Studying black holes with tidal disruption events

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IRAP/L2IT mini-symposium sur les ondes gravitationnelles, 10 December 2021

Université Toulouse III Paul Sabatier

cnrs

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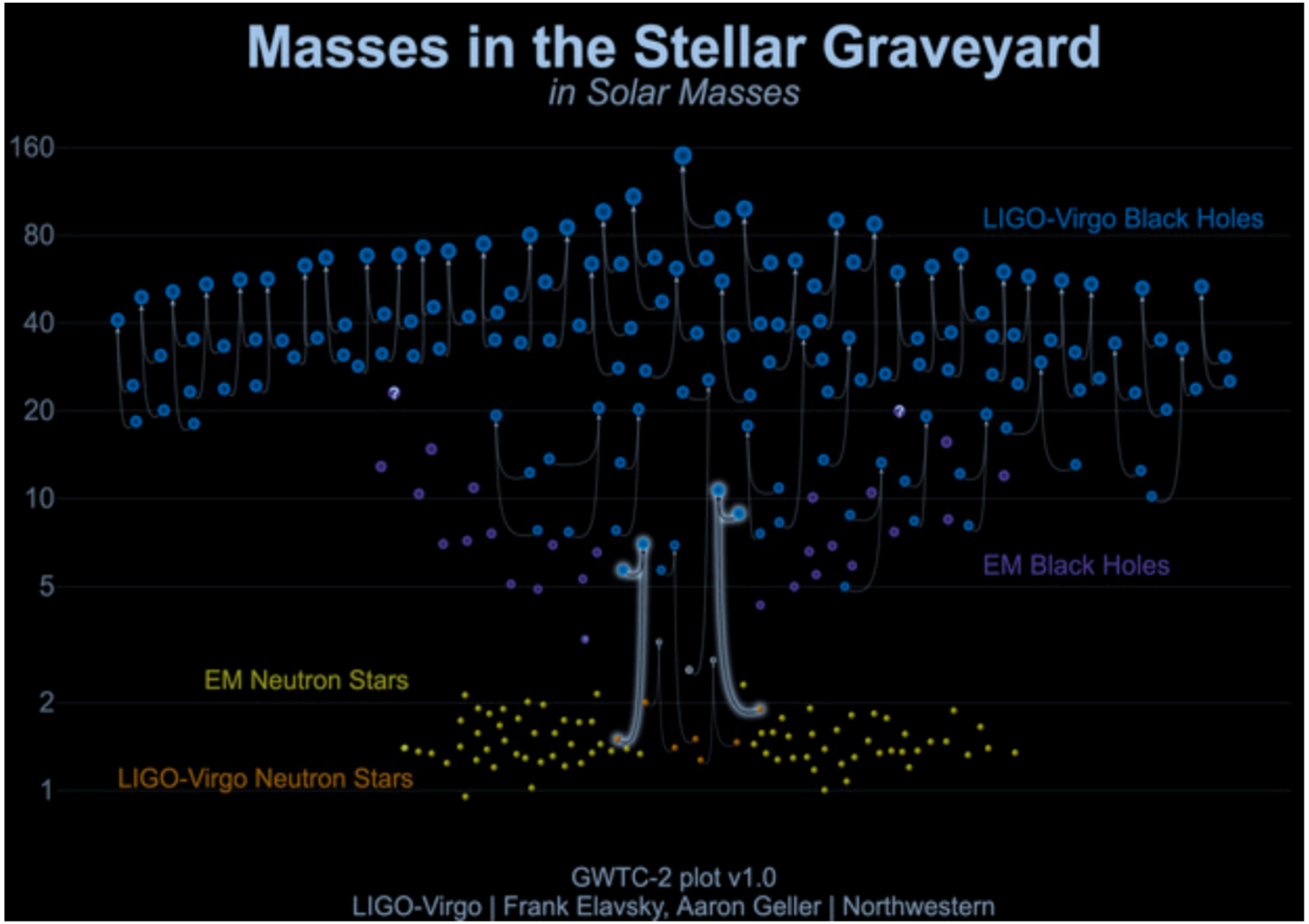
L2IT

Black Holes (BHs) ↔ regions of space-time where gravity is so strong that not even light can escape

discoveries in this field **rejuvenated** by the advent of gravitational wave (GW) astronomy

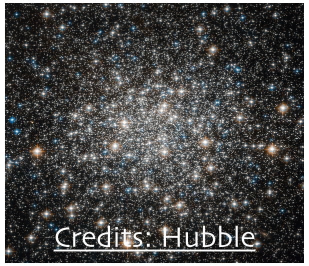


stellar BHs: originating from dying stars

massive BHs

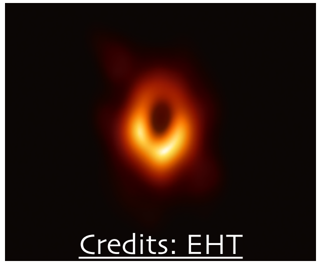
intermediate mass BHs (IMBHs)

- to date no population detected
- globular clusters (GCs), dwarf galaxy cores
- masses in the range $10^3 - 10^5 M_\odot$


Credits: Hubble

supermassive BHs (SMBHs)

- EM radiation
- both in active and in quiescent galaxies
- masses in the range $10^6 - 10^{10} M_\odot$


Credits: EHT

no GW detections yet! ⟷ $f \sim \text{mHz} - \text{dHz}$

Spaced-based observatories

LISA + 天琴计划（TianQin）, DECIGO, ALIA, BBO

Tidal Disruption Events (TDES) : star torn apart by BH tides

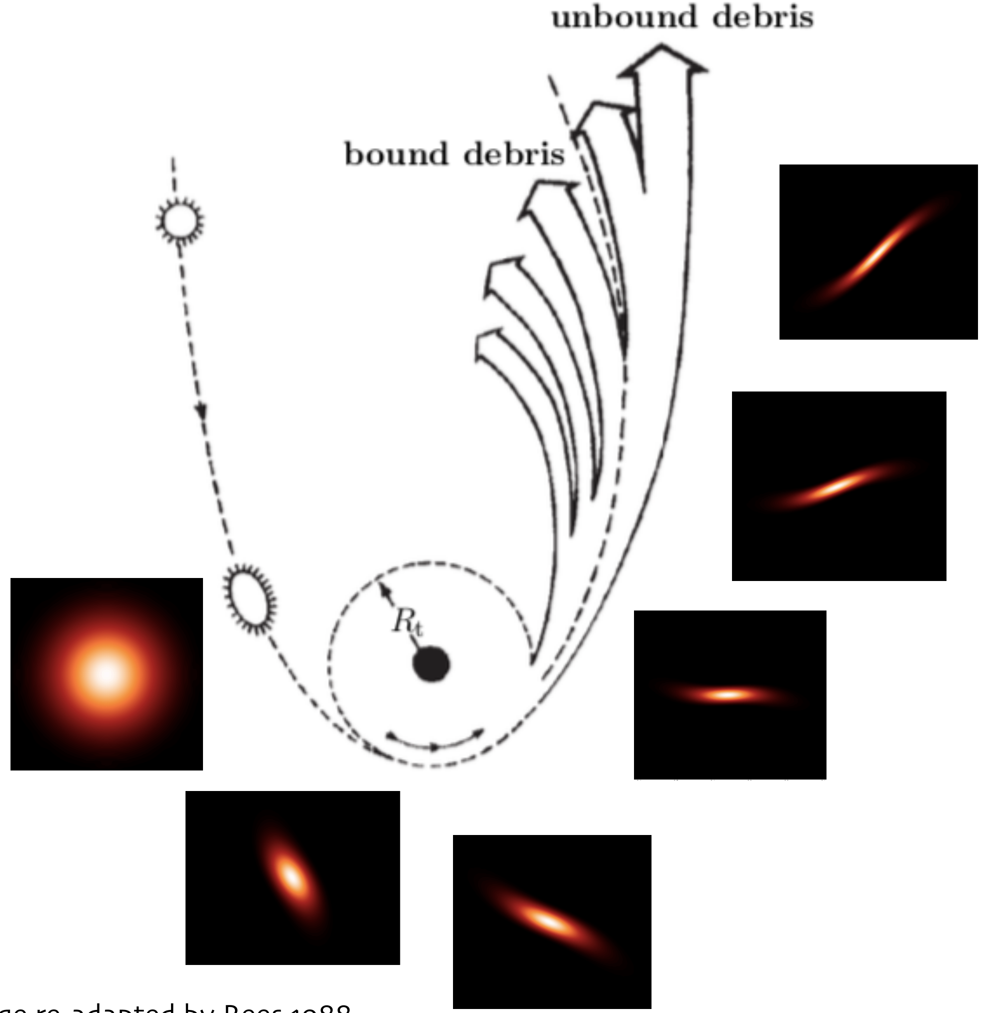
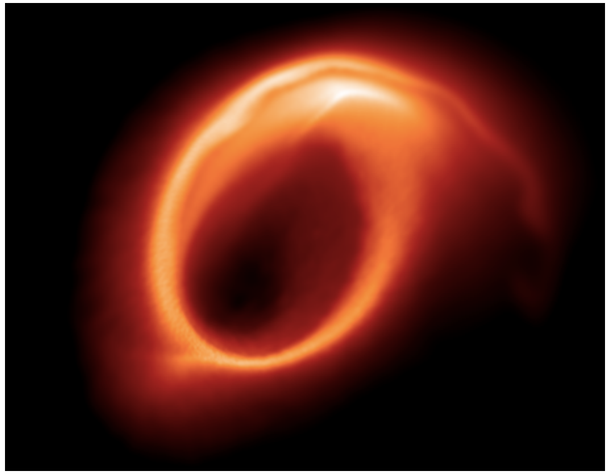


Image re-adapted by Rees 1988.
Snapshots by M. Toscani with GRPHANTOM (Liptai and price 2019)

- distance BH-star $< R_t = R_* \left(\frac{M_h}{M_*}\right)^{1/3}$
- strength of event $\beta = \frac{R_t}{R_p}$
- half debris circularize

Rees 1988, Phinney 1989, Luminet and Carter 1982



Snapshot by M. Toscani with GRPHANTOM (Liptai and price 2019)

optical, X-ray events

~ 50 events

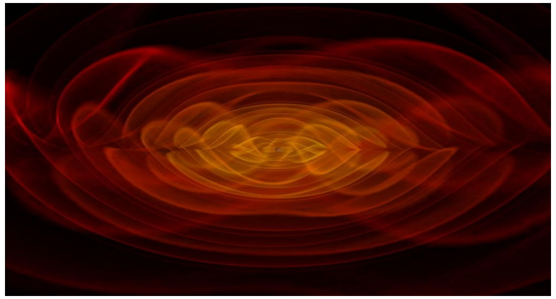
lightcurve $\propto t^{-5/3}$

see reviews: vanVelzen et al 2020, Saxton et al. 2020,

high energy neutrinos

a few potential candidates

Stein et al. 2021, Hayasaki 2021, Reusch et al. 2021



GWs →

- stellar mass quadrupole — Guillochon & Ramirez-Ruiz 2009, Stone et al. 2013
- BH-star mass quadrupole — Kobayashi et al. 2004, **Toscani** et al. 2019, **Toscani** et al. 2021
- during circularization — **Toscani** et al. 2020

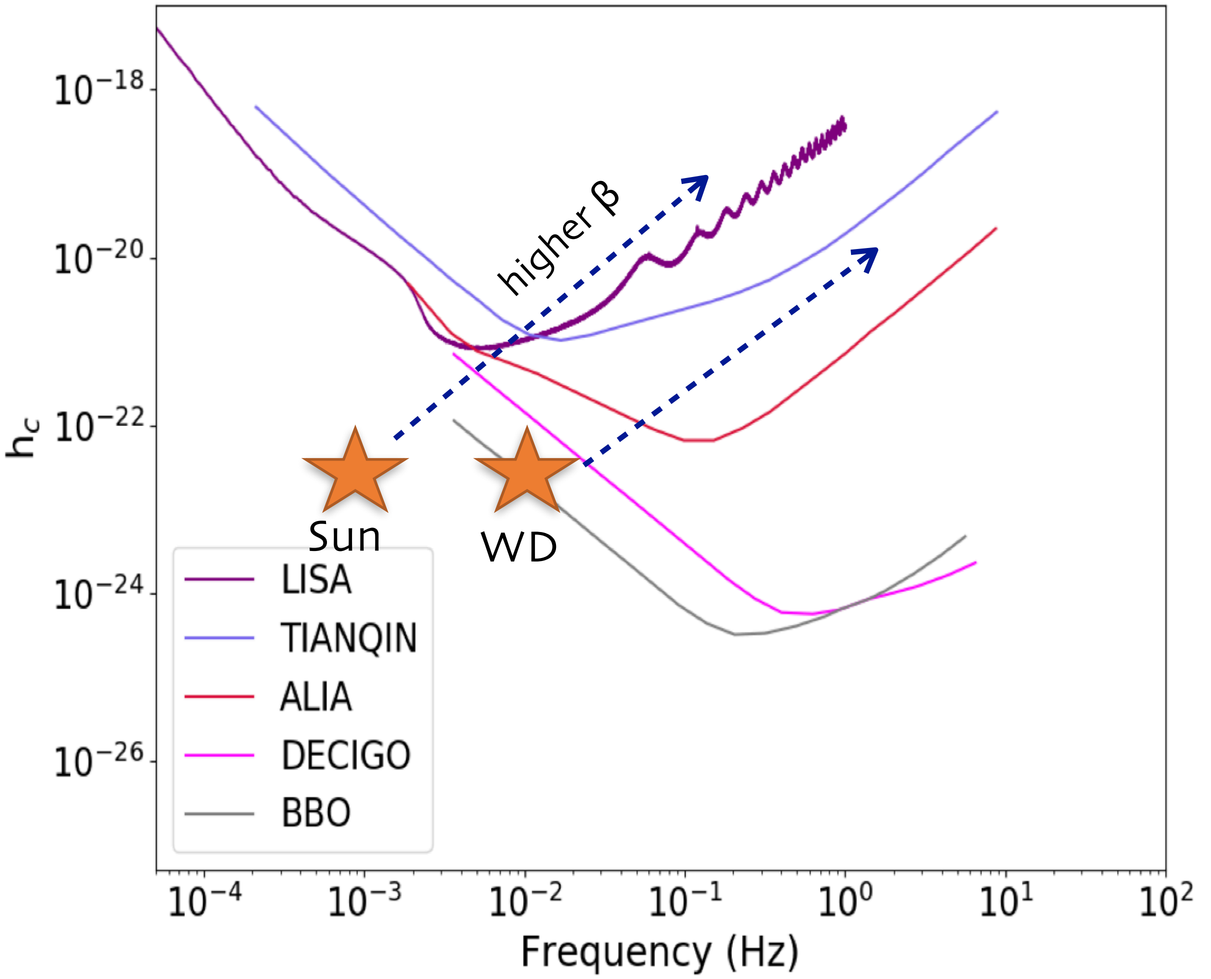
distance 20 Mpc

Sun-like star disrupted by a BH $M_\mathrm{h} = 10^6 \mathrm{M}_\odot$

$$h \approx 10^{-22}, \quad f \approx 10^{-4}\mathrm{Hz}$$

White dwarf (WD) with $M_* = 0.5\mathrm{M}_\odot, \mathrm{R}_* = 0.01\mathrm{R}_\odot$
disrupted by a BH $M_\mathrm{h} = 10^4 \mathrm{M}_\odot$

$$h \approx 10^{-22}, \quad f \approx 10^{-2}\mathrm{Hz}$$



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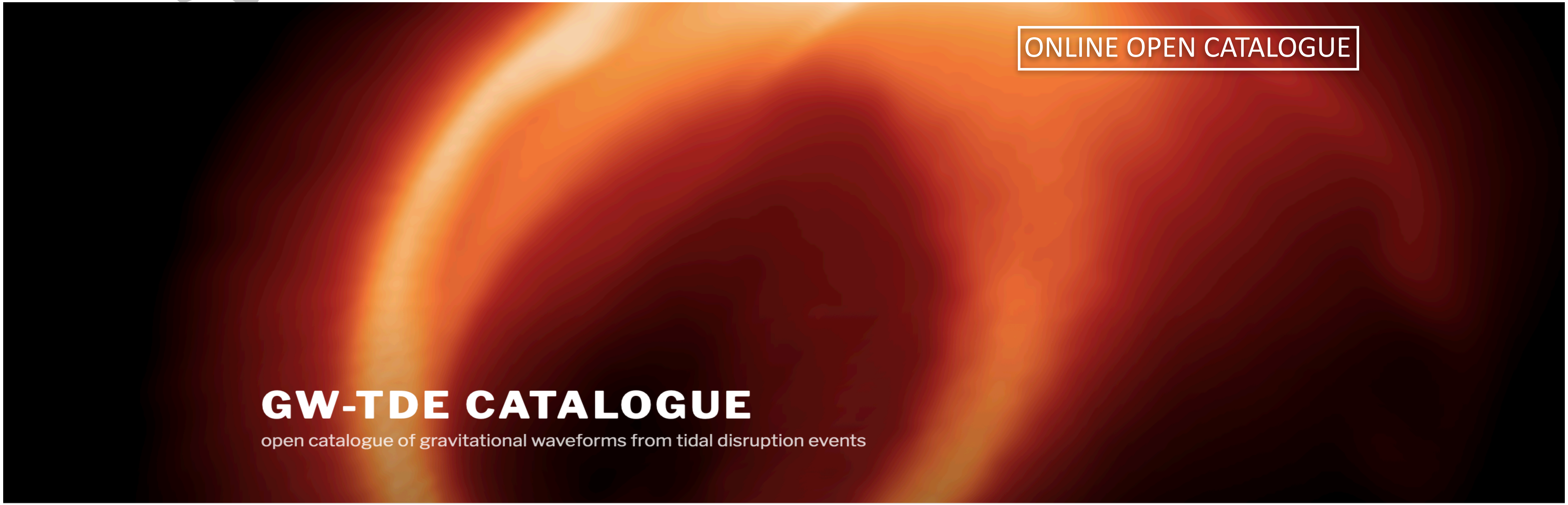
Smoothed particle hydrodynamic (SPH) code general relativistic fluid-dynamics

(Price et al 2018, Liptai and Price 2019)



Home Catalogue Download Links

https://gwcataloguetdes.fisica.unimi.it

243 simulations

Eccentricity e, BH spin a, penetration factor β, orbital inclination θ

Standard TDE at 20 Mpc

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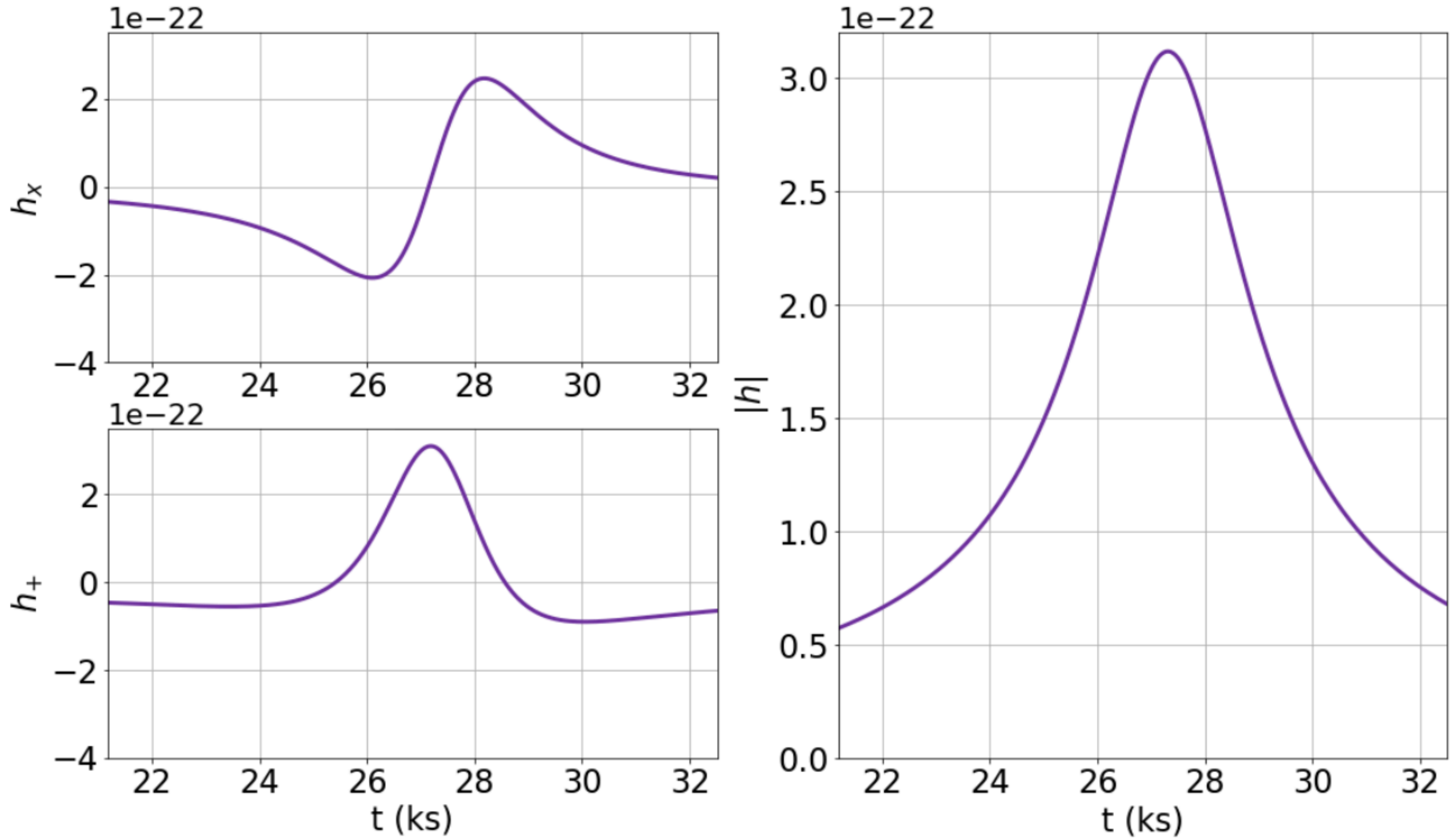


Kerr metric

Face-on signals

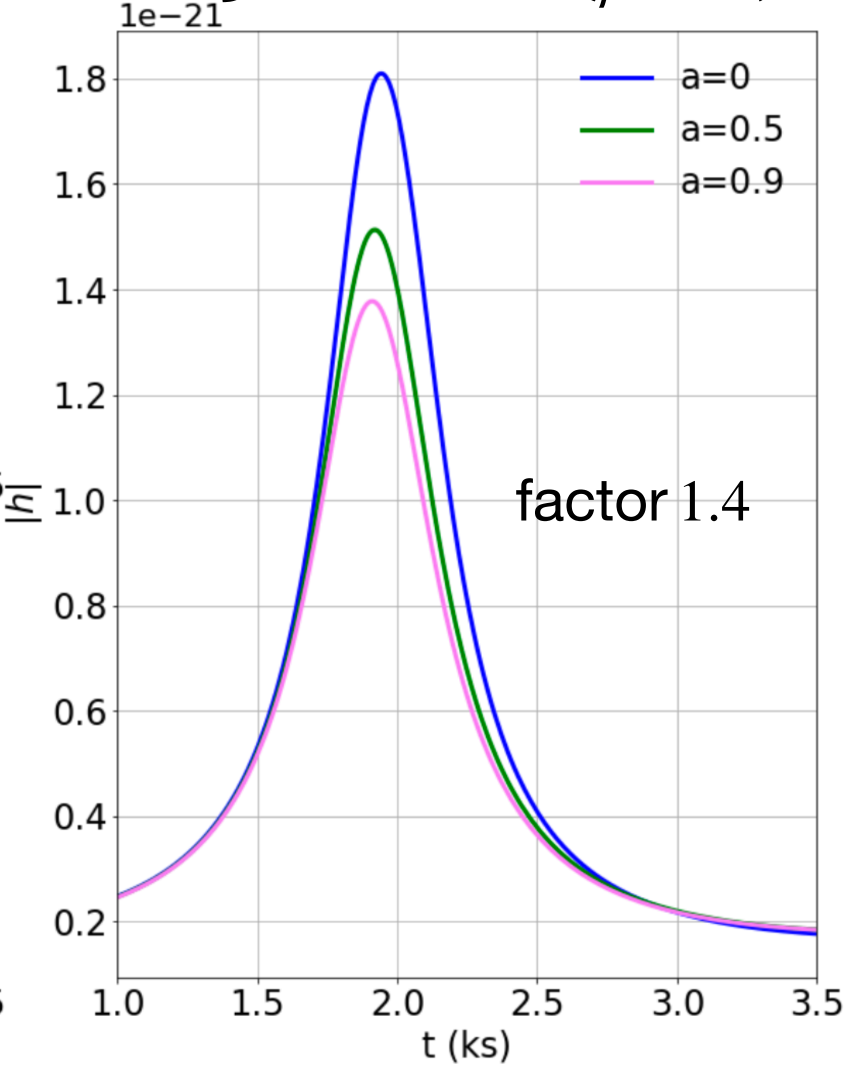
$$h \approx 10^{-22}$$

$$\tau \approx 10^{4}\mathrm{ks}$$

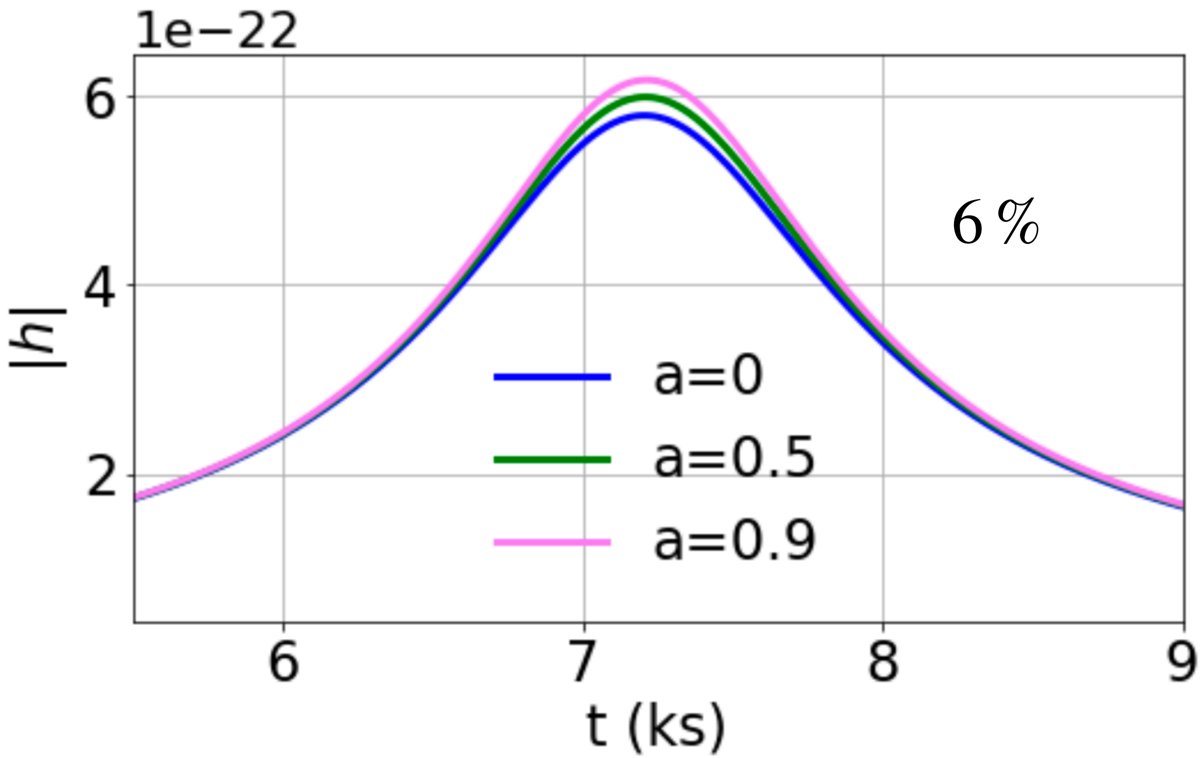
cf. Kobayashi et al. 2004

eccentricity 0.6, orbital inclination angle 0 **Toscani M.** et al. 2021

Prograde orbits ($\beta = 5$)



Retrograde orbits ($\beta = 2$)



GW signal increases for high retrograde orbits, decreases for high prograde orbits

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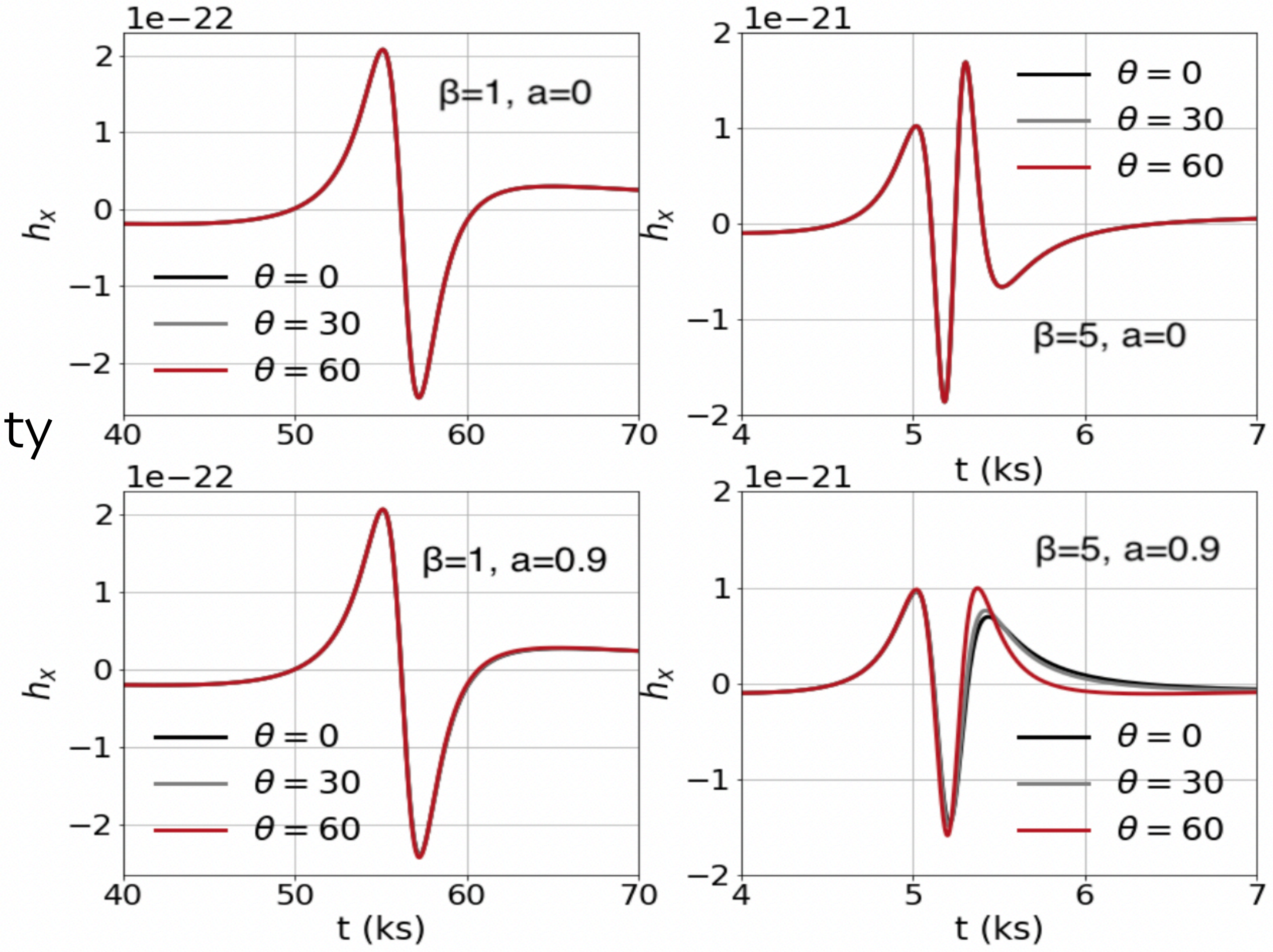
eccentricity
0.6



static
BH

rotating
BH

inclination angles affect signal only with spin AND penetrating events

GW signal from the entire cosmic population of TDEs

↓

GW background from TDES

↙ ↘

nuclear TDEs

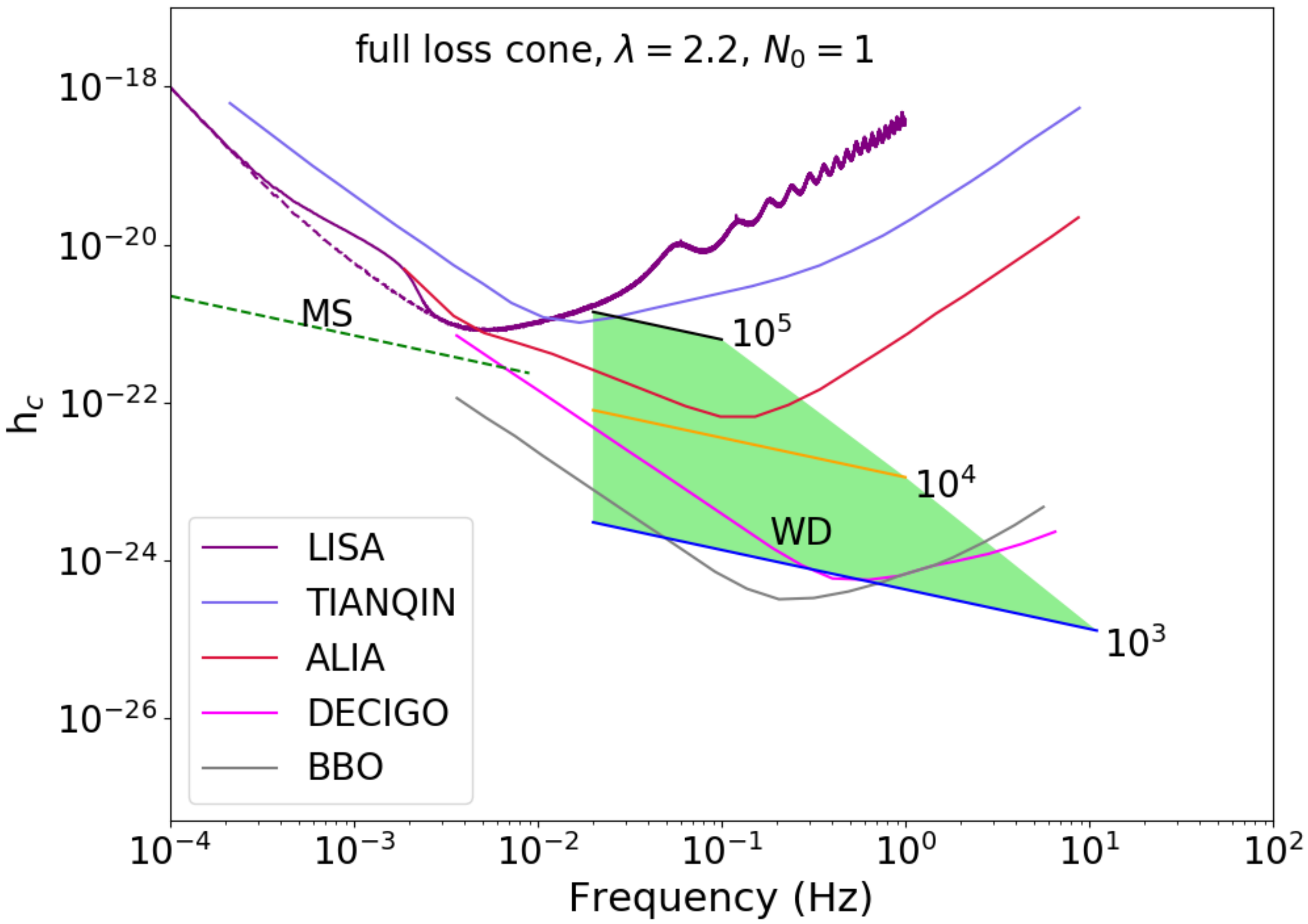
globular TDEs

Main sequence (MS) stars disrupted by SMBHs

Vs

White dwarfs (WDs) stars disrupted by IMBHs

Toscani M. et al. 2020



$$h_c \propto f^{-1/2}$$

TDEs of WDs promising to map IMBHs up to redshift 3

↓

Deci-Hertz observatories

Take Home Messages

GWs from TDEs → LISA & CO

The most likely GW contribution from TDEs → GW burst

Individual TDEs emission → BH and stellar orbit parameters

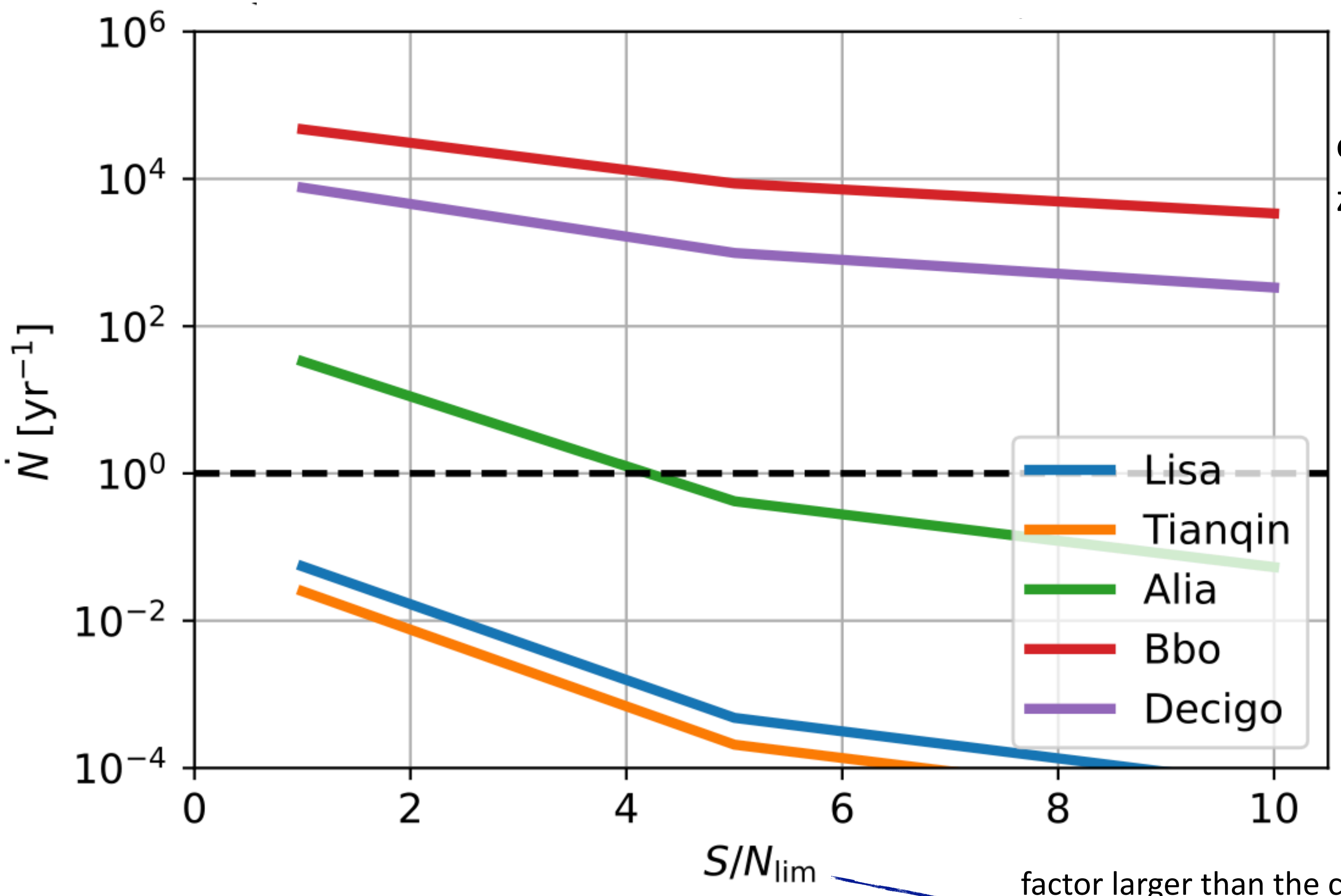
Background TDEs → BH (IMBH!!) population

THANKS FOR YOUR ATTENTION!

Fin

BACKUP SLIDES

Pfister H., **Toscani M.** et al. 2021



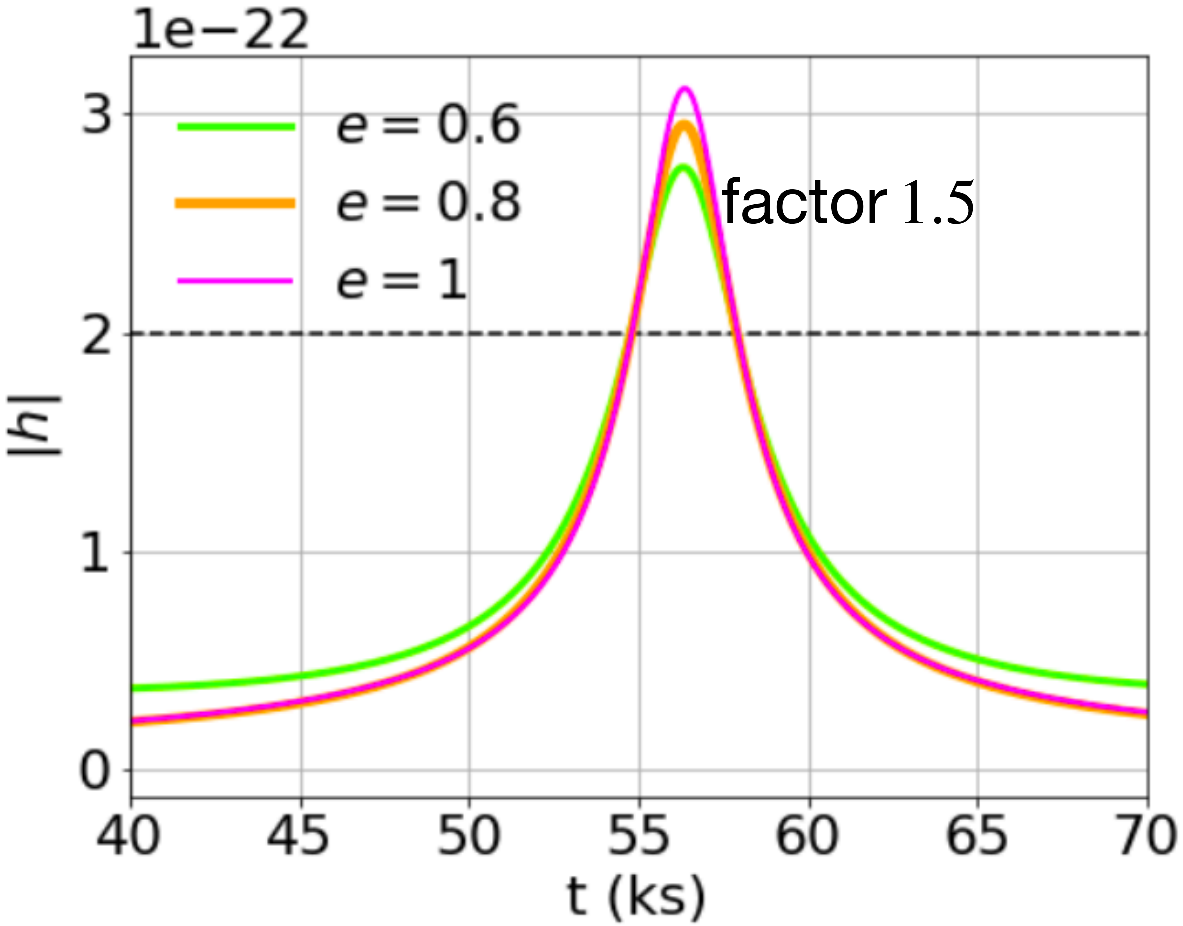
LISA could detect gravitational waves from extreme TDEs (high stellar mass+high beta) up to z=0.1 (400 Mpc)

Following generation of detectors (ALIA, BBO, DECIGO) thousands to millions of TDEs at cosmological redshift

factor larger than the characteristic amplitude noise of the detector at the observed frequency

Toscani M. et al. 2021

Penetration factor 1, orbital inclination angle 0



GW amplitude increases for higher eccentricities