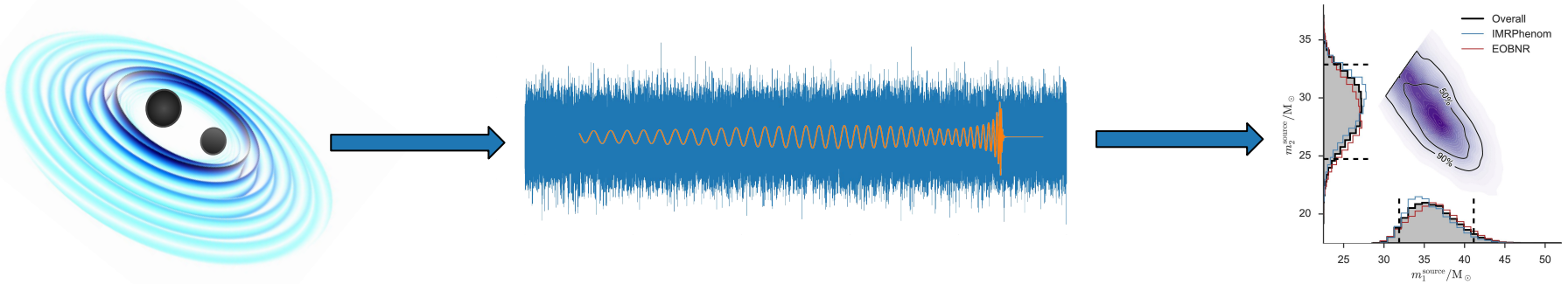
The Status of Phenomenological Inspiral-Merger-Ringdown Waveform Models

GWPAW, Annecy, May 2017

S. Khan, L. London, M. Hannam, S. Husa, X. Forteza, C. Kalaghatgi, F. Ohme, F. Pannarale, E. Fauchon-Jones, A. Vano-Vinuales, D. Keitel, G. Pratten, M. Colleoni, C. García, A. Ramos and R. Jaume.



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Binary Merger Observations & Numerical Relativity

Improving Phenomenological Models

Two Main Updates

1 - Higher Harmonics: Developed aligned-spin model

- Most models assume we can describe the GW with leading order quadrupole only (l = |m| = 2)
- As mass-ratio increases, the strength of the higher modes increases.
- Neglecting higher modes can impact search sensitivity [Capano et al (2013), Vijay et al (2017)]

We extend the non-precession phenomenological model *(IMRPhenomD)* to include higher order modes

2 - Precession: Improving the Inspiral - two spin description

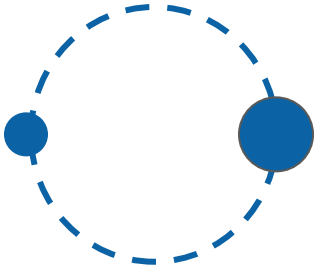
- Two main IMR models:
  1. **E**ffective-**O**ne-**B**ody *(SEOBNRv3)* [Pan et al (2014), Babak et al (2016)].
  2. **Phenom**enological (*IMRPhenomPv2*) [Hannam et al (2014), Schmidt et al (2015)].
- PhenomP uses a single-spin approximation.
- Precession can be modelled as time dependent rotation of equivalent non-precessing system. [Schmidt et al (2011), O'Shaughnessy et al (2011), Boyle et al (2011)].

We replace this with the recently derived (two-spin) closed-form expression of Chatziioannou et al (2017)

Impact of Higher Modes

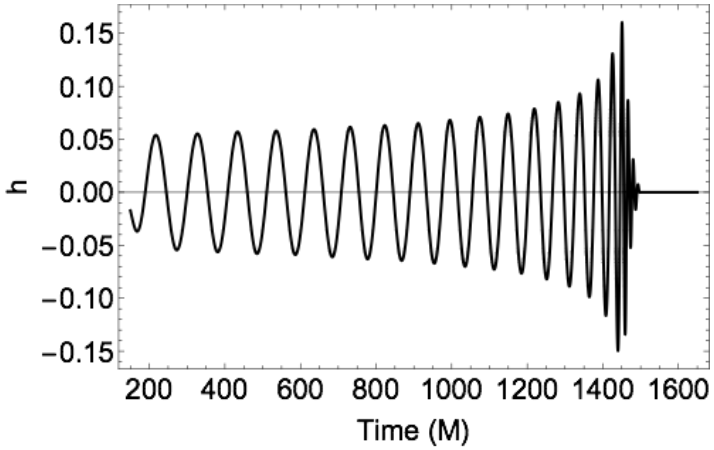
Orientation

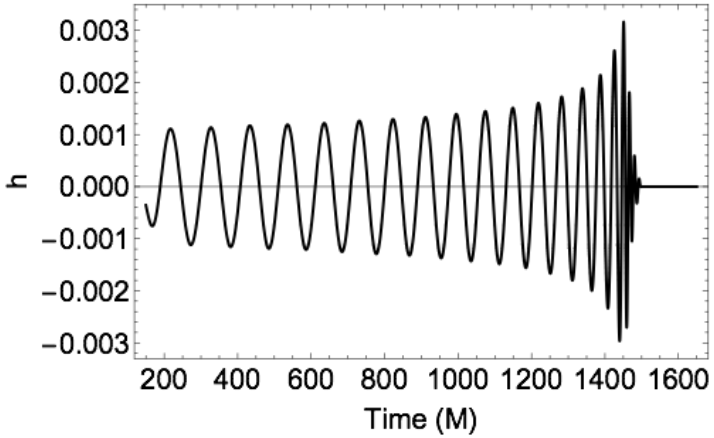
face-on



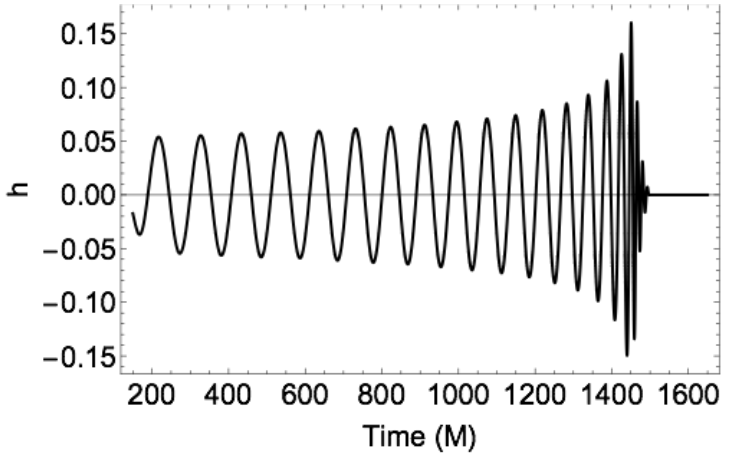
edge-on

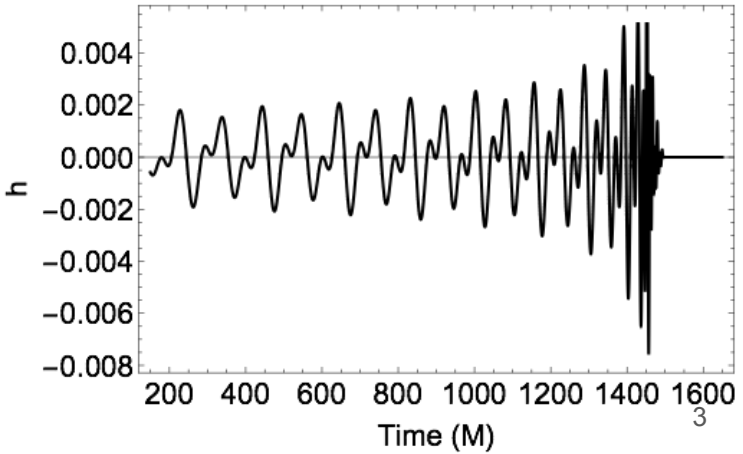
(2,2) and (2,-2) only





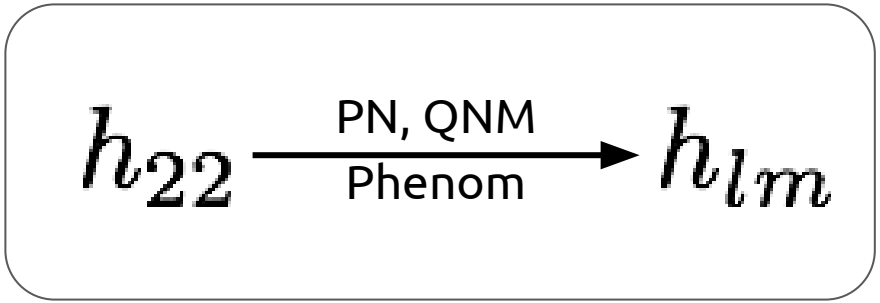
All modes





Non-Precessing Higher mode model

A simple model - Frequency dependent mapping



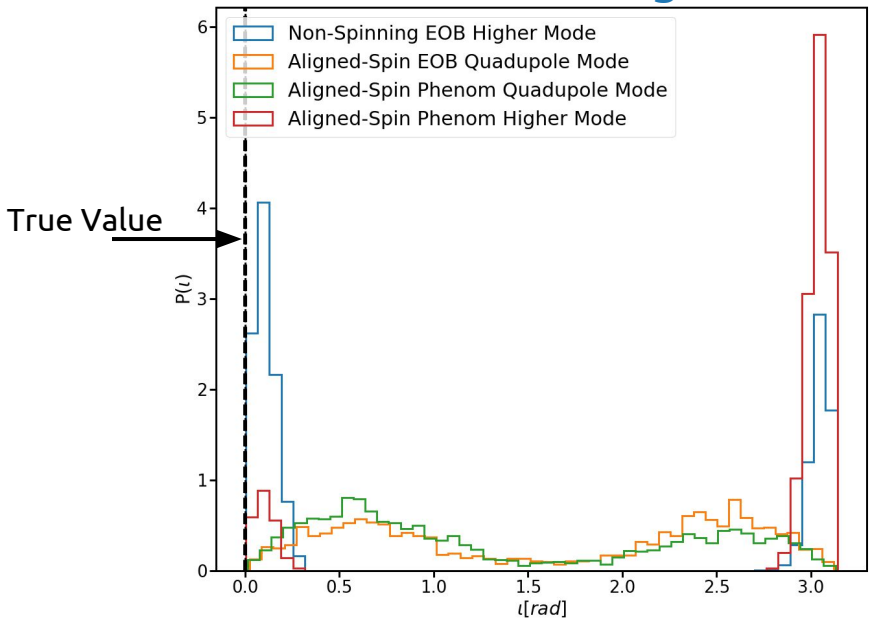
Preliminary Inference Results

Numerical Relativity Injection Recovery with various models

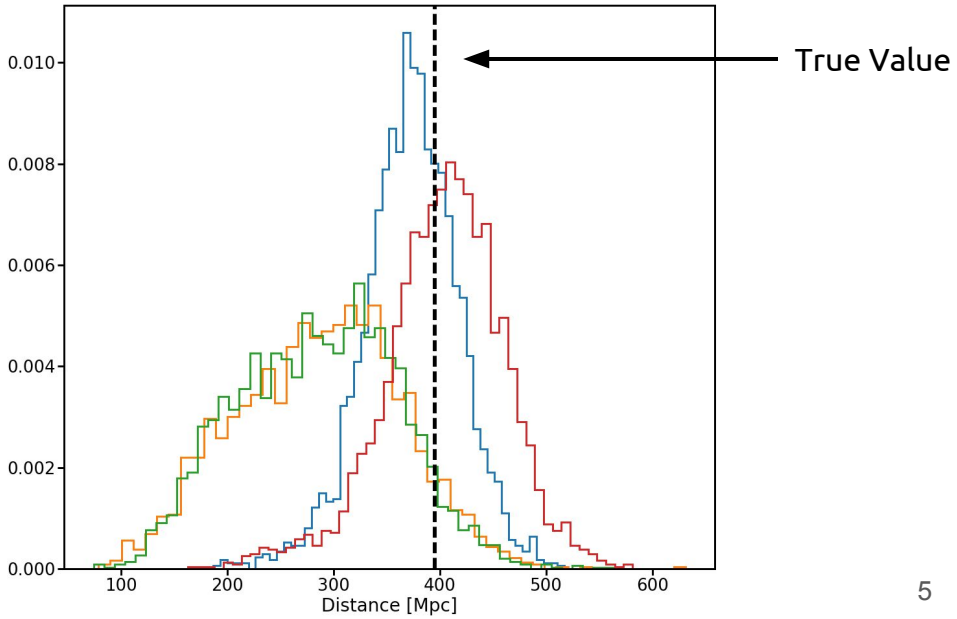
Injection Parameters:
- Non-spinning, mass-ratio 1:8, with Higher Modes
- Face-On orientation

Higher modes helps **improve** inclination / distance recovery

Inclination Angle



Distance



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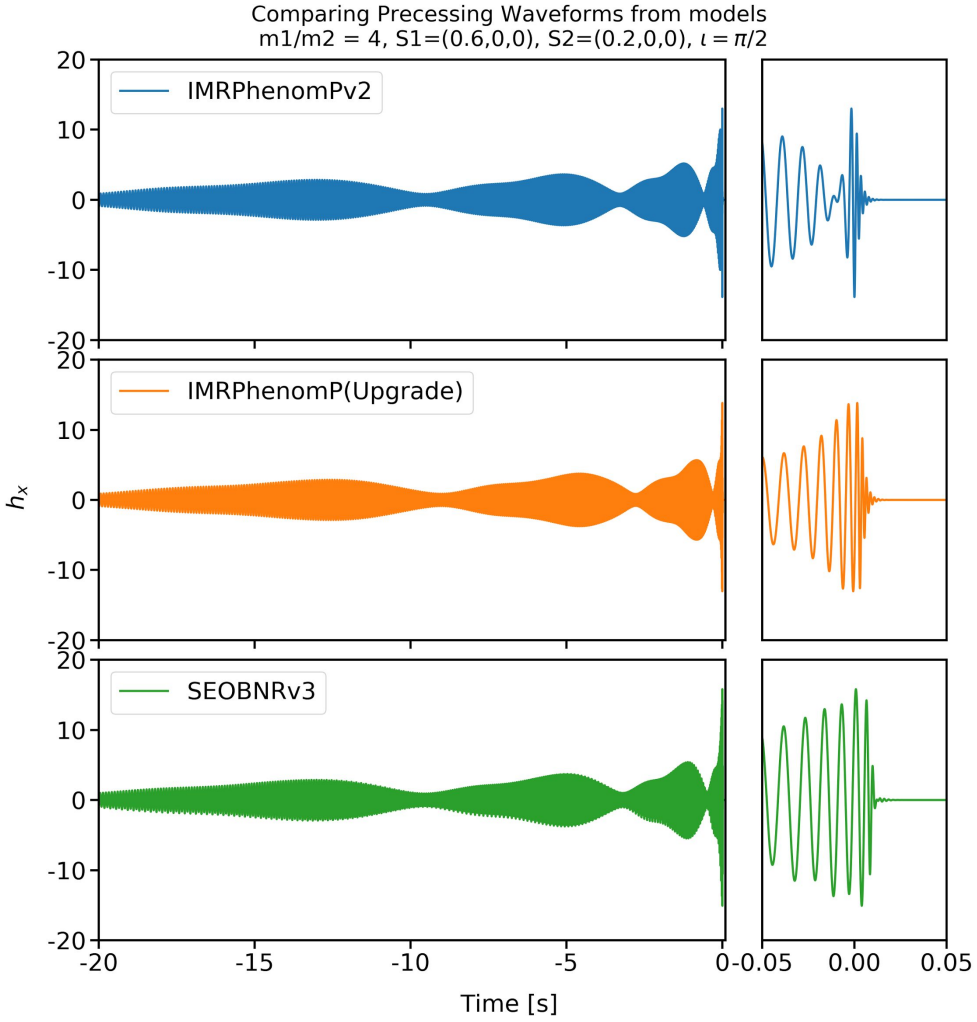
Precessing IMR models

Qualitative Comparison - General agreement

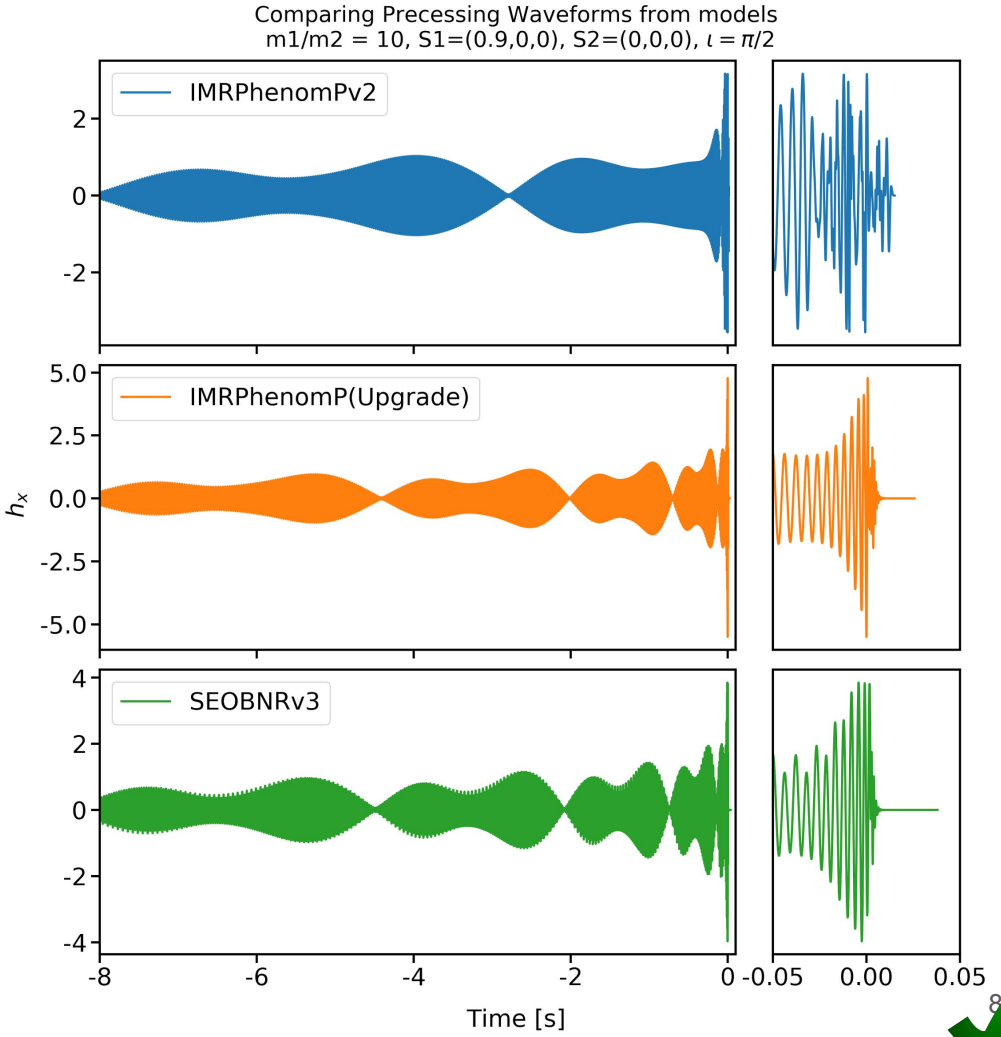
- Ideal comparison: Compare waveform models with independent Numerical Relativity simulations
- In lieu of this we perform cross comparisons between independent waveform models
- *IMRPhenomP(Upgrade):*
  - Uses double spin precession equations [Chatziioannou et al (2017)]



Improved Inspiral Precession

Qualitative Comparison

- Agreement between independent models
- Pathologies in Merger-Ringdown reduced
- 6 spin degrees of freedom in the precession equations
- Spin-Spin effects now included



Conclusions

Work in progress

- Extending non-precessing model to include:
  - Two spin effects during late-inspiral and merger. - ****See poster S. Husa et al****
  - Improve extrapolation via calibration to extreme mass-ratio limit (Teukolsky waveforms)
- First **non-precessing** BBH model with **higher modes** (finalising results + paper)
  - Vast improvement where higher modes are important but a calibrated model would be better.
  - Quantify the impact of higher modes on GW searches and parameter estimation.
- Upgrading PhenomP to use **6-spin** model of *inspiral* precession angles.

Future Work

- Precession during late-inspiral, merger and ringdown to be calibrated to Numerical Relativity