Supernova physics with gravitational waves: Newborn black holes are “kicked”

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GW151226: Gravitational waves from a black hole binary

• GW151226 is the second, less massive binary black hole confidently detected by LIGO following section and are consistent with our expectations for an astrophysical BBH source. The inferred component masses of LVT151012 lie roughly between the masses of GW150914 and GW151226, as shown in Fig. 4.

IV. SOURCE PROPERTIES

In this section, we present the inferred properties of the sources of GW150914, LVT151012, and GW151226, assuming that the signals each originate from a binary coalescence as described by general relativity. Tests of the consistency of the signal with the predictions of general relativity are presented in Sec. V. Full results for GW150914 have been provided in Refs. [39,40], and key results for LVT151012 have been given in Ref. [44]. Here, we give results based upon an updated calibration of the data. The analyses of all three signals closely mirror the original analysis of GW150914, as detailed in Ref. [39] and described in Appendix B. The analysis makes use of two waveform models, the double aligned spin waveform model (EOBNR) [8,9] and an effective precessing spin model (IMRPhenom) [36–38]. Results from the two waveforms are similar, and the data give us little reason to prefer one model over the other. We therefore average the posterior distributions from two waveforms for our overall results. These are used for the discussion below, except in Sec. IV B, where we also consider measurements of spin alignment from the precessing IMRPhenom waveform.

The results match our expectations for a coherent signal in both detectors and give us no reason to suspect that any of the signals are not of astrophysical origin. All three signals are consistent with originating from BBHs. Key parameters for the three events are included in Table I and plotted in Figs. 4, 5, and 6. Detailed results are provided in Table IV in Appendix B.
GW151226: A precessing binary black hole?

- GW151226 is the **only** binary black hole with evidence for nonzero spin.
- The more massive BH in GW151226 seems to be **misaligned and precessing**.
- Misalignment seems to be 25 - 80 degrees.

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![Diagram](Abbott et al, PRX 6, 041015 (2016))
Misalignment can be explained by a black hole (BH) birth kick

- BHs can be kicked when they are born. [Neutron stars are known to be strongly kicked]
- Kicks tilt the binary orbit
- Significant kicks are required for the GW151226 tilt
What we did: One of LIGO’s BHs has a tilted orbit. A strong BH birth kick matches the data.

Impact

- GW enable (more) insight into lives and deaths of massive stars, billions of years ago
- Challenges models of stellar explosions to make a kick this large and a heavy BH
- Alternative explanation for GW170104 is a kick. (None needed - no requirement for BH spin)
- Must be factored in to observations & models involving stellar mass BHs
- Reduces contribution to LIGO rate from other formation channels (i.e., globular clusters)

Testable (now):

- Support for BH birth kicks has been seen in observations of X-ray binaries (motion, jets)
- Near-future LIGO measurements will let us pin down the kick (e.g. more GW151226’s)
- “Black hole sudoku”: test this interpretation against multiple boundary conditions
GW151226: The only LIGO observation with confirmed nonzero spin

- GW170104 and GW150914 have spins consistent with zero

Abbott et al, PRL 118 221101 (2017) : supplementary material