Direct current memory effects in the effective-one-body waveform models

E. Grilli, A. Placidi, S. Albanesi, G. Grignani, and M. Orselli, Phys. Rev. D 111, 044045 (2025)

Elisa Grilli

Cortona, May 20-23, 2025

New Frontiers in Theoretical Physics: XXXVIII Convegno Nazionale di Fisica Teorica

Memory Effect

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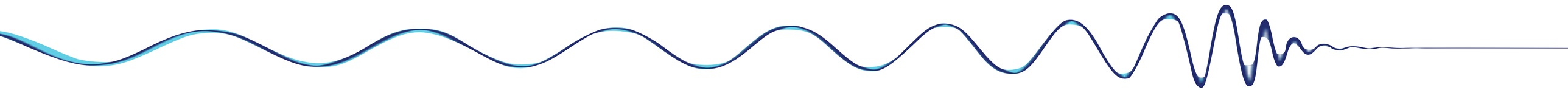
Memory Effect

Gravitational memory effect is an hereditary contribution present in all GW signals, and it is a manifestation of the non-linear nature of the General Relativity .

The memory is given by the difference in the baseline of the GW strain between early and late times

$$\Delta h_{mem} = \lim_{t\to\infty} h(t) - \lim_{t\to-\infty} h(t)$$

[D. Christodoulou, Phys. Rev. Lett. 67, 1486 (1991)]
[A. G. Wiseman and C. M. Will, Phys. Rev. D 44, R2945(1991)]
[K. S. Thorne, Phys. Rev. D 45, 520 (1992)]



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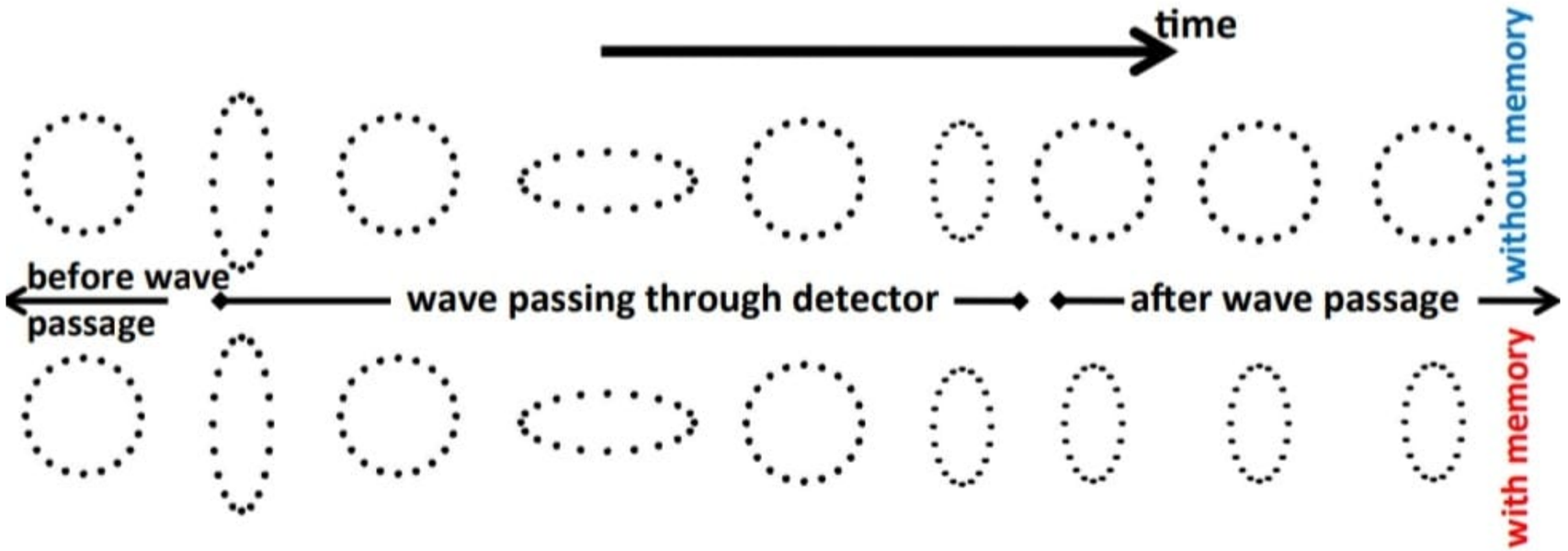

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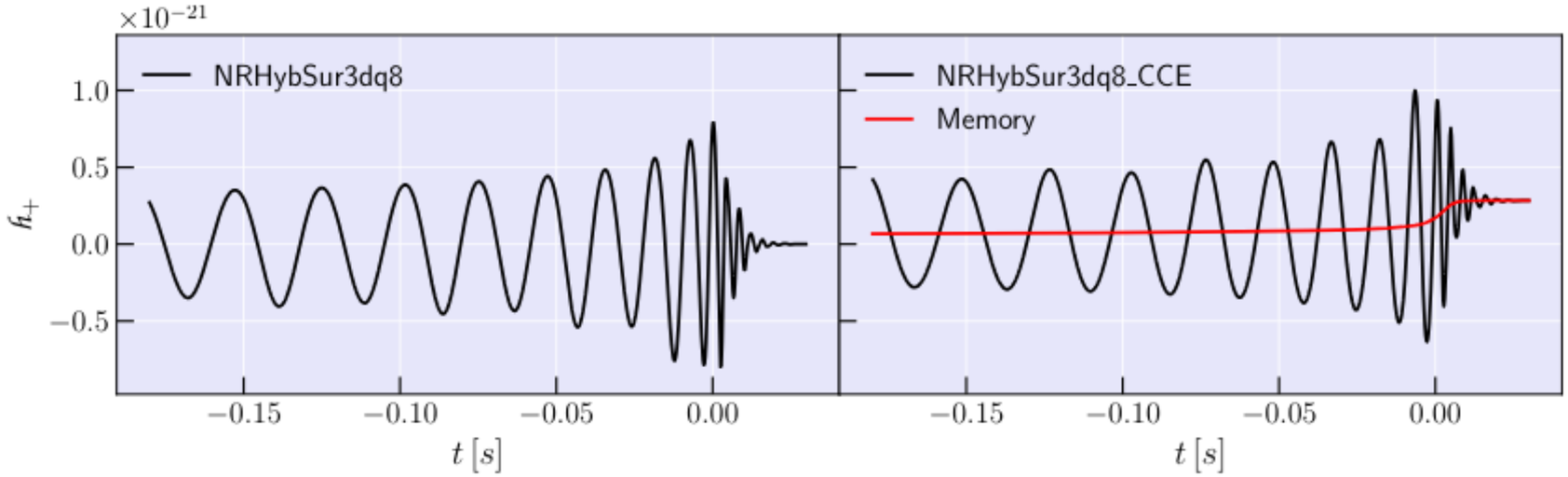


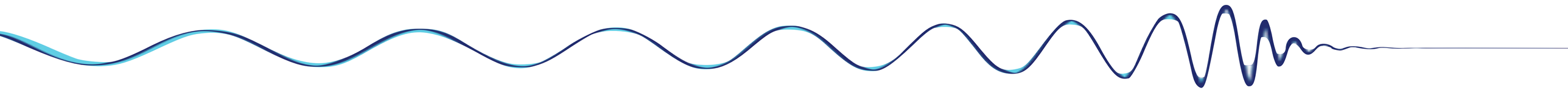
[J. Yoo et al, Phys. Rev. D 108, 064027 (2023)]

Spherical Modes of the waveform

[L. E. Kidder, Phys. Rev. D 77, 044016 (2008)]
[M. Favata, Phys. Rev. D 84, 124013 (2011)]
[M. Ebersold, et al, Phys. Rev. D 100, 084043 (2019)]

$$h_+ - i\,h_x = \sum_{\ell=2}^{\infty} \sum_{m=-\ell}^{\ell} h^{\ell m}\, {}_{-2}Y^{\ell m}(\theta, \phi)$$

Spin-weighted spherical harmonic decomposition



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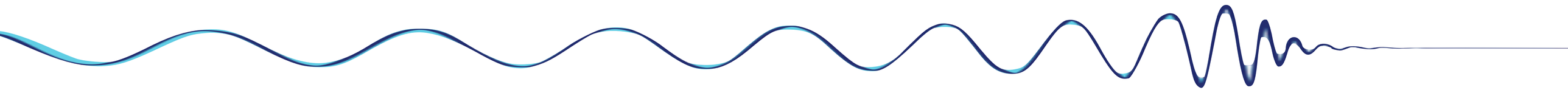
Spin-weighted spherical harmonic decomposition

$$h_{\ell m} = -\frac{1}{\sqrt{2}Rc^{\ell+2}}\left(U_{\ell m} - \frac{i}{c}V_{\ell m}\right)$$

Spherical harmonic modes are defined in terms of the radiative mass and current multipoles

$$U_{\ell m} = U^{\rm inst}_{\ell m} + U^{\rm tail}_{\ell m} + U^{\rm mem}_{\ell m} + \delta U_{\ell m}$$

$$V_{\ell m} = V^{\rm inst}_{\ell m} + V^{\rm tail}_{\ell m} + \delta V_{\ell m}$$



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$$U_{\ell m} = U^{\text{inst}}_{\ell m} + U^{\text{tail}}_{\ell m} + U^{\text{mem}}_{\ell m} + \delta U_{\ell m}$$

$$U^{\text{mem}}_{\ell m} = \frac{32\pi}{c^{2-\ell}} \sqrt{\frac{(\ell-2)!}{2(\ell+2)!}} \int_{-\infty}^{T_R} dt \int d\Omega \frac{d^2 E_{\text{GW}}}{dt d\Omega} \bar{Y}_{\ell m}(\Omega)$$

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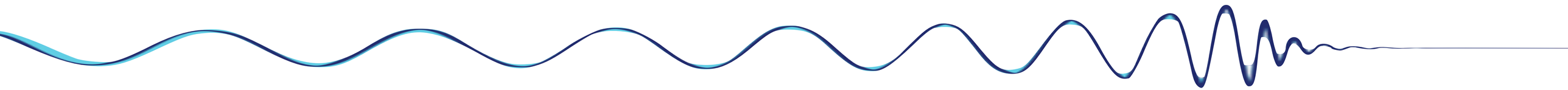

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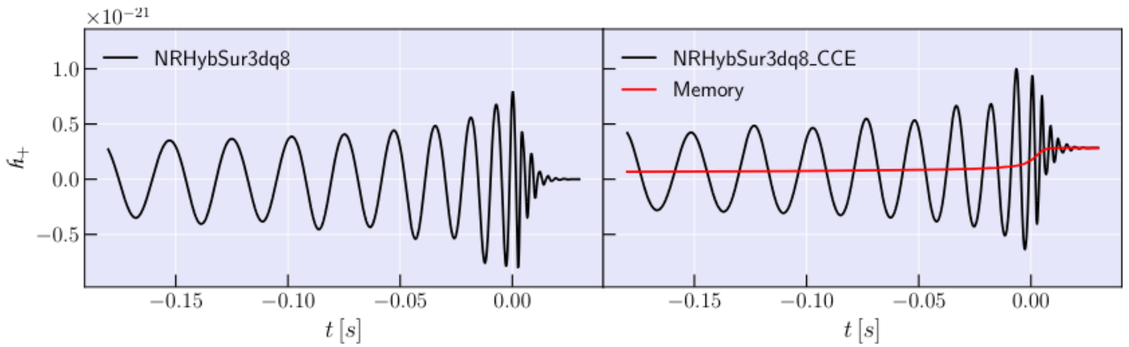

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Effective One Body

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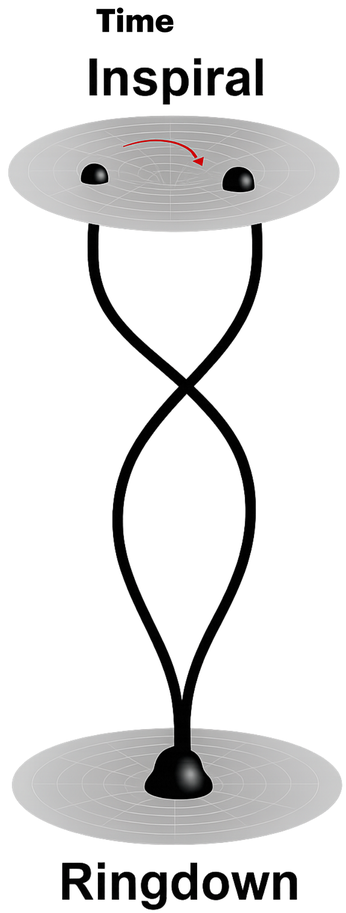
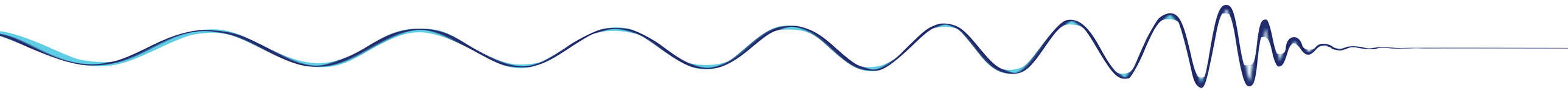
[A. Buonanno and T. Damour, Phys. Rev. D 59, 084006,(1999)]
[T. Damour, P. Jaranowski, and G. Schaefer, Phys. Rev.D62, 084011 (2000)]
[T. Damour, A. Nagar, et al, Phys.Rev.D77, 084017, (2008)]



$$h^{inspiral}(t,\theta)$$

$$h^{ringdown}(t,\theta)$$



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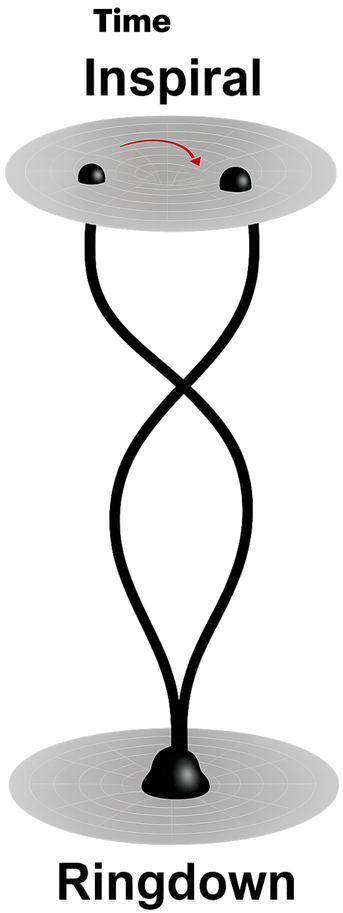
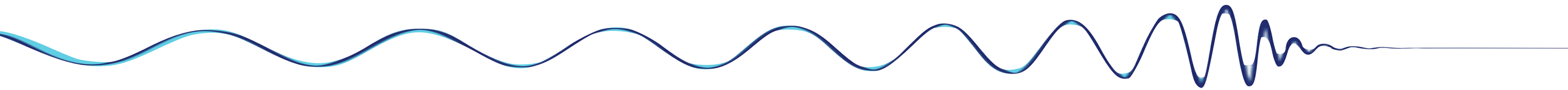


$$h^{inspiral}(t,\theta)$$

$$h^{EOB}(t,\theta) = \theta(t - t_{mer})\, h^{inspiral}_{EOB}(t,\theta) + \theta(t_{mer} - t)\, h^{ringdown}_{EOB}(t,\theta)$$

$$h^{ringdown}(t,\theta)$$



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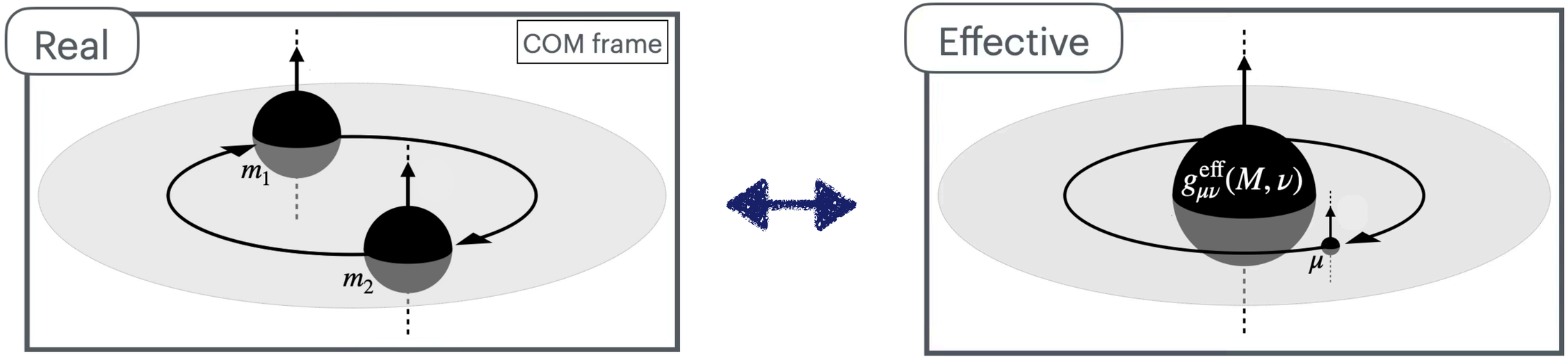

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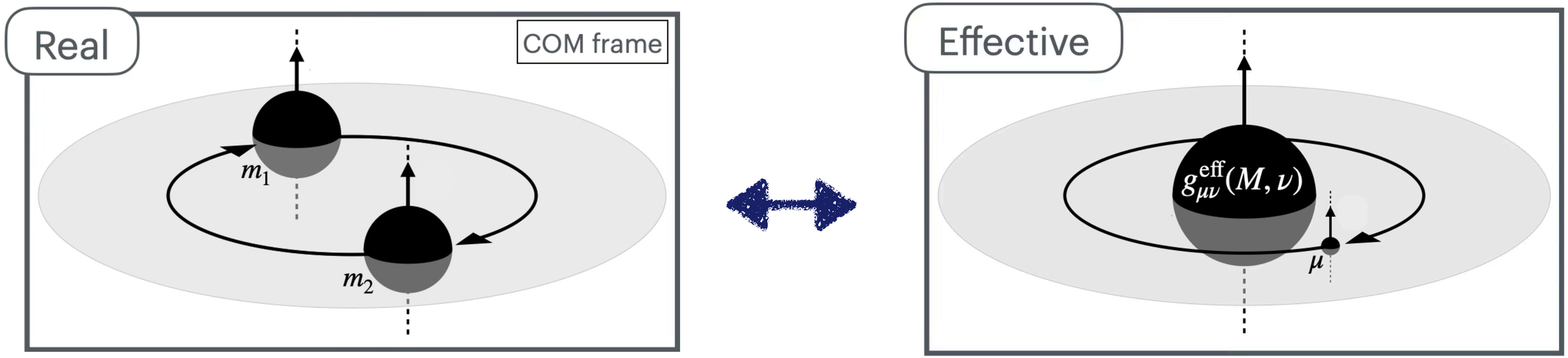

- conservative dynamics

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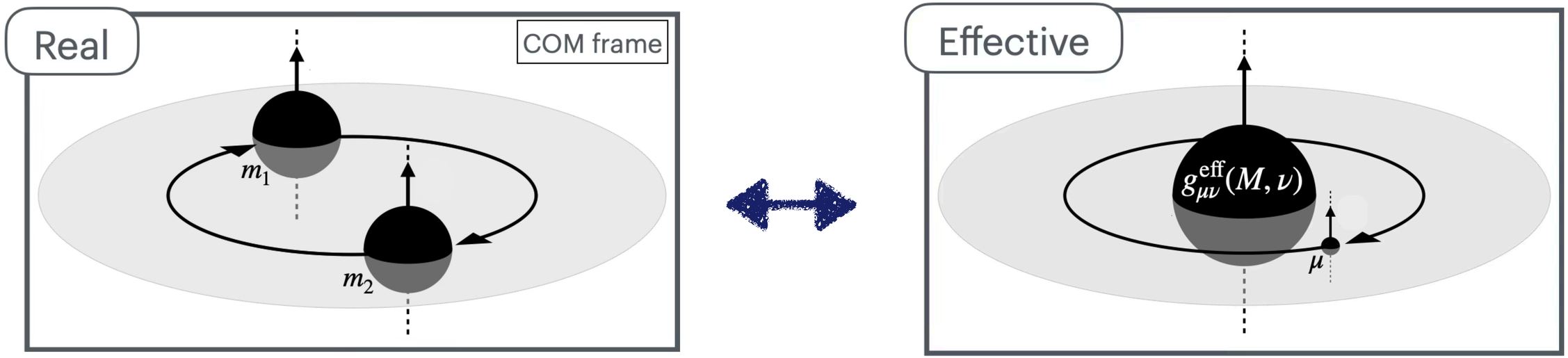
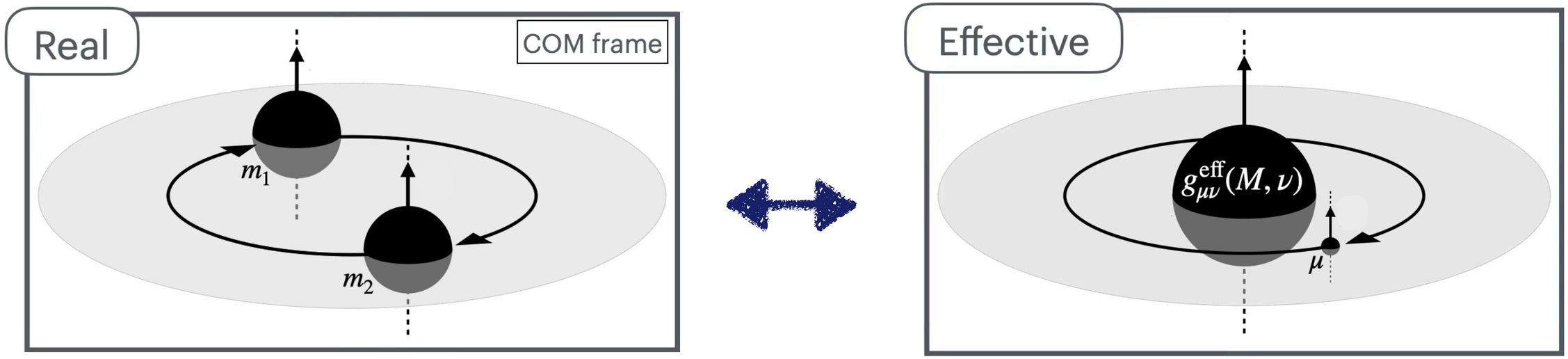


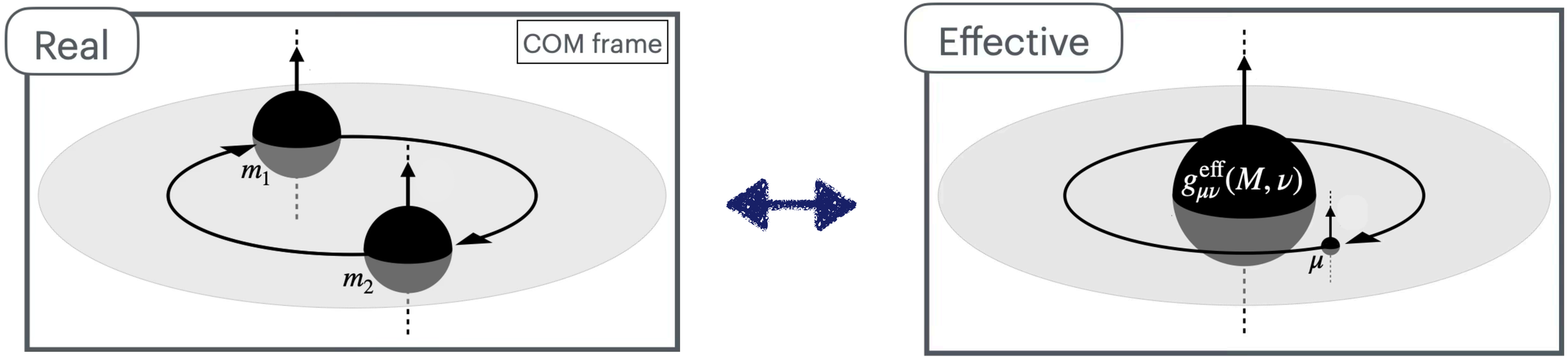
- conservative dynamics
- radiation reaction and dissipative dynamics

Effective One Body model



- conservative dynamics
- radiation reaction and dissipative dynamics
- waveform at infinity

Effective One Body model



$$(r, \varphi, p_r, p_\varphi)$$

TEOBResumS-DALì: EOB waveform model

[A. Nagar, A. Bonino, and P. Rettegno, Phys. Rev. D 103, 104021 (2021)],
[A. Nagar, P. Rettegno, Phys. Rev. D 104, 104004,(2021)]
[A. Nagar, R. Gamba, P. Rettegno, V. Fantinii and S.Bernuzzi, Phys. Rev. D 110, 084001, (2024)]
[A. Nagar, D. Chiaramello, R. Gamba, S. Albanesi, and S.Bernuzzi, Phys. Rev. D 111, 064050, (2025)]

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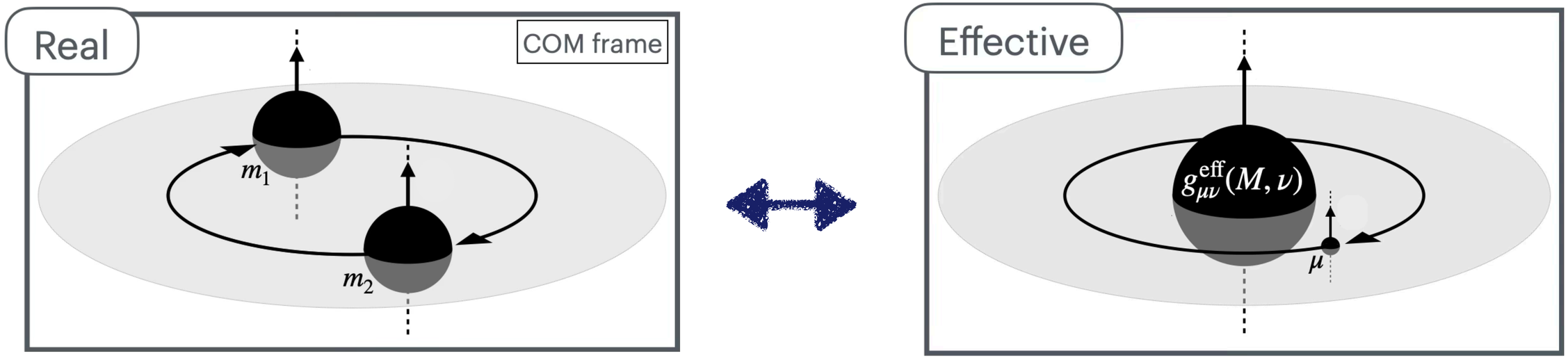

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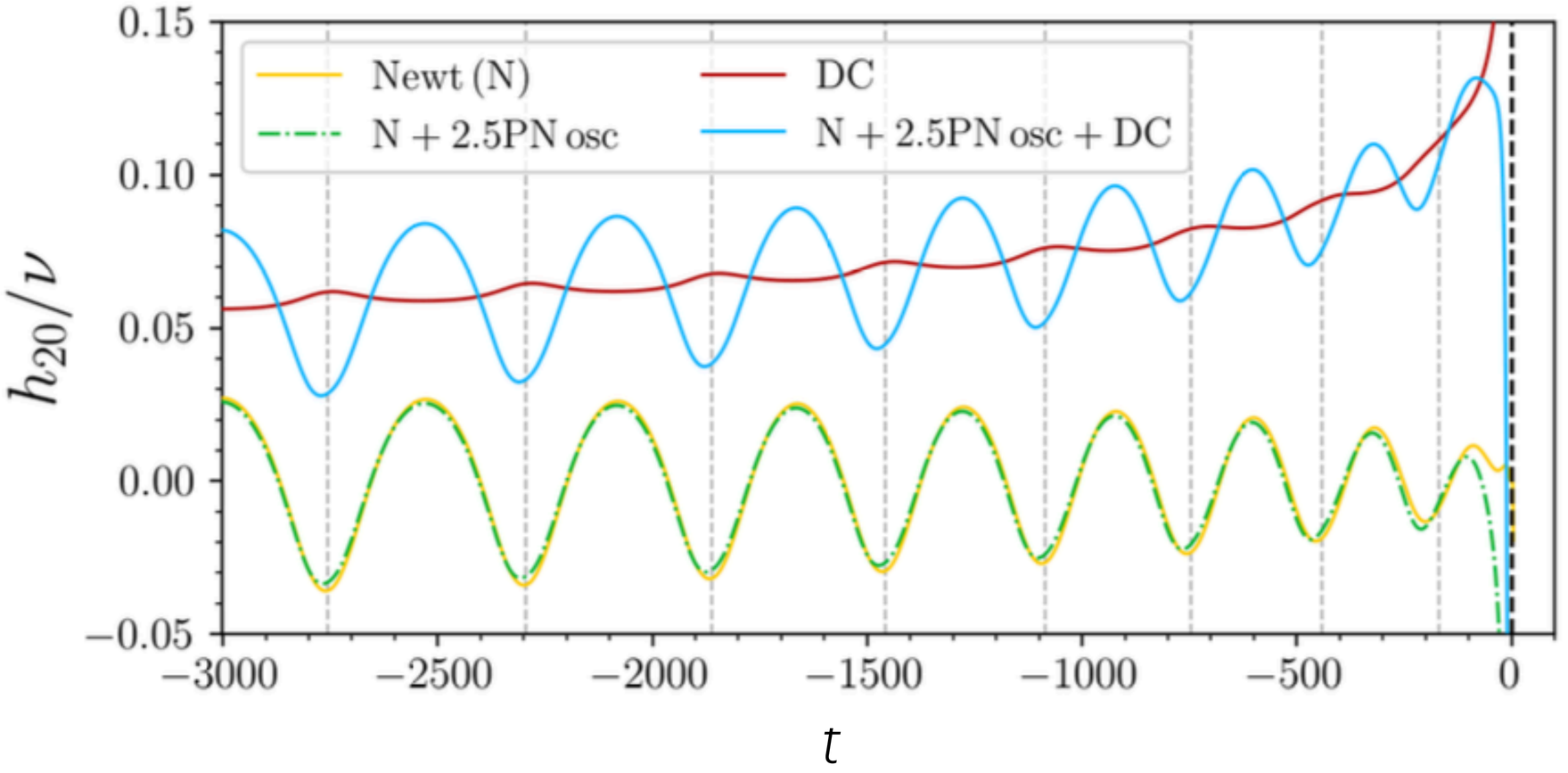
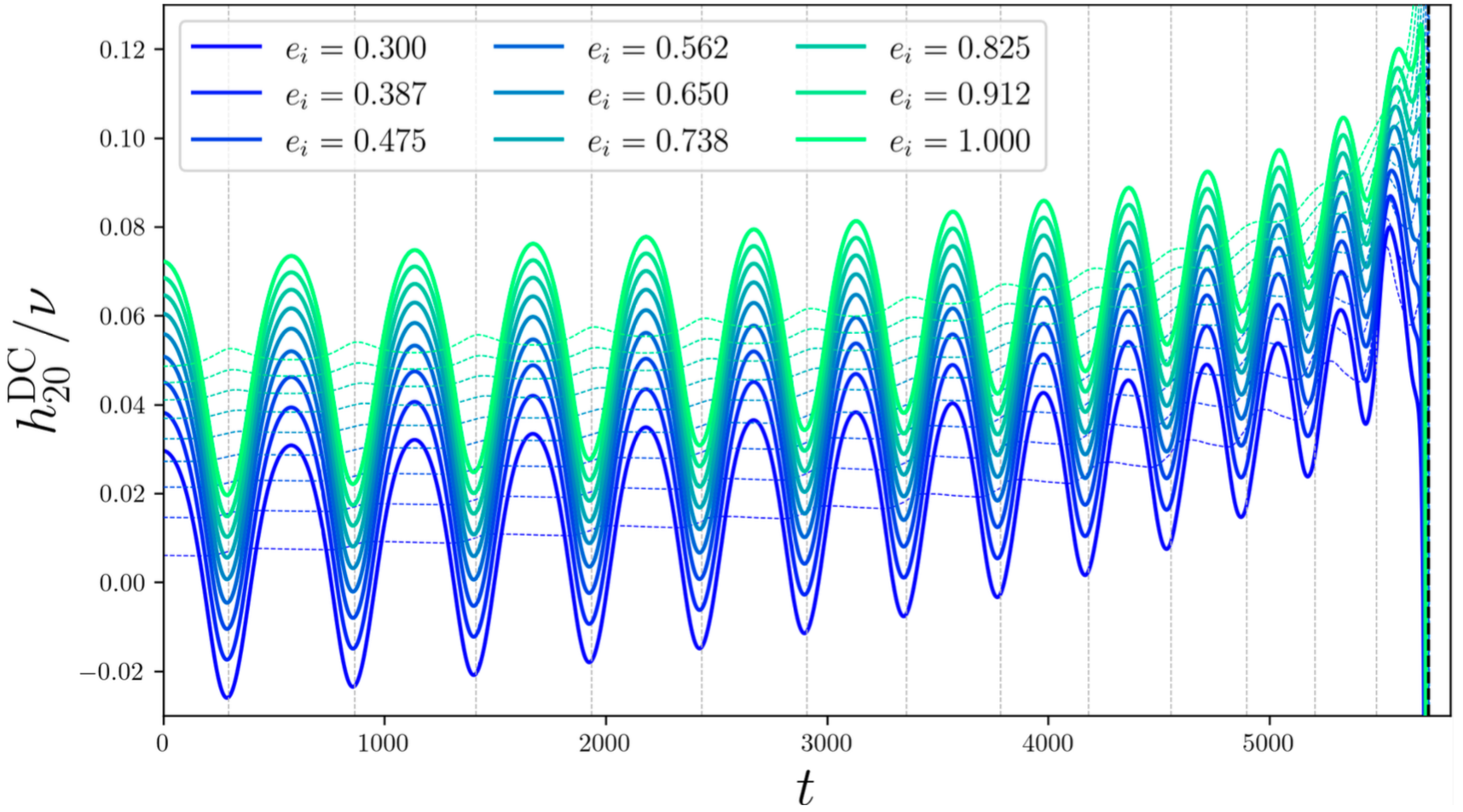
"2.5PN accurate waveform information for generic-planar-orbit binaries in effective one-body models"
A. Placidi, G. Grignani, T. Harmark, M. Orselli, S. Gliorio, and A. Nagar, Phys. Rev. D 108, 024068 (2023)


0.15
0.10
0.05
0.00
−0.05
h_{20}/ν
Newt (N)
N + 2.5PN osc
DC
N + 2.5PN osc + DC
−3000
−2500
−2000
−1500
−1000
−500
0
t


$e_i = 0.300$
$e_i = 0.387$
$e_i = 0.475$
$e_i = 0.562$
$e_i = 0.650$
$e_i = 0.738$
$e_i = 0.825$
$e_i = 0.912$
$e_i = 1.000$
h_{20}^{DC}/ν
t
0.12
0.10
0.08
0.06
0.04
0.02
0.00
−0.02
0
1000
2000
3000
4000
5000

Conclusions

The memory effect is a manifestation of the non-linear nature of General Relativity.
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1479 FVNDATÆ

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Thank you!

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