Calibrating EOB waveforms with numerical simulations

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(arXiv:0902.0790)

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- Generation of Numerical Waveforms
- Generation of EOB Waveforms
- Comparing Numerical and EOB Waveforms

Introduction and Motivation

- Gravitational wave detectors need accurate theoretical waveforms to use as templates in order to detect and extract information using matched filtering.
- Post-Newtonian (PN) waveforms are not accurate during last several orbits and merger.
- Numerical waveforms are too expensive to generate necessary templates.
- Effective one-body (EOB) formalism extends PN waveforms through merger and ringdown, but must be calibrated with numerical simulations.

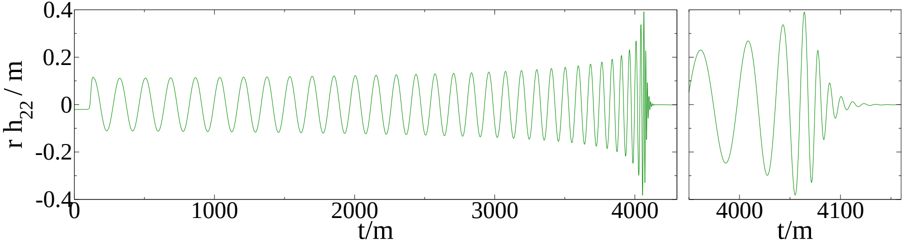
Spectral Einstein Code

[Kidder, Pfeiffer, Scheel]

- Generalized harmonic formulation of Einstein's equations
  - 10 coupled first-order wave equations (50 variables)
  - Constraint damping (Lindblom et al 2006)
- Dual frame method with dynamic tracking of the black holes
  - Time-dependent rotation and scaling (Scheel et al 2006)
  - Use control theory to adjust mapping to track holes
- Boundary conditions
  - Excision boundary is pure outflow (no BC needed)
  - Constraint preserving (Lindblom et al 2006)
  - No incoming physical radiation
  - Minimize reflections of gauge modes (Rinne et al 2007)
- Multidomain pseudospectral method
  - Exponential convergence for smooth solutions
  - Highly efficient for high accuracy

Equal-mass non-spinning binary black hole

- 16.5 orbit inspiral-meger-ringdown (Boyle et al 2007; Scheel et al 2009)
- Non-spinning $S_i/m_i^2 < 10^{-5}$
- Low eccentricity $e \approx 6 \times 10^{-5}$



Effective-one-body formalism

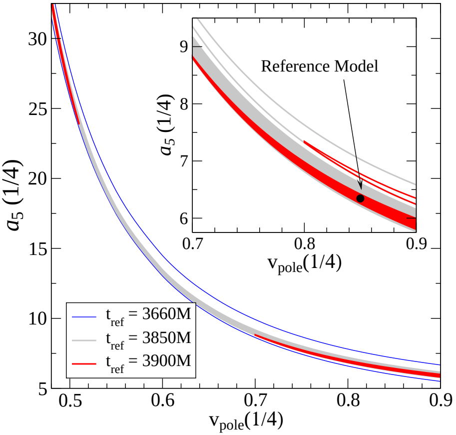
[Buonanno, Damour; PRD 59, 084006 (1999)]

[Damour; arXiv:0802.4047]

- Based on re-summed PN results
- "Flexibility" parameters to describe unknown physics
- Conservative Hamiltonian one-body dynamics
  - $a_5(\nu)$ pseudo-4PN correction to radial potential
- Radiation-reaction force from flux
  - A_8 pseudo-4PN correction to energy flux
  - $v_{pole}(\nu)$ resummation parameter
  - a^r_{RR} and a^Φ_{RR} non-quasi-circular terms
- Description of inspiral waveform
  - Resummed PN modes of $h_{\ell,m}$ (Damour,Iyer,Nagar,2008)
  - Add non-quasi-circular corrections (4 parameters)
- Ringdown waveform
  - quasi-normal modes based on final mass and spin from NR
  - attach modes to inspiral-plunge waveform
  - $t^{\ell,m}_{match}$ and $\delta t^{\ell,m}_{match}(\nu)$

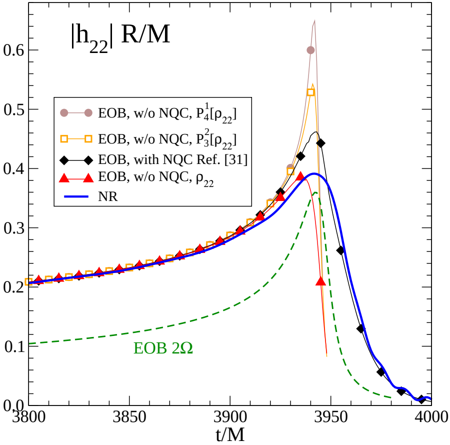
EOB calibration: inspiral

- Phase evolution depends only on inspiral dyanamics
- Two parameters suffice: $a_5 = 6.344$, $v_{pole} = 0.85$

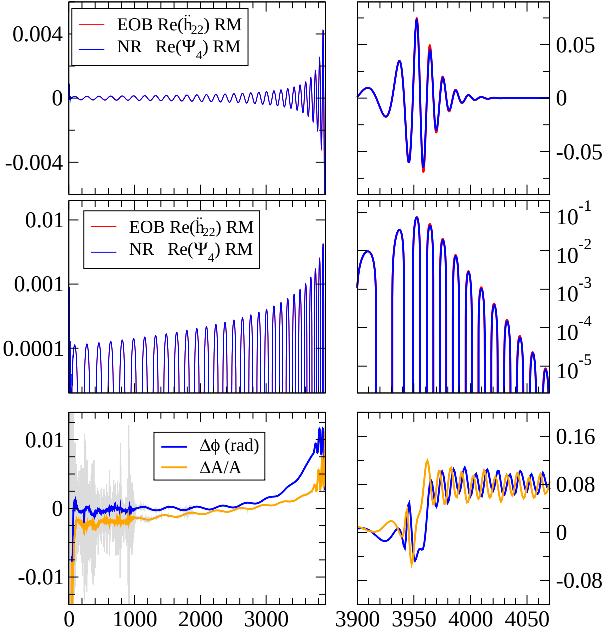


EOB calibration: Plunge-merger

- choice of resummation matters
- fix four NQC parameters by
  - max of h_{EOB} at same t as max of Ω_{EOB}
  - max of h_{EOB} is equal to max of h_{NR}
  - least square fit of remaining two parameters



EOB vs NR



EOB Re($\ddot{h}_{22}$) RM
NR Re(Ψ_4) RM
0.004
0
-0.004
0.05
0
-0.05
EOB Re($\ddot{h}_{22}$) RM
NR Re(Ψ_4) RM
0.01
0.001
0.0001
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
$\Delta\phi$ (rad)
$\Delta A/A$
0.01
0
-0.01
0.16
0.08
0
-0.08
0
1000
2000
3000
3900
3950
4000
4050

Conclusions and Future Work

- Conclusions
  - EOB can be calibrated to match NR
  - waveforms are consistent for higher-order modes
  - waveforms are consistent for 2:1 and 3:1 inspirals if $a_5(\nu)$.
  - Similar conclusions reached by [Damour and Nagar, arXiv:0902.0136]
- Future Work
  - longer BBHs inspiral+merger+ringdown for mass ratios 2:1, 3:1, 4:1, 6:1
  - comparison with BBHs with aligned spins
  - improve EOB formalism for spinning binaries
  - look at tidal effects in EOB by comparing with NS-BH