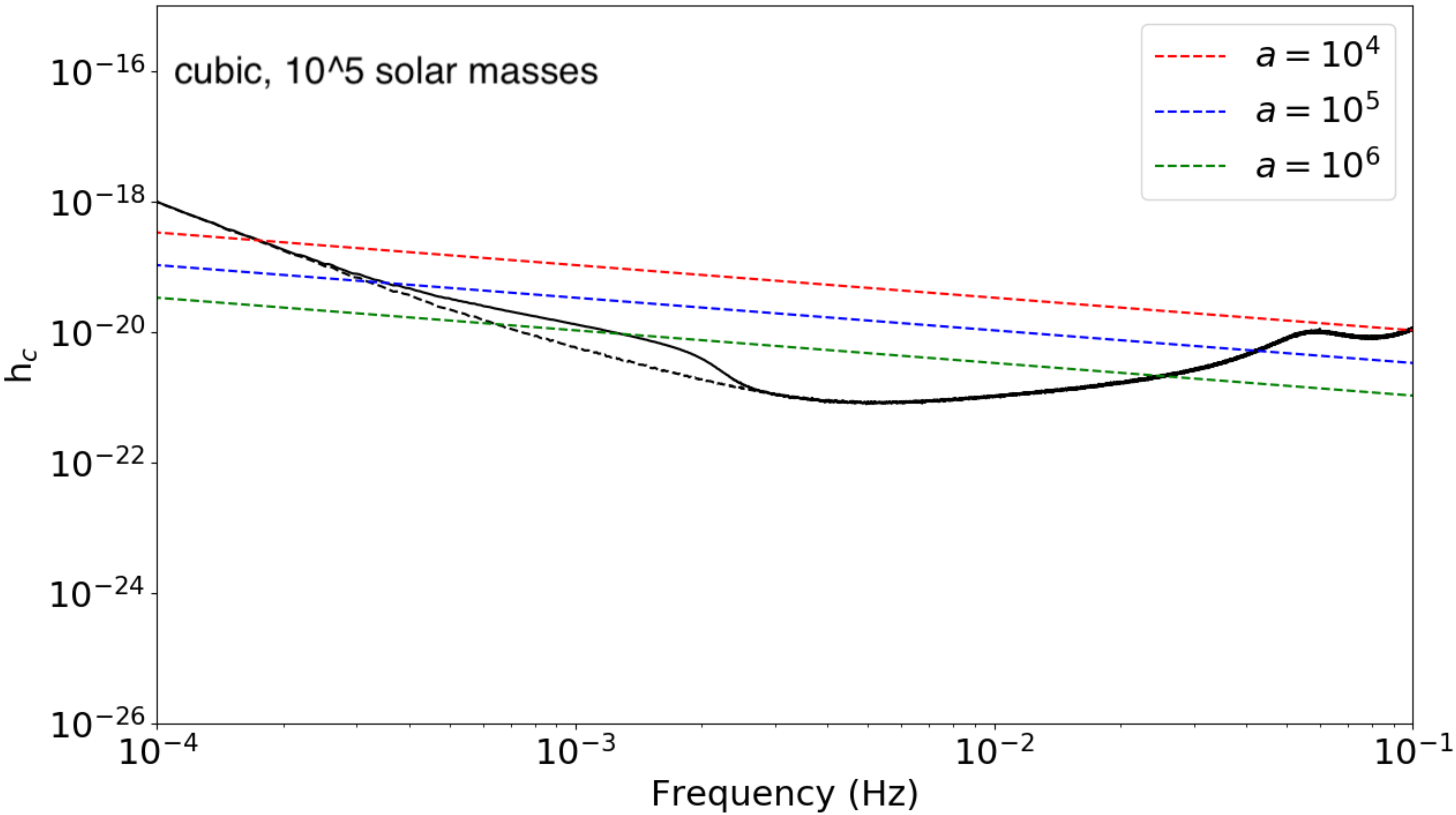
at what distance from the IMBH?

at what rate?

Many parameters to study!

MORE INVESTIGATIONS ABOUT TDEs

WORK IN PROGRESS



Toscani et al, in prep

PHANTOM

smoothed particle hydrodynamics and magnetohydrodynamics code for three dimensional simulations of astrophysical events

Price et al 2018

- low- memory, fast, highly efficient
- widely tested for accretion, star formation, star cluster formation, turbulence …

Liptai & Price, 2019

- full general relativistic code

✓ able to capture relativistic shocks

✓ precise and accurate treatment for orbital dynamics

✓ ability to work in Kerr geometry

PHANTOM

IDEA: add a tool for the derivation of the gravitational wave emission

central time difference

$$\ddot{M}^{\mathrm{kl}}_{\mathrm{j}} = \frac{M^{\mathrm{kl}}_{\mathrm{j+1}} - 2M^{\mathrm{kl}}_{\mathrm{j}} + M^{\mathrm{kl}}_{\mathrm{j-1}}}{\Delta t^2}$$

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using particle velocities and accelerations

$$\ddot{M}^{\mathrm{kl}} = \sum_{\mathrm{a}} m_{\mathrm{a}}(\ddot{x}^{\mathrm{l}} x^{\mathrm{k}} + 2\dot{x}^{\mathrm{k}} \dot{x}^{\mathrm{l}} + x^{\mathrm{l}} \ddot{x}^{\mathrm{k}})$$

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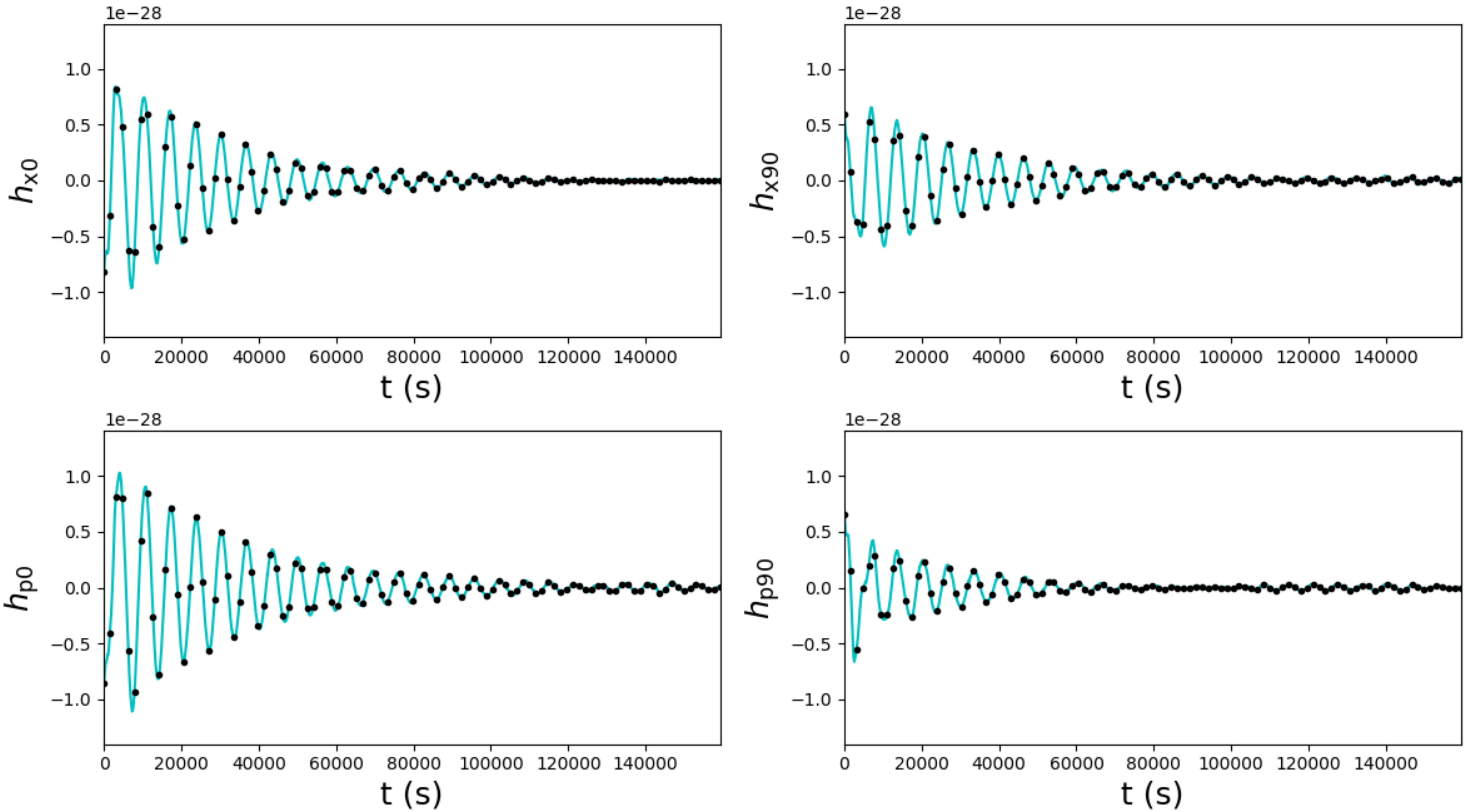
Tests (I)

☑ GW emission from a relaxed star

Toscani et al, in prep



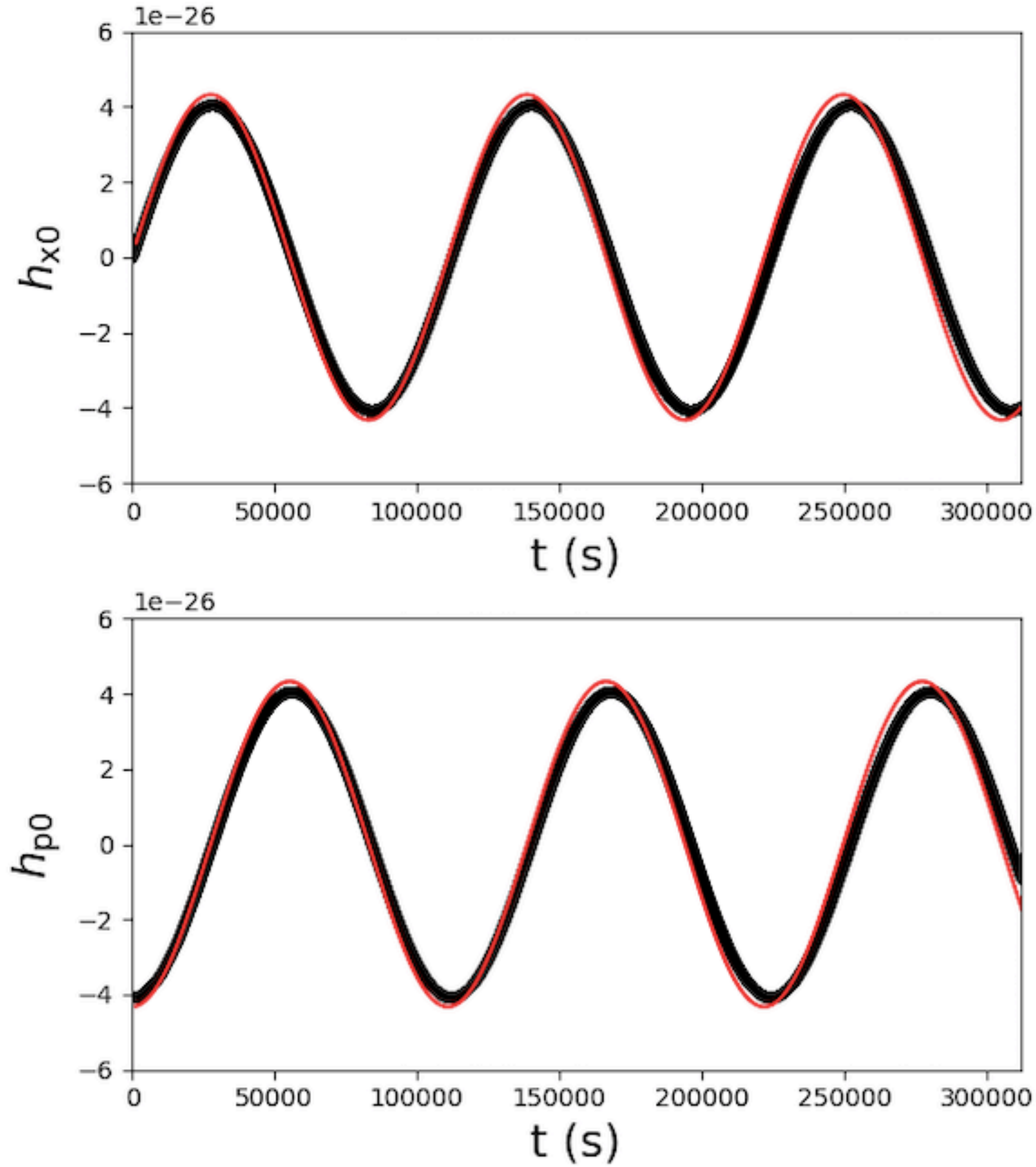
Tests (II)

☑ GW emission from a binary of two main sequence stars

$\mathbf{M}_1 = \mathbf{M}_2 = 1\mathbf{M}_\odot$

radial distance $= \mathbf{10R}_\odot$

$\mathbf{d} = 1$ **Mpc**



— analytical solution

— numerical solution

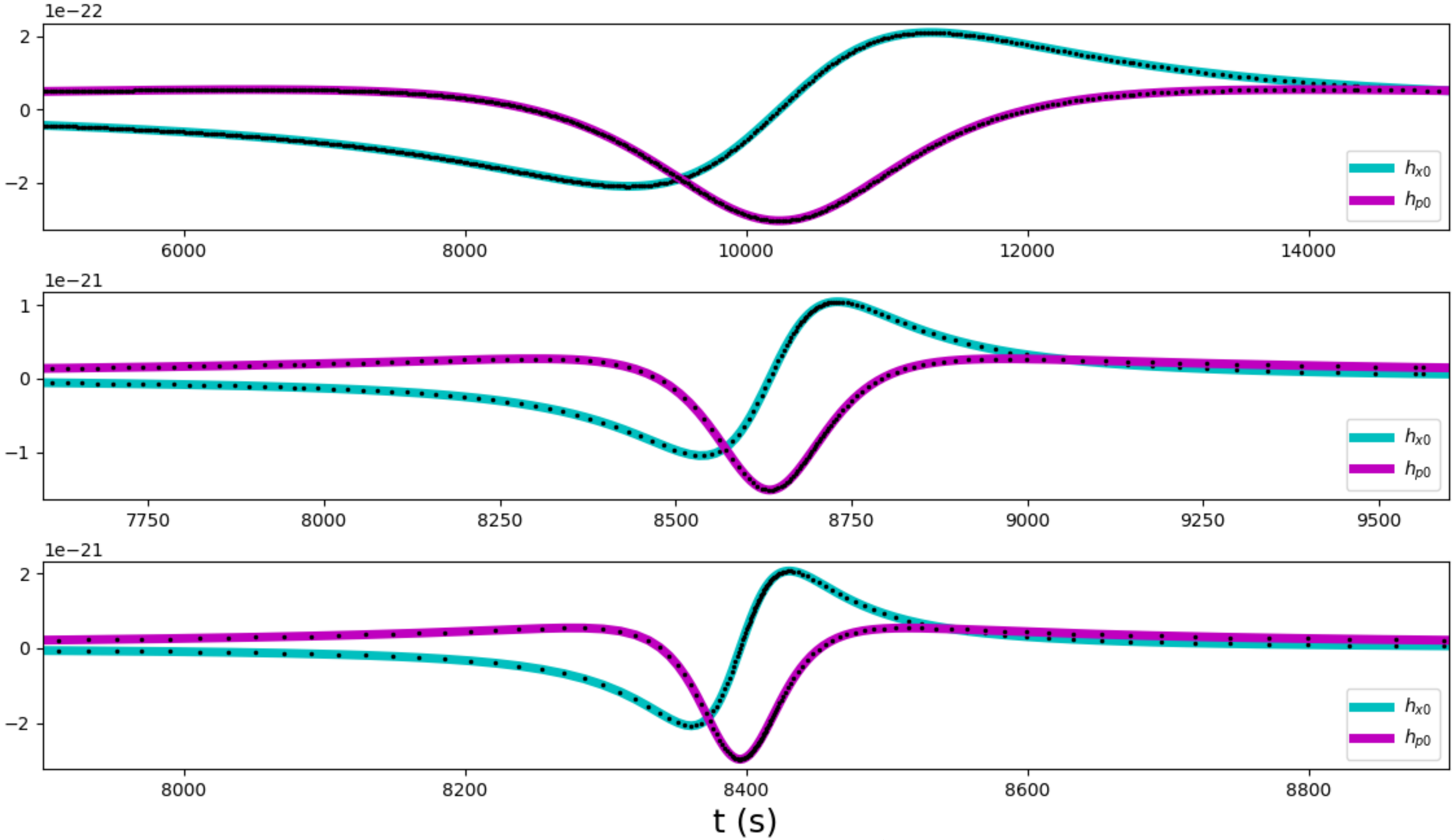
Toscani et al, in prep

PHANTOM

Physical application

GW emission from tidal disruption events

Toscani et al, in prep



good agreement with previous studies (e.g. Kobayashi et al, 2004)

Next steps…

1) soon available for everyone
2) manage to simulate the mergers (of neutron stars, black holes …) also in GR PHANTOM (already possible with the previous version of PHANTOM)

We hope that this open source & efficient code can be a useful tool for the multi-messenger astronomy community!

THANKS FOR YOUR ATTENTION

Please check my work

1) Toscani et al, 2019, MNRAS, Volume 489, Issue 1, October 2019, Pages 699–706
2) Toscani et al, 2019b, International Journal of Modern Physics
DOI: 10.1142/S0218271819440152

ANY QUESTIONS?