Accuracy of hybrid waveform families

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Post-Newtonian
→ Analytical expansion for small velocity

Considered approximants:
• TaylorT1, TaylorT4 (re-expansion of T1), TaylorF2 (approx. Fourier transform of T4)
• 3.5PN-phase, 3PN/amplitude, 2.5PN/spin

Complete waveforms for black-hole binaries

Combining PN & NR data
... yields a description of the entire coalescence process.
... potentially increases the signal-to-noise ratio in a matched-filter search.
... allows for a unified template bank from low to high total masses,
but
... how reliable are these hybrid waveforms?
... which is the best PN approximant to use?
... how long do the NR waveforms need to be?

Do PN & NR waveforms agree?
Comparison of NR and PN phase over 10 cycles backwards from the GW frequency \( M\omega = 0.1 \) [1].

Results:
• Consistently good agreement for nonspinning cases, TaylorT4 approximant excellent agreement with NR.
• Generally worse for increasing spin magnitudes (equal, aligned spins), TaylorT4 improves when keeping incomplete spin terms at relative 3PN and 3.5PN order.

Are hybrid waveform families good enough for detection?

Mass optimization
Given a limited number of NR waveforms, we can only optimize the mismatch with respect to the total mass \( M \) which is a simple scaling factor.

The mismatch error decreases considerably for all matching frequencies (cf. faithfulness discussion).

Black lines: Optimal rescaling of the PN+NR data-sets by varying \( M \)

Red lines: No NR data needed! Although phase values above \( M\omega_\text{m} \) are not required, we now need the phase variation with \( M \) which we take again from the phenomenological functions provided in [3] or alternatively [4].
This still sets challenging bounds on \( M\omega_\text{m} \) for unequal mass, highly spinning systems.

Full fitting factors
Producing artificial hybrids with phenomenological models allows for the optimization with respect to all model parameters \( \tilde{M} \), \( \tilde{\eta} = m_1 m_2 / M^2 \) and \( \chi \).

Mismatch for \( M\omega_\text{m} \) = 0.06 and aligned spins \( \chi_1 = \chi_2 = 0.5 \). ⇒ Yes!

Application: length requirements for NR
Given a PN+NR hybrid with a fixed matching frequency, the above analyses provide the range in total mass the model is sufficiently accurate for (defined by a tolerable mismatch).
Likewise, we can estimate the required matching frequency for a given system by demanding that the maximal error (e.g., maximal fitting factor for detection) is below some threshold.

References

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