Lessons learned from the LIGO-Virgo-KAGRA collaboration

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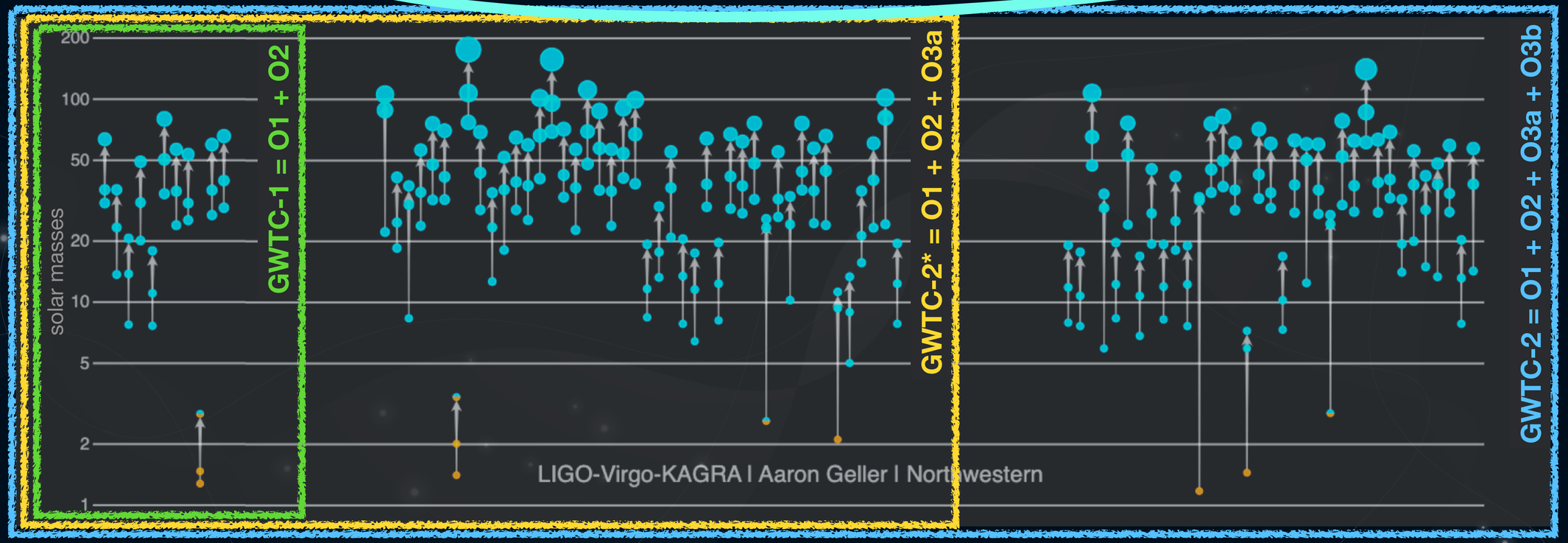
My opinions $\neq$ views representing the LVK

- Part of the LVK since 2018 (Honours + PhD)
- Worked on collaboration companion papers (GWTC-2 & GWTC-3 population papers arXiv:2010.14533, arXiv:2111.03634) that used downstream data products from the main catalogue publication.
- Also was the liaison between catalogue paper and companion paper. Find all collaboration papers here: https://www.ligo.caltech.edu/page/detection-companion-papers

What is a catalogue?

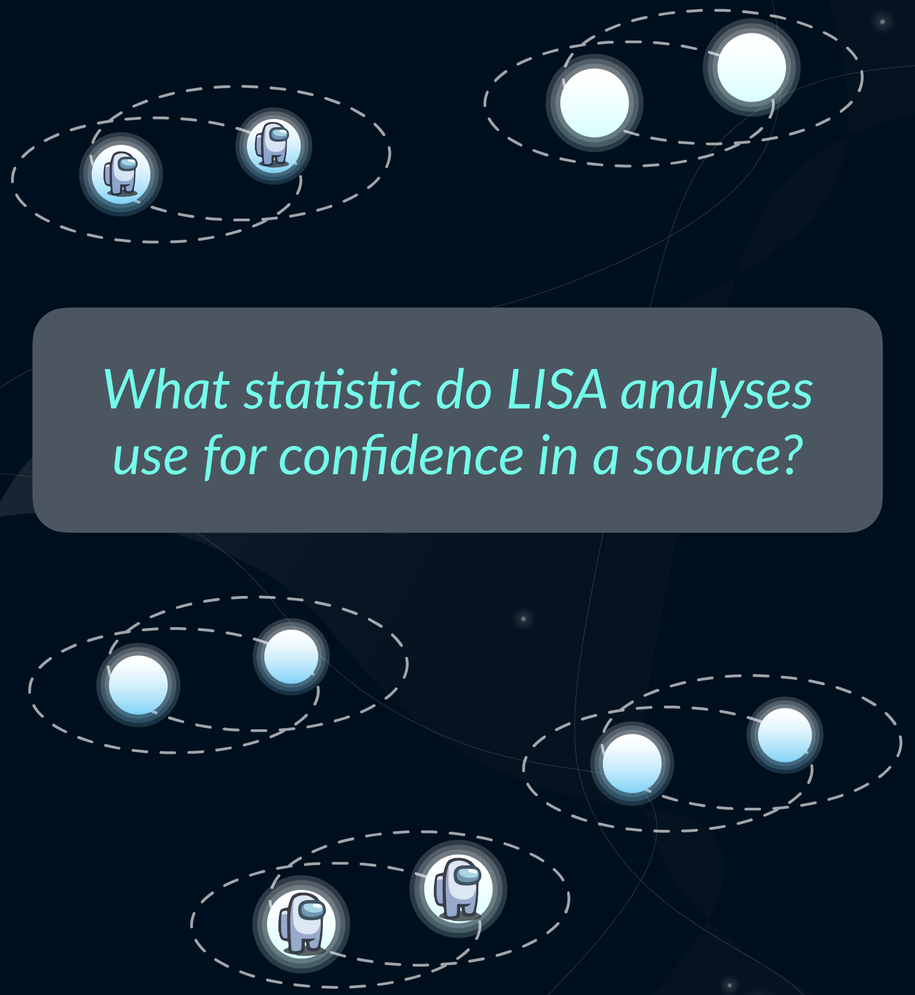
- Grouped by some type (e.g. source type / observation period)
- Selected by some threshold (e.g. SNR / False Alarm Rate / p_{astro})



* Some events here are in GWTC-2.1 catalogue

Frequently used detection statistics in LVK

- False Alarm Rate (FAR): determines how regularly we would expect to see a event from noise with the same, or higher, ranking statistic as the candidate.
- Probability of Astrophysical origin ($p_{\rm astro}$): a measure of how likely the source is astrophysical. Can be broken up into source type probabilities. Uses the rate at which triggers are generated by both astrophysical signals and noise.



What statistic do LISA analyses use for confidence in a source?

Is one detection statistic better than the rest?

- Short answer? No. But having both are useful.
- LVK uses FAR and $p_{\rm astro}$ to determine what's included in a catalogue and events for population analyses… but…

LVK arXiv:2111.03634 (part of table 1)

Name	Inst.	cWB			GstLAL			MBTA			PyCBC-broad		
		FAR (yr^{-1})	SNR	$p_{\rm astro}$	FAR (yr^{-1})	SNR	$p_{\rm astro}$	FAR (yr^{-1})	SNR	$p_{\rm astro}$	FAR (yr^{-1})	SNR	$p_{\rm astro}$
GW191204_171526	HL	$< 8.7 \times 10^{-4}$	17.1	> 0.99	$< 1.0 \times 10^{-5}$	15.6	> 0.99	$< 1.0 \times 10^{-5}$	17.1	> 0.99	4.8	9.3	0.77
GW191215_223052	HLV	0.12	9.8	0.95	$< 1.0 \times 10^{-5}$	10.9	> 0.99	0.22	10.8	> 0.99	0.012	9.8	> 0.99
GW191216_213338	HV	–	–	–	$< 1.0 \times 10^{-5}$	18.6	> 0.99	9.3×10^{-4}	17.9	> 0.99	0.096	13.2	> 0.99
GW191219_163120	HLV	–	–	–	–	–	–	–	–	–	1.1×10^{4}	8.3	< 0.01
GW191222_033537	HL	$< 8.9 \times 10^{-4}$	11.1	> 0.99	$< 1.0 \times 10^{-5}$	12.0	> 0.99	0.0099	10.8	> 0.99	22	8.5	0.39
GW191230_180458	HLV	0.050	10.3	0.95	0.13	10.3	0.87	8.1	9.8	0.40	20	9.5	0.47

no single value for these statistics!

Selecting detection threshold

- FAR? Sometimes significant in one and not found in another.
- $p_{\rm astro}$? Outliers events can have lower significance (e.g. NSBH significance).
- If we can combine the statistics across pipelines, it can get information about a signal that is not available with any one single pipeline (Banagiri+ arXiv:2305.00071)

		Mass distribution	Mass range ($M_\odot$)
GstLAL $p_{\rm astro}$	BBH	log-uniform	$3 < m_1 < 300$ $3 < m_2 < 300$
	NSBH	log-uniform	$3 < m_1 < 300$ $1 < m_2 < 3$
	BNS	log-uniform	$1 < m_1 < 3$ $1 < m_2 < 3$
MBTA $p_{\rm astro}$	BBH	POWER LAW + PEAK [107] with $\alpha = 2.5$, $\beta_q = 1.5$, $m_{\rm min} = 5M_\odot$, $m_{\rm max} = 80M_\odot$, $\lambda_{\rm peak} = 0.1$, $\mu_m = 34M_\odot$, $\sigma_m = 5M_\odot$, $\delta_m = 3.5M_\odot$	$5 < m_1 < 80$ $5 < m_2 < 80$
	NSBH	Same as injections	
	BNS	Same as injections	
PyCBC-broad $p_{\rm astro}$	BBH		$\mathcal{M} > 4.353$
	NSBH		$2.176 < \mathcal{M} < 4.353$
	BNS		$\mathcal{M} < 2.176$

LVK arXiv:2111.03634 (part of table 10)

Marginal events: to use or not to use

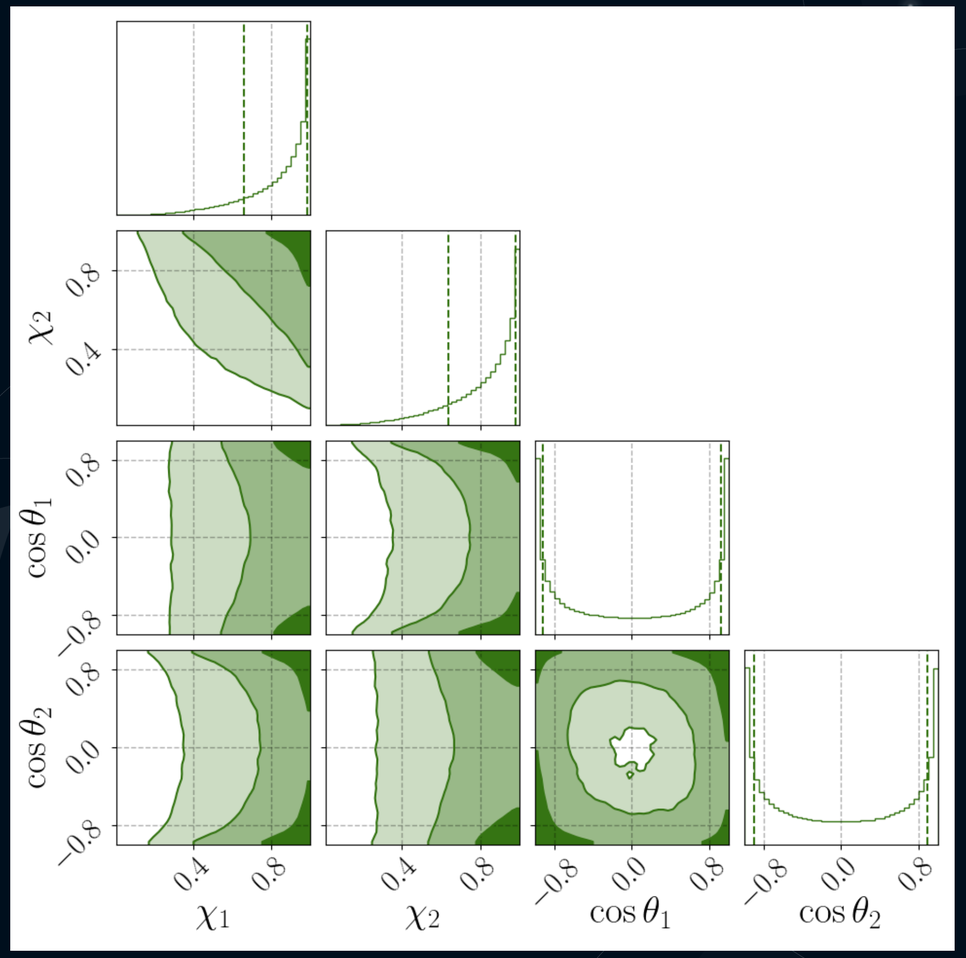
- Thresholds for LVK catalogue: $p_{\rm astro}$>0.5 (additional FAR cut for population analyses to only include events that we are confident are real).
- Ongoing work is looks at not applying threshold, and weighting all events by $p_{\rm astro}$ (Galaudage+ arXiv:1912.09708, Roulet+ arXiv:2008.07014)

How deep into the Global Fit analysis is good enough?

What threshold is needed to be confident we have similar catalogue across Global Fits?

Take caution with priors

- Important to consider hidden assumptions when using a parameterisation in effective spin space ($\chi_{\rm eff}$)
- Example: Using uniform in $\chi_{\rm eff}$ and other assumptions for their prior distributions, leading to prior distributions in physical parameters.



Provide all information for interpretation!

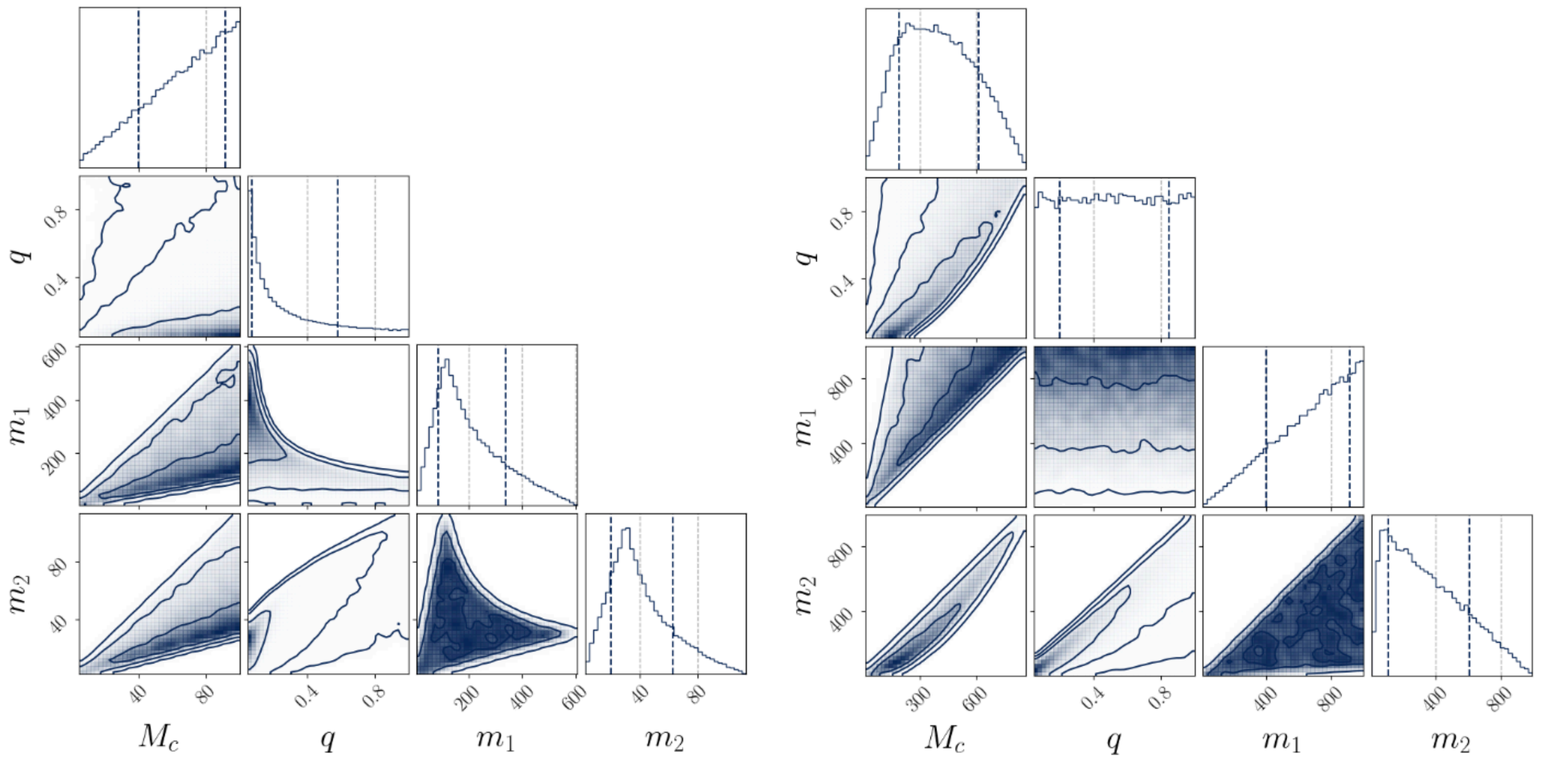


Figure A.1: Prior distribution on mass parameters where the chirp mass bound is *Left:* $\mathcal{M} = (5, 100)$ and *Right:* $\mathcal{M} = (5, 1000)$. The differences in these bounds impact the 1D and 2D posterior distributions of the component masses.

Source classification

- LVK has pipelines that determine the probability that a source we detect is a has a neutron star based on mass of components (< or > 3 $M_\odot$) rather than astrophysical informed analyses.
- Other information can help classify (e.g. electromagnetic counterpart, tidal effects).
- Some events still ambiguous (e.g. GW190814 may be a BBH or NSBH).

How do you distinguish between Galactic Binaries?

(e.g. Tauris+ arXiv:1809.03504, Lau+ arXiv:1910.12422)

Will LISA be able to provide information why there might more DNS in one fit than another?

Astrophysics + Publications

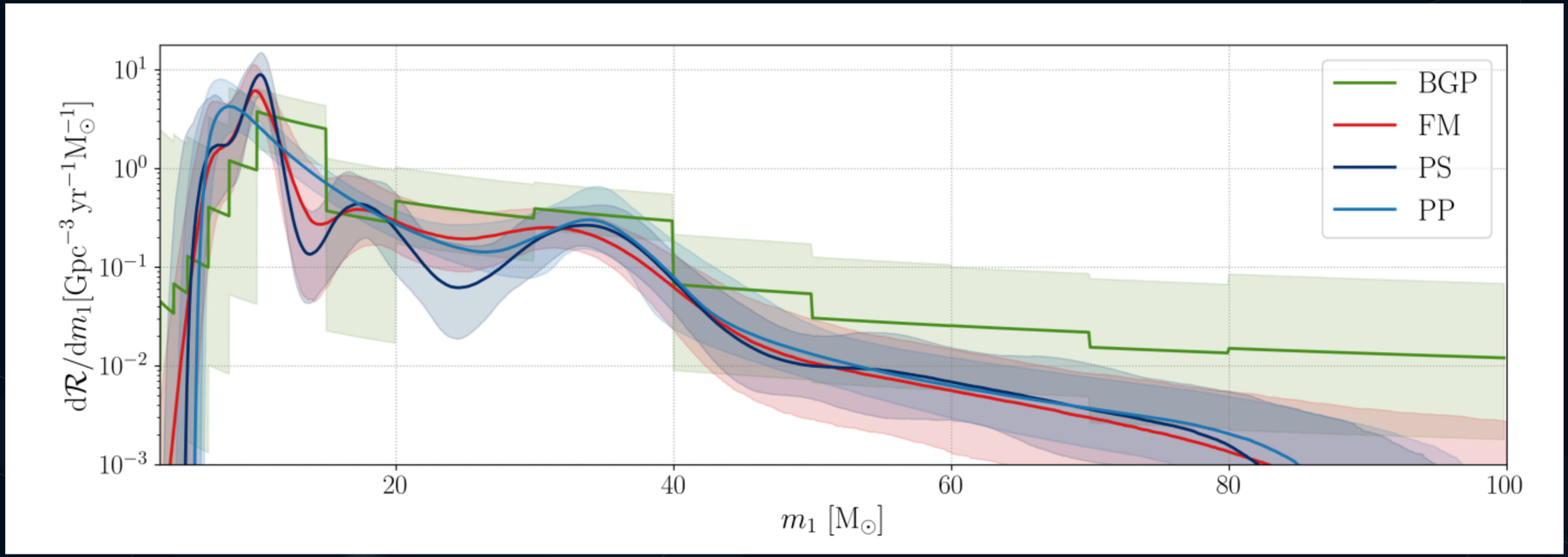
- The LVK has companion publications that focus on astrophysics (e.g. tests of general relativity, coincident GRBs, cosmology & population studies).
- Can be challenging to coordinate, relies on catalogue outputs, delays may impact downstream products and publications.
- Automation is very important!

Will LISA have astrophysical interpretations as outputs beyond providing posteriors for sources?

How challenging would it be to interpret difference in # of sources in different catalogs?

Multiple fits = confusion?

- LVK GWTC-3 population analyses had LOTS of different models with different motivations. It can be difficult to communicate with the broader scientific community (e.g. which model should I use? which one is the best model?)



LVK arXiv:2111.03634 (Figure 11)

Early Career Researcher (ECR) contributions

- ECRs (PhDs + postdocs) do huge amounts of work in collaborations, but it can be hard to gain recognition for these efforts outside the collaboration.
- LVK has some methods to address this, but could be improved.
- Timelines for projects do cover a bulk of a PhD or postdoc (e.g. GWTC-2 took over a year of commitment for paper writing team members).

How will you decide which models to have in collaboration outputs and which are for short author?

How will the LISA group work to highlight ECR contributions?

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