Impact of GW Memory in parameter estimation of BBH mergers

Based on 2301.13228

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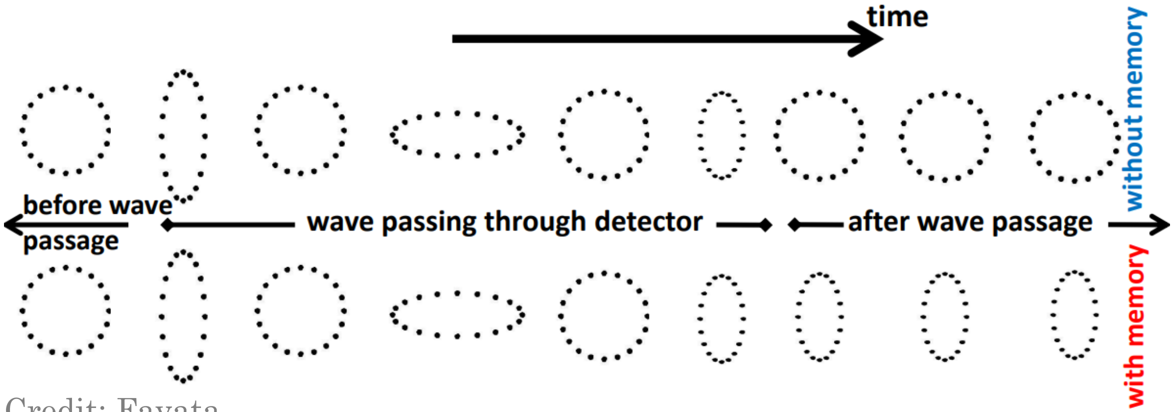
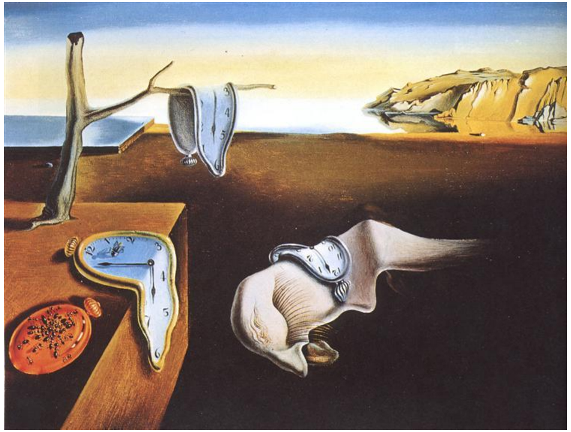
GRAVITATIONAL WAVE MEMORY???

Persistent deformation of space-time due to the passing of the gravitational wave…

Two kinds: linear and non-linear



Credit: Favata



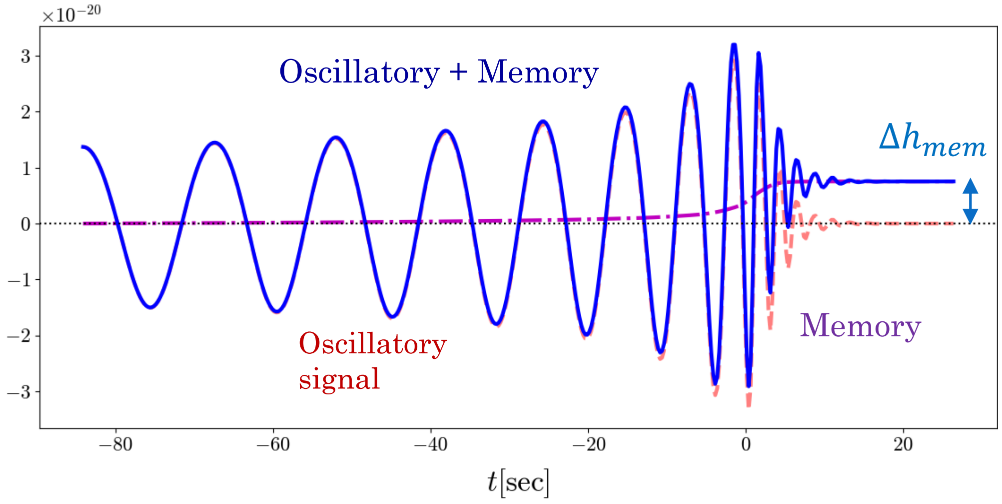
"The Persistence of Memory"
(also known as "The Soft Watches")

Salvador Dalí, 1931

Non-linear Gravitational Wave Memory

Christodoulou '91,
Blanchet & Damour '92
Wiseman & Will '91

Waveform of a binary black hole:



$$\partial^{\mu}\partial_{\mu}\bar{h}^{\ j,k} = 16\pi\left(T^{jk}_{matter} + T^{jk}_{GW}\right)$$

The GW itself sources GWs!

$$T^{jk}_{GW} = \frac{1}{R^2}\frac{dE_{GW}}{dtd\Omega}n_j n_k \sim \mathcal{O}(h^2)$$

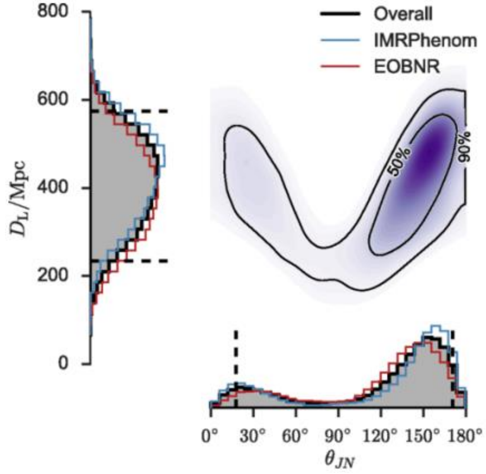
- Concentrated in the merger phase
- Persistent off-set

Abbott et al., 2016d

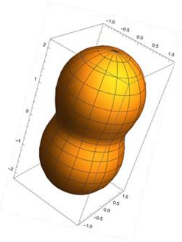
Can memory helps for parameter estimation?

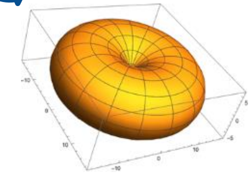
$$h_{+,0PN} = \left[-(1+\cos^2\iota)\cos 2\Phi(t) + \frac{1}{96}\sin^2\iota(17+\cos^2\iota)\right]\frac{2\eta M(M\omega(t))^{2/3}}{d_L}$$

Dominant mode (2,2) Dominant mode (2,0) $\eta = \frac{m_1 m_2}{M^2}$



Maximised for face-on $\iota = 0$

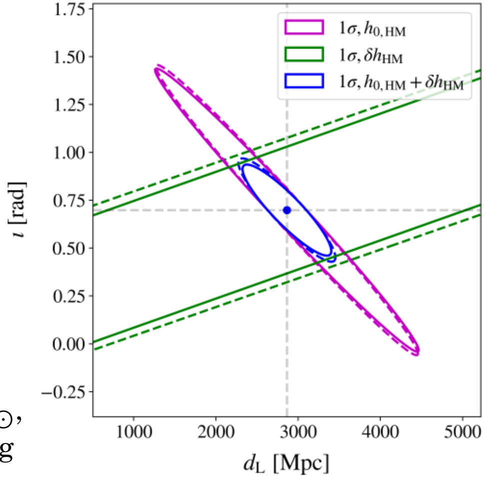




Maximised for edge-on $\iota = \frac{\pi}{2}$

Opposite inclination ι dependence

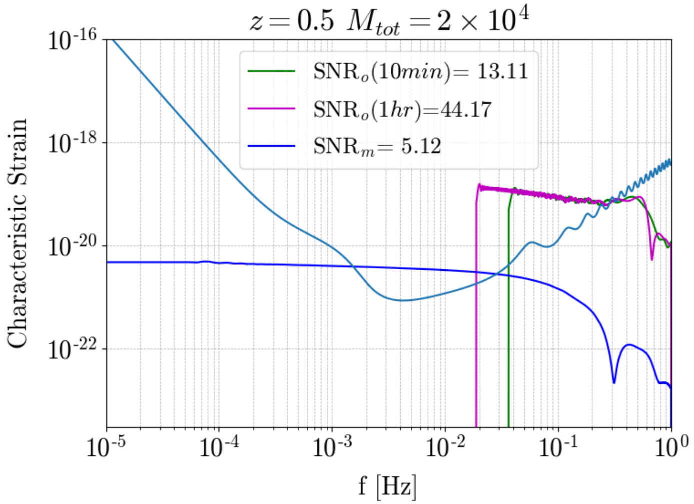
Q: Can it break the distance-inclination degeneracy?

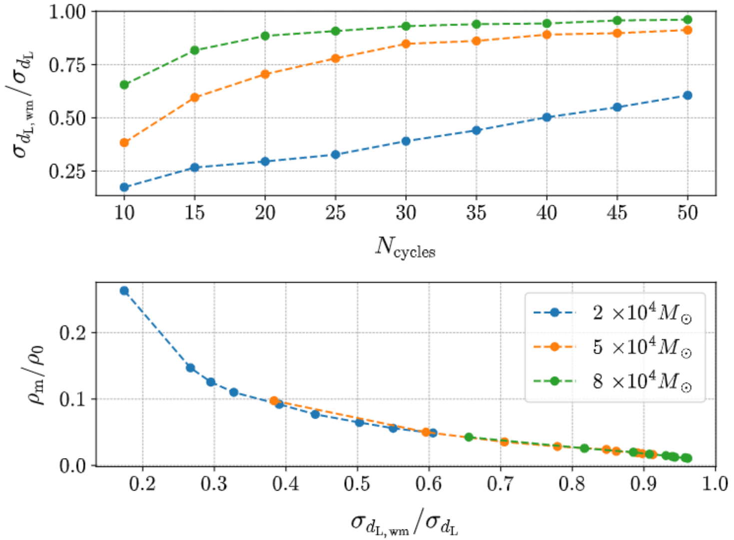


$M_{tot} = 2\times 10^4\, M_\odot$, $z = 0.5$, $\iota = 40$ deg

Fisher analysis: Lisa case study

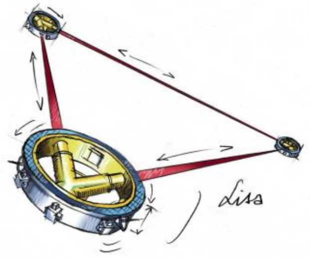
$h(\vec{\theta},t) = h_0(\vec{\theta},t) + \delta h(\vec{\theta},t)$ NRHybSur3dq8 to generate $h_0 \Longrightarrow \delta h$ via **GWMemory** (C. Talbotet al)





The memory helps ($\sigma_{d_{l,wm}} < \sigma_{d_l}$) → for "**light**" and "**short**" signals prior merger

How many memory events do we expect to detect with LISA?



N_{th} number of events with detectable memory, i.e. $SNR \geq 1$ (or $SNR \geq 5$), in 4 yeas

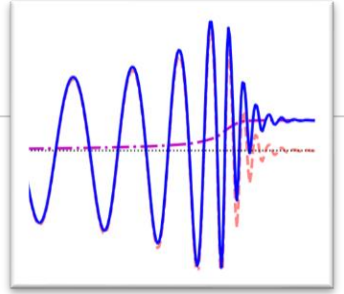
8 different population models of massive binary black hole mergers
Barausse et al (2020)

→ main astrophysical uncertainties:

- SN feedback on nuclear matter
- Delay in SMBH merger (*last parsec problem*)
- Initial seed mass (Light or Heavy)

→ Heavy Seeds most promising model

Astrophysical Catalogues	**Light seeds**	**Heavy seeds**
SN-delays	$N_{\rm tot} = 47$ $N_{\rm th} = 0.4\,(0.1)$ $\langle\rho\rangle = 0.04$ $\rho_{\rm max} = 7$	$N_{\rm tot} = 27.3$ $N_{\rm th} = 21.2\,(10)$ $\langle\rho\rangle = 6$ $\rho_{\rm max} = 97$
noSN-delay	$N_{\rm tot} = 191$ $N_{\rm th} = 6\,(1)$ $\langle\rho\rangle = 0.17$ $\rho_{\rm max} = 11.64$	$N_{\rm tot} = 10$ $N_{\rm th} = 7.5\,(4)$ $\langle\rho\rangle = 6.9$ $\rho_{\rm max} = 68.7$
SN-short Delays	$N_{\rm tot} = 149$ $N_{\rm th} = 1\,(1)$ $\langle\rho\rangle = 0.04$ $\rho_{\rm max} = 5.01$	$N_{\rm tot} = 1245$ $N_{\rm th} = 418\,(33)$ $\langle\rho\rangle = 1$ $\rho_{\rm max} = 43$
noSN-short Delays	$N_{\rm tot} = 1203$ $N_{\rm th} = 12\,(2)$ $\langle\rho\rangle = 0.06$ $\rho_{\rm max} = 17$	$N_{\rm tot} = 1251$ $N_{\rm th} = 392\,(29)$ $\langle\rho\rangle = 1.1$ $\rho_{\rm max} = 51$



Conclusions and Outlook

Q: What's the real impact of the memory for parameter estimation in the presence of (unscheduled) gaps in the data?

→ For the most promising HS model (~400 events) **only** 0.14 have a 5% improvement of $\sigma_{d_{l,wm}}$ with the memory (gaps model used in Dey et al 2021)

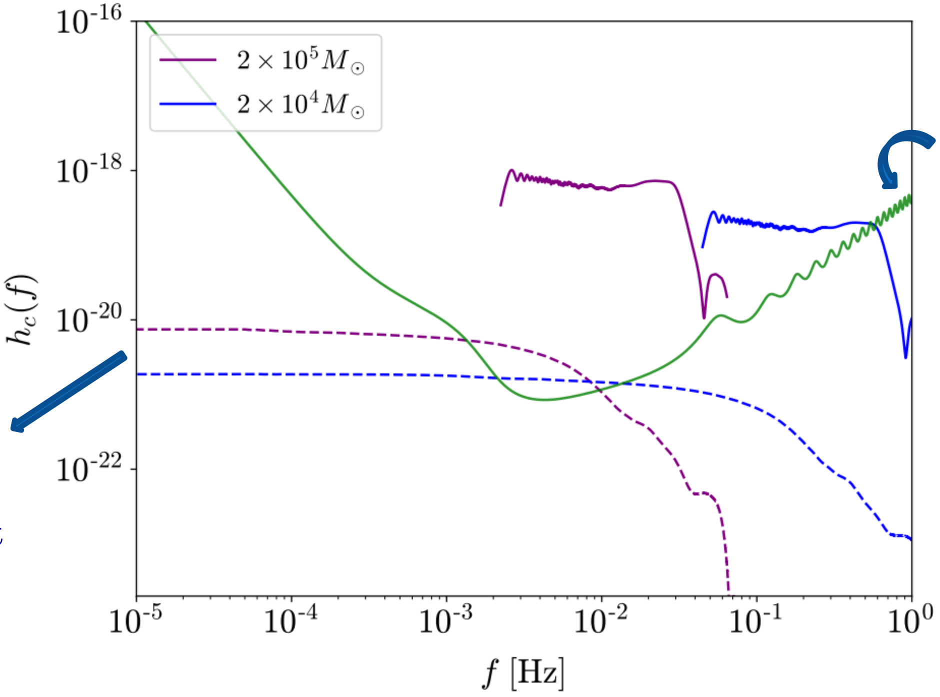
Using new synthetic catalogues we predict a **larger number of events with significant memory** compared with previous studies...

Future directions:

- Other systems where the memory helps in breaking degeneracy?
- As a probe of GR in the highly non-linear regime
- "Orphan memory", Stochastic gravitational wave background…

Thank you for the attention!

Primary vs Memory



Sensitivity curve of the detector (LISA)

Extends the signal at lower frequencies, but **subdominant**