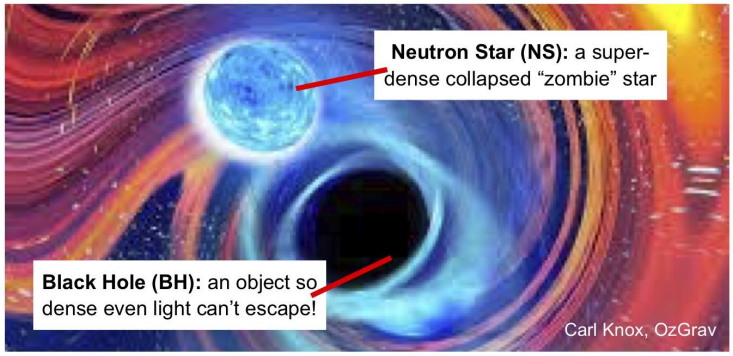
and Lower Mass Gap in Neutron Star-- Black Hole Systems with Spin

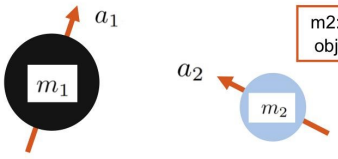
Gravitational Waves



Gravitational waves are ripples in the fabric of spacetime itself, predicted by Einstein's Theory of General Relativity. The **Laser Interferometer Gravitational-Wave Observatory (LIGO)** has been detecting gravitational-wave signals from colliding **black holes** and **neutron stars** since 2015!

Black Holes and Neutron Stars

m1: the more massive object (black hole)



m2: the less massive object (neutron star)

A Neutron Star-Black Hole Binary System

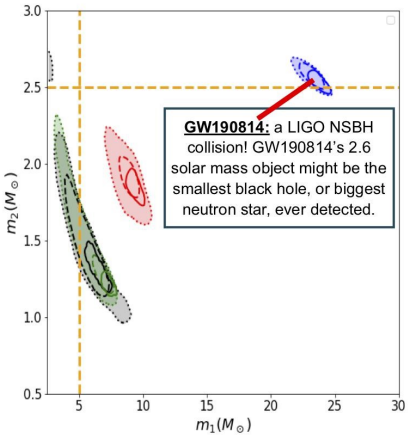
BLACK HOLE MASSES (m1): the **minimum mass** of a black hole determines the width of the **lower mass gap** between neutron stars and black holes.

NEUTRON STAR MASSES (m2): the **maximum mass** of a non-spinning neutron star is set by the unknown physics of super-dense nuclear matter

BLACK HOLE SPINS (a1): black holes in NSBH binaries could be **nonspinning**

NEUTRON STAR SPINS (a2): neutron stars can have **significant spins**, which could allow them to be **extra massive**, above the allowed "maximum mass"

Data and Inference Methods



NS mass vs. BH mass for LIGO'S NSBH collisions.

Real data and parameter estimation samples from neutron star-black hole collisions observed at the LIGO was used to build statistical models (left).

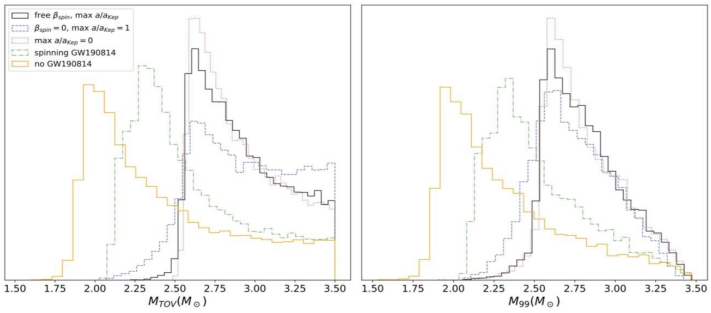
Simulated data from possible future LIGO NSBH detections was generated using a post-Newtonian approximation.

Population properties of LIGO's neutron star-black hole binaries were inferred using a Hierarchical Bayesian inference method, accounting for selection effects.

I focused on studying the neutron star and black hole populations while modeling the effects of spin on the neutron star maximum mass.

Neutron Star Maximum Mass

What is the maximum mass of a neutron star, as a function of its spin?

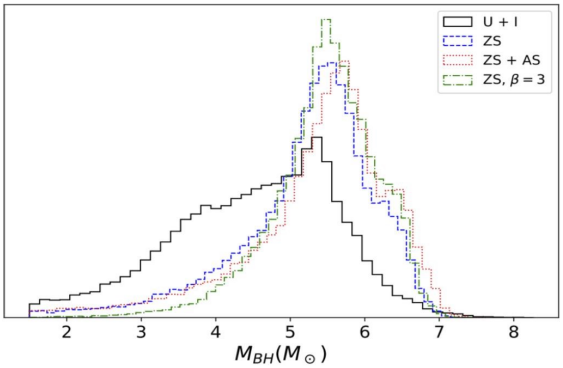


Estimates of mTOV and m99 for different assumptions about the NS spin distribution.

Modeling NSBH events with massive neutron stars like GW190814 (black/red/blue), we infer a maximum NS mass ~2.6 solar masses. Without GW190814 (yellow), it is ~2.2 solar masses. **But if GW190814 has significant spin (green), allowing it to be extra massive, it becomes more consistent with the NSBH population.**

Lower Mass Gap

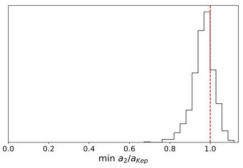
How wide is the mass gap between black holes and neutron stars?



There is strong evidence for the lower mass gap's existence: the minimum black hole mass (above) is significantly greater than the maximum neutron star mass. This is especially true if the **black hole is nonspinning** (blue/green/red lines).

Projections for Future Observations

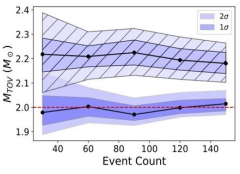
1. Given a large NSBH population, it is possible to measure spins of individual extra-massive NS in NSBH binaries.



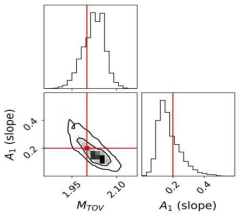
LEFT: the minimum possible spin for the neutron star to be consistent with the population, if it is rotation-supported.

2. Failing to model rotation-supported massive neutron stars can quickly lead to significant bias in the inferred neutron star maximum mass.

RIGHT: inferred maximum mass when modeling (solid) vs. not modeling (striped) a spin-dependent maximum mass. True value shown by red line.



3. Future observations may reveal the relationship between spin and rotation-supported maximum mass directly from the data, without outside assumptions.



LEFT: posterior from modeling the maximum mass and spin dependence jointly. Both are recovered correctly.