LSC LIGO Scientific Collaboration

UNIVERSITY OF BIRMINGHAM

Gravitational-wave parameter estimation for binary neutron-star coalescences during the advanced-detector era

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Advanced LIGO will begin operation in 2015, with binary neutron-star (BNS) mergers expected to be one of the main sources of gravitational-wave (GW) signals. We investigate the ability to do parameter estimation (PE) for these signals using the early Advanced LIGO two-detector network. We focus on locating sources on the sky, which is important for electromagnetic (EM) follow-up. We find that the median 90% (50%) credible region is ∼600 deg^2 (∼150 deg^2), with 3% (30%) of detected events localized within 100 deg^2, which will make electromagnetic follow-up challenging. This work [1,2] provides an update to the 2015 Observing Scenario [3], which was based on sky-localization estimates, rather than an end-to-end analysis.

Simulated GW Signals

To test our ability to do PE for BNS mergers, simulated GW signals were injected into **realistic noise** (instead of Gaussian noise as in [2]). These were recovered using the data-analysis pipeline intended for real data. The noise was estimated from detector data taken in 2010 and adapted (recoloured) to model the noise of early Advanced LIGO. The injections were produced using the SpinTaylorT4 waveform approximant, which includes the effects of precession [5]. The injected component-mass range was 1.2–1.6$M_\odot$ (the prior range for mass recovery was much wider) and spin-magnitude range was 0–0.05.

PE Methods

BAYESTAR [2]: Uses only output from the detection pipeline to provide rapid sky location in a short computational time. The total CPU time required is $\sim 10^3$ s, corresponding to a wall time of ~ 30 s.

LALINFERENCE [4]: Uses waveforms to construct probability distributions on all BNS parameters including location. Here, an inexpensive waveform is used (TaylorF2 without spins [5]). To collect 5000 independent posterior samples takes $\sim 2 \times 10^6$ s of CPU time. The wall time depends upon parallelization used, here it was ~ 5 days. Speed-ups are possible with further parallelization or decreasing the number of samples.

Sky Localization Results

The results of PE give a probability distribution for the location of the source on the sky. An example sky map is shown in Figure 1. Sky localization is quantified by the area that encompasses a given total posterior probability p, the p credible region. This is shown for the population of detected signals by Figure 2. There is good agreement between the methods (LALINFERENCE provides marginally smaller areas than BAYESTAR) and the noise models. The median sky areas are: **∼600 deg^2 for the 90% credible region** and **∼150 deg^2 for 50% credible region**.

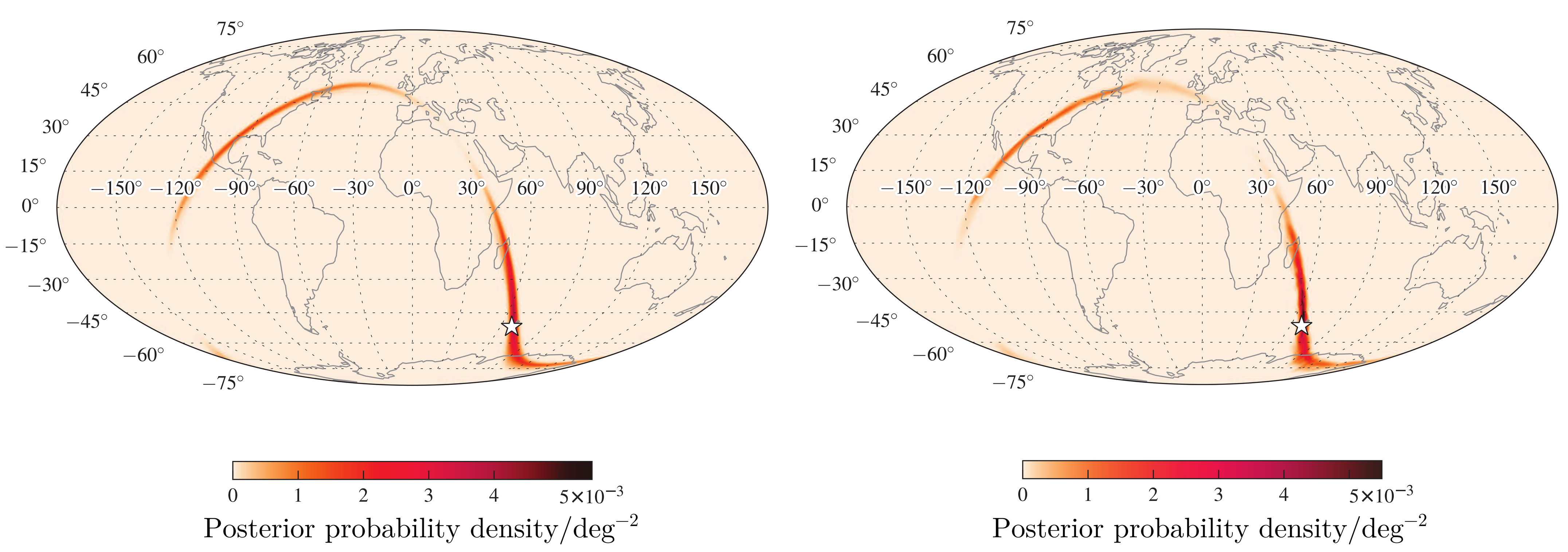

Figure 1. Example posterior probability distribution for the sky location of a BNS signal from BAYESTAR (left) and LALINFERENCE (right). The signal-to-noise ratio (SNR) is ~ 13. The bimodal structure is common, it is due to symmetry in the detector sensitivity for a two-detector network. The star indicates the true position of the injected signal. A catalogue of similar events can be seen at www.ligo.org/scientists/first2years/.

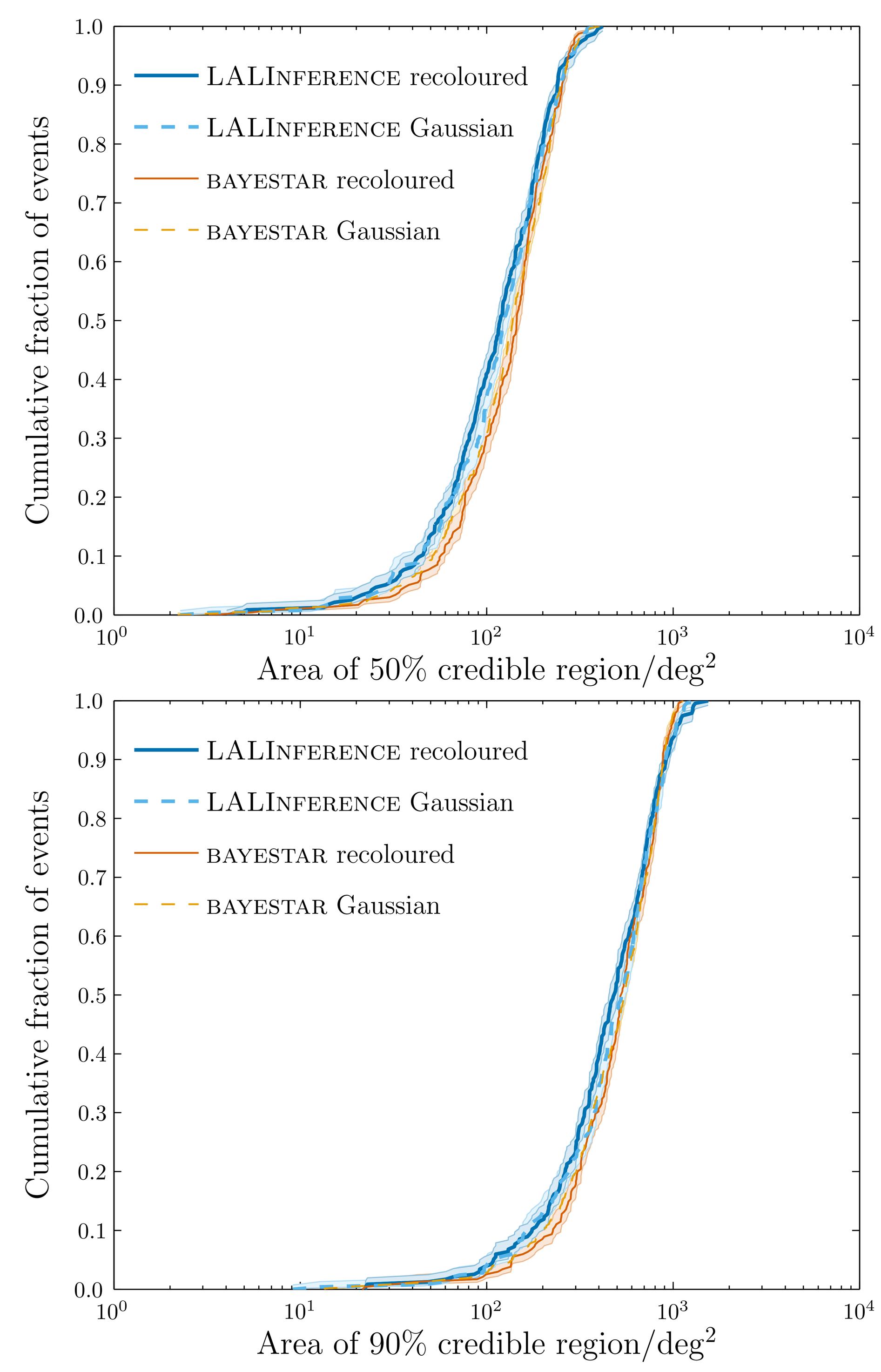

Figure 2. Cumulative fraction of events located with 50% (top) and 90% (bottom) credible regions smaller than the abscissa value. These signals have an SNR threshold ≥ 12.

Chirp Mass Results

As well as source location, LALINFERENCE also finds probability distributions for other parameters, including chirp mass: a combination of the BNS component masses

$$\mathcal{M}_c = (m_1 m_2)^{3/5}/(m_1 + m_2)^{1/5}.$$

We find that the estimated $\mathcal{M}_c$ has a small systematic bias due to recovery with a waveform that does not include spins. However, the offset is small, with the **median offset being $\sim 2.5 \times 10^{-4} M_\odot$**. This distribution of offsets is shown in Figure 3. Despite the error, **our estimated chirp masses are highly accurate**.

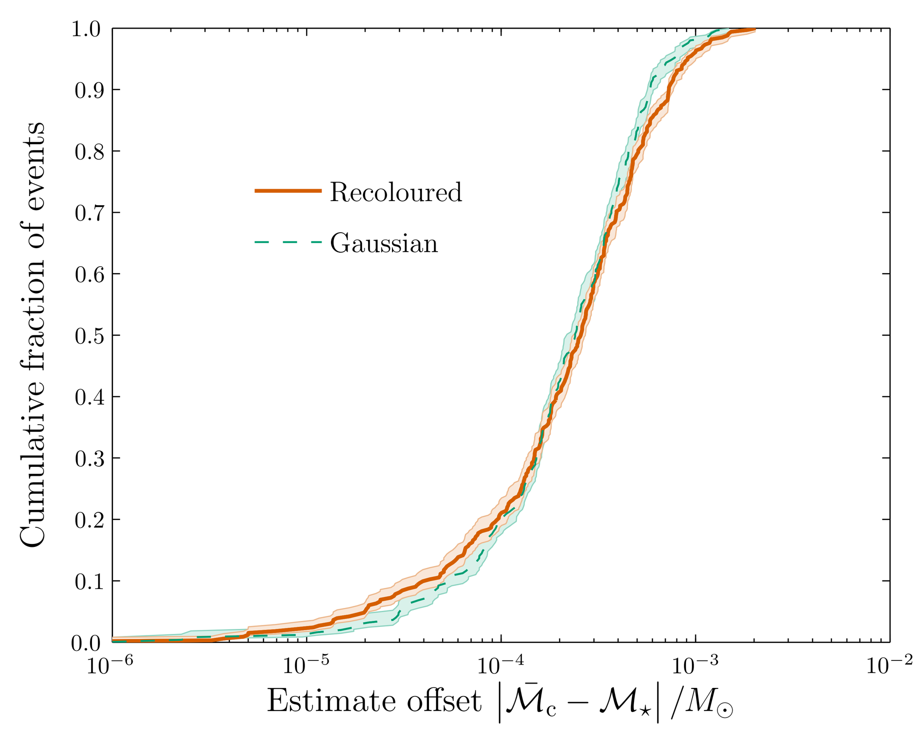

Figure 3. Estimated offset between the posterior mean chirp mass from PE $\bar{\mathcal{M}}_c$ and the true value $\mathcal{M}_*$. The offset is consistent between noise models.

Conclusions

- For BNS signals, the use of idealised Gaussian or realistic glitchy noise makes little difference to PE performance.
- BAYESTAR and LALINFERENCE produce similar sky areas. However, the sky areas are large ($\sim 10^2$ deg^2) and covering them will be challenging.
- The addition of further detectors will reduce sky-localization areas [2].
- The difference between injected and recovered waveform leads to a small bias in chirp mass, but the estimated values are still accurate.

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References:
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