Bayesian identification of strongly lensed GW events

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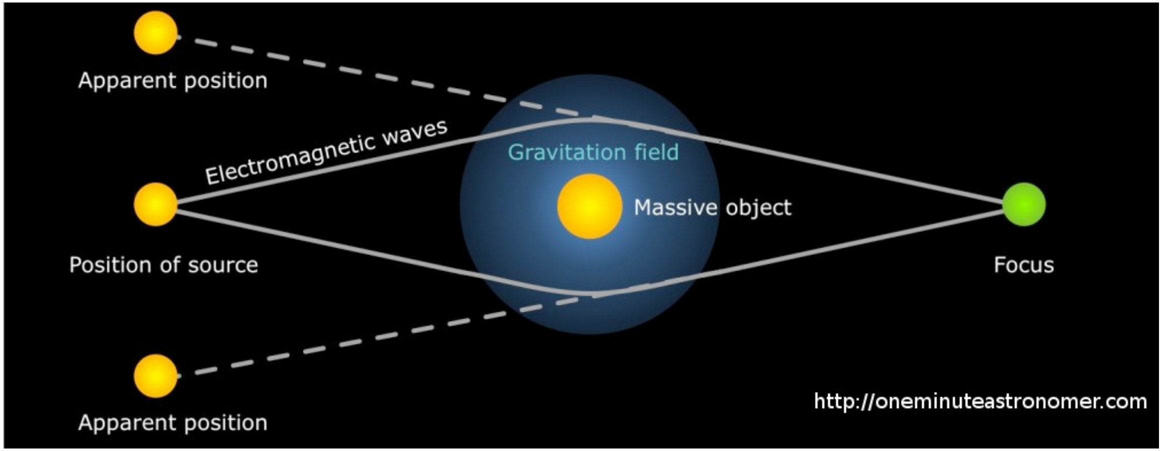
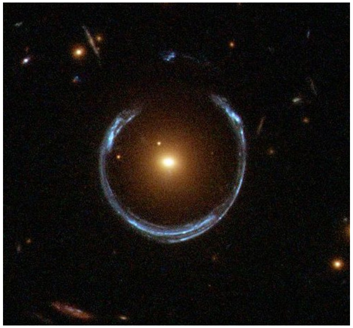
Gravitational lensing



- A distribution of matter between a source and the observer deflects the radiation.
- Produce visible distortions such as the Einstein rings, arcs, and multiple images.
- Examples: cluster of galaxies, dark matter.



Lensing of gravitational waves

- Lensing magnifies the GW strain amplitude:

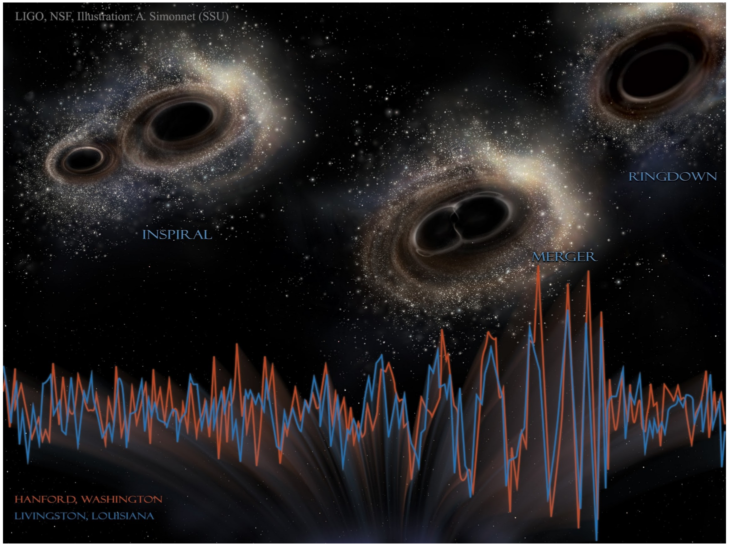
$$\rho' = \sqrt{\mu}\rho \implies d'_L = d_L/\sqrt{\mu}$$

- Frequency profile remain unaffected (geometric optics approximation; when $\lambda_{GW} << R_{Sch.}$ of the lens). *i.e.* Observed intrinsic parameters like masses, spins etc. remain same.

- *Strong lensing can produce multiple GW events from the same sources (analogous to multiple images) typically separated by time delays of weeks to months.*

Gravitational Lenses, P. Schneider et al. (1992)

Lensing of BBH merger events



- Expected to observe hundreds of BBH merger events per year with advanced detectors.
- Possible to see more than 1 lensed events per year.

B. P. Abbott et a. (2016), Ken K. Y. Ng et al. (2017)

Identifying lensed BBH mergers: Bayesian formalism

- $\mathcal{H}_1$: the data sets d_1 and d_2 contain lensed BBH merger signals from a single event with intrinsic parameters $\vec{\theta}$.
- $\mathcal{H}_0$: the data sets d_1 and d_2 contain BBH merger signals from two independent events with intrinsic parameters $\vec{\theta}_1$ and $\vec{\theta}_2$.

$$\text{Odds ratio, } \mathcal{O} = \frac{\mathbf{P}(\mathcal{H}_1|d_1, d_2, I)}{\mathbf{P}(\mathcal{H}_0|d_1, d_2, I)} \ ,$$

Identifying lensed BBH mergers: Bayesian formalism

Bayes factor, $\mathcal{B}$ — Ratio of prior odds, α

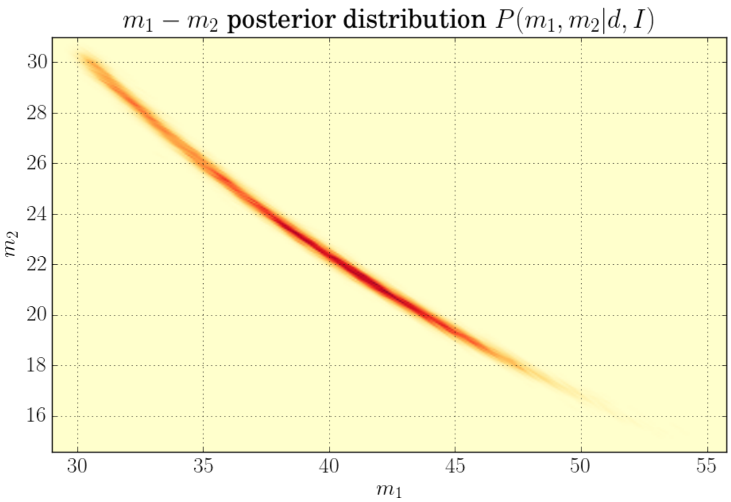
$$\mathcal{O} = \frac{\mathbf{P}(d_1, d_2, I|\mathcal{H}_1, I)}{\mathbf{P}(d_1, d_2|\mathcal{H}_0, I)} \frac{\mathbf{P}(\mathcal{H}_1|I)}{\mathbf{P}(\mathcal{H}_0|I)}$$

Posterior dist.

$$\mathcal{B} = \int d\vec{\theta}\ \frac{\mathbf{P}(\vec{\theta}|d_1, I)\ \mathbf{P}(\vec{\theta}|d_2, I)}{\mathbf{P}(\vec{\theta}|I)}$$

Prior dist.

Preliminary simulations: non spinning BBH merger



- Nonspinning BHH merger injections with component masses $\in (5, 50) M_\odot$.
- Unifomly sampled network SNR from $(10, 25)$.
- Gaussian noise with Advanced LIGO-Virgo PSD.

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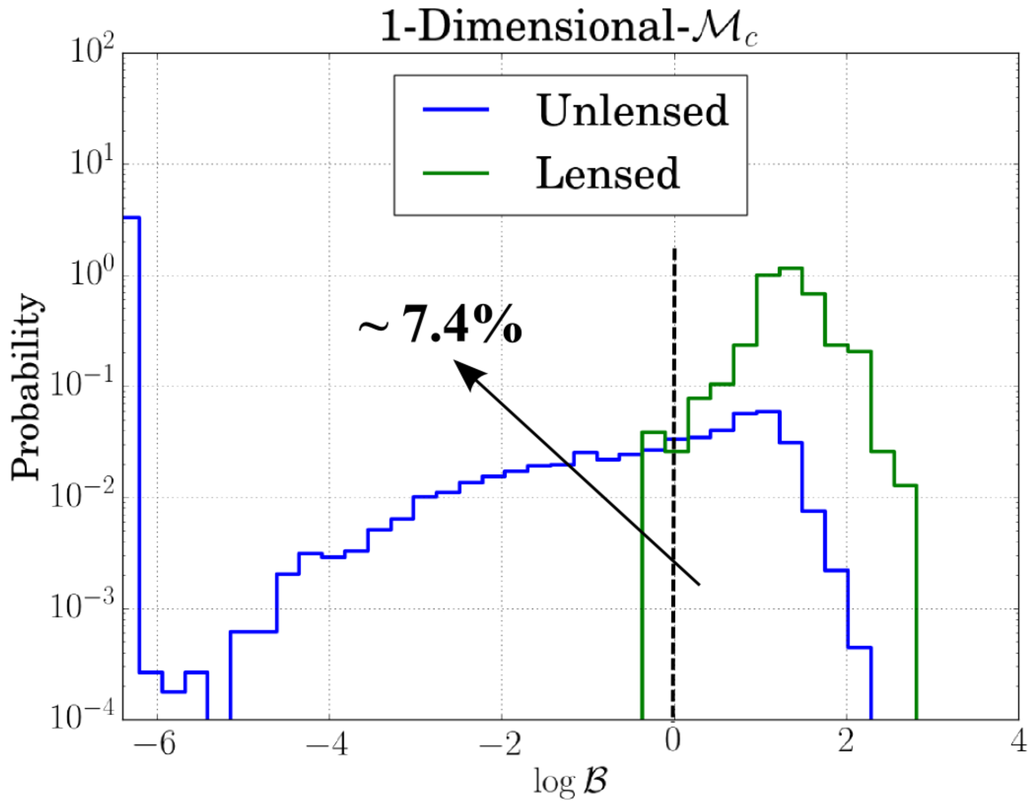
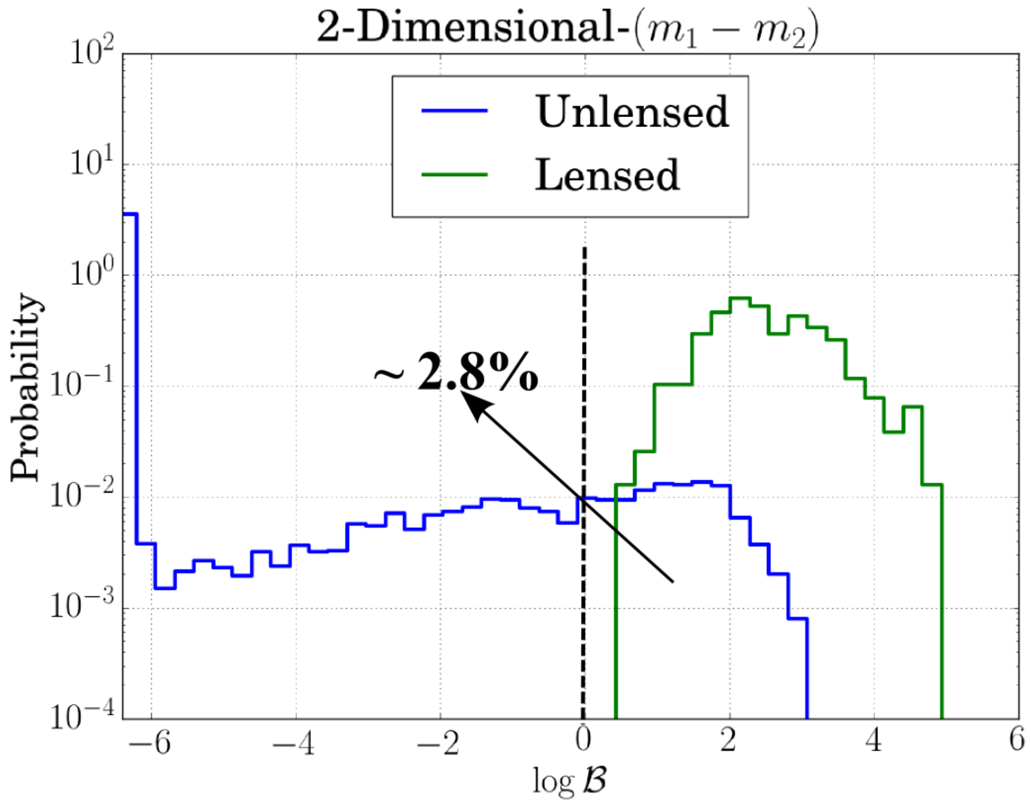
Priliminary simulations: One parameter



Priliminary simulations: Two parameter



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Directions and challenges

- Add more parameters to improve discriminatory power.
- Use realistic source and lens distributions.
- Test on real noise.
- Infer the properties of lens.

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thank you!