Effective Field Theory Approach to Gravitational Radiation From Binary Systems in Massive Scalar-Tensor Theory

Robin Fynn Diedrichs

with

Daniel Schmitt and **Laura Sagunski**

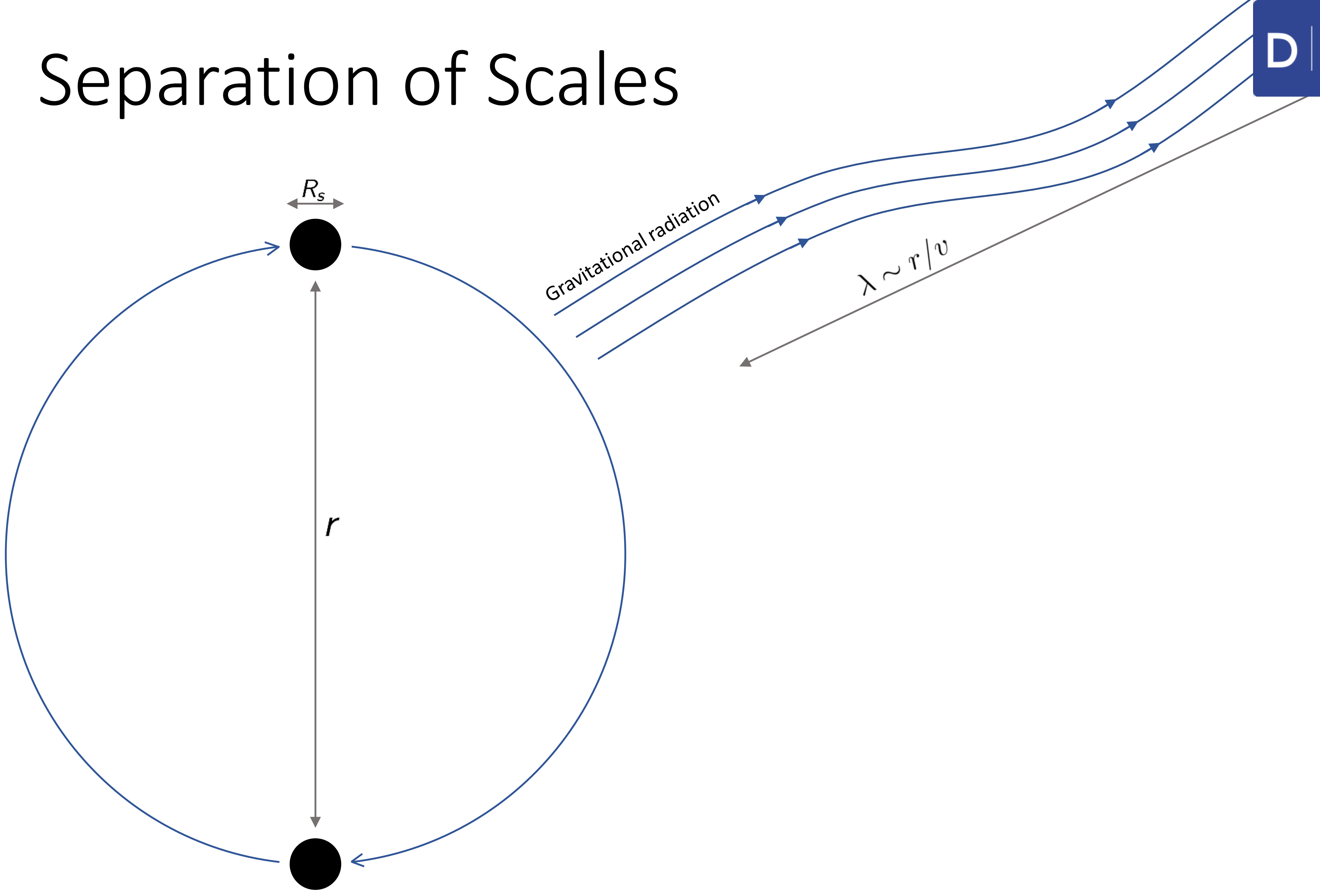
and

Niklas Becker, Edwin Genoud-Prachex, Yannik Schaper and Jun Zhang

What is Scalar-Tensor Theory?

$$S = \int d^4x\sqrt{-g}\left[R + \partial_\mu\phi\partial^\mu\phi + V(\phi)\right] + S_{\mathrm{matter}}\left(f(\phi)g_{\mu\nu}, \psi\right)$$

Separation of Scales



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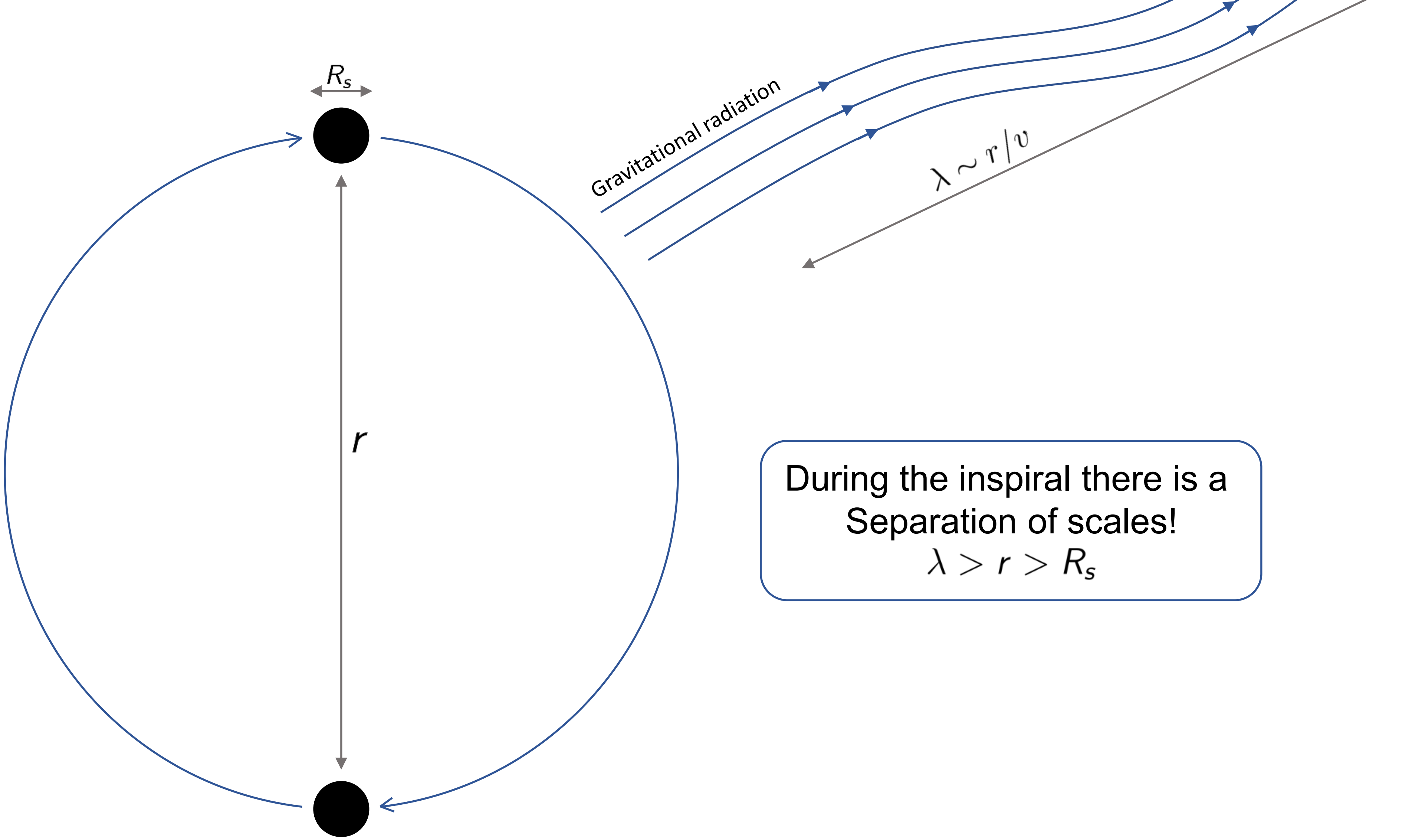

During the inspiral there is a Separation of scales!

$\lambda > r > R_s$

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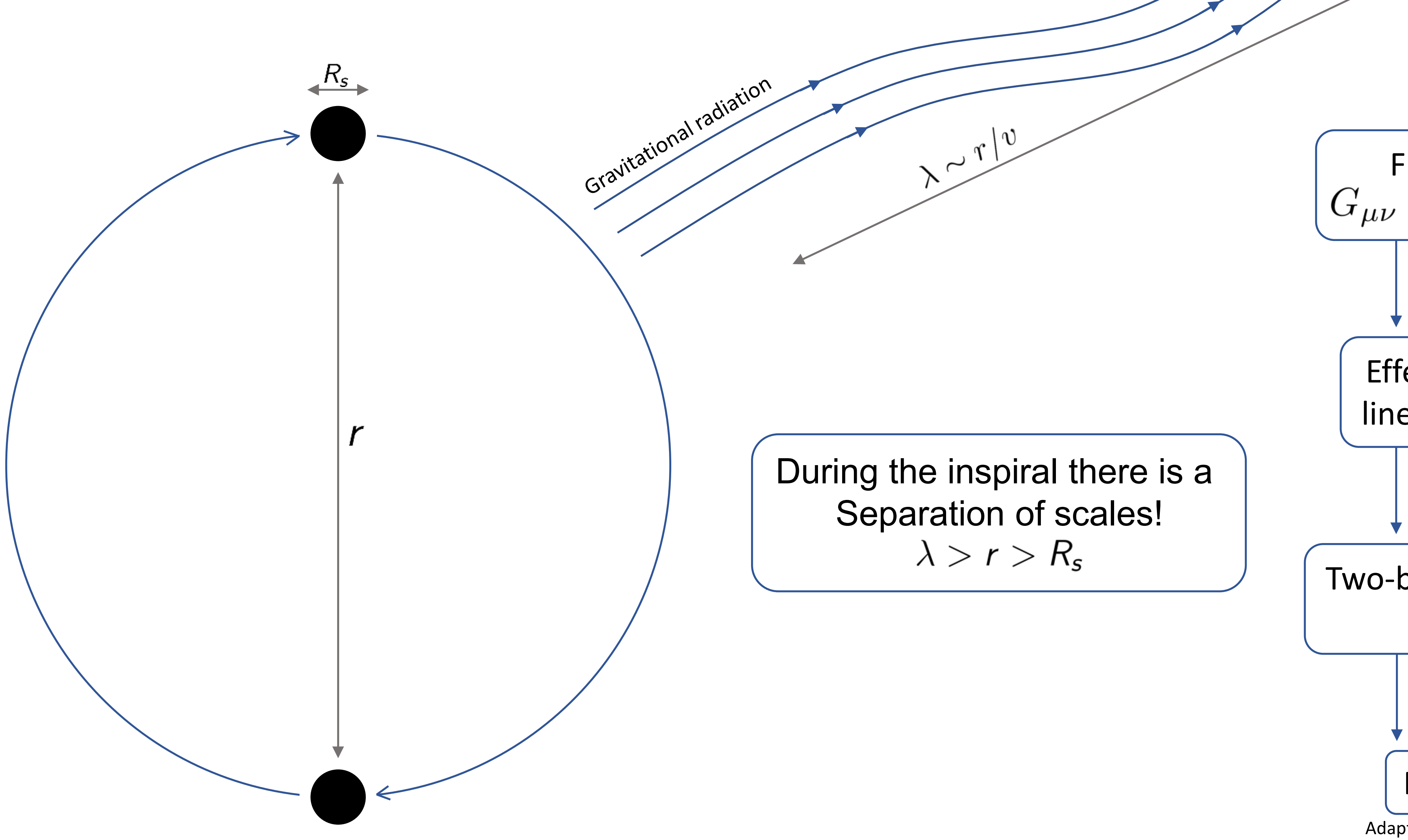

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Full theory:
$G_{\mu\nu} = 8\pi G_N T_{\mu\nu}$

$\mu \sim 1/R_s$

Effective world line description

$\mu \sim 1/r$

Two-body dynamics: NRGR

$\mu \sim 1/\lambda$

Radiation

Adapted from 2206.14249

Originally presented by Goldberger and Rothstein - Phys.Rev.D 73 (2006) 104029

Expanding the Einstein-Hilbert Action

$$\int d^4x \sqrt{-g} R \approx \int d^4x \left[(\partial h)^2 + \frac{1}{M_{\rm pl}} h (\partial h)^2 + \mathcal{O}(h^4) \right]$$

$$S_{\rm pp} = -M \int d\tau \approx -M \int dt \left[\mathcal{O}(h^0) + \frac{1}{M_{\rm pl}} \mathcal{O}(h^1) + \frac{1}{M_{\rm pl}^2} \mathcal{O}(h^2) + \ldots \right]$$

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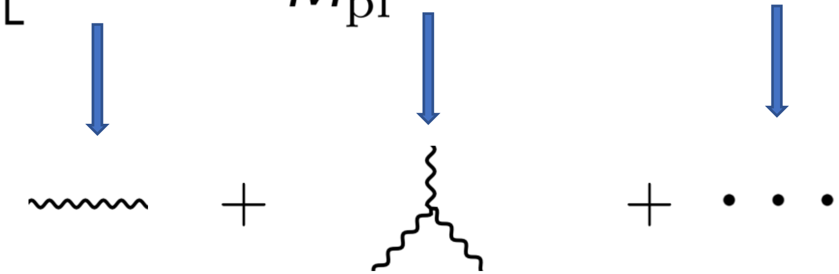

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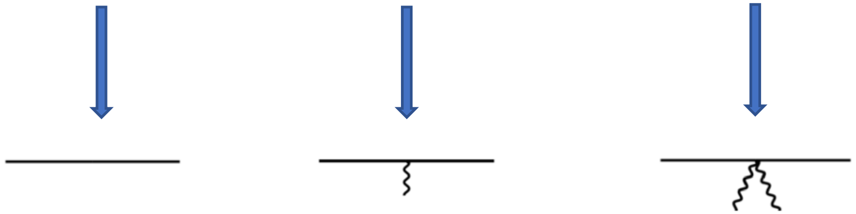

Adding a Scalar

$$S_{\rm pp} = -\int d\tau \left[M + q\frac{\phi}{M_{\rm pl}} + p\left(\frac{\phi}{M_{\rm pl}}\right)^2 + \mathcal{O}\left(\phi^3\right) \right]$$

$$S_\phi = \int dx^4 \sqrt{-g} \left[\frac{1}{2}(\partial\phi)^2 - \frac{1}{2}m_s^2\phi^2 + \mathcal{O}(\phi^3) \right]$$

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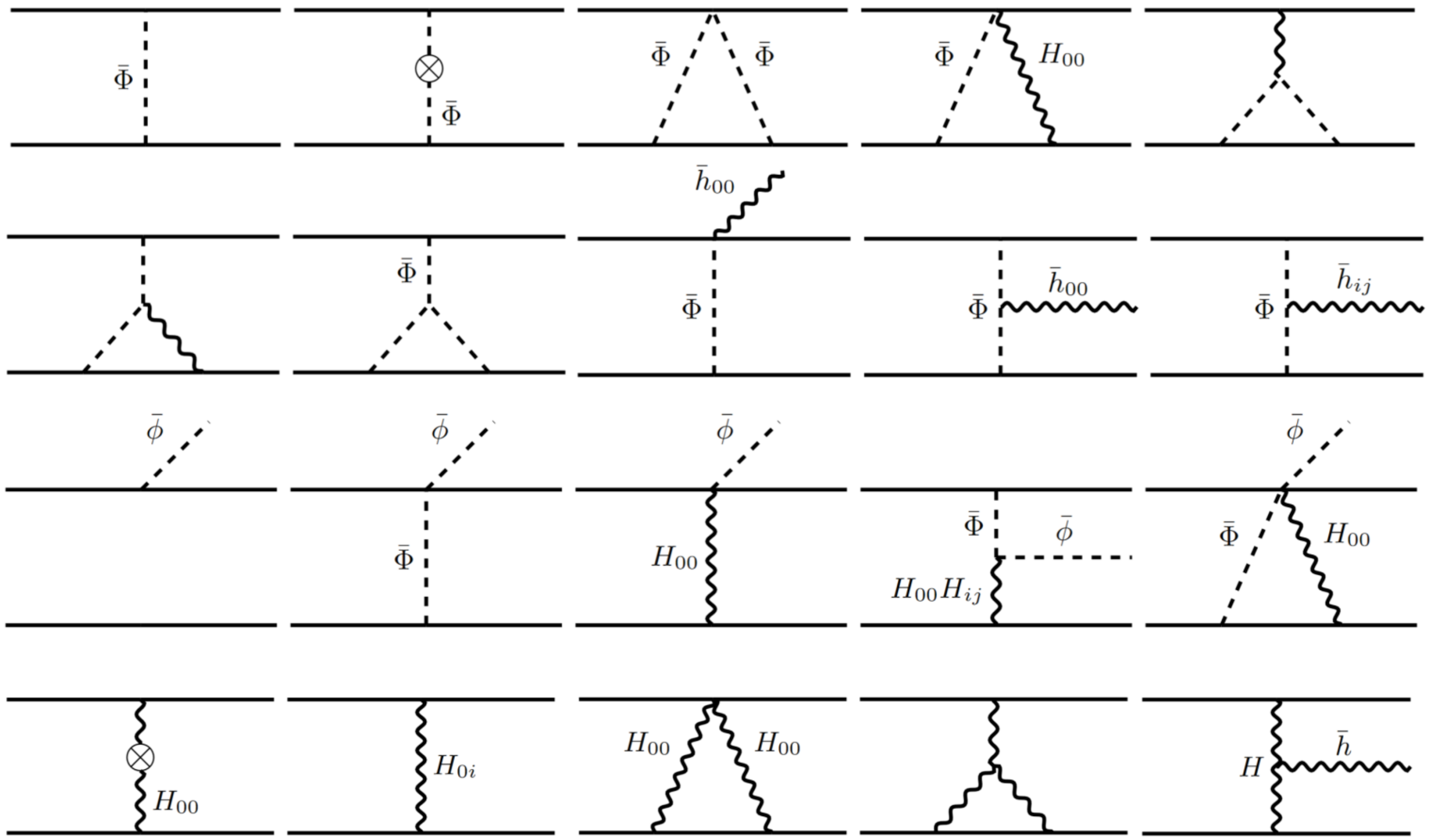
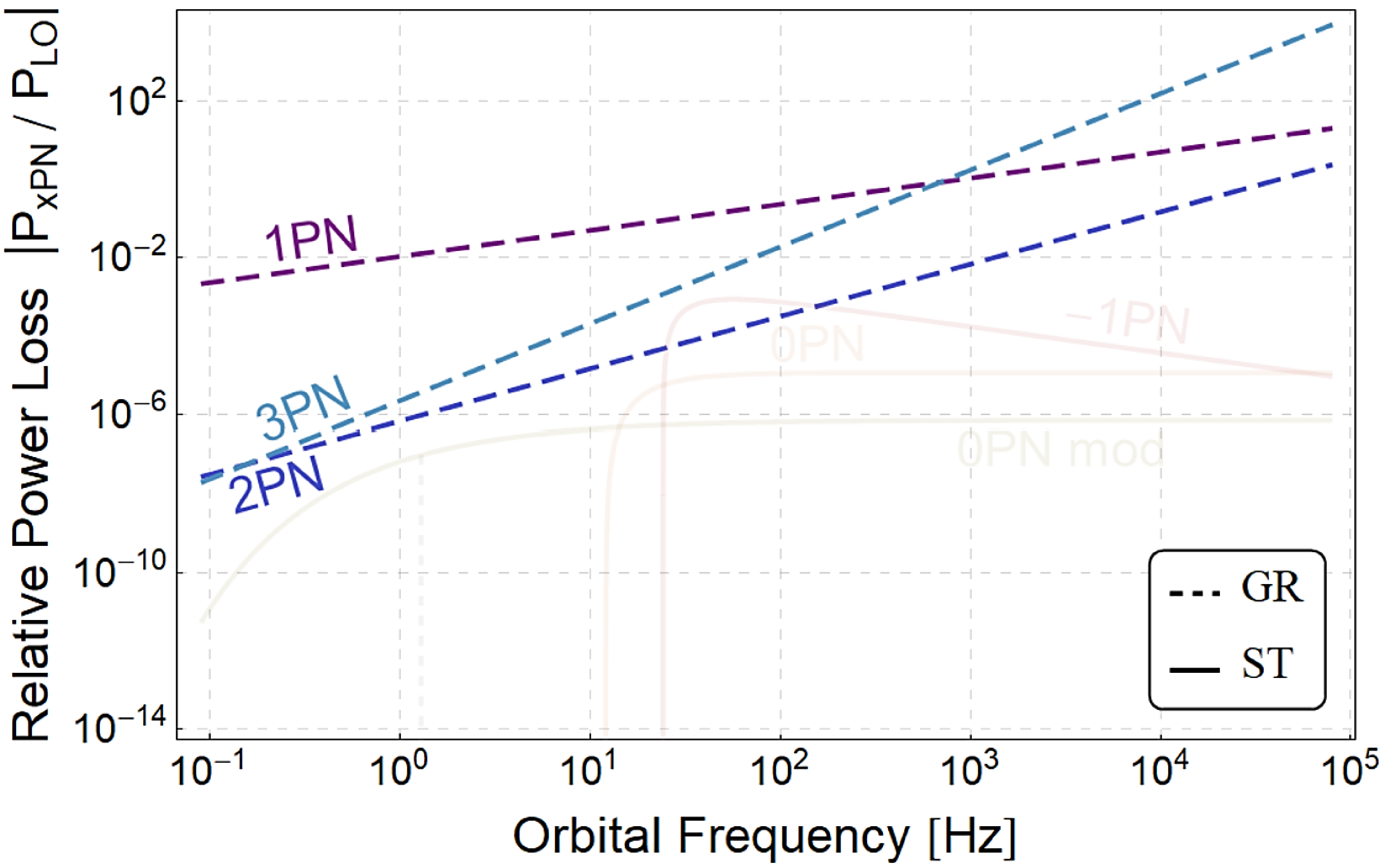
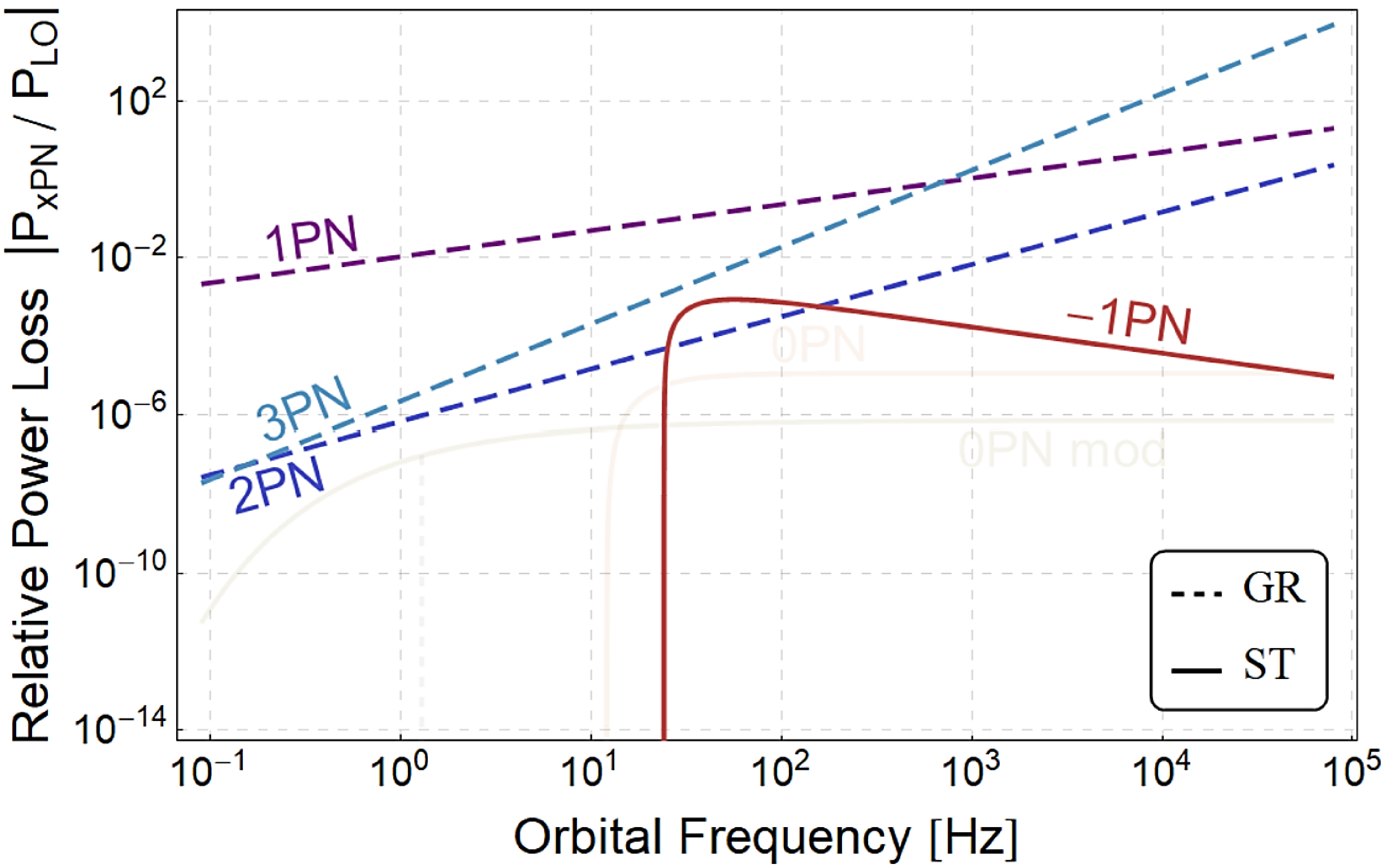


Partly done by Huang et al. in 2018 (Phys.Rev.D 99 (2019) 6, 063013)



$$M_1 = 1.8\,M_\odot$$
$$M_2 = 2.0\,M_\odot$$
$$q_1 = 0.018\,M_\odot$$
$$q_2 = 0.0\,M_\odot$$

Dark Matter Modified Gravity Gravitational Waves



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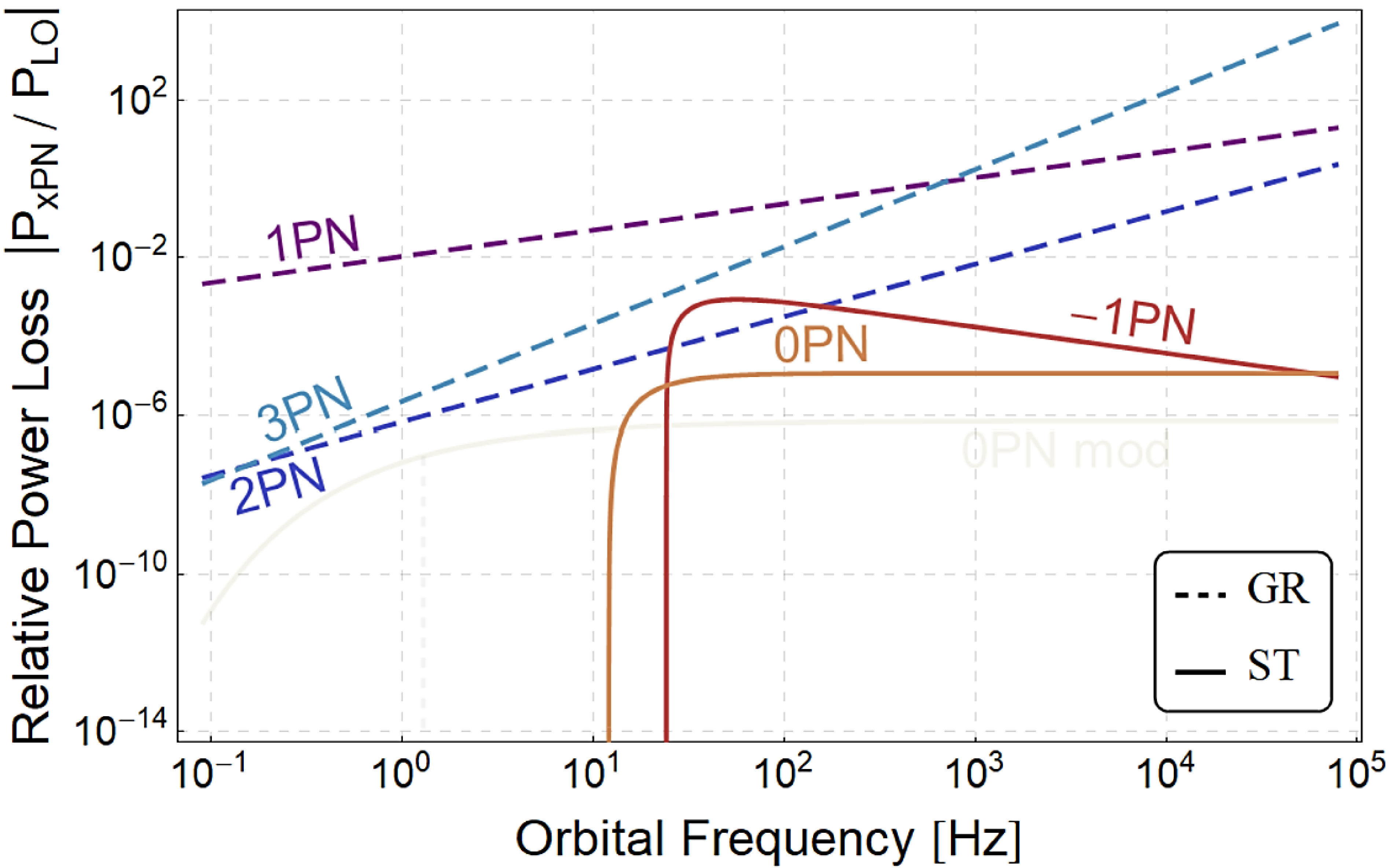

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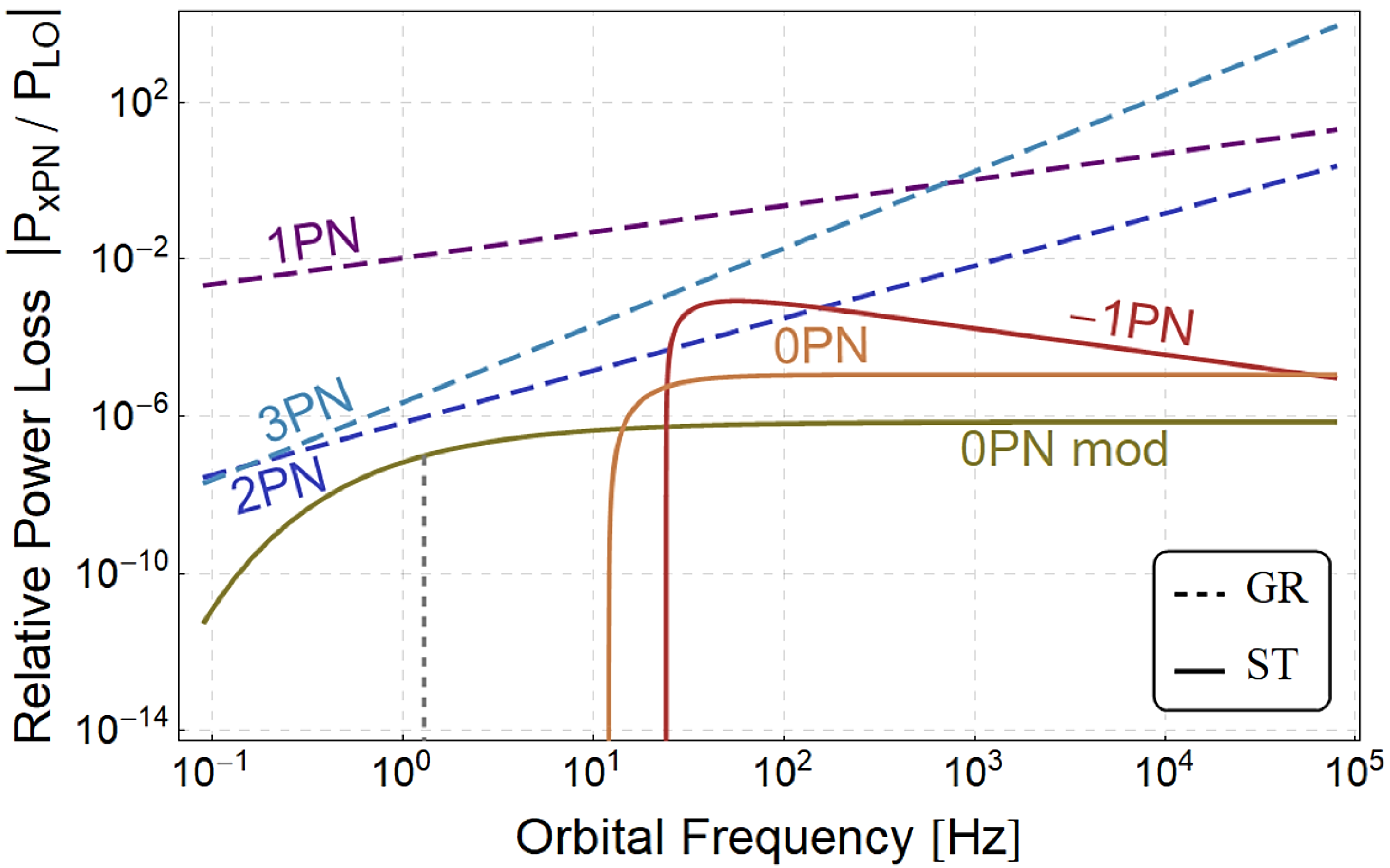

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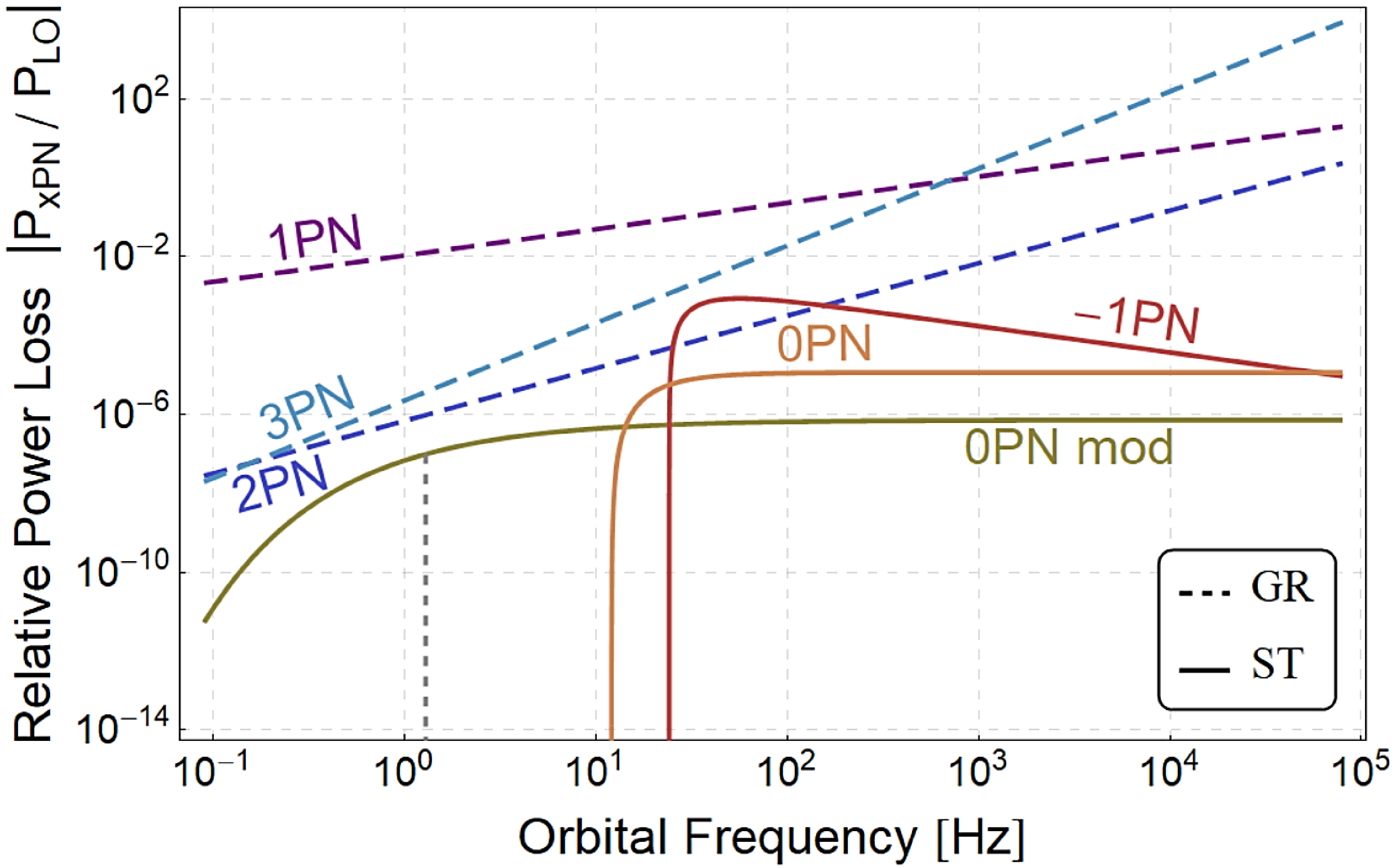

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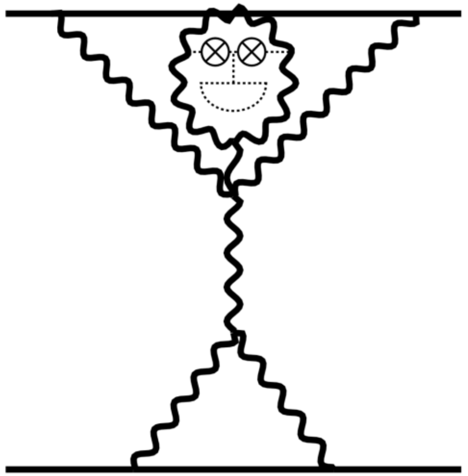
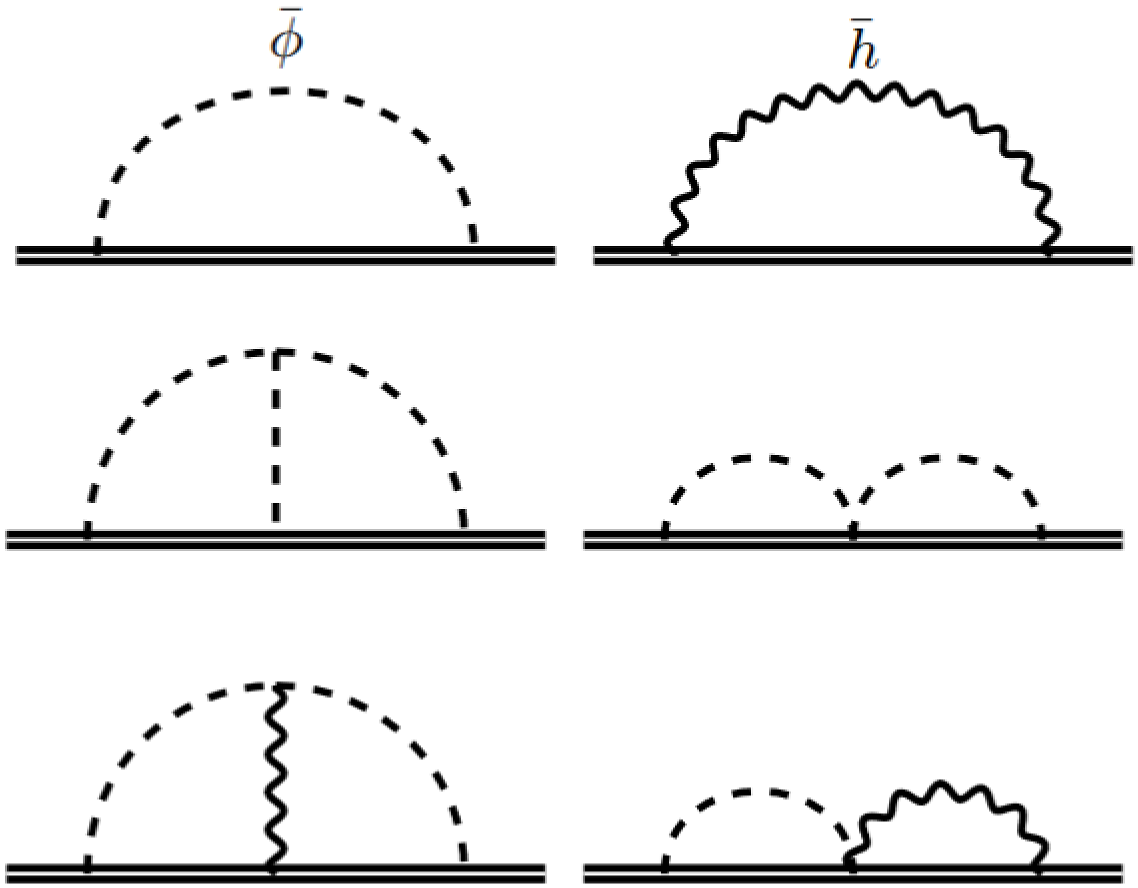


Thank you!

$$L_{\mathrm{0PN}} = \frac{1}{2}\sum_i M_i \mathbf{v}_i^2 + G\,\frac{M_1 M_2}{r},$$

$$L_{\mathrm{1PN}} = \frac{1}{8}\sum_i M_i \mathbf{v}_i^4 + G\,\frac{M_1 M_2}{2r}\left[3(\mathbf{v}_1^2 + \mathbf{v}_2^2) - 7(\mathbf{v}_1\cdot\mathbf{v}_2) - \frac{(\mathbf{v}_1\cdot\mathbf{r})(\mathbf{v}_2\cdot\mathbf{r})}{r^2}\right] - G^2\,\frac{M_1 M_2(M_1+M_2)}{2r^2}\ .$$

$$\begin{aligned}
L_\phi =& 8G\,q_1 q_2\,\frac{e^{-m_s r}}{r}\left[1 - G\,\frac{M_1+M_2}{r} - \frac{\mathbf{v}_1^2+\mathbf{v}_2^2}{2} - \frac{(\mathbf{v}_1\cdot\mathbf{r}_1)(\mathbf{v}_2\cdot\mathbf{r}_2)}{2\,r^2}(1+m_s r) + \frac{\mathbf{v}_1\cdot\mathbf{v}_2}{2}\right] \\
& - 64\,G^2(p_1 q_2^2 + p_2 q_1^2)\,\frac{e^{-2m_s r}}{r^2} + 4 m_s G^2\,\frac{M_1 q_2^2 + M_2 q_1^2}{r}\left[e^{-2m_s r} + 2 m_s r \mathrm{Ei}(-2m_s r)\right] \\
& - 8 m_s G^2 q_1 q_2\,\frac{M_1+M_2}{r}\left[\log(2m_s r)e^{-m_s r} - \mathrm{Ei}(-2m_s r)e^{m_s r}\right] \\
& + G\,c_3 q_1 q_2\,\frac{q_1+q_2}{2\pi r}\left[\mathrm{Ei}(-m_s r)e^{-m_s r} - \mathrm{Ei}(-3m_s r)e^{m_s r}\right]
\end{aligned}$$


$\bar{\phi}$
$\bar{h}$