Statistical techniques can be used to gain insight into binary black hole inspiral dynamics in the post-Newtonian approximation.

And to help identify structure in the parameter space of binary inspirals.

Sample the 7d parameter space

- Masses (total mass = 1), spin angular momenta components
- 3.5 PN equations of motion for quasi-circular inspirals with spin effects up to 2PN in covariant SSC

Principal Component Analysis

- Seek to determine the statistically most and least relevant variables
- Diagonalize covariance matrix of (stochastic) spin variables

RESULTS:

- We find a new conserved quantity involving spin-orbit and spin-spin variables

\[ \mathcal{E}_{6}^{NL} = \frac{1}{\sqrt{5}} [2\hat{S}_1 \cdot \hat{S}_2 + (\hat{S}_1 \cdot \mathbf{L})(\hat{S}_2 \cdot \mathbf{L})] \]

- This new quantity is better conserved than previous ones (\( S_0 L \), \( S_{\text{eff}} L \), ...)

- The quantities with least relevance are statistically conserved

- From numerical simulations of binary BHs with randomly chosen spins, the statistically conserved quantities seem to remain so during plunge phase
Reduced Basis Catalogs for Gravitational Wave Templates


**RESULTS:**

- **RB method** embeds space of waveforms into a larger linear vector space.
- **Advantages of RB method:**
  - Can be used when parameters must be chosen on the fly (e.g., spinning binaries, numerical relativity waveforms)
  - Generates nested catalogs
  - Computationally efficient \(O(N)\)
  - RB catalogs are nearly optimal in terms of error in representing the space of waveforms

<table>
<thead>
<tr>
<th>Detector</th>
<th>Overlap Error</th>
<th>BBH</th>
<th>BNS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(10^{-2})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AdvLIGO</td>
<td>1.058</td>
<td>19,336</td>
<td>5,395</td>
</tr>
<tr>
<td></td>
<td>(10^{-5})</td>
<td>1.687</td>
<td>1.1 \times 10^{7}</td>
</tr>
<tr>
<td></td>
<td>(2.5 \times 10^{-13})</td>
<td>1,700</td>
<td>8.0 \times 10^{13}</td>
</tr>
</tbody>
</table>

- RB method constructs an exponentially converging and hierarchical waveform catalog
- For high accuracies the RB method produces dramatically fewer templates than standard approaches
- RB catalogs are robust to typical variations in the PSD
- RB method can be used for searches and parameter estimation with a single catalog
Singular Value Decomposition Applied to Binary Black Hole Waveforms

Drew Keppel\textsuperscript{1,2}, Kipp Cannon\textsuperscript{3}, Melissa Frei\textsuperscript{4}, Chad Hanna\textsuperscript{5}

\textsuperscript{1}Albert-Einstein-Institut, Hannover, \textsuperscript{2}Leibniz Universität, \textsuperscript{3}Canadian Institute for Theoretical Astrophysics, \textsuperscript{4}University of Texas at Austin, \textsuperscript{5}Perimeter Institute for Theoretical Physics

- Template banks are used to search for different types of GWs
- Redundancy in the template banks can be eliminated using singular value decomposition to generate basis vectors that enclose the signal manifold
- We apply these techniques to CBC waveforms made up of the inspiral, merger, and ringdown phases
- We find the point at which the number of basis vectors saturates decreases for increasing dimensionality of the parameter space
Parameter Space Dependence of Junk Radiation in Binary Black Hole Simulations

Nick Tacik, Harald Pfeiffer

- At the start of binary black hole simulations, “junk radiation” is emitted from the system.
- This is because the initial data does not perfectly capture the configuration that results from a long inspiral.
- We investigate how junk radiation scales with the spin of the black holes, and their initial separations.
- A better understanding of junk radiation should help create initial data configurations that result in less junk radiation.
The eccentricity distribution of compact binaries

I. Kowalska¹, T. Bulik¹,2, K. Belczynski¹,3, M. Dominik¹, D. Gondek-Rosinska⁴,2

¹Astronomical Observatory, University of Warsaw, Al Ujazdowskie 4, 00-478 Warsaw, Poland
²Nicolaus Copernicus Astronomical Center, Bartycka 18, 00716, Warsaw, Poland
³Dept. of Physics and Astronomy, University of Texas, Brownsville, TX 78520, USA
⁴Institute of Astronomy, University of Zielona Góra, ul. Lubuska 2, 65-265 Zielona Góra, Poland

ikowalska@astrouw.edu.pl

We use the StarTrack binary population code to answer following questions:

• When eccentricity is important?

• Can it affect GW data analysis?

• What can we learn, if we could detect it?
Evaluating Errors in Hybrid Waveforms
Ilana MacDonald, Harald Pfeiffer, Samaya Nissanke

- Templates required for AdvLIGO matched filtering.
- Create hybrids out of NR and PN waveforms.
- We do comprehensive error analysis of hybrid waveforms:
  - Choice of matching region of PN & NR waveforms
  - Choice of PN approximant
  - Systematic errors in NR waveform
Accuracy of hybrid waveform families

Frank Ohme

in collaboration with Mark Hannam, Sascha Husa and P. Ajith

1 Albert-Einstein-Institut
Potsdam, Germany
2 Cardiff University
Cardiff, UK
3 Univ. de les Illes Ballears
Palma, Spain
4 CalTech
Pasadena, USA

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?

Numerical Relativity

→ Numerical approx. of full GR
Computationally very expensive ⇒ infeasible to simulate arbitrarily long waveforms or provide NR data for every needed set of physical parameters.

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.

⇒ Yes!

Are PN+NR hybrids faithful?

Consider matching early time/low frequency PN data to later time/high frequency NR data. $M \omega_{\text{m}}$ be the transition point (matching frequency). Different PN approximants lead to different hybrid waveforms for fixed parameters → mismatch defines our error estimate.

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.

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

Mismatch of equal-mass nonspinning hybrids for Advanced LIGO ($f_{\text{low}} = 20$Hz)
Black lines: PN (TaylorT1/T4) + NR (SpEC [5])
Modeling of Chi-square veto in Inspiral searches
Rahul Biswas, Sarah Caudill, Patrick R. Brady and Gabriela Gonzalez

1. Chi-square veto is a computationally expensive veto applied in the inspiral Search.

2. The veto discriminates possible gravitational-wave signals from noise transients. This is done using calculating a goodness of fit parameter.

3. The output from the pipeline are characterized by its signal-to-noise ratio, time of coalescence known as “Trigger”.

4. The idea behind modeling the chi-square is to consider the contribution of power from a glitch to the matched filter.

5. We have derived a non-central parameter as a function of SNR for a non-central chi-square distribution to model the chi-square.