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

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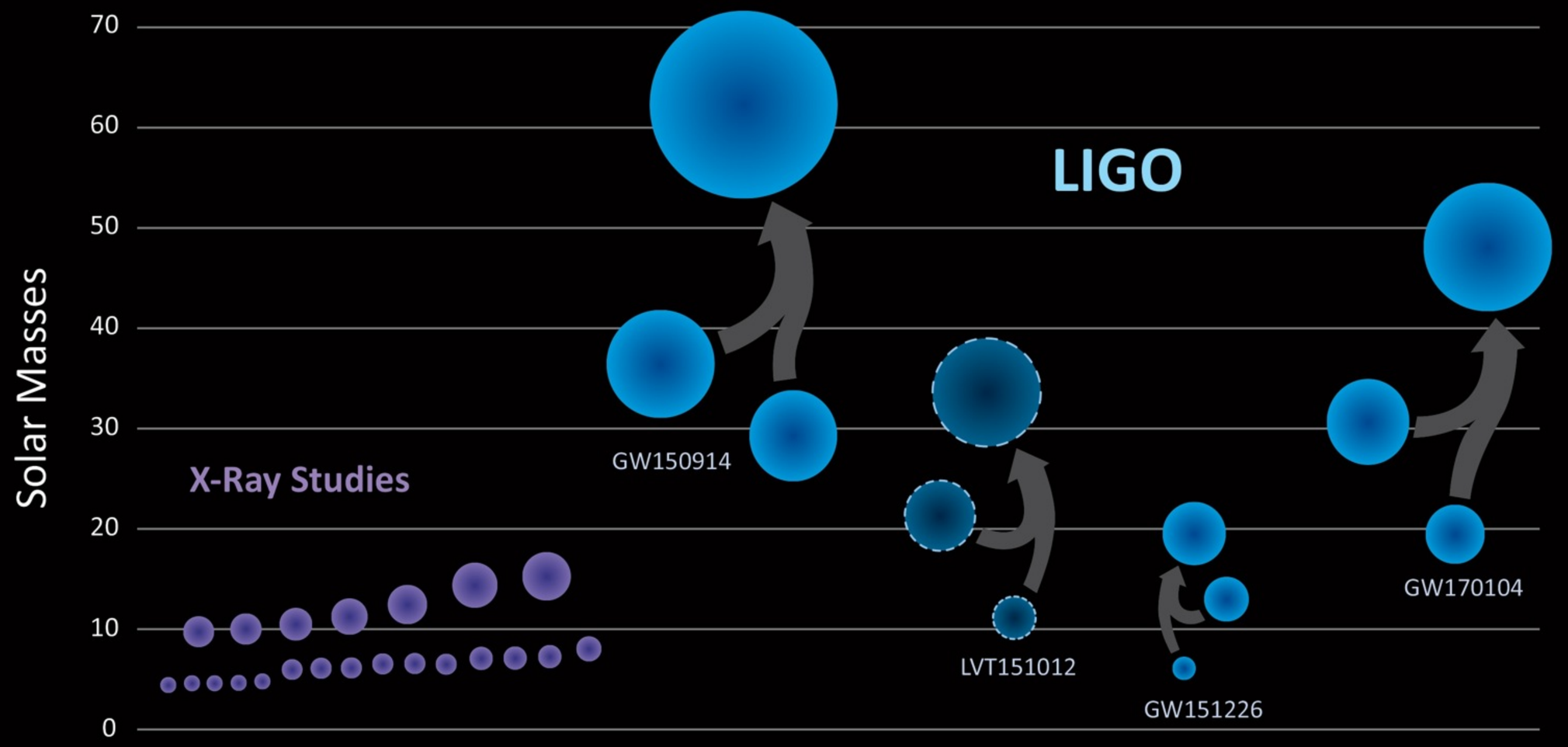
Black Holes of Known Mass



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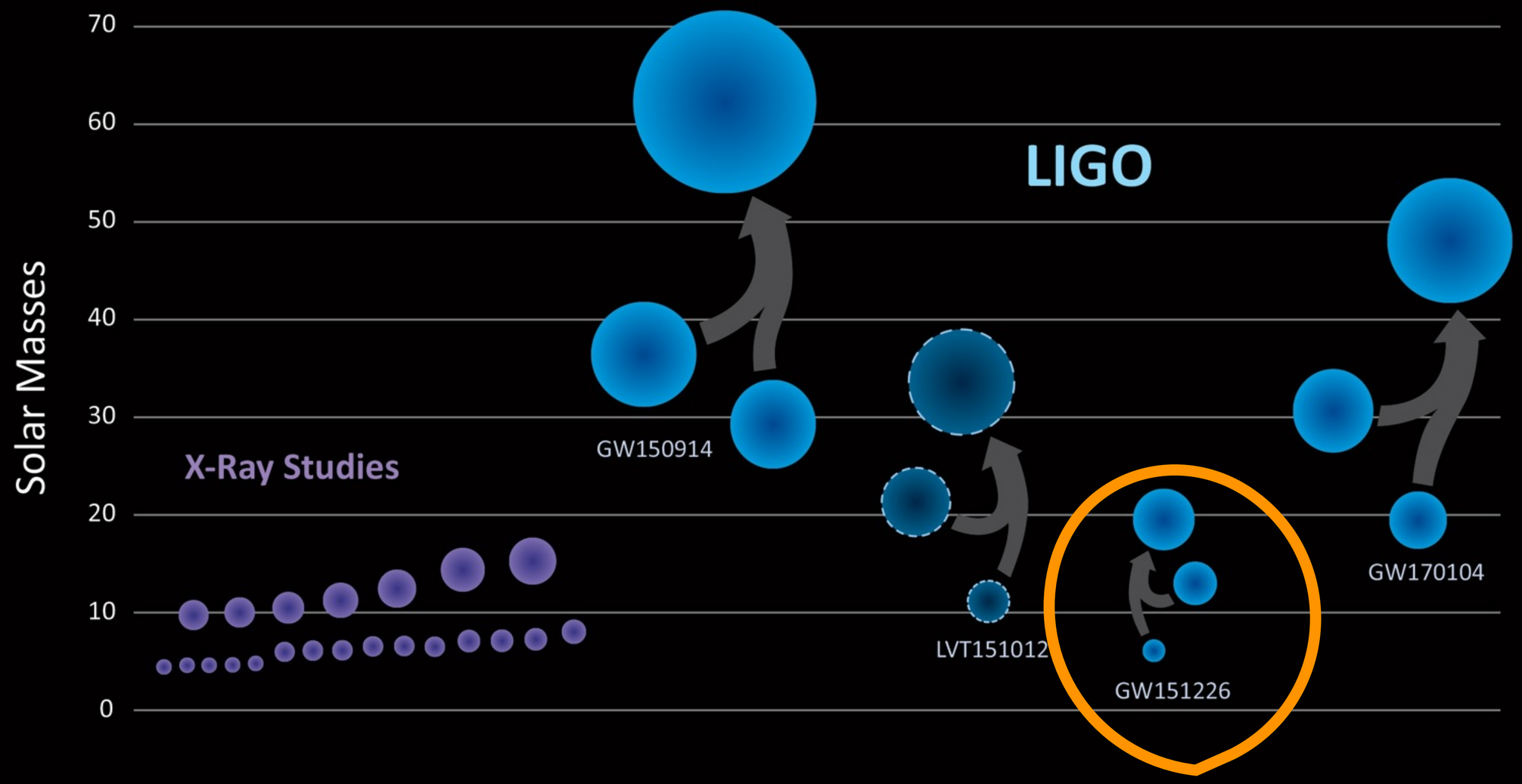
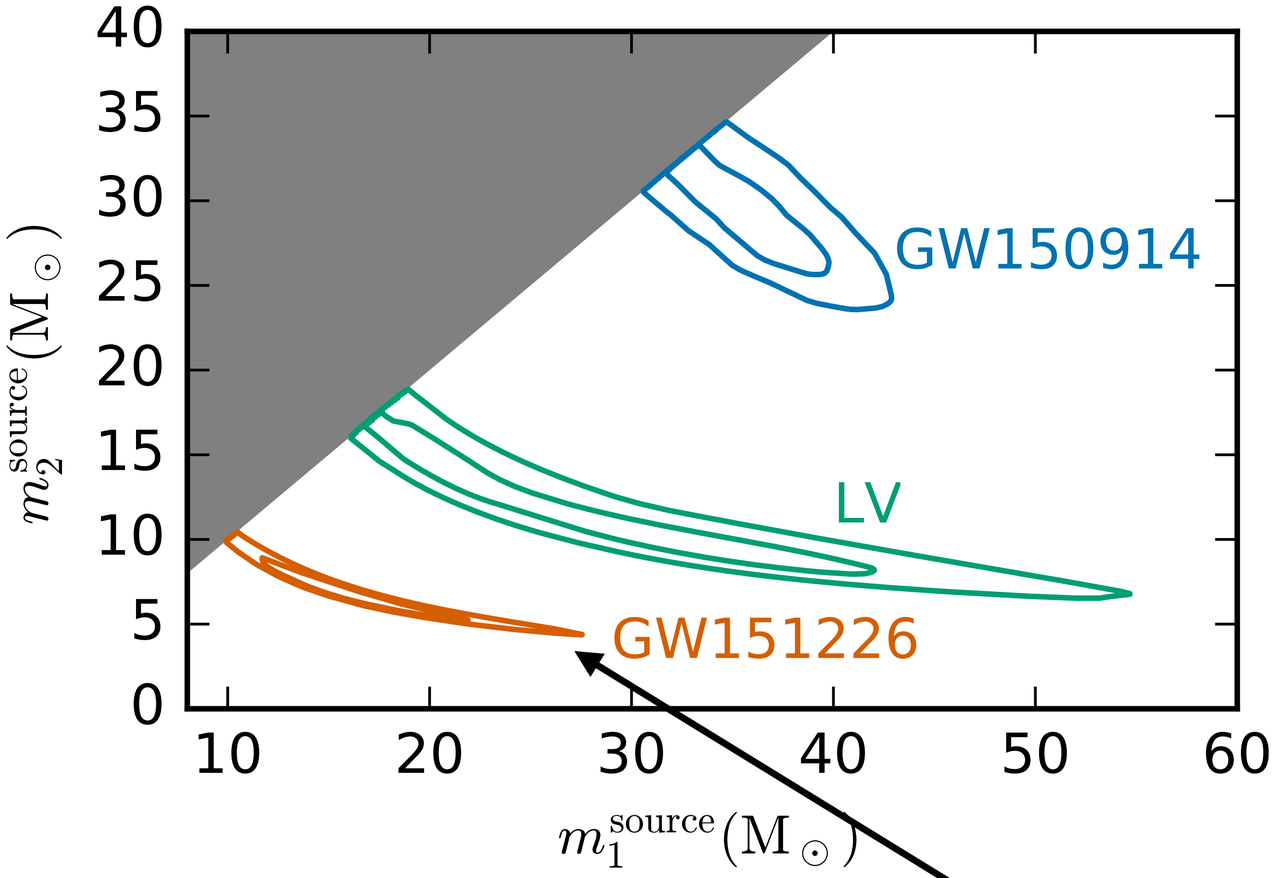
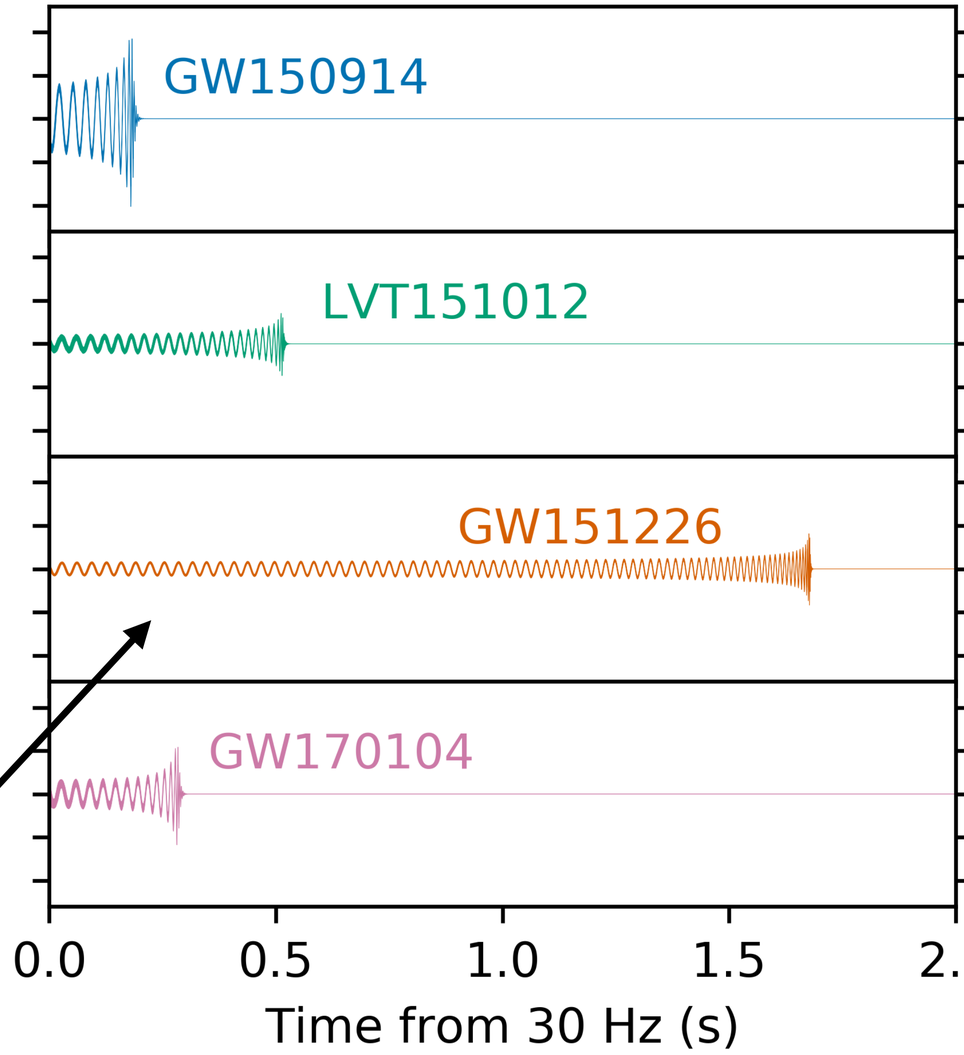


GW151226: Gravitational waves from a black hole binary

- GW151226 is the second, less massive binary black hole confidently detected by LIGO



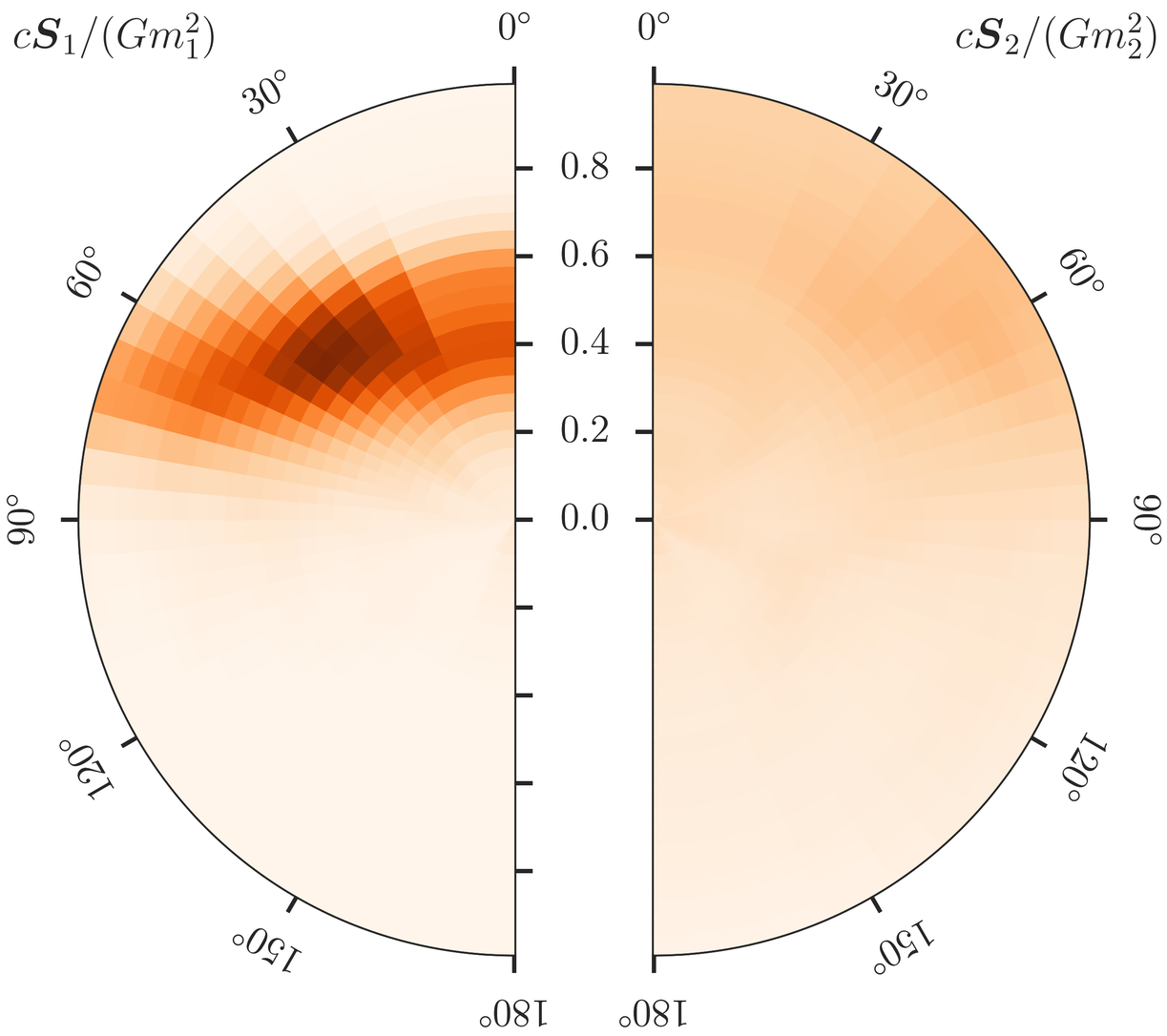


GW151226

Abbott et al, PRX 6, 041015 (2016) ; PRL 118 221101 (2017)

GW151226: A precessing binary black hole?

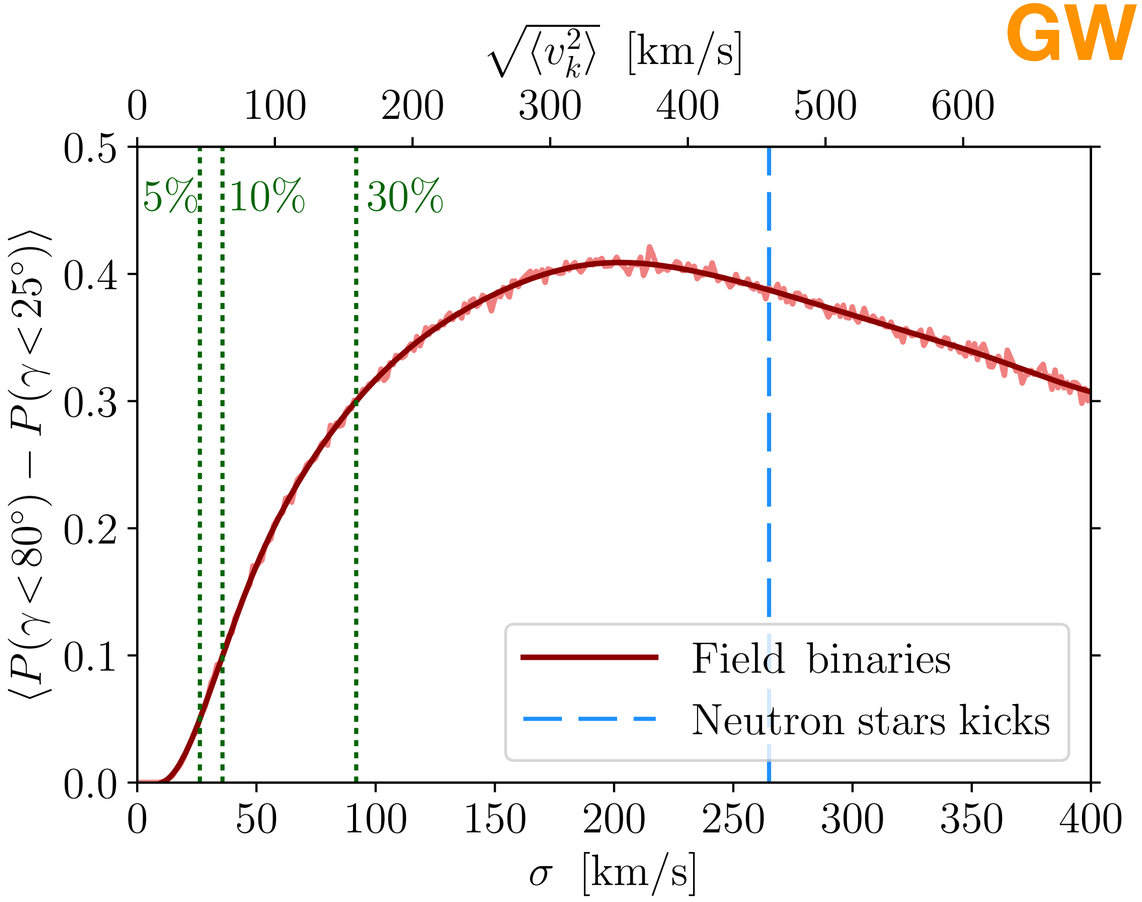
- GW151226 is the **only** binary black hole with evidence for nonzero spin
- The more massive BH in GW151226 seems to be **misaligned and precessing**
- Misalignment seems to be 25 - 80 degrees



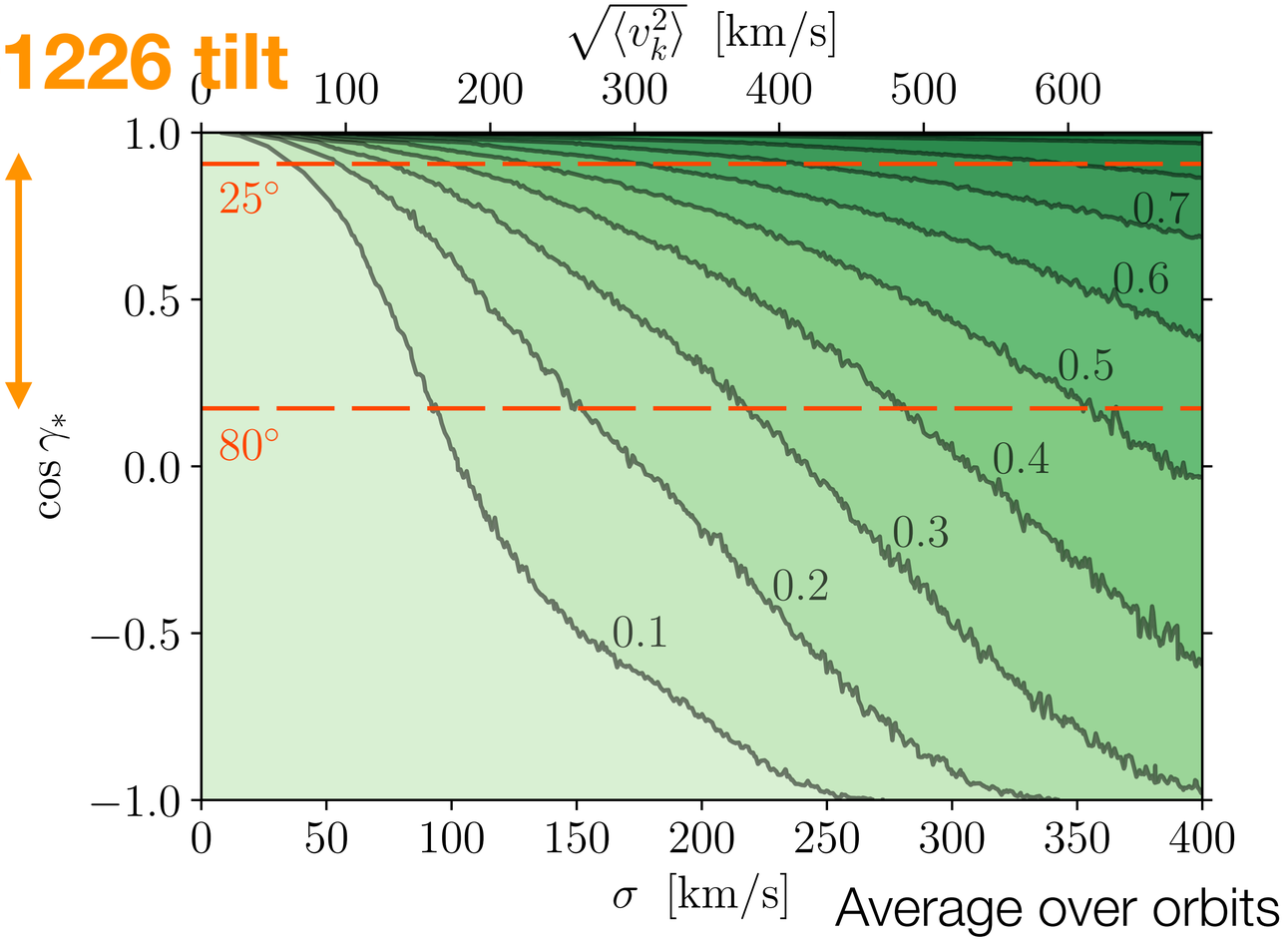
Abbott et al, PRX 6, 041015 (2016)

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



GW151226 tilt



Average over orbits

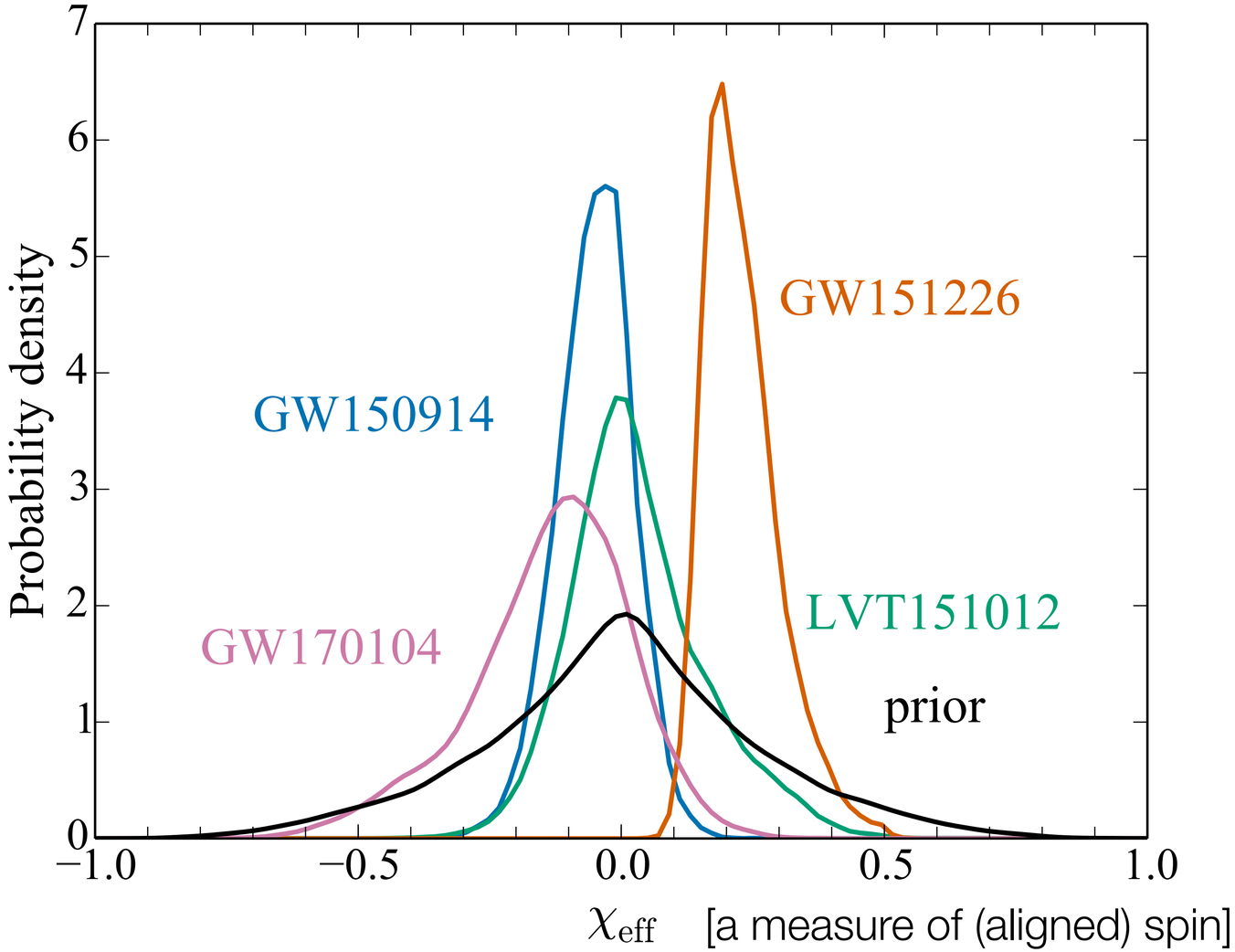
Summary

- **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