

Complete phenomenological waveforms from spinning coalescing binaries

R. Sturani

S. Fischetti, L. Cadonati, G. Guidi, J. Healy, D.
Shoemaker and A. Viceré

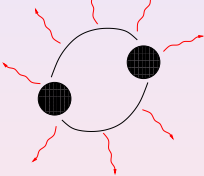
Università di Urbino (Italy), UMass Amherst (USA), GeorgiaTech (USA)

Cascina, May 4th, 2010

Coalescing templates

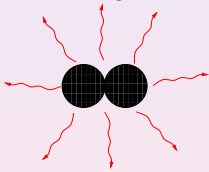
- GW from coalescing binaries
- Coalescing signal searches
- Spinning binaries
- Complete phenomenological waveforms from spinning binaries
- Results
- Conclusions

Inspiral



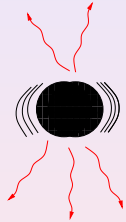
Perturbative
PN-series

Merger



Non Perturbative

Ring-down



Expansion in
pseudo-normal
modes



Coalescing signal

GW from
coalescing
binaries

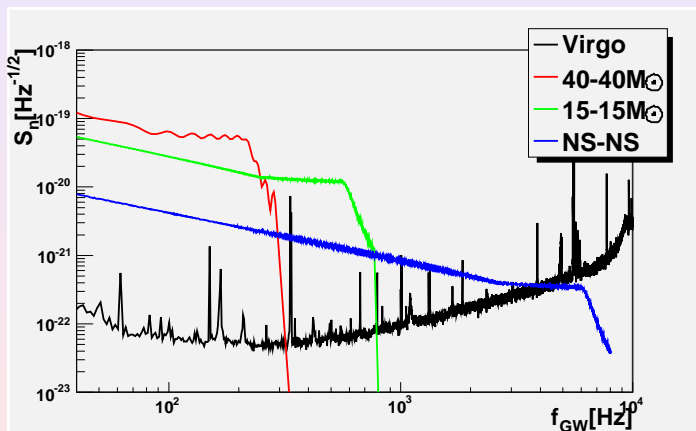
Coalescing
signal
searches

Spinning
binaries

Complete
phenomeno-
logical
waveforms
from spinning
binaries

Results

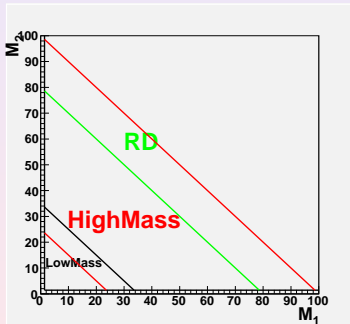
Conclusions





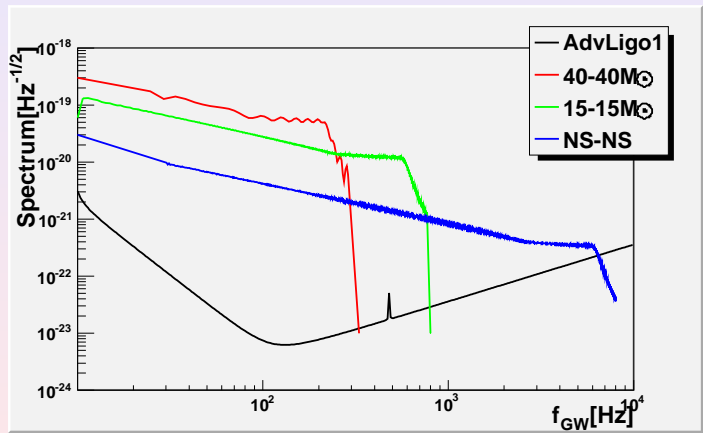
Matched filtering and templates

- 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

- GW from coalescing binaries
- Coalescing signal searches
- Spinning binaries
- Complete phenomenological waveforms from spinning binaries
- Results
- Conclusions



“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**:

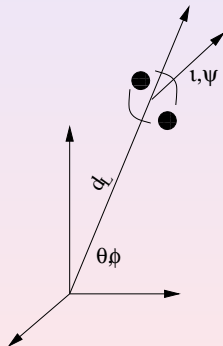
m_1, m_2 : intrinsic

$\theta, \phi, \iota, \psi, \phi_0, t_0, d_L$: extrinsic

Spin adds $2 \times 3S_i$'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 parameter 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:

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

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 $\dot{\phi}, \ddot{\phi}, \ddot{\phi}$.

- **Ring down**

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

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

GW from
coalescing
binaries

Coalescing
signal
searches

Spinning
binaries

Complete
phenomeno-
logical
waveforms
from spinning
binaries

Results

Conclusions

Decomposition in spherical harmonics:

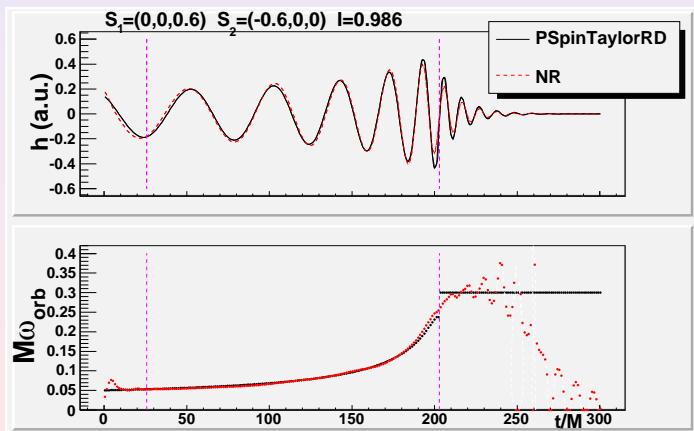
$$h(t) = \sum_{lm} h_{lm}(\psi(t), \mathbf{L}(t), \mathbf{S}_1(t), \mathbf{S}_2(t)) {}_{-2}Y^{lm}(\theta, \phi)$$

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)



GW from
coalescing
binaries

Coalescing
signal
searches

Spinning
binaries

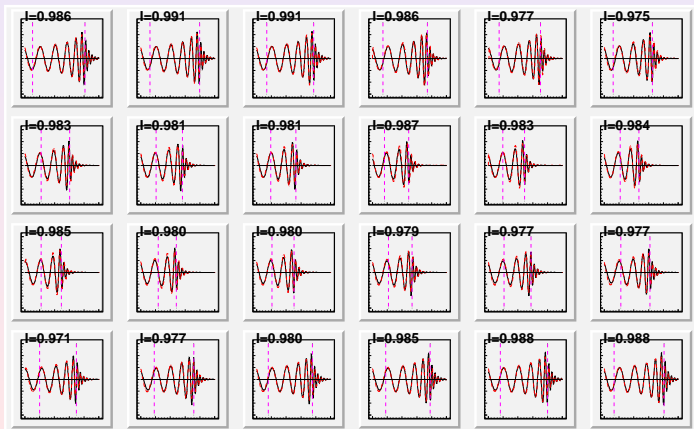
Complete
phenomeno-
logical
waveforms
from spinning
binaries

Results

Conclusions

Short waveforms summary

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



GW from
coalescing
binaries

Coalescing
signal
searches

Spinning
binaries

Complete
phenomeno-
logical
waveforms
from spinning
binaries

Results

Conclusions

Fixing the only crucial free parameter: f_m

$$Mf_m = \mathbf{a}_0 + \mathbf{a}_1(\mathbf{S}_{1z} + \mathbf{S}_{2z}) + \mathbf{a}_2\delta(\mathbf{S}_{1z} - \mathbf{S}_{2z}) + \mathbf{a}_3(\mathbf{S}_1 \mathbf{S}_2)_\perp + \mathbf{a}_4(\mathbf{S}_{1\perp}^2 + \mathbf{S}_{2\perp}^2) + \mathbf{a}_5\delta(\mathbf{S}_{1\perp}^2 - \mathbf{S}_{2\perp}^2) + \mathbf{a}_6(\mathbf{S}_{1z}^2 + \mathbf{S}_{2z}^2) + \mathbf{a}_7(\mathbf{S}_{1z}\mathbf{S}_{2z}) + \mathbf{a}_8\delta(\mathbf{S}_{1z}^2 - \mathbf{S}_{2z}^2) + \dots,$$

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

$$\mathbf{a}_i(\delta) = \mathbf{a}_i + \delta \mathbf{a}_i^{(1)} + \delta^2 \mathbf{a}_i^{(2)} + \dots$$

GW from
coalescing
binaries

Coalescing
signal
searches

Spinning
binaries

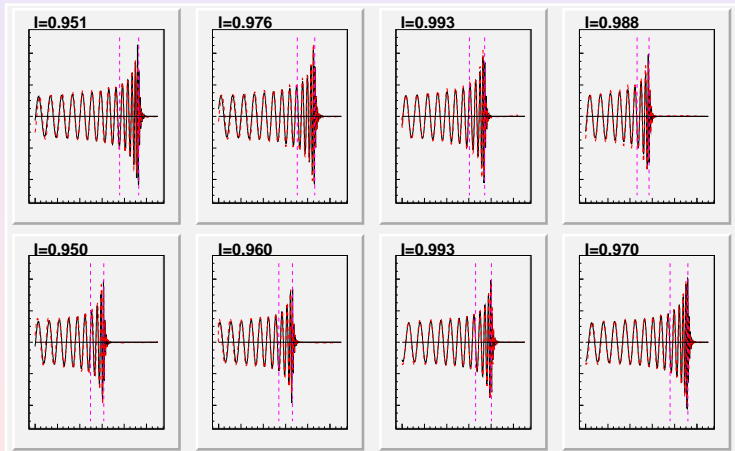
Complete
phenomeno-
logical
waveforms
from spinning
binaries

Results

Conclusions

Long waveforms

No parameters have been tuned on this waveforms!



GW from
coalescing
binaries

Coalescing
signal
searches

Spinning
binaries

Complete
phenomeno-
logical
waveforms
from spinning
binaries

Results

Conclusions



Generic spin and mass ratios

GW from
coalescing
binaries

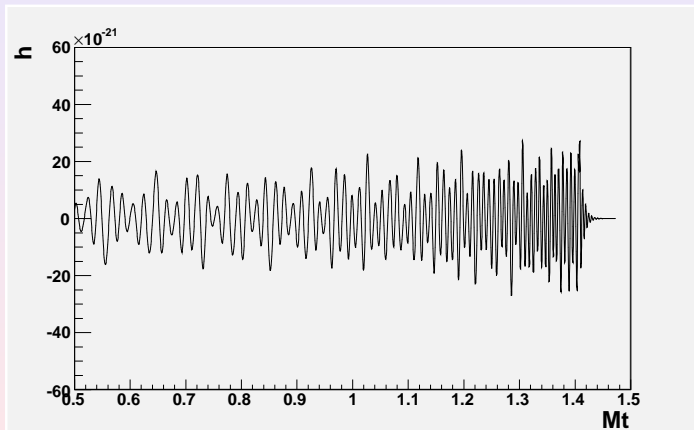
Coalescing
signal
searches

Spinning
binaries

Complete
phenomeno-
logical
waveforms
from spinning
binaries

Results

Conclusions



Untested!

GW from
coalescing
binaries

Coalescing
signal
searches

Spinning
binaries

Complete
phenomeno-
logical
waveforms
from spinning
binaries

Results

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