Characterizing Compact Object Binaries in the Lower Mass Gap with Gravitational Waves

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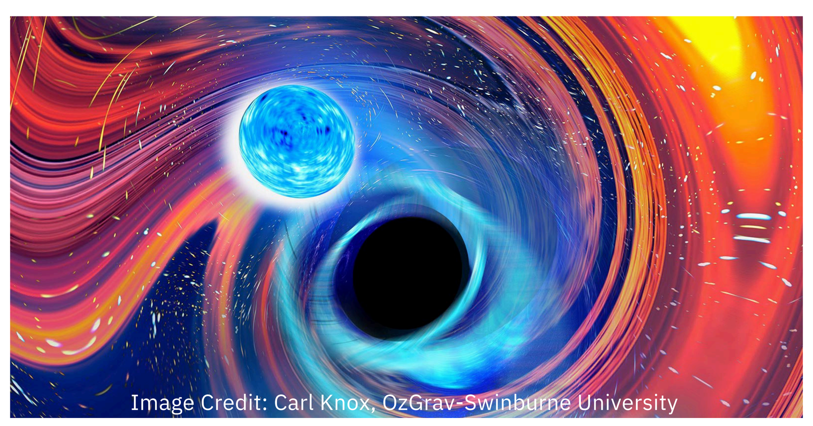
INTRODUCTION

The gravitational wave signal **GW230529** was observed by the LIGO-Livingston detector on 2023 May 29. Parameter estimation of the signal indicates that the primary object in the system is in the **lower mass gap** between the heaviest neutron stars (~3 Msun) and the lightest black holes (~5 Msun) [1]. However, measurement uncertainties make it unclear whether the primary object is a massive neutron star or a low-mass black hole.

In this work, we explore the measured uncertainties in the parameters of the binary system by performing parameter estimation on synthetic signals to determine how well we can characterize GW230529-like systems. Specifically, we investigate how noise realizations, the signal-to-noise-ratio (SNR), and the intrinsic parameters of the system impact the uncertainties.



METHODS

We perform **parameter estimation** on **simulated** gravitational wave signals with properties similar to GW230529 using the Bilby software package [2] .

We use the waveform approximant IMRPhenomPv2_NRTidalv2 [3] and the standard low secondary-spin prior used in the original GW230529 analysis [4] for our simulations.

We choose true parameter values corresponding to discrete samples of the posterior obtained in the original GW230529 analysis [4]. The three different sets of intrinsic parameters used for our simulations are shown in the table below:

Table 1. True parameter values corresponding to the posterior sample chosen for each simulation.

Sample Name	$m_1/M_\odot$	$m_2/M_\odot$	q	$\chi_{\rm eff}$	$D_{\rm L}/{\rm Mpc}$	SNR
Max Likelihood	4.03	1.28	0.32	-0.02	259.8	11.83
Equal Mass	2.21	2.21	1.00	-0.21	250.72	11.38
Secondary Peak	2.77	1.73	0.63	-0.2	317.39	10.47

NOTE—m_1 and m_2 represent the source-frame masses. The optimal SNR listed is for a L1-only detector configuration.

For each set of intrinsic parameters, we perform simulations with the following noise realizations and detector configurations:

- Zero noise; L1 (LIGO-Livingston) detector only
- Zero noise; both L1 and H1 (LIGO-Hanford) detectors
- Gaussian noise; L1 detector only

We also perform additional zero-noise simulations using the Max Likelihood parameters with varying luminosity distances and SNRs.

We **cannot confirm** whether GW230529 resulted from a collision between **two heavy neutron stars** or a neutron star and a **low mass black hole.**

A **stronger signal** (and/or a **second detector**) is needed to determine the nature of the compact objects in GW230529-like systems.

The specific **noise realization** is **not** the reason for the ambiguity in the results of the parameter estimation.

The **low signal-to-noise ratio** (SNR) of the system is the primary reason for the **uncertainty** and the **multimodality** in the posterior distributions for the mass and spin parameters. The impact of the **priors** on the posterior distribution is significant and we cannot obtain a precise measurement.

Future work will include experimenting with different waveform systematics, real noise realizations, and more sets of intrinsic parameters.

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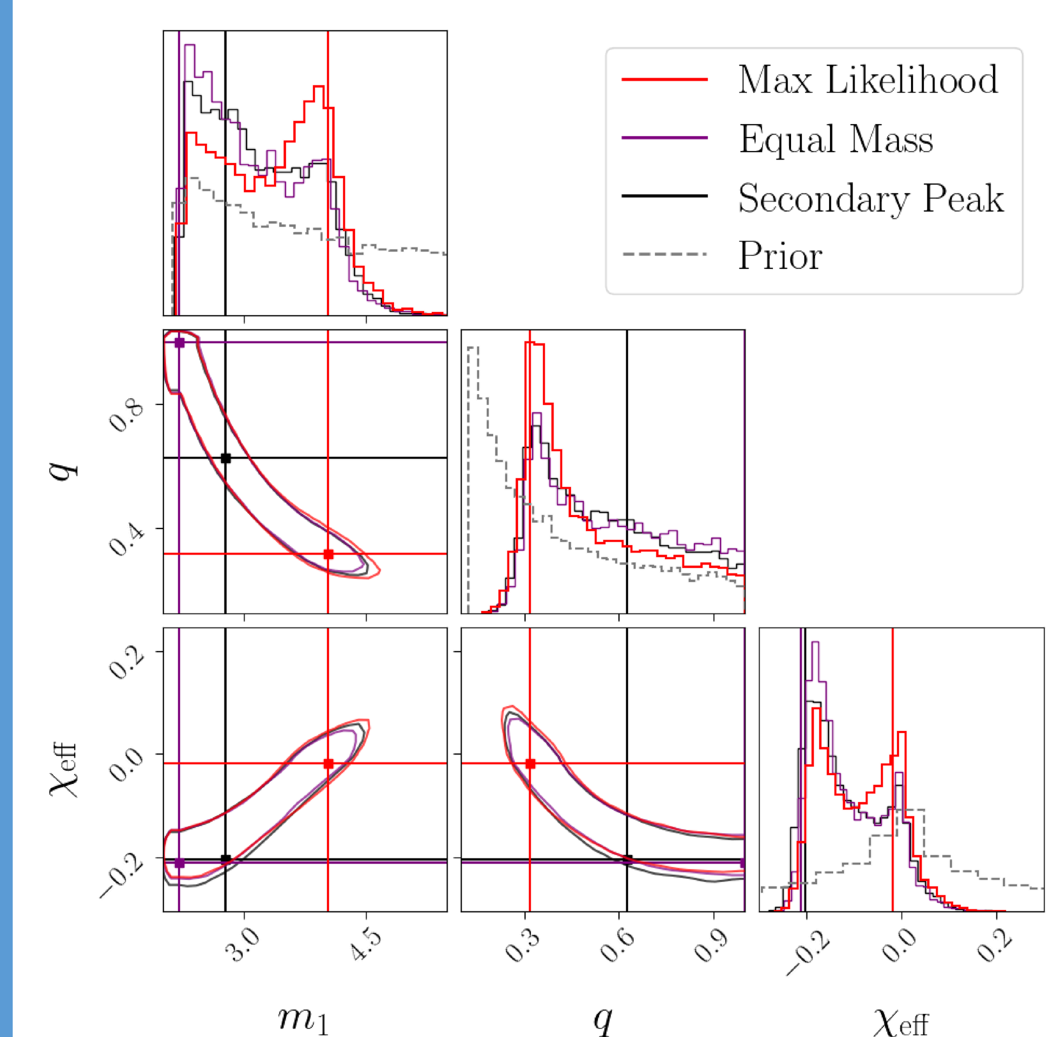
Posterior probability distributions of the primary mass, mass ratio, and effective inspiral spin inferred from parameter estimation on GW230529-like events.

Note: In both figures, the true values used for each simulation are represented by the solid lines in the corresponding color.

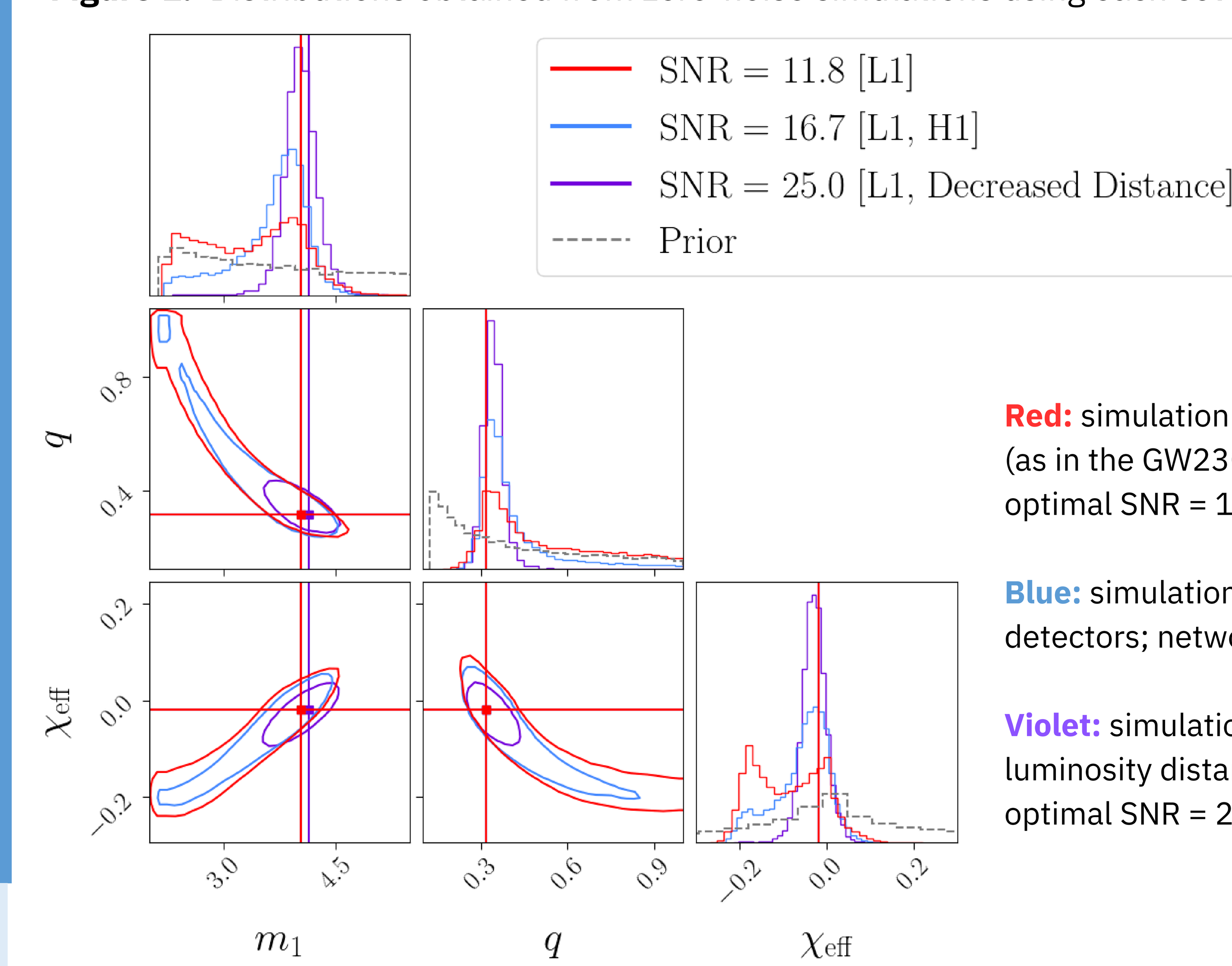


Red: simulation using **maximum likelihood** sample (unequal masses characteristic of a mass-gap black hole and a neutron star)

Purple: simulation using the sample with the most **equal mass** (like two heavy neutron stars)

Black: maximum likelihood sample from the **secondary peak** in the mass distribution (where primary mass is less than 3 Msun).

Figure 1: Distributions obtained from zero-noise simulations using each set of intrinsic parameters.



Red: simulation using L1 detector only (as in the GW230529 LVK analysis); optimal SNR = 11.8

Blue: simulation using both L1 and H1 detectors; network optimal SNR = 16.7

Violet: simulation using a decreased luminosity distance and L1 detector only; optimal SNR = 25.0

Figure 2: Distributions obtained by using the Max Likelihood sample and a zero-noise realization but varying the signal-to-noise ratio (SNR).

ACKNOWLEDGEMENTS & REFERENCES

This material is based upon work supported by the National Science Foundation under Grant No. AST2149425, a Research Experiences for Undergraduates (REU) grant awarded to CIERA at Northwestern University. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. This research was supported in part through the computational resources and staff contributions provided for the Quest high performance computing facility at Northwestern University which is jointly supported by the Office of the Provost, the Office for Research, and Northwestern University Information Technology. A special thank you to Drs. Michael Zevin, Sylvia Biscoveanu, Chase Kimball, Vicky Kalogera, and Aaron Geller for their expert guidance and support.

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