DISTINGUISHING BINARY BLACK HOLE PRECESSIONAL MORPHOLOGIES WITH GRAVITATIONAL WAVE OBSERVATIONS

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MOTIVATION: SPIN MORPHOLOGIES

- There is now evidence that the binary black holes observed by LIGO and Virgo have precessing spins (e.g., the evidence for the population presented in LVK, arXiv:2111.03634)

- One can classify the precessional motion into three morphologies, depending on the evolution of $\Delta\Phi$:

  Circulating (C)
  Librating around 0 (L0)
  Librating around π (Lπ)

- All binaries are circulating at infinite separation and can transition to one of the librating morphologies as they evolve to smaller separations.

  Transitions to the L0 and Lπ morphologies as a function of the binary's orbital velocity *v* for two cases we consider.

- As discussed in Gerosa et al. (PRD, 2013), the specifics of the binary's formation (e.g., efficiency of tides in the isolated channel) determines the morphology in the LIGO band.

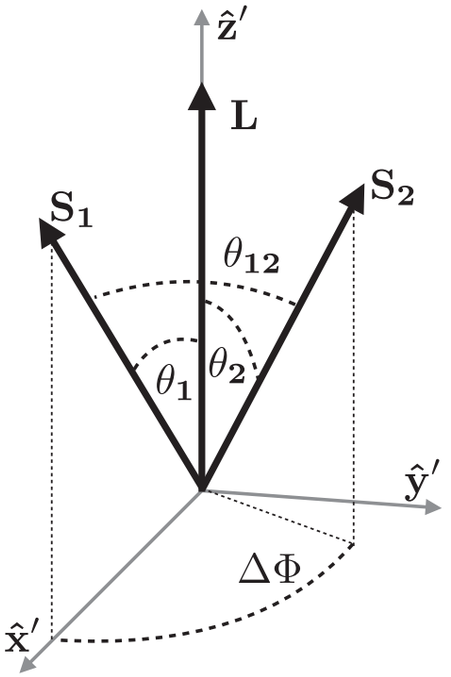
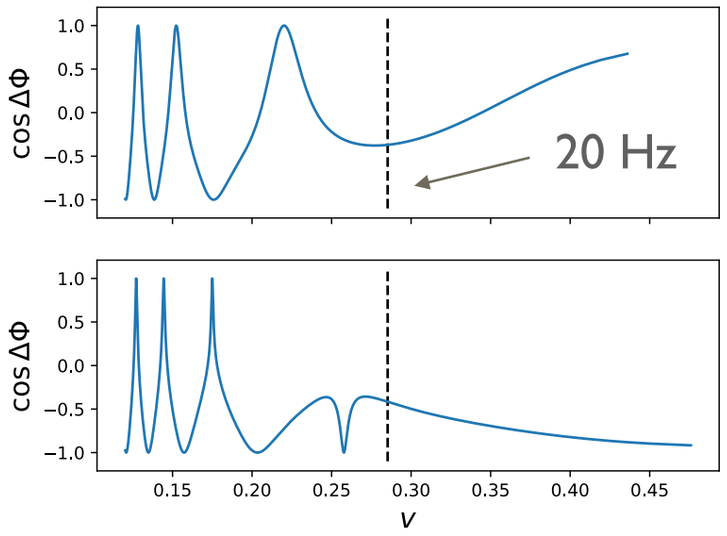


Figure from Gerosa et al. (PRD, 2015)

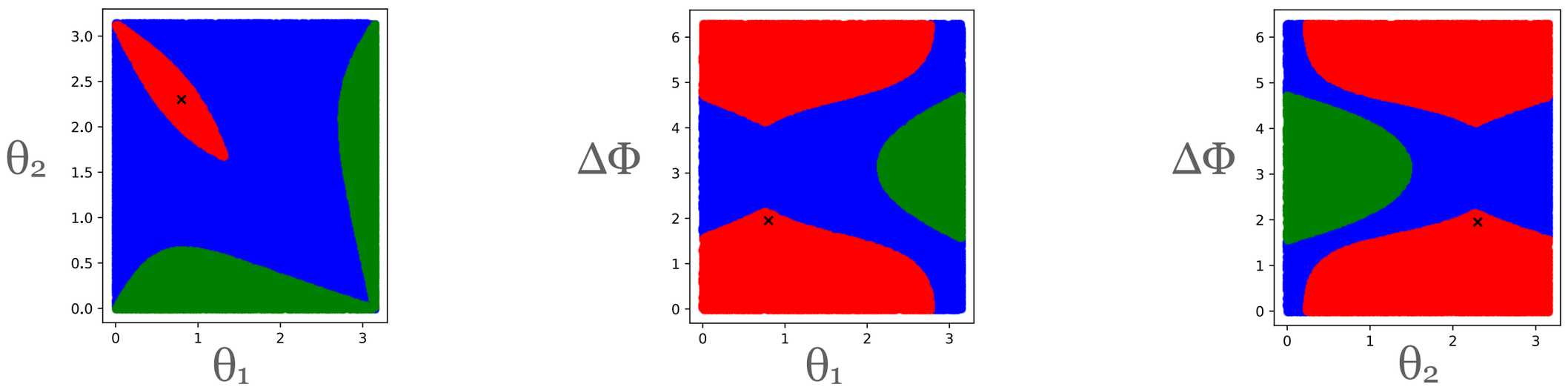


INFERRING THE MORPHOLOGY OF GRAVITATIONAL WAVE DETECTIONS

- One can compute the morphology easily for a given binary using the expressions from Gerosa et al. (PRD, 2015).
- We have implemented a fast version of this calculation, allowing us to restrict to a given morphology in stochastic sampling. This lets us compute a Bayes factor comparing one morphology with another one for a given event.
- Specifically, we use parallel Bilby (Smith et al., MNRAS 2020) and the precessing, higher mode binary black hole waveform model IMRPhenomXPHM (Pratten et al., PRD 2021).
- We are currently checking using injections how strongly this analysis will support the correct morphology. We have found that it is more difficult to distinguish two morphologies in the cases where the parameters are close to the boundary between two morphologies, as expected.

Dependence of morphology on spin angles for an L0 case near the boundary

C morphology, L0 morphology, Lπ morphology



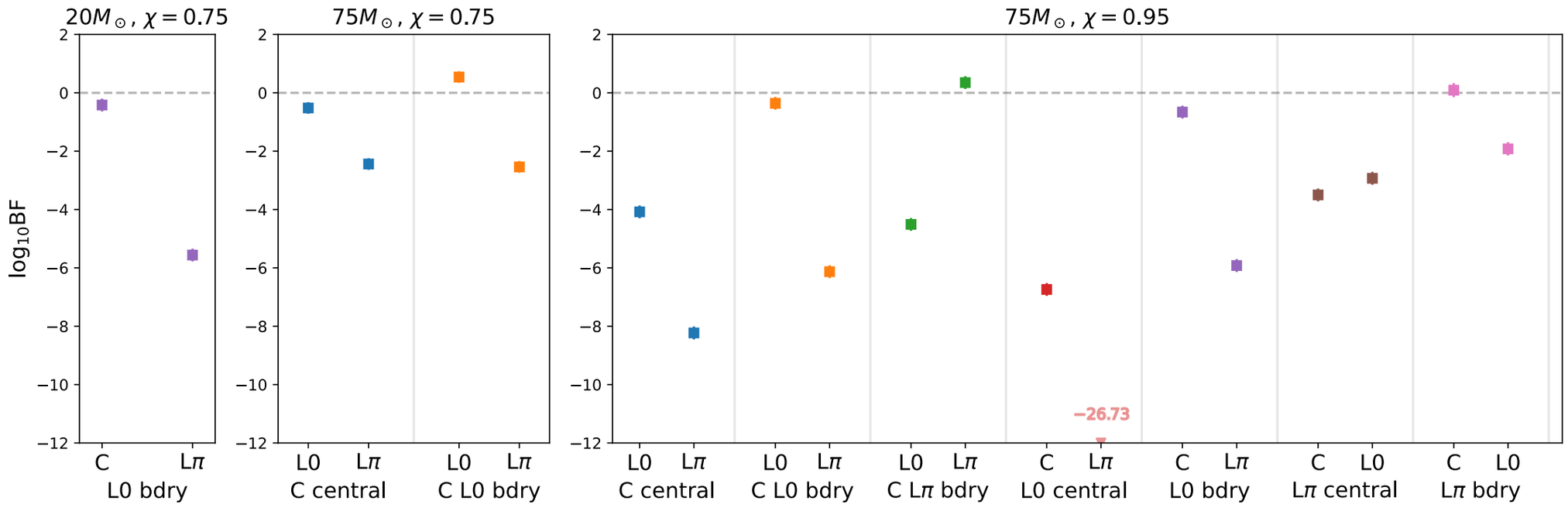
BAYES FACTOR RESULTS

- We consider injections of binaries with redshifted total masses of 20 or 75 $M_\odot$, a mass ratio of 1.2, and equal spin magnitudes of 0.75 or 0.95, with an inclination angle of 60° and a fixed sky location.

  Spin angles are chosen to give a specific morphology, either away from or near the boundary, and the distance to a binary is chosen so that it has an SNR of 89 in the plus-era LIGO-Virgo network.

  We consider the morphology at 20 Hz.

- Quite a few of the runs are still underway, but we have all results for the larger mass, larger spin case. Here we show the $\log_{10}$ Bayes factors comparing the other two morphologies to the injected morphology (noted at the bottom of the horizontal axis, including whether the parameters are central or near the boundary, with the comparison morphologies as the tick marks).



CONCLUSIONS AND FUTURE WORK

- We have developed a Bayesian method for determining the precessional morphology of a binary black hole from its gravitational wave signal and tested it on injections.

- We found that the true morphology can be strongly favoured ($\log_{10}$ Bayes factors of $\gtrsim 4$), at least for large spins and SNRs ~90 in the plus-detector era.

  However, the true morphology is only strongly favoured over both alternative morphologies when the parameters are not near a boundary between morphologies.

- We find that computing the ratios of the number of samples in each morphology in a standard PE run gives a reasonable approximation to the Bayes factors when they are fairly close to unity. However, it cannot give the large Bayes factors (favouring the true morphology) that we find in the most favourable cases.

- We ultimately plan on inferring the fraction of binaries in each morphology in the population of detected binaries.