Generic Tests of Gravity Theories with Gravitational Waves from Compact Binary Inspirals

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Gravitational waves

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If the theory of nature is not GR and we try to filter the signal with GR templates

1. We might end up with the wrong parameters for the signal.
2. Or even miss the signal entirely.

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We would like to have generic templates that could cover all well motivated alternative theories known to date.

Original ppE

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$$\tilde{h} = \tilde{h}_{GR}(1 + \alpha u^a)e^{i\beta u^b}$$

where

$$u = (\pi \mathcal{M} f)^{1/3}$$

Yunes, Pretorius PRD 80,122003(2009)

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1. The time domain response function accounts only for the two tensor polarization modes of the gravitational wave.

$$h(t) = F_+ h^+ + F_\times h^\times + F_{\rm se} h^{\rm se} + F_{\rm sn} h^{\rm sn} + F_{\rm b} h^{\rm b} + F_{\rm L} h^{\rm L}$$

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2. The parameter α is detector-dependent, since it depends on the sky location of the source.

Complete polarization content

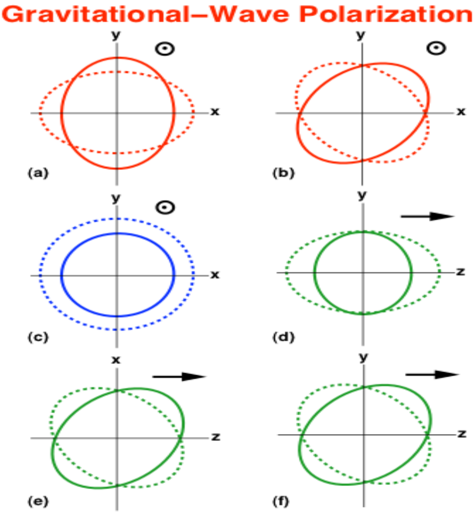

Figure: Polarization modes of the gravitational waves

Brans-Dicke theory of Gravity

$$\tilde{h}^{(2)}_{\text{BD}} \sim \; u^{-7/2} e^{-i\Psi^{(2)}_{\text{BD}}} \; + \; u^{-11/2} e^{-i\Psi^{(2)}_{\text{BD}}}$$

$$\tilde{h}^{(1)}_{\text{BD}} \sim \; u^{-9/2} e^{-i\Psi^{(1)}_{\text{BD}}}$$

$$\delta\Psi^{(\ell)}_{\text{BD}} \sim \; \ell u^{-7}$$

Deviations

$$h^{(\ell)}(t) = Q(\iota, \theta, \phi, \psi)\, \eta^{2/5}\, \frac{\mathcal{M}}{D} v^{\ell} e^{-i\ell\Phi}$$

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$$\dot{E} = \dot{E}_{\rm GR}\left[1 + B\left(\frac{m}{r}\right)^{q}\right]$$

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There seems to be a pattern in the possible waveforms that can be produced by theories of gravity.

Single Detector

$$\tilde{h}^{\mathrm{SD}}_{\mathrm{ppE},0} = \mathcal{A}\ u_2^{-7/2} e^{-i\Psi^{(2)}_{\mathrm{GR}}}\left(1+\alpha u_2^{a}\right) e^{i\beta u_2^{b}}$$

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However, we have seen that the various parameters are related to each other.

Reduced ppE model

$$\tilde{h}^{\rm SD}_{\rm ppE,1} = \mathcal{A}\, u_2^{-7/2} e^{-i\Psi^{(2)}_{\rm GR}} \left[1 + c\,\beta u_2^{b+5}\right] e^{i2\beta u_2^b} + \gamma\, u_1^{-9/2} e^{-i\Psi^{(1)}_{\rm GR}} e^{i\beta u_1^b}$$

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with parameters $\vec{\lambda}_{\rm ppE,1} = (b, \beta, \gamma, \Phi_c^{(1)})$.

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$$\alpha \to (\alpha_{\rm b} F_{\rm b} \sin^2\iota + \alpha_{\rm L} F_{\rm L} \sin^2\iota + \alpha_{\rm sn} F_{\rm sn} \sin\iota + \alpha_{\rm se} F_{\rm se} \sin 2\iota)$$
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If we introduce a further phase correction $e^{i\kappa u^k}$ we can account for propagation modifications.

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3. We proposed two extensions to the single-detector ppE framework: a generic one with a total of 9 ppE theory parameters; and a reduced one with 4 ppE theory parameters.
4. We carried out a multiple-detector extension with a large increase in ppE parameters, necessary to test for the existence of all 4 additional non-GR polarizations.

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1. Test the validity of General Relativity *without assuming that it is the correct theory of gravity*.
2. Use the potentially non zero value of the ppE parameters to search among the existing alternative theories for the correct one.

Thank you