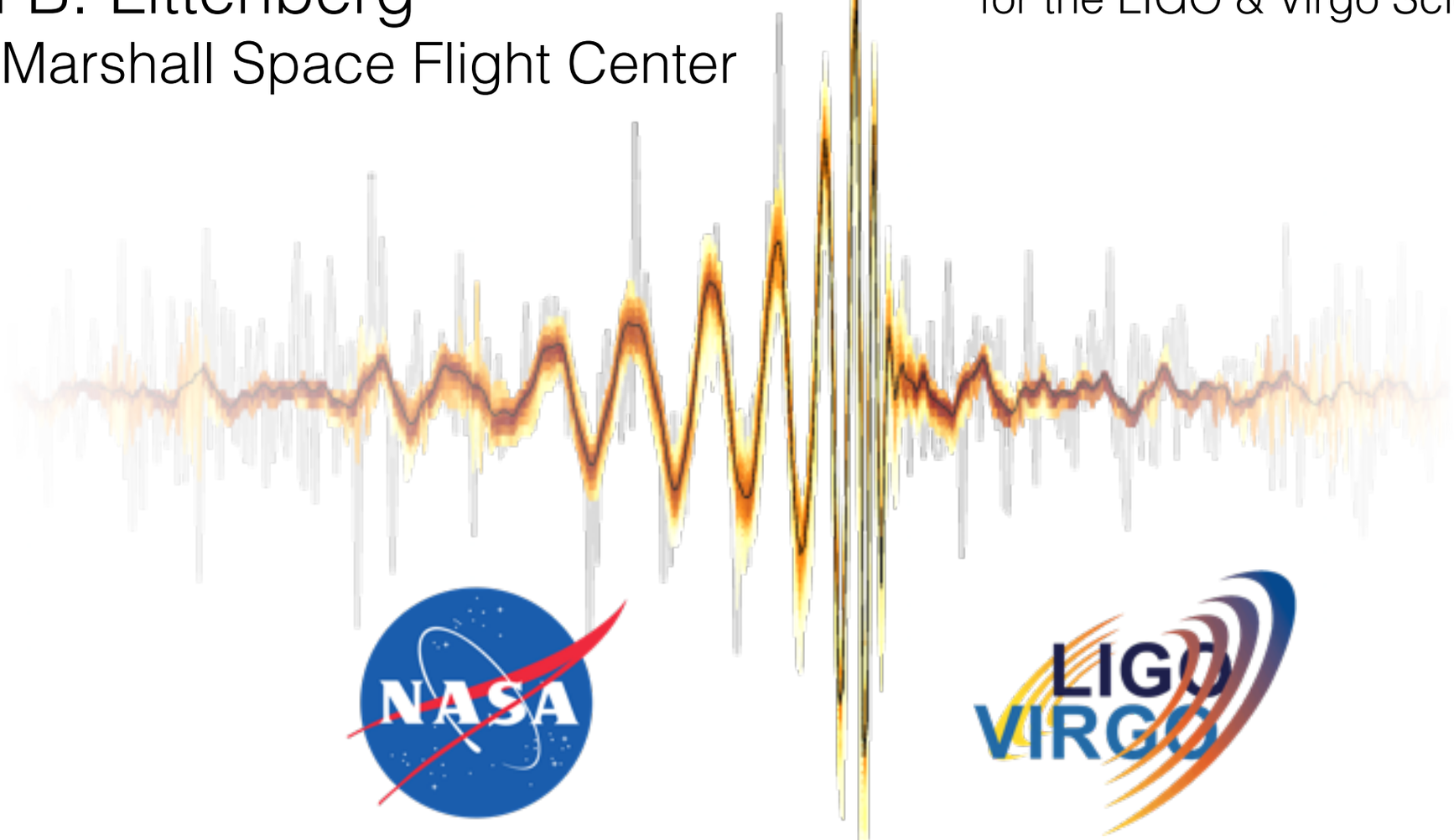
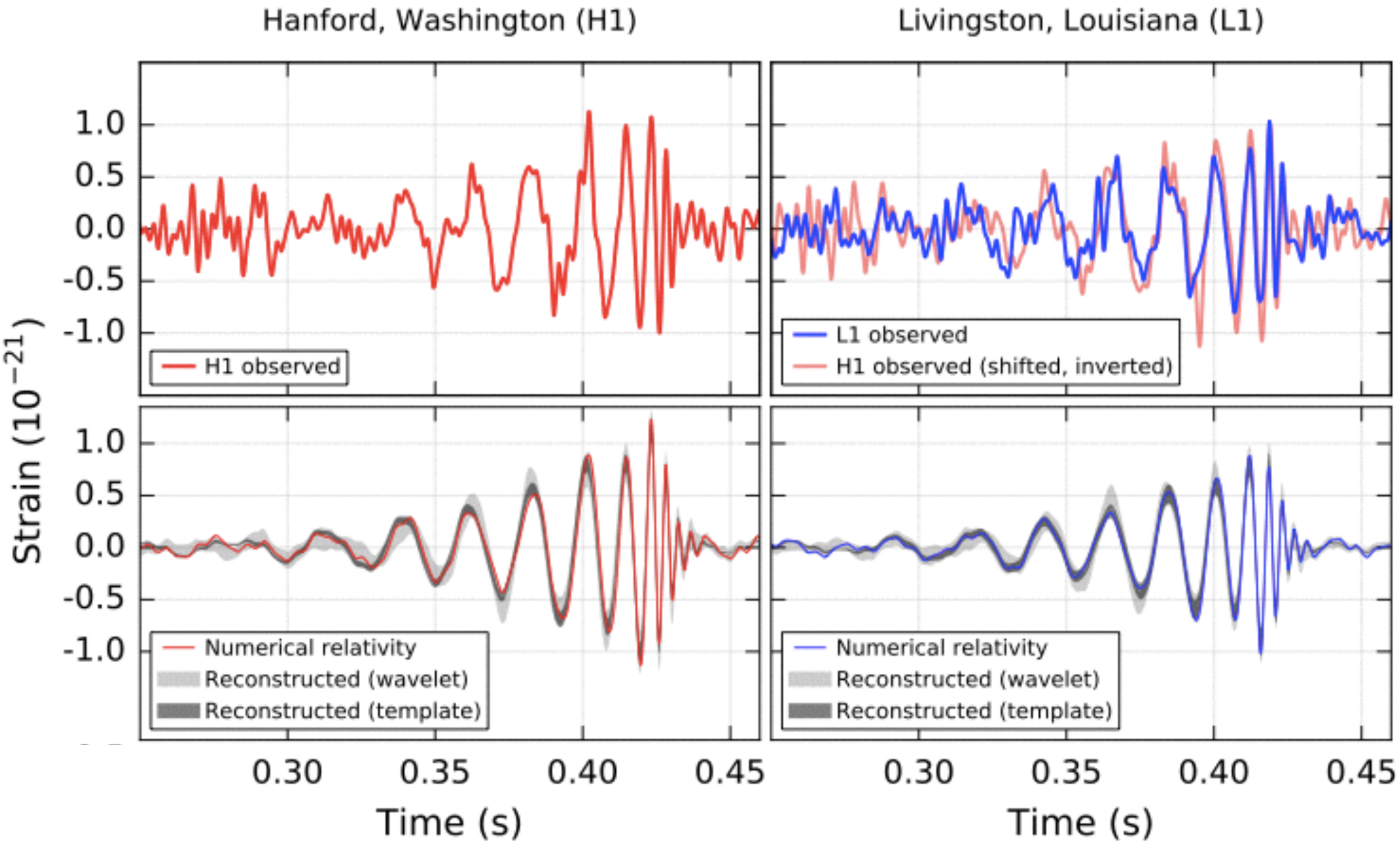
Results from the 1st Advanced LIGO observing run and their astrophysical implications

Tyson B. Littenberg
NASA Marshall Space Flight Center

for the LIGO & Virgo Scientific Collaborations

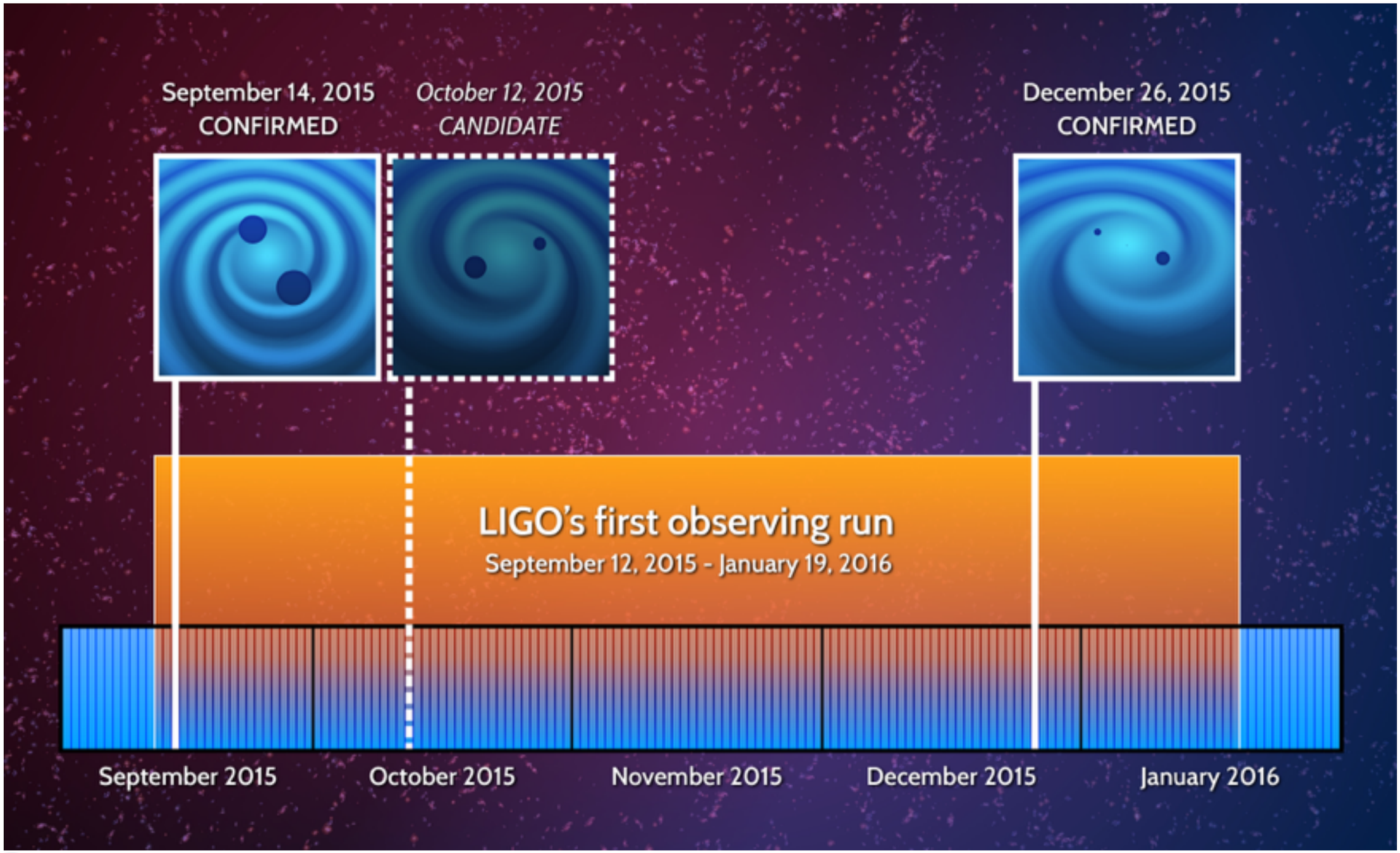


The chirp heard ‘round the world



Phys. Rev. Lett. **116**, 061102

LIGO's First Observing Run (O1)



Binary black holes in O1

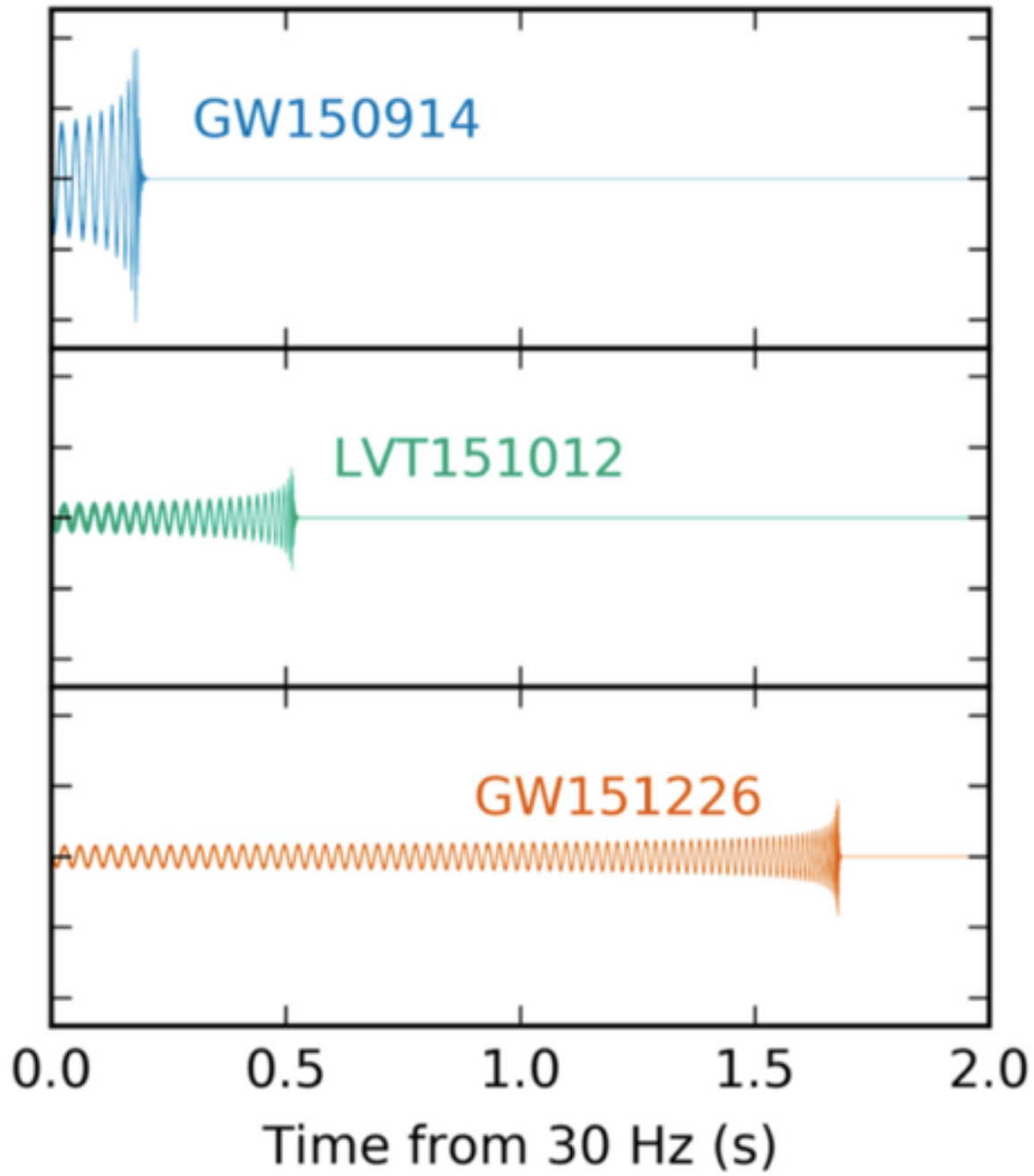
Phys. Rev. X 6, 041015 (2016)

Naming GW events:

XXYYMMDD

LVT=candidate
GW=confirmed

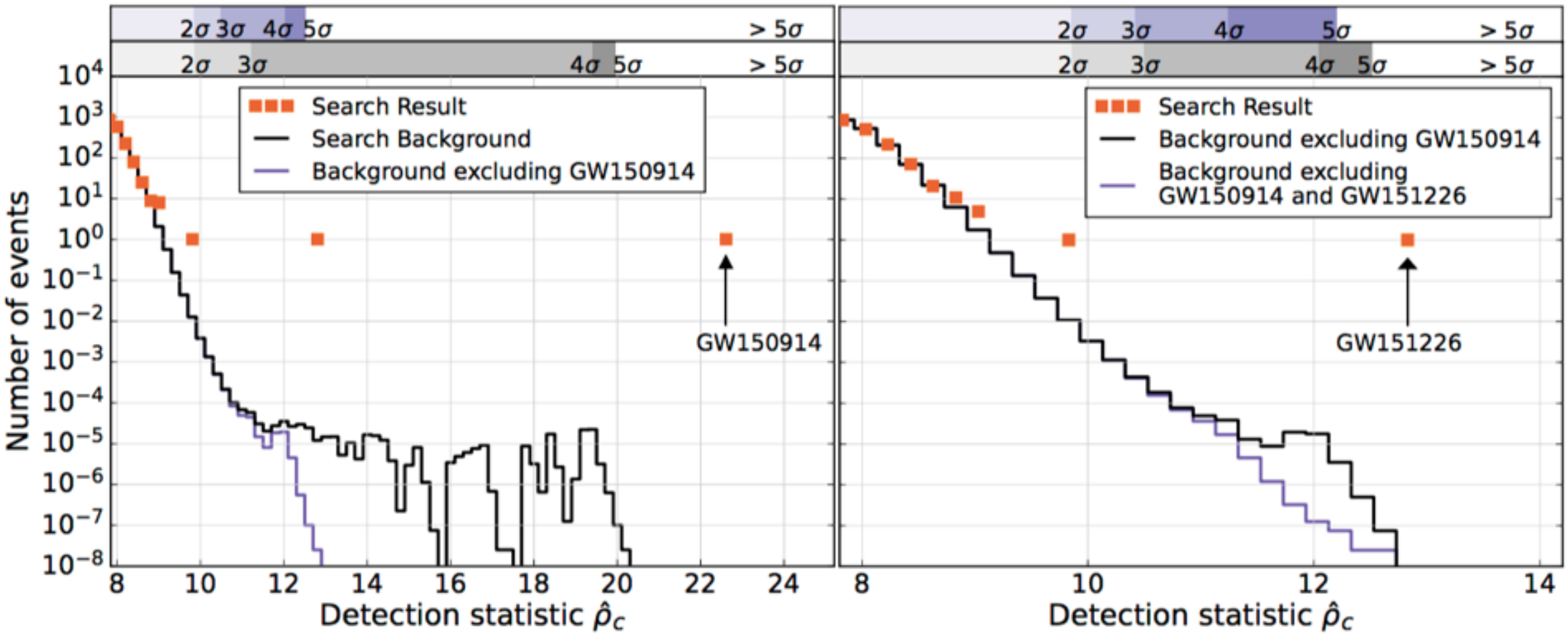
Date of detection



Finding BBHs in the data

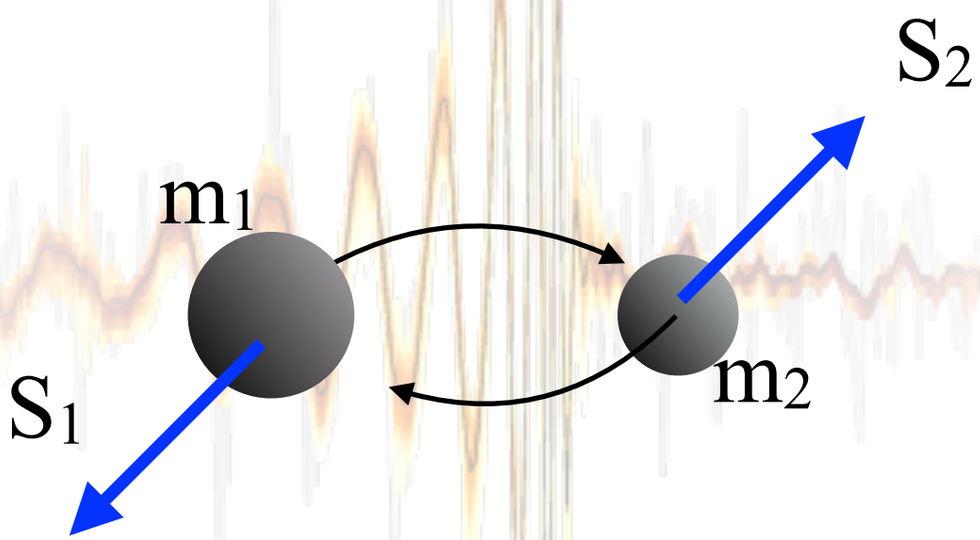
Phys. Rev. X 6, 041015 (2016)

- GW150914 and GW151226 were both > 5-sigma detections



BBH Characterization

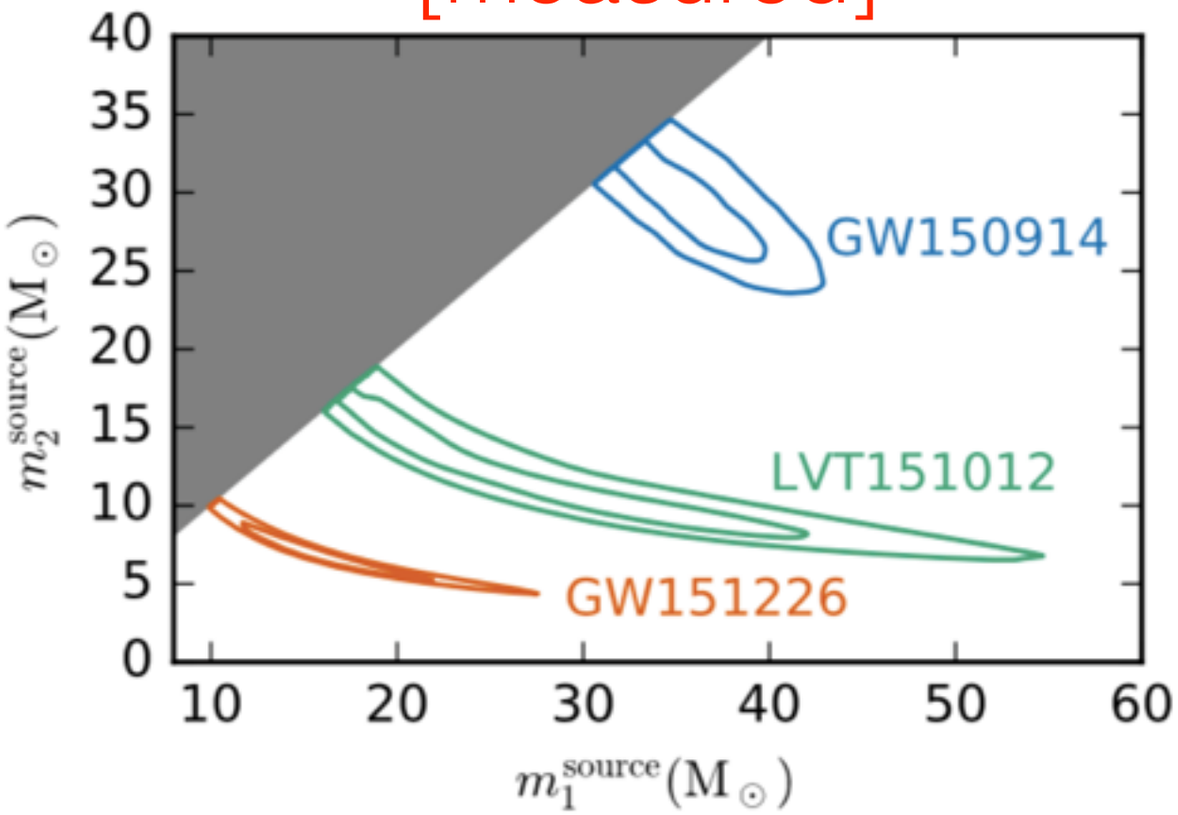
Mass & Spin



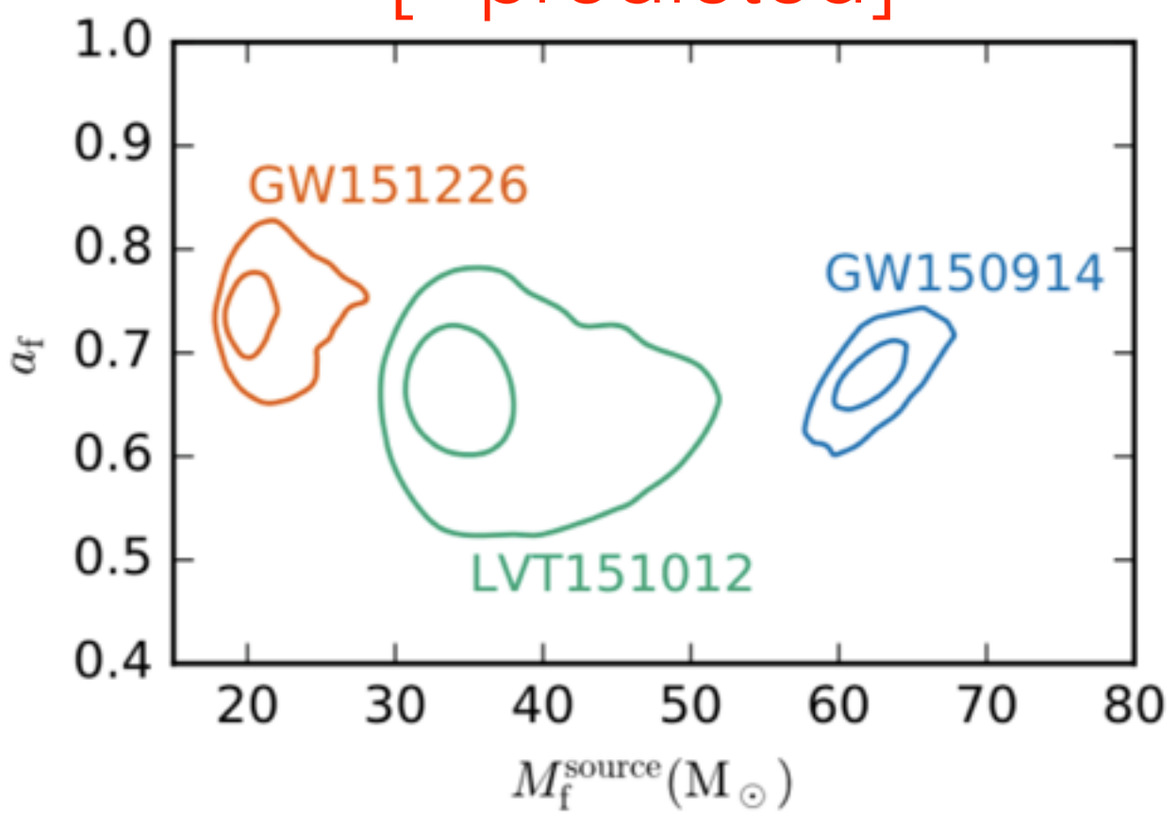
BBH Characterization — Masses

Phys. Rev. X 6, 041015 (2016)

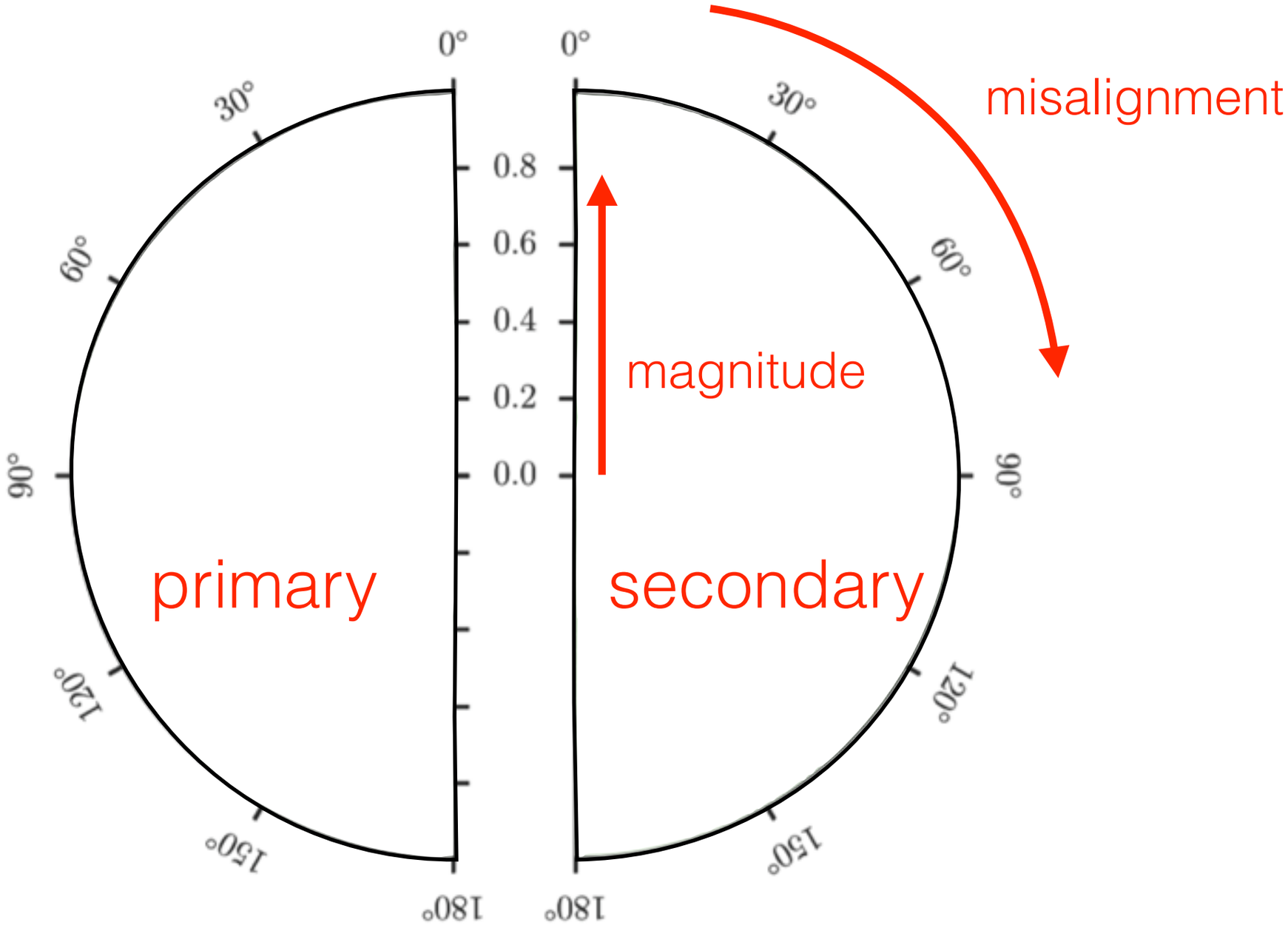
component masses
[measured]



remnant mass & spin
[~predicted]



BBH Characterization — Spins

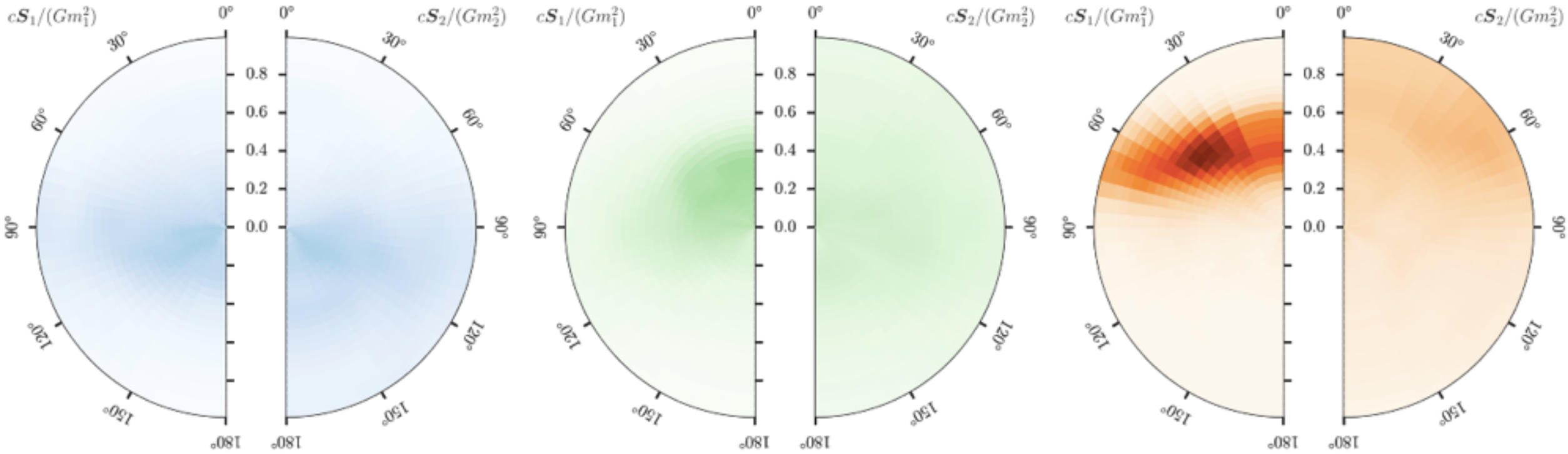


BBH Characterization — Spins

Phys. Rev. X 6, 041015 (2016)

- Spin will typically be difficult to pin down precisely except for ideally oriented systems (edge-on)

GW150914 LVT151012 GW151226

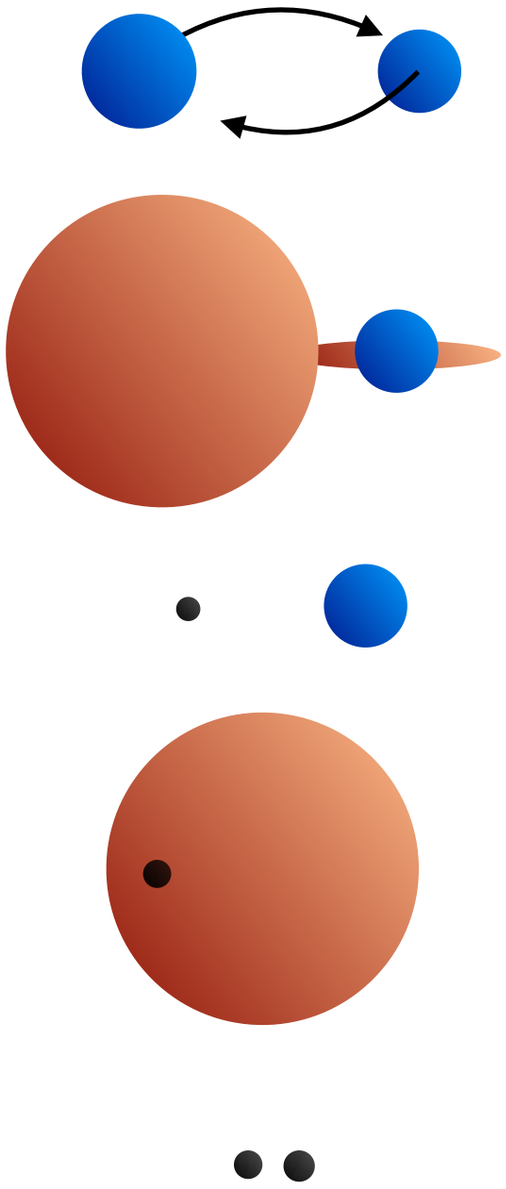


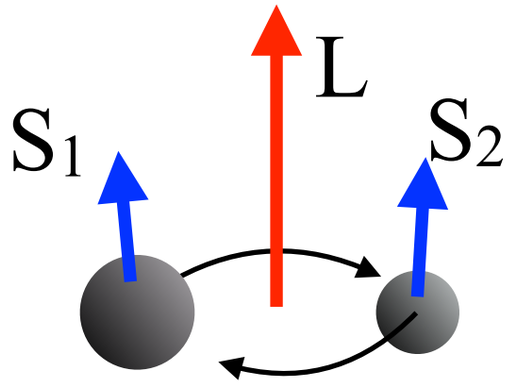
- GW151226 shows evidence for non-negligible spin of m_1, *not* anti-aligned with **L**

Why is spin so important?

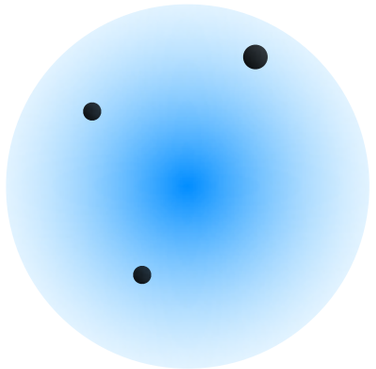
Creating binary black holes

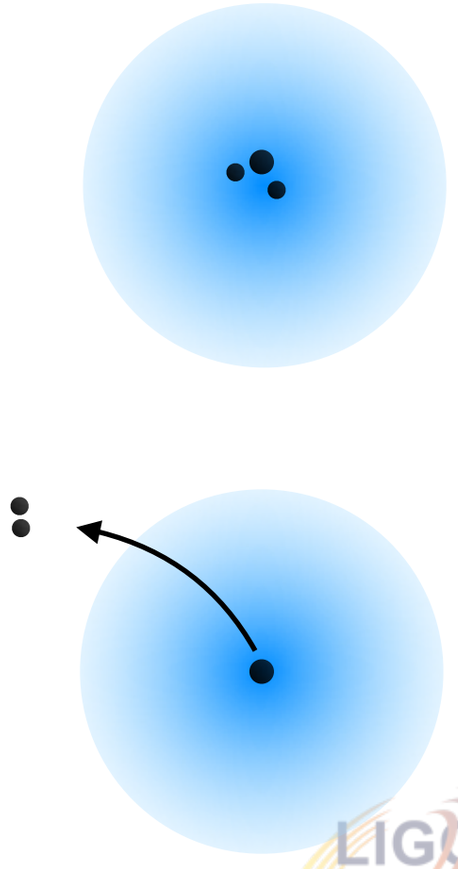
"Field"

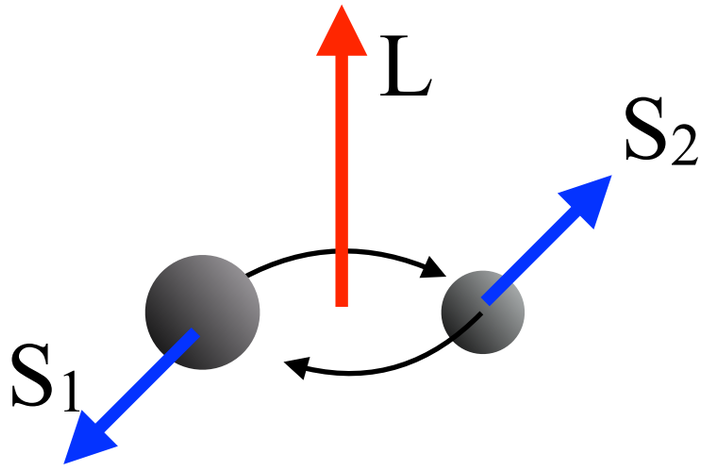




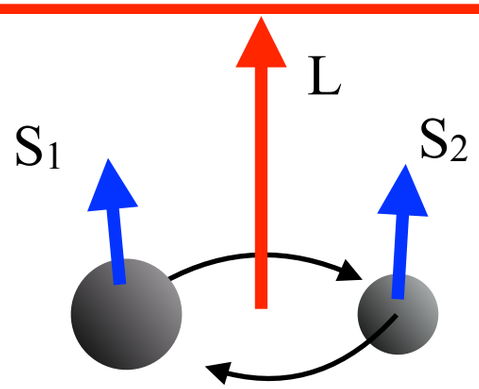
"Cluster"

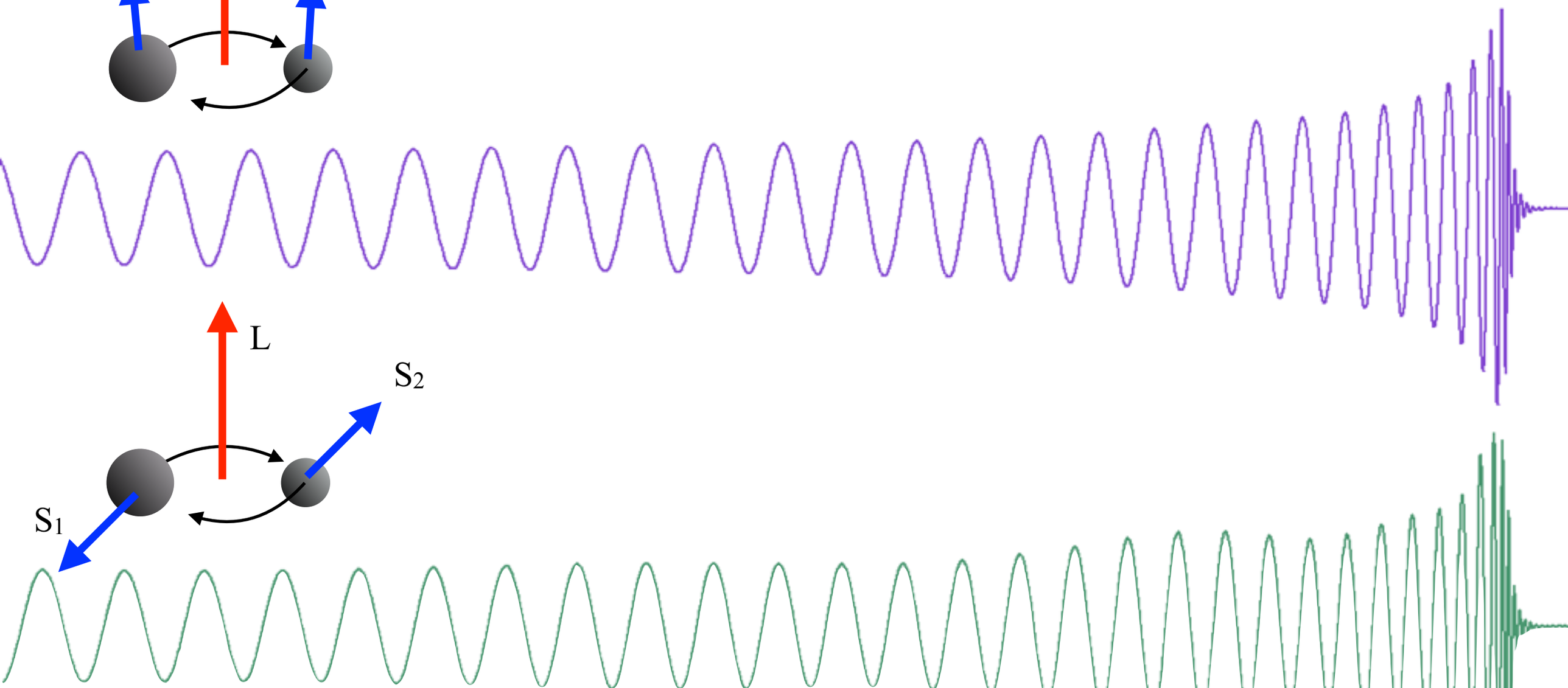






Creating binary black holes





Why is spin so important?

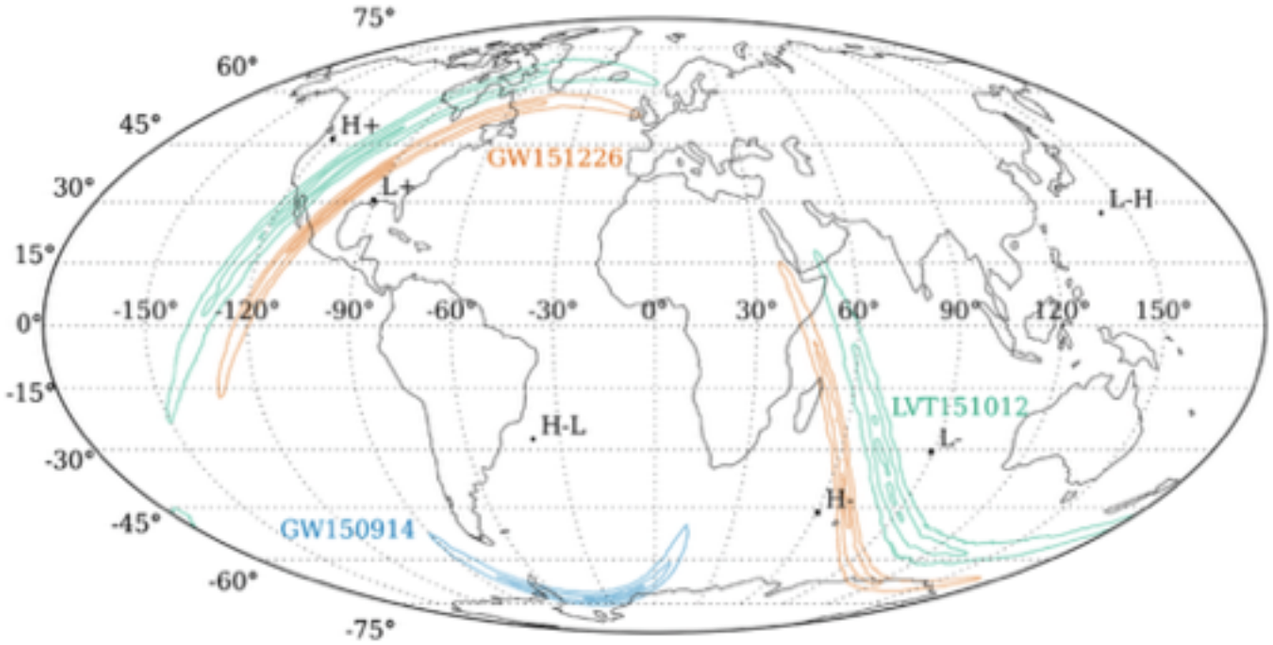
Spin alignment is a window into the BBH formation channel

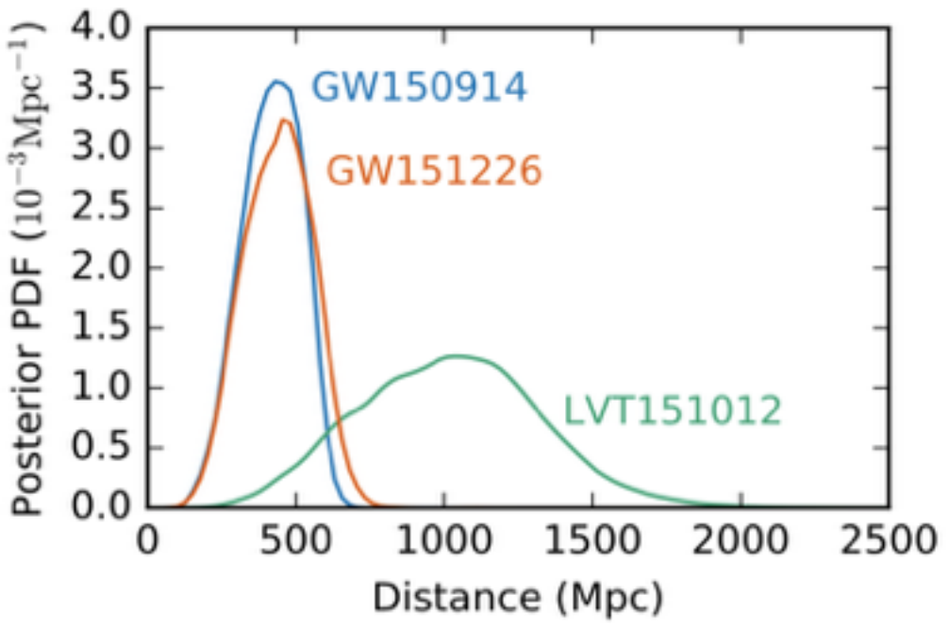
BBH Localization

BBH Localization

Phys. Rev. X 6, 041015 (2016)

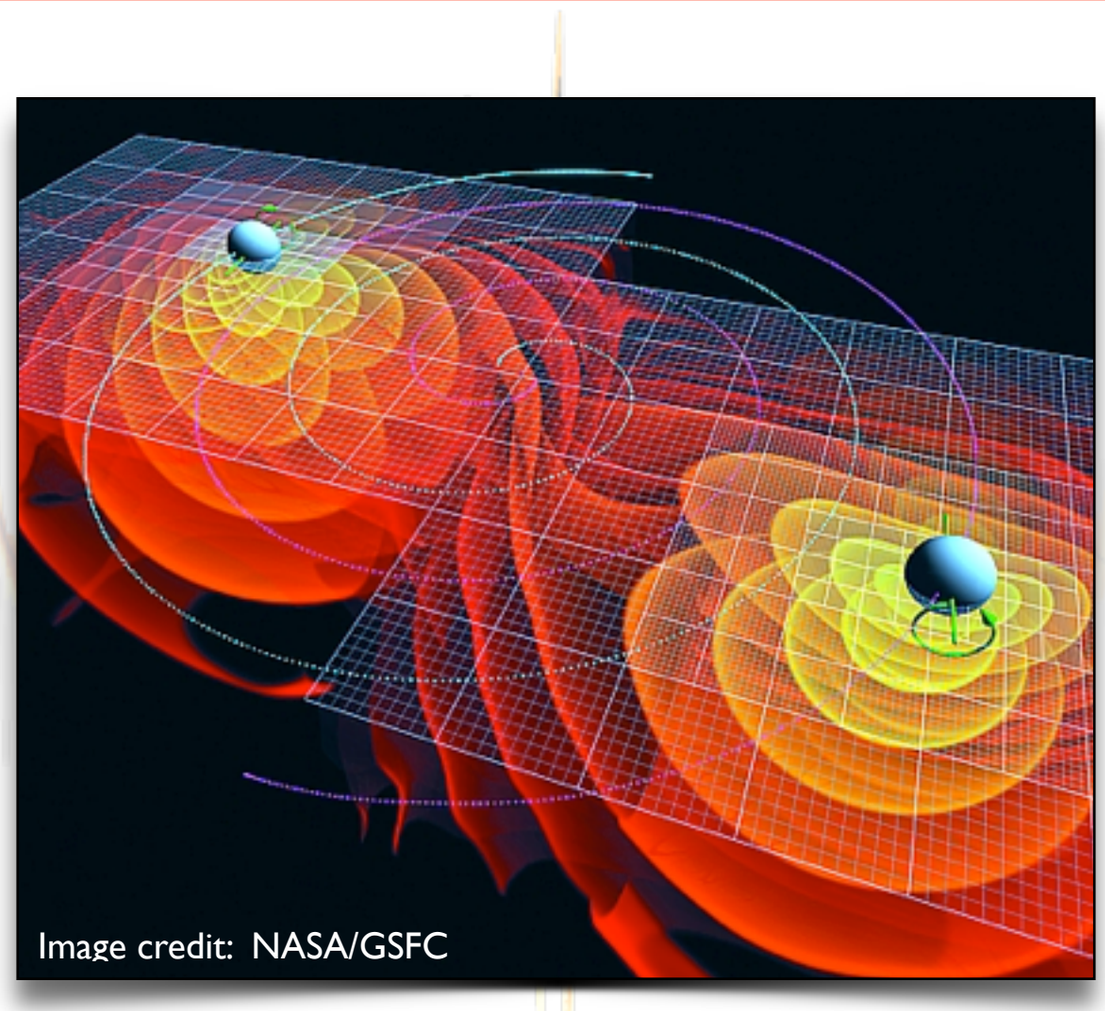
- Position reconstruction is a challenge for 2-detector networks.





- This will improve as Virgo and others join the network at comparable sensitivity [see Living Rev. Relativity 19 (2016), 1].

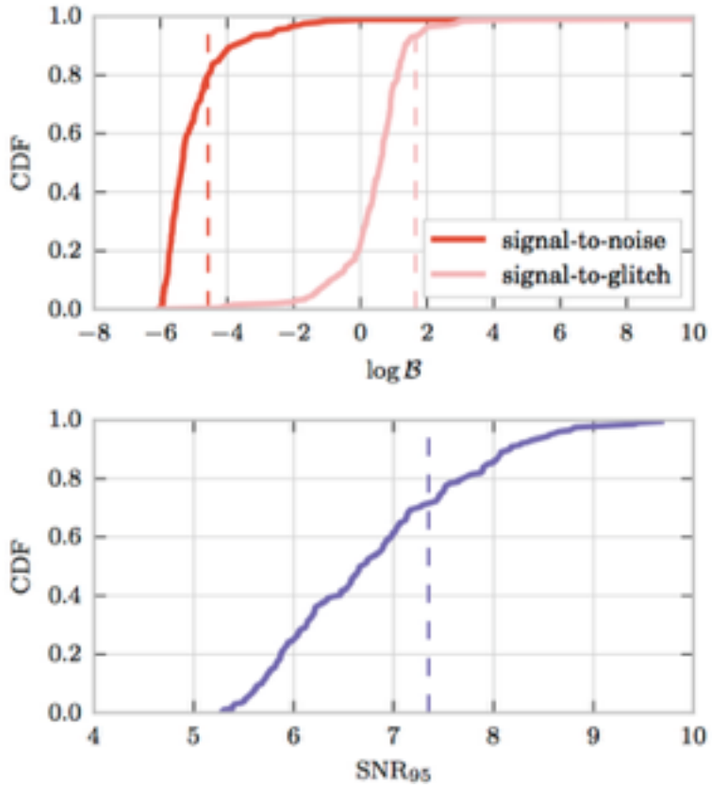
Testing GR

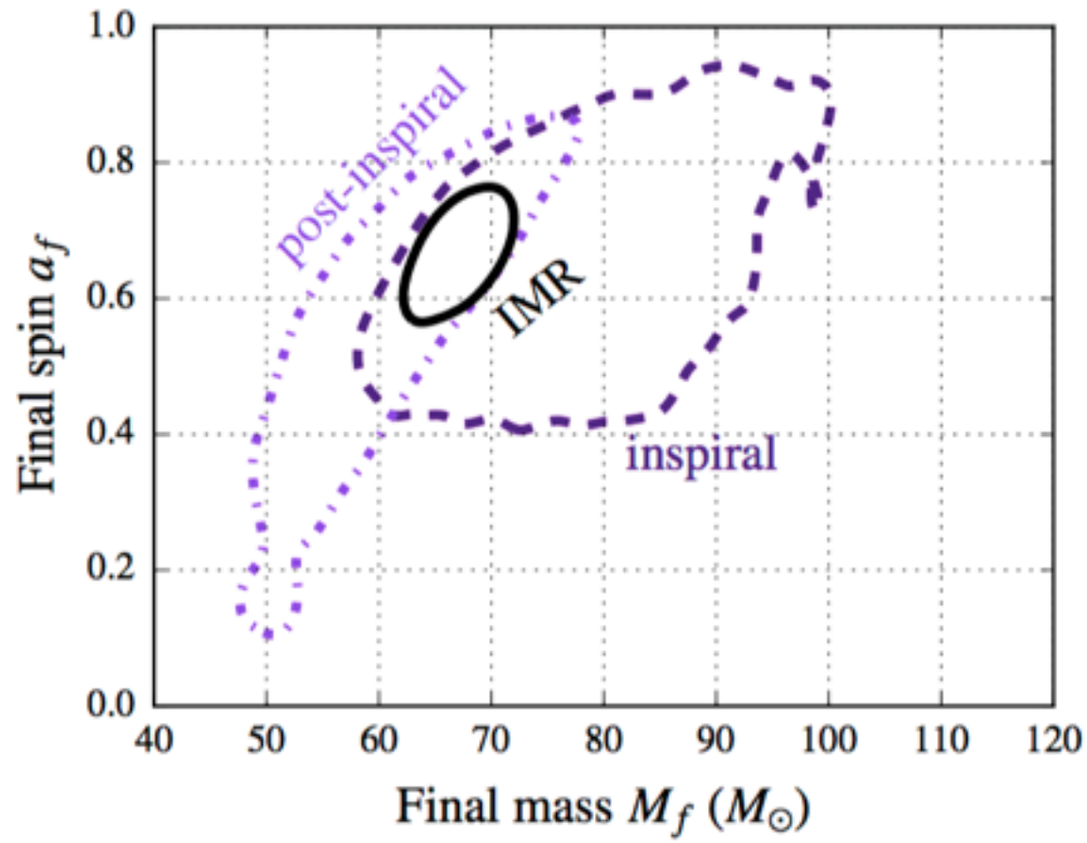


Testing GR — consistency tests

Phys. Rev. Lett. 116, 221101 (2016)

- **GW150914** signal was dominated by merger which facilitated some interesting tests:
  - Detectable by excess power searches, enabling analysis of *residuals* after GR model was removed from data.
  - Consistency tests for final mass and spin of remnant black hole



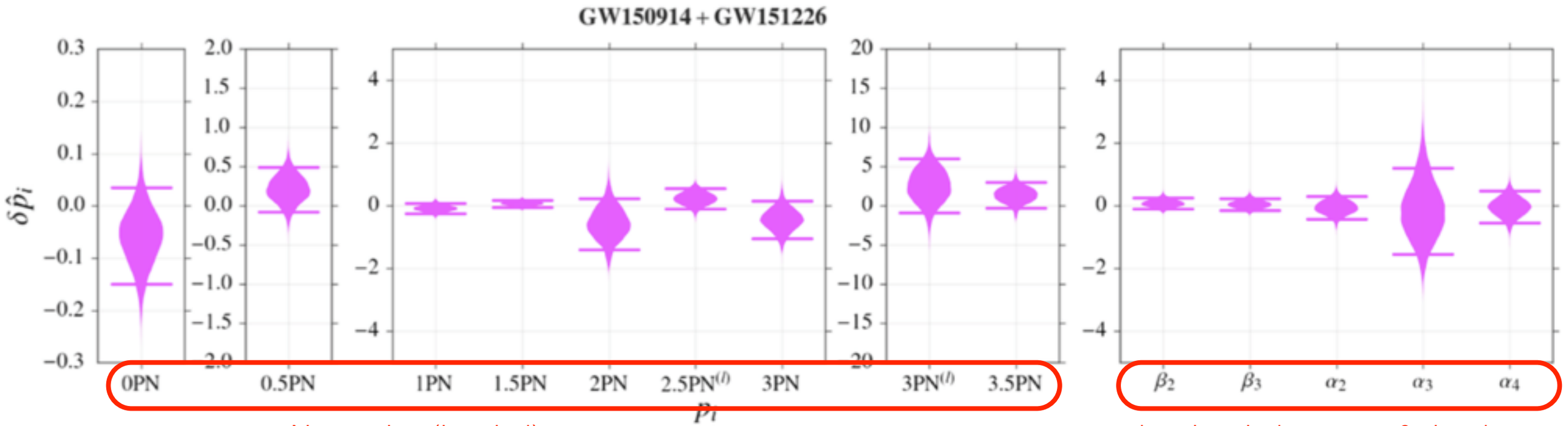


Testing GR — parameterized tests

Phys. Rev. X 6, 041015 (2016)

- Inspiral waveforms computed using *post-Newtonian* (PN) expansion. Analyses search for departures from the GR values of PN coefficients.

- Additional modification parameters included for late-inspiral, merger, and ringdown stage of the signal.



post-Newtonian (inspiral)

late inspiral, merger & ringdown

- ***So far*, measurements are consistent with GR**

Astrophysics Rates of Compact Mergers

Inferred rates for
BBH

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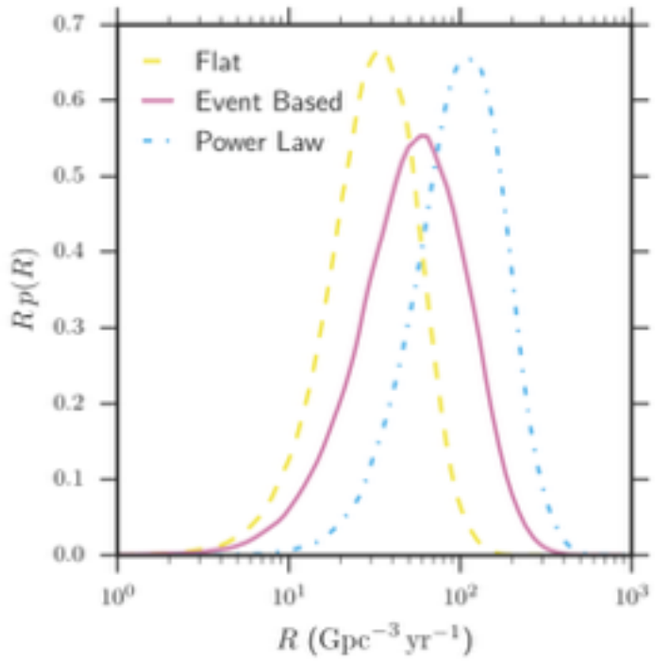
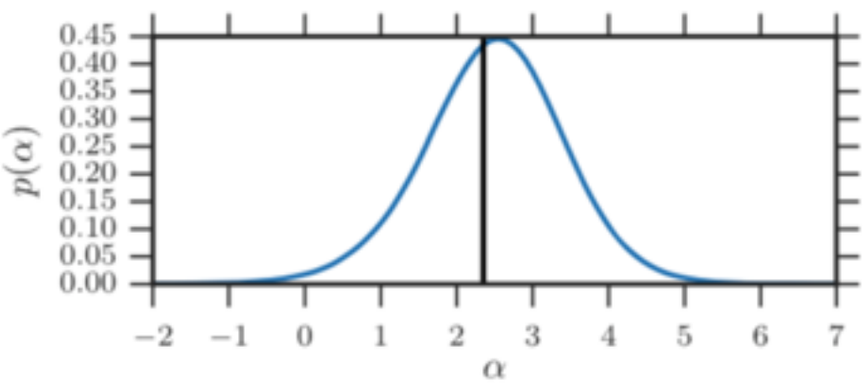
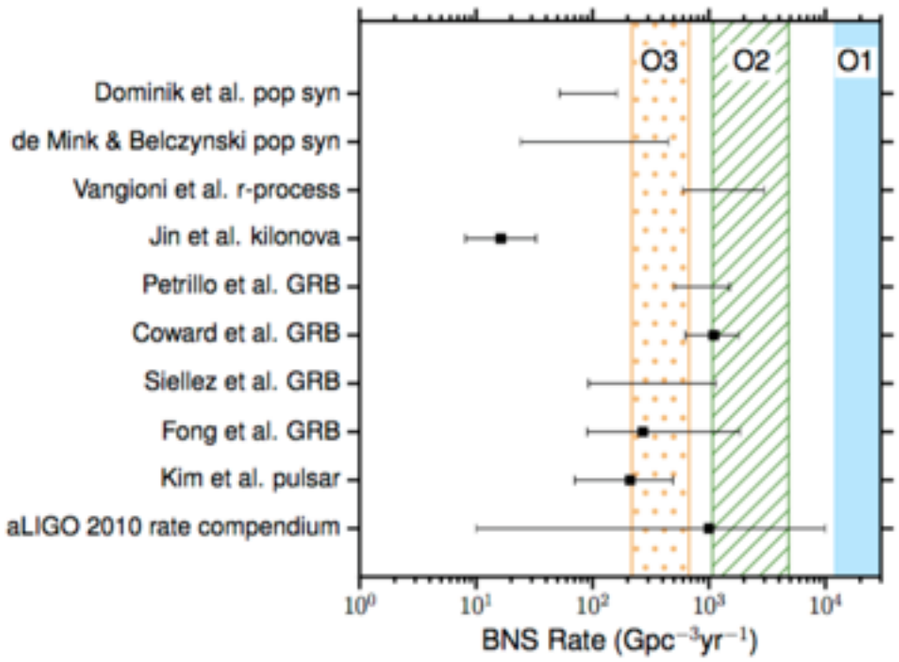


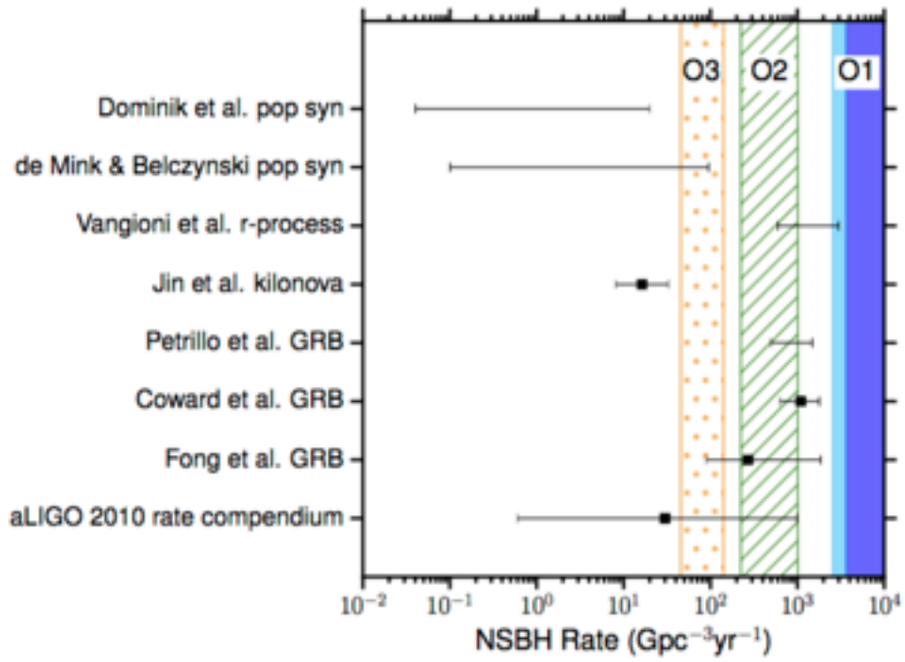


Assuming $p(m_1) \propto m_1^{-\alpha}$

Upper limits on
BNS (left)
NSBH (right)

arXiv:1607.07456 [astrop-ph.HE]





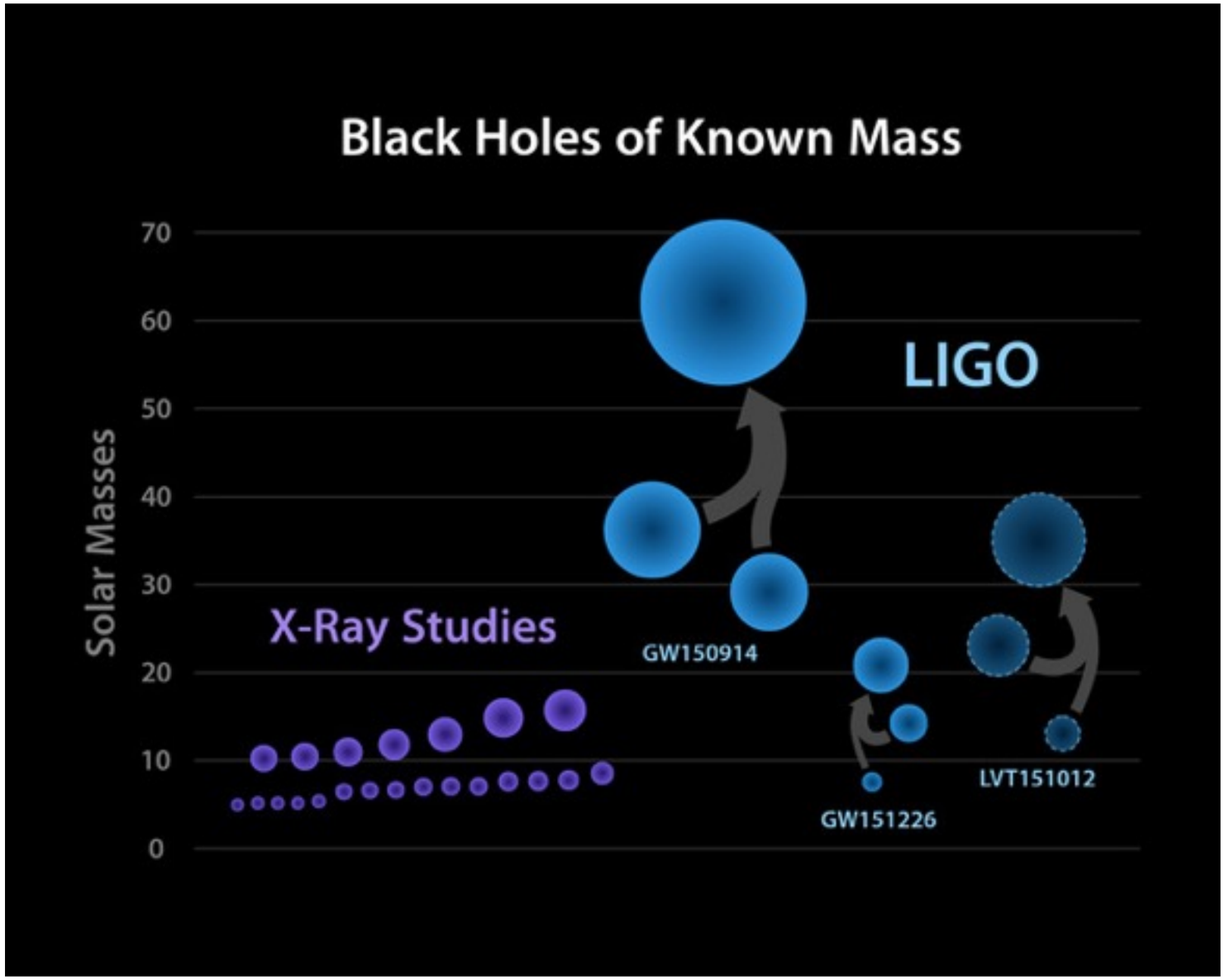
In Summary

What did we learn about the Universe from O1?

- O1 significantly added to the zoo of known stellar-mass black holes

- GW150914 contained the **largest stellar-mass black holes** ever detected.

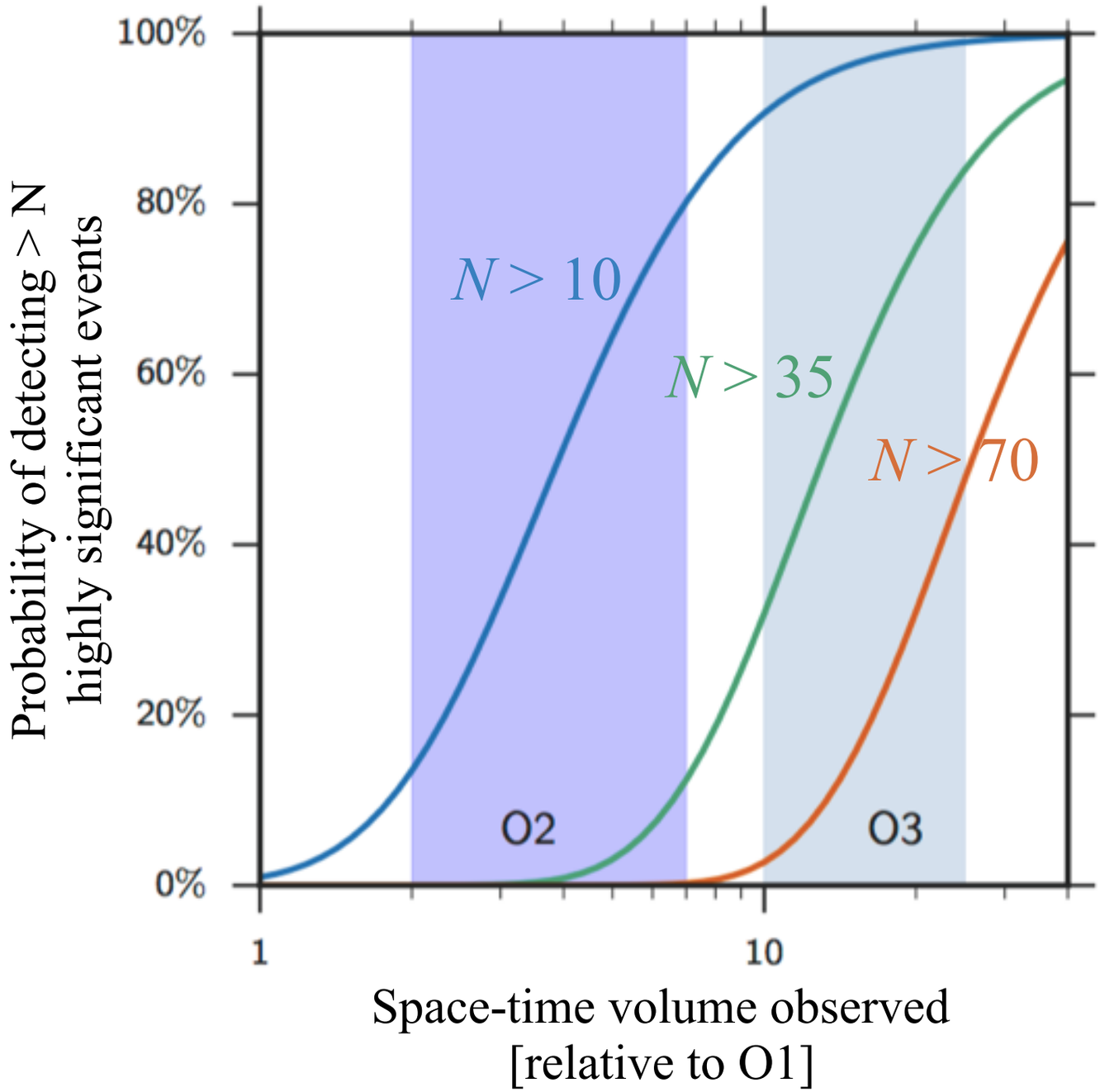
- So far, the observed gravitational waves are **consistent with Einstein's general theory of relativity**.



What to expect from O2

What we will be asking about black hole mergers:

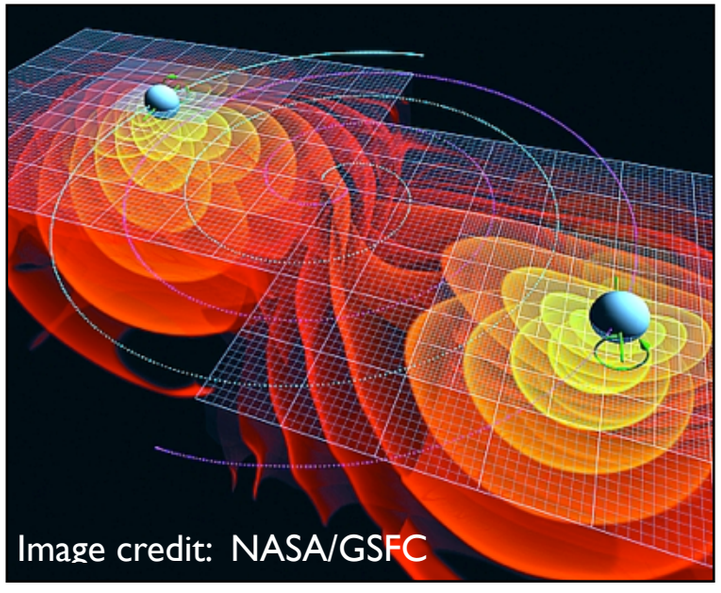
- How & where are the black holes formed?
- How large can black holes be? How small?
- Are the waves consistent with Einstein's theory?
- Do they produce any electromagnetic signals?

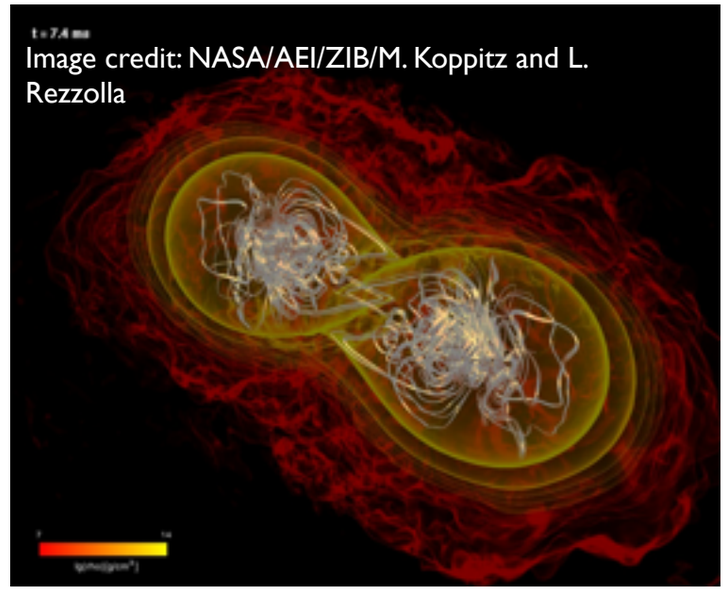


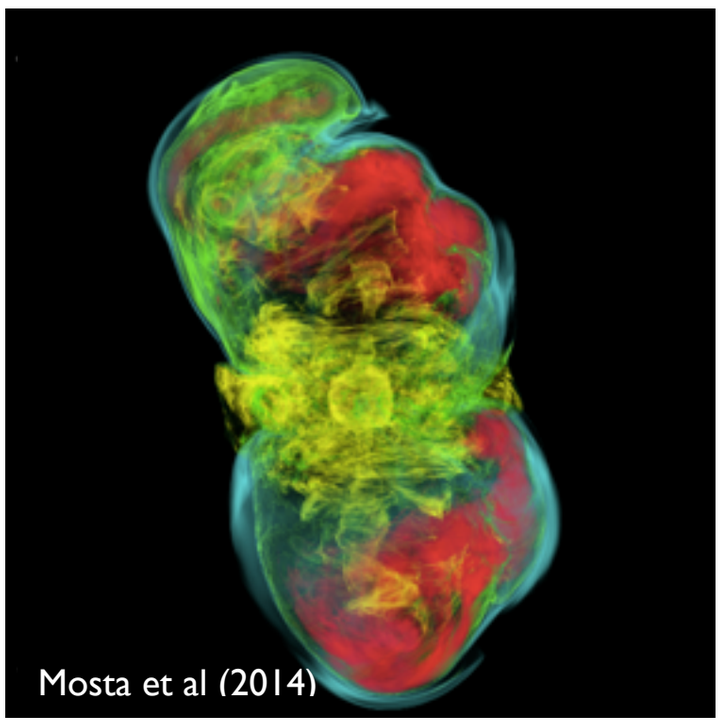
What to expect from O2

What we will be asking about other transient sources:

- What is the rate of binary neutron star mergers? NSBH?
- Do binary neutron star mergers create GRBs?
- What other sources of GW transients are out there?







Gravitational wave detectors