Complete phenomenological waveforms from spinning coalescing binaries

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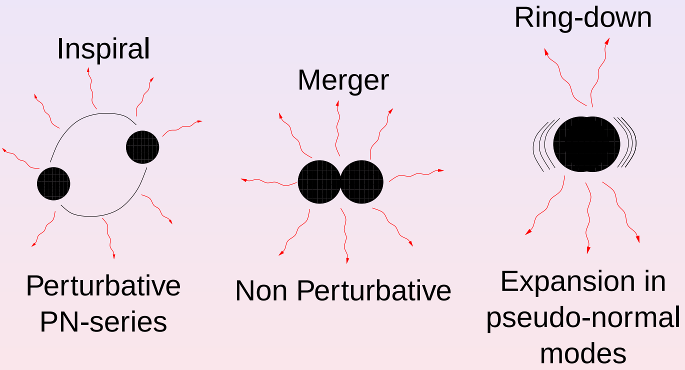
Coalescing templates



Coalescing signal

GW from coalescing binaries

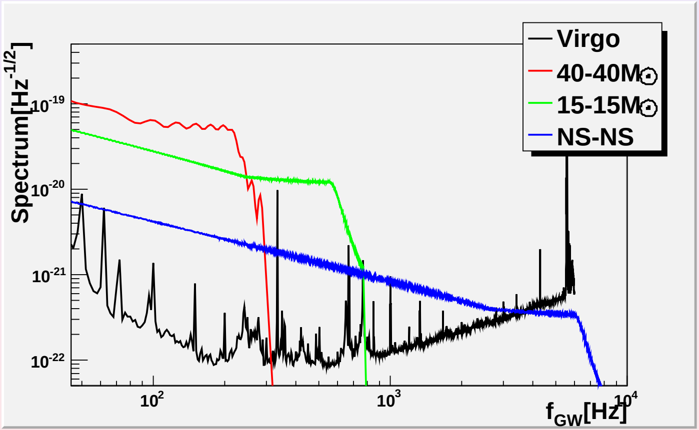
Coalescing signal searches

Spinning binaries

Complete phenomeno-logical waveforms from spinning binaries

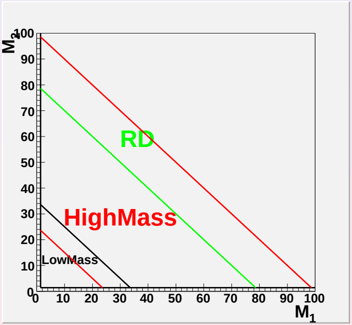
Results

Conclusions

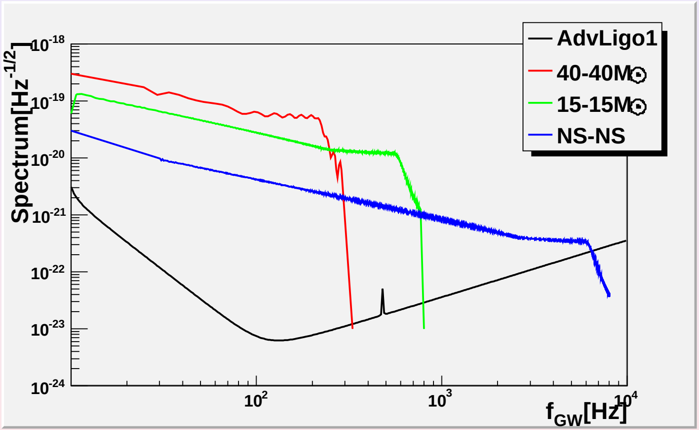


Matched filtering and templates

- Inspiral only
  $2.8 < M/M_{\odot} < 35$
  (spin-less)
- Inspiral+Merger+RingDown
  $25 < M/M_{\odot} < 100$,
  EOBNR non-perturbative templates, calibrated on PN inspiral and numerically generated wf's (spin-less)
- Ring down only
  $80 < M/M_{\odot} < 500$



Coalescing signal for Advanced LIGO

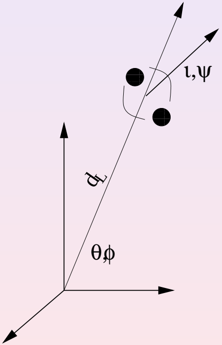


"High"-mass is a relative concept!

The importance of spinning waveforms

Matched filtering search:
Template bank exists only for spinless systems:

Spinless systems have 9 parameters:
$m1, m2$:intrinsic
$\theta, \phi, \iota, \psi, \phi_0, t_0, d_L$: extrinsic
Spin adds $2 \times 3 S_i'$s intrinsic
and makes ϕ_0, ψ, ι intrinsic because of $\vec{L} \cdot \vec{S}_i$ interactions



However most Black Holes in nature should be spinning: it is necessary to quantify how bad is a non-spinning search

Present situation

For spinning waveforms a 11-D template bank is unfeasible, attention focused on injections.
Simplified systems with manageable number of degrees of freedom

- Physical Template Family of Spinning Waveforms (PTF, by D. Fazi) includes inspiral description with one significant spin (NS-BH system, 2 extra parameters)
- Phenomenological IMR waveforms for aligned spins (by P. Ajith et al.), full coalescence joining PN inspiral to numerical simulations for aligned spins, only 1 more parameters than in the spinless case
- EOB w/ aligned spin by A. Buonanno et al.: full analytic non-perturbative description

Spinning waveform project coordinates efforts in developing an S6 search using spinning templates.

The method

- Inspiral

System is evolved (via a Taylor T4) approximant until a matching frequency f_m is reached:

$$\frac{d\phi}{dt} = \frac{v^3}{m} \qquad \frac{dv}{dt} = -\frac{F(v)}{dE/dv}$$

f_m is determined empirically.

- Phenomenological part

$$\frac{d\phi}{dt} = \frac{f_1}{1 - \frac{t}{T_A}} + f_0$$

f_0, f_1, T_P are determined by imposing continuity of $\dot{\phi}, \ddot{\phi}, \dddot{\phi}$.

- Ring down

When $d\phi/dt$ reaches $0.8 \times f_{RD}$, the ring down is attached

$$f_{RD} = f_{RD}(S_1, S_2, L, \eta)$$

By L. Rezzolla et al. arXiv 0904.2507

Waveform setup

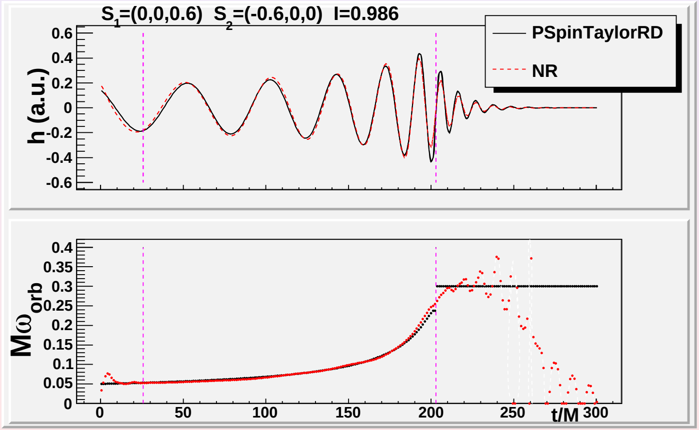
Decomposition in spherical harmonics:

$$h(t) = \sum_{lm} h_{lm}(\psi(t), \mathbf{L}(t), \mathbf{S_1}(t), \mathbf{S_2}(t)) \; {}_{-2}Y^{lm}(\theta, \phi)$$

Dominant modes (for moderate precession): $l = 2$, $m = \pm 2$
Confrontation with numerical waveforms from GeorgiaTech group:
equal masses, $|\mathbf{S_1}| = 0.6$, and initially $\mathbf{S}_2/m_2^2 = (-0.6, 0, 0)$

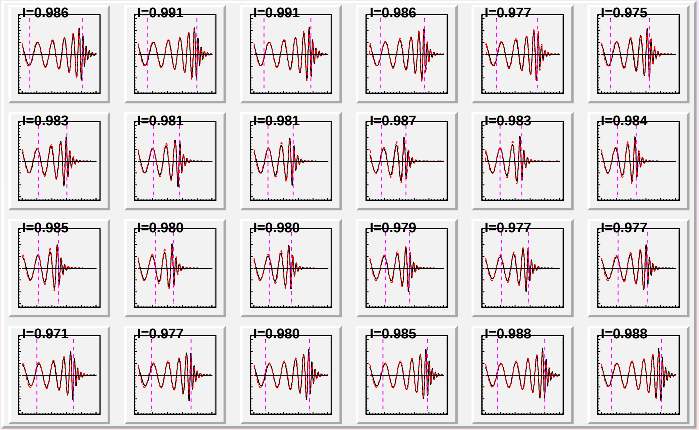
Short Waveforms

Phenomenological SpinTaylor RD vs. NR wforms by Georgia Tech ($l = 2, m = 2$ mode)



Short waveforms summary

Phenomenological Spin-Taylor RD vs. NR wforms by Georgia Tech ($l = 2, m = 2$ mode)



Fixing the only crucial free parameter: f_m

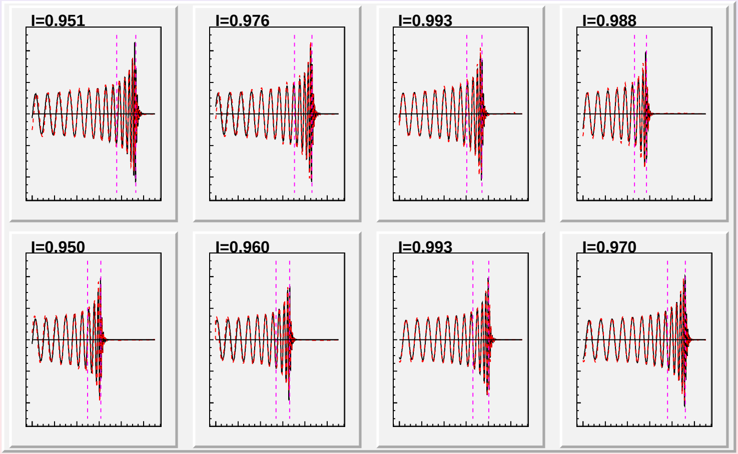
$$
\begin{aligned}
Mf_m \;=\;& a_0 + a_1(S_{1z}+S_{2z}) + a_2\delta(S_{1z}-S_{2z}) + a_3(S_1S_2)_\perp + \\
& a_4(S^2_{1\perp}+S^2_{2\perp}) + a_5\delta(S^2_{1\perp}-S^2_{2\perp}) + a_6(S^2_{1z}+S^2_{2z}) + \\
& a_7(S_{1z}S_{2z}) + a_8\delta(S^2_{1z}-S^2_{2z}) + \ldots\,,
\end{aligned}
$$

More numerical simulations (spins and mass ratios) needed to complete the determination of f_m

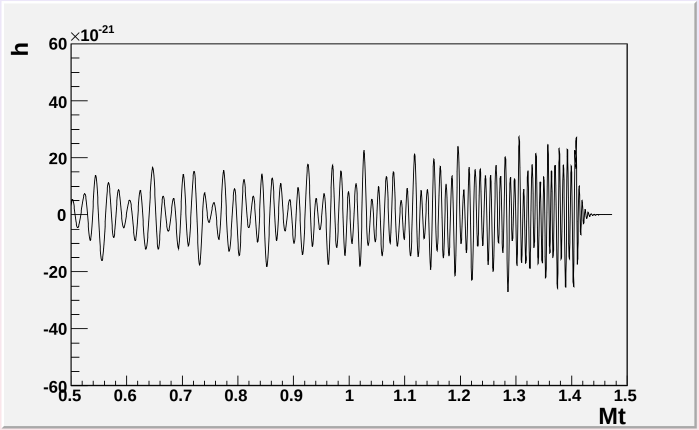
$$a_i(\delta) = a_i + \delta\, a_i^{(1)} + \delta^2\, a_i^{(2)} + \ldots$$

Long waveforms

No parameters have been tuned on this waveforms!



Generic spin and mass ratios



Untested!

Conclusions

Work still in progress in order to model more generic spins (so far $|S| = 0.6$) and mass ratios (so far $m_1 = m_2$) and test higher modes than $l = 2, m = 2$

Goal: waveforms for generically spinning binaries