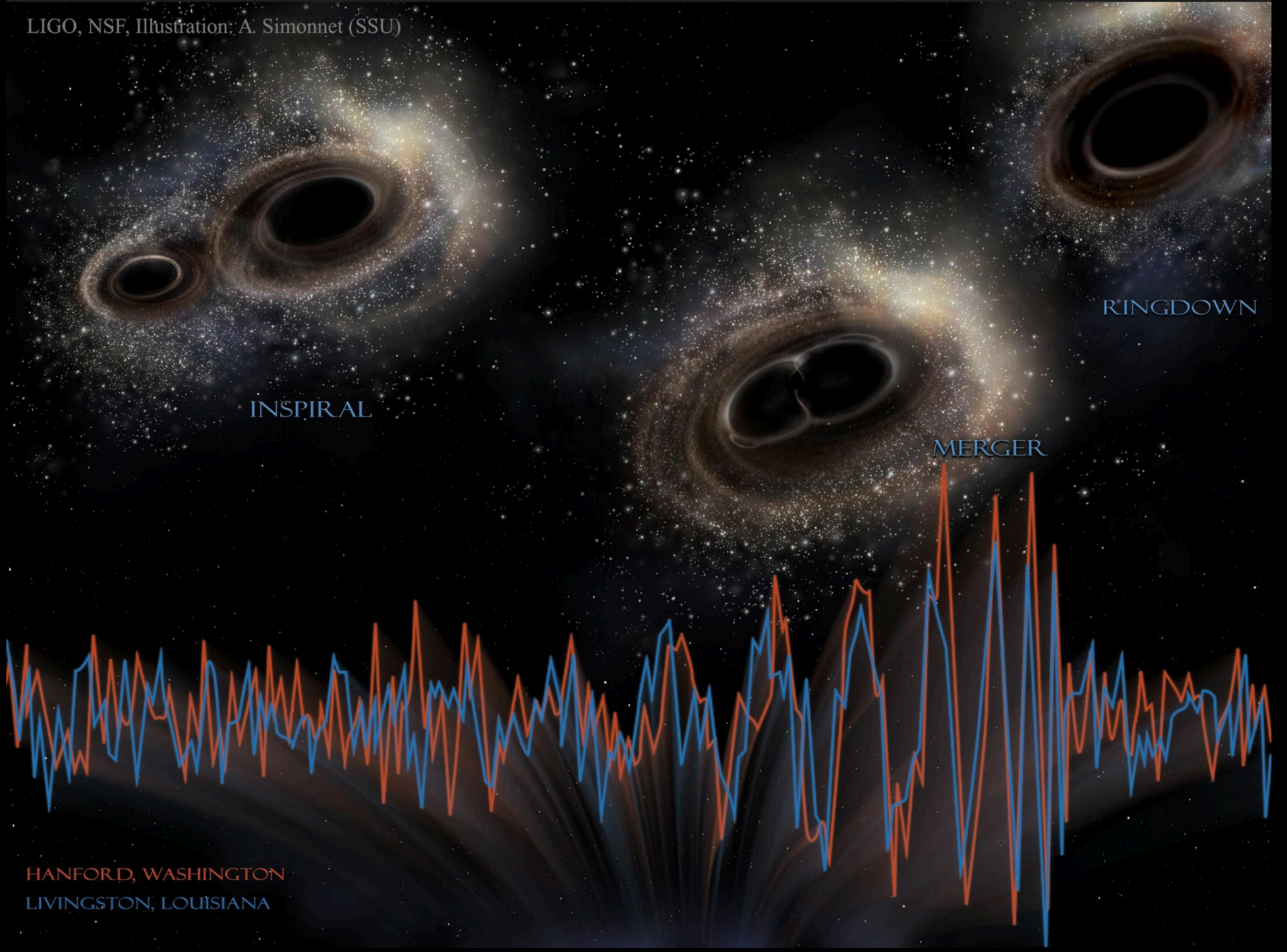
LIGO, NSF, Illustration: A. Simonnet (SSU)
INSPIRAL
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HANFORD, WASHINGTON
LIVINGSTON, LOUISIANA

New binary black hole mergers in the LIGO-Virgo O3 data

Ajit Kumar Mehta

University of California, Santa Barbara (UCSB)

with

D. Wadekar (JHU), J. Roulet (Caltech), T. Venumadhav (UCSB), J. Mushkin (WI), B. Zackay (WI), M. Zaldarriaga (IAS), T. Islam (KITP), I. Anantpurkar (UCSB)

Talk

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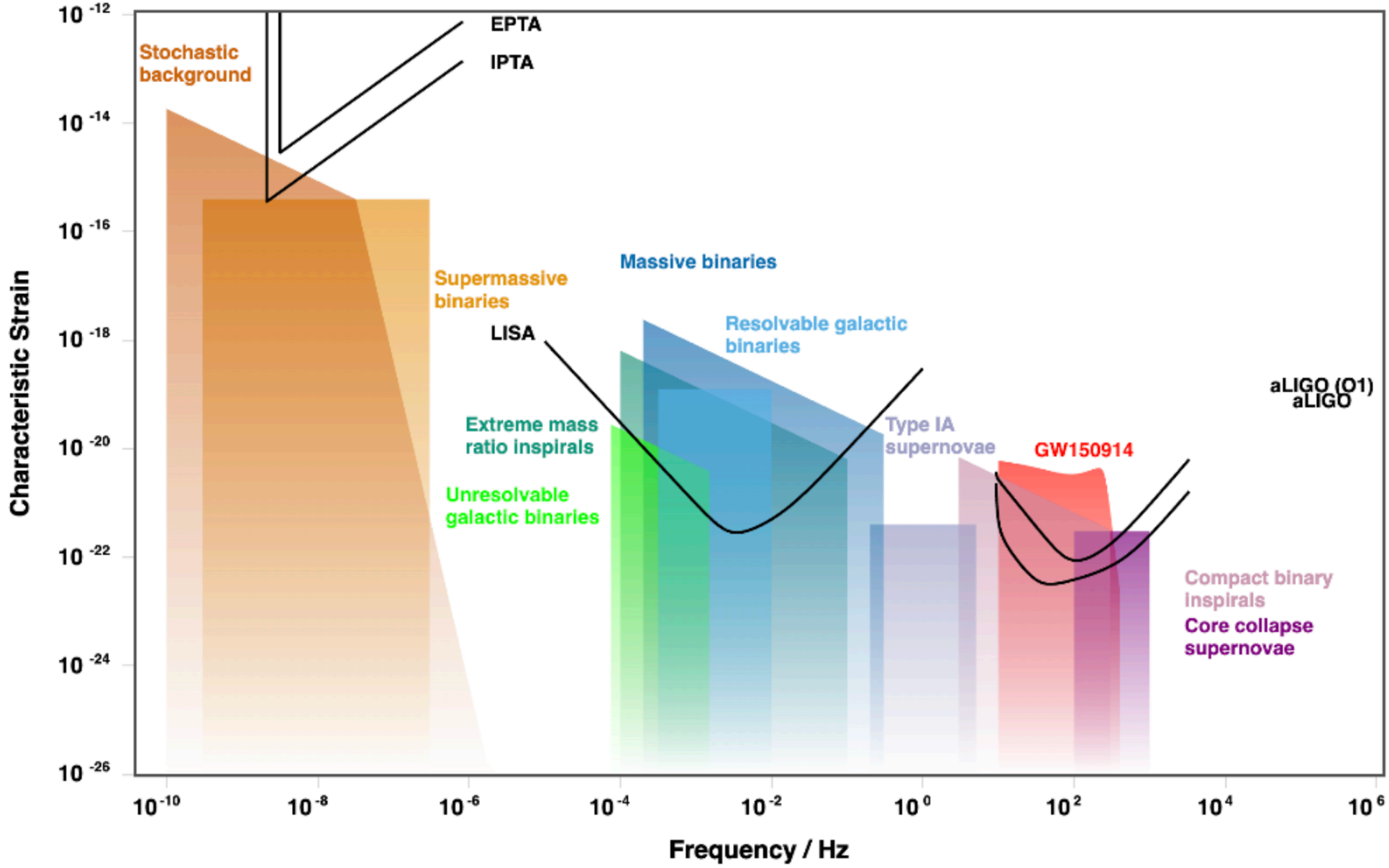
Moscow State University

August 26, 2025

Mehta et al. 2508.15350, 2311.06061 & 2501.17939, Wadekar et al. 2312.06631 & 2405.17400

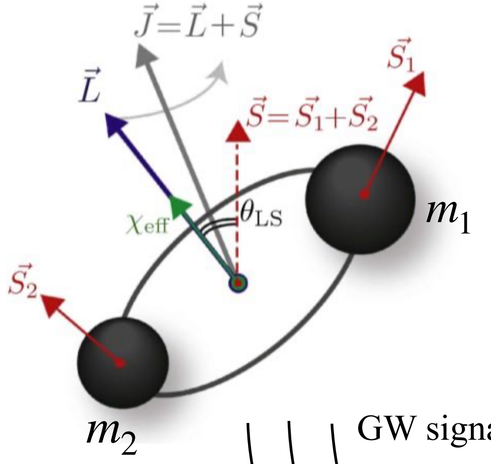
Gravitational Wave Detectors and Sources



Credit: http://www.sr.bham.ac.uk/~cplb/GWplotter/

The overall goal

- The data $d(t)$ generated by LIGO detectors looks just like noise.

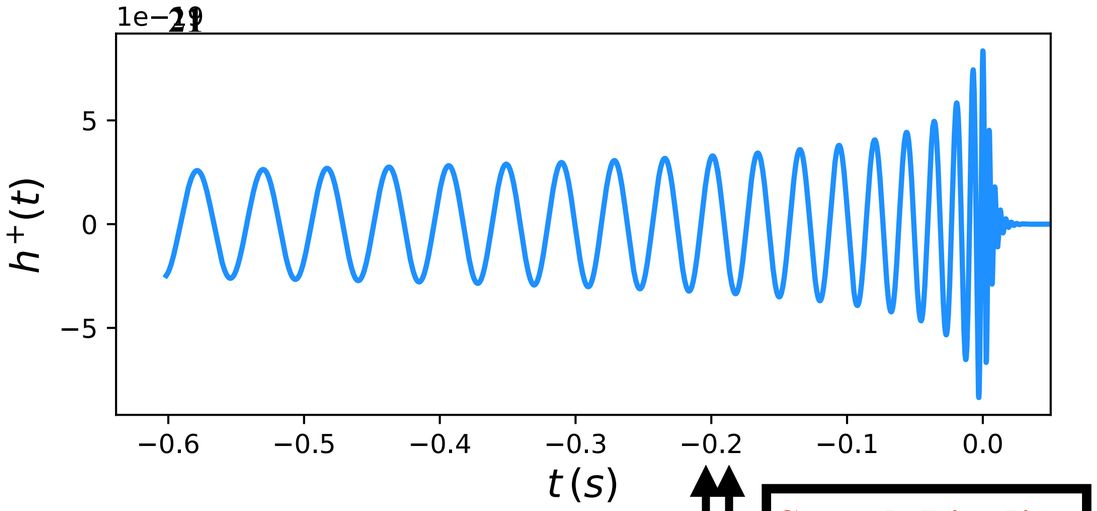


GW signal

$h^{+,\times}(t;\vec{\theta})$

Intrinsic Extrinsic

$\vec{\theta} \equiv \{m_1, m_2, \vec{S}_1, \vec{S}_2, D_L, \iota, t_c, \phi_c, \psi, \alpha, \delta\}$



Search Pipeline

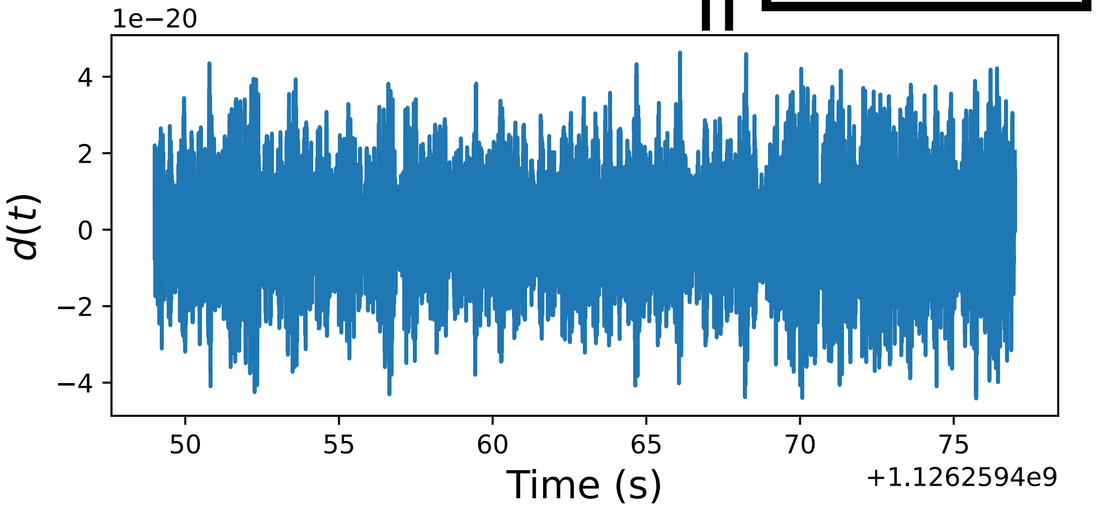
Livingston detector

Recorded strain

Detector noise

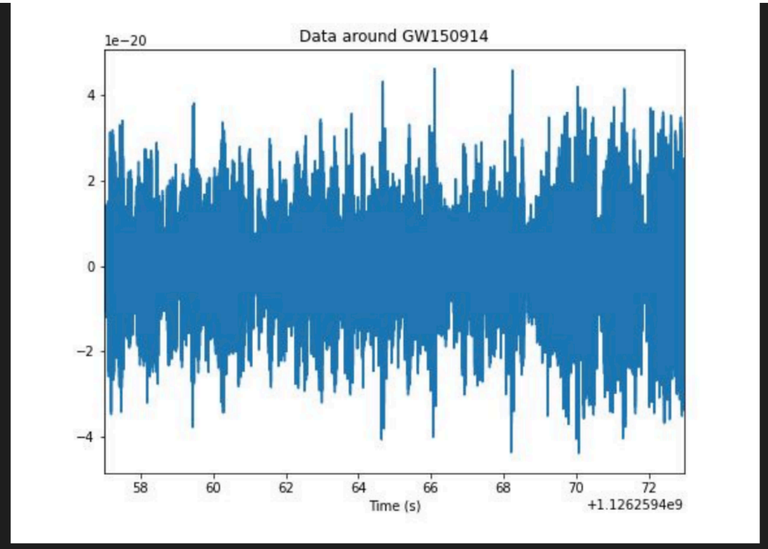
$d(t) = h(t) + n(t)$

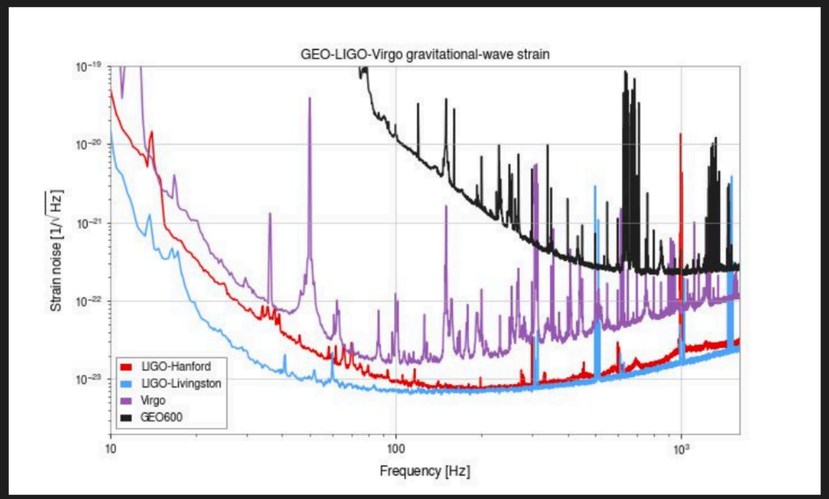
Expected strain

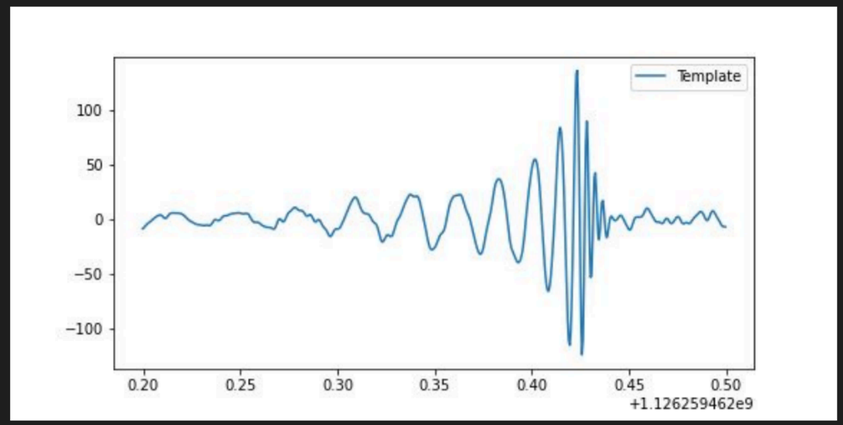


Matched filtering

$$(s|h) = 4\mathcal{R}\int_0^\infty \frac{\tilde{s}(f)\tilde{h}^\star(f)}{S_h(f)}df$$



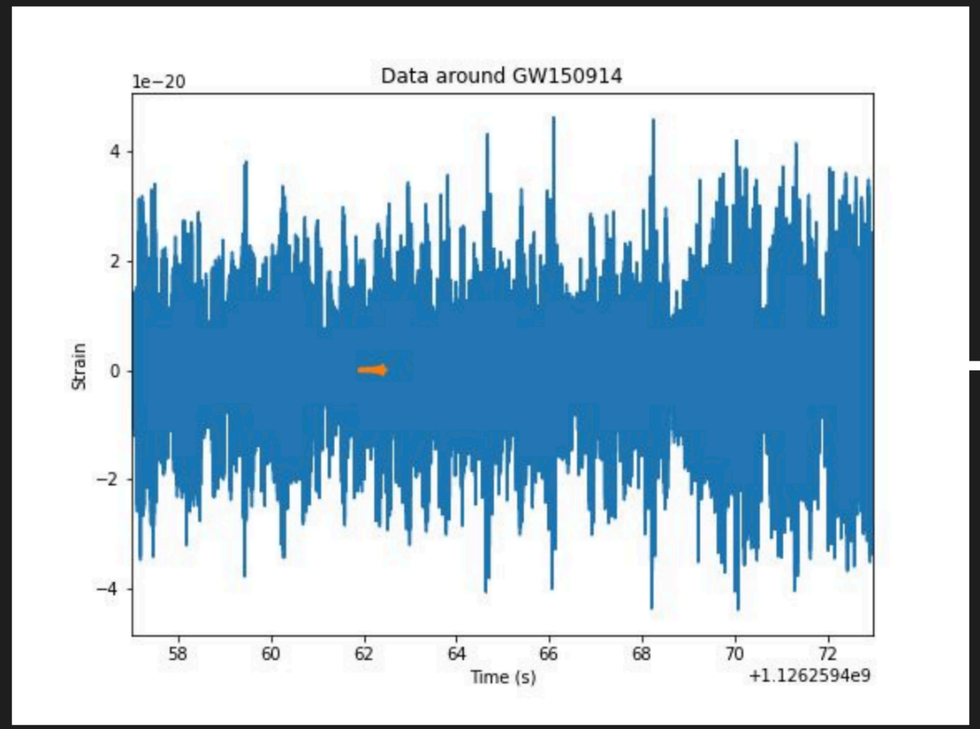


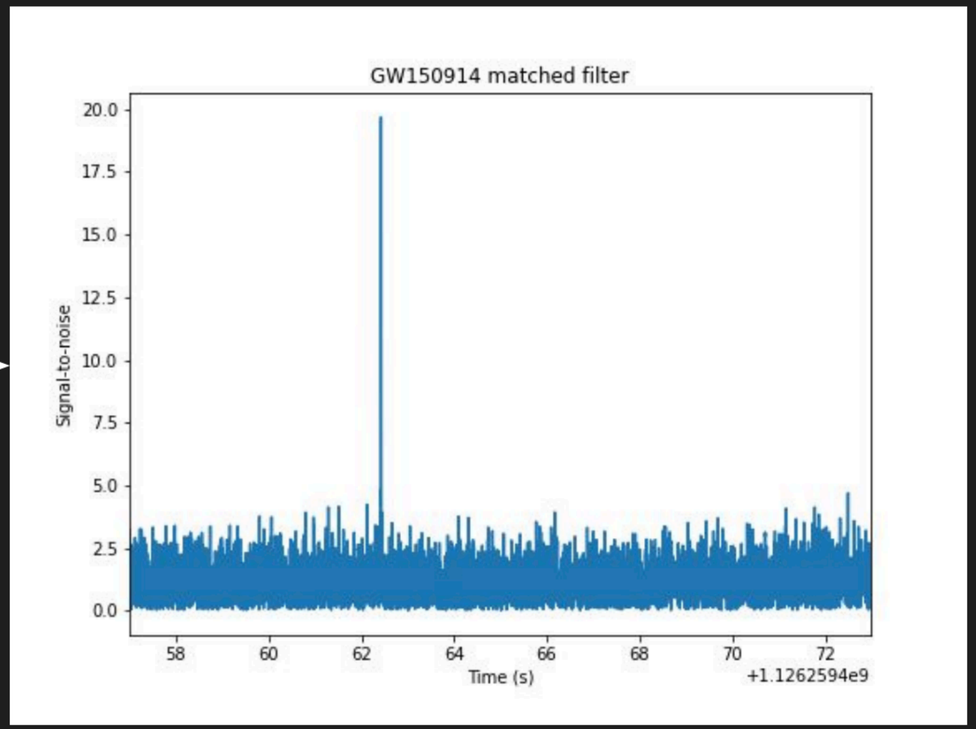


Plots produced using code from Tutorials 1.2 and 2.2

Credit: Derek Davis

Matched filtering result





Plots produced using code from Tutorials 2.1 and 2.2

Credit: Derek Davis

Challenges

Large parameter space

Only considering black hole binaries, signals depend on 15 parameters

It is not computationally possible to search for every possible combination of parameters in this 15+ dimensional space

In order to detect unknown gravitational-wave signals, we must significantly reduce the size of the parameter space

7

What about the noise?

LIGO-Virgo data was stationarity and Gaussian, all we would need is the matched filter

However, we know that over the timescales we need to analyze, these assumptions are definitely not the case

Data is non-stationary and non-Gaussian

In order to identify gravitational-wave signals, we need additional methods to separate signals from noise

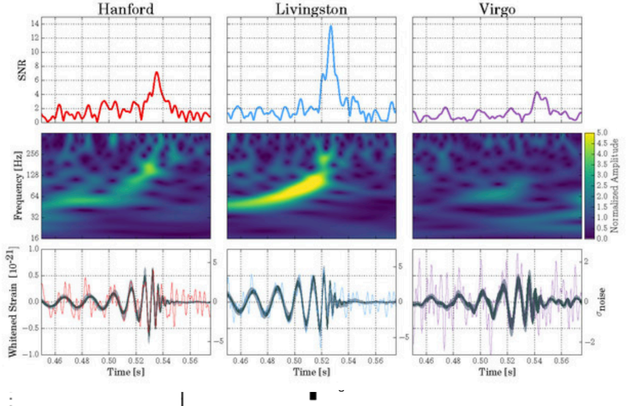
We can use our knowledge of CBC signals to help reject noise artifacts

Overview of a GW search pipeline

Convolve LVK data with templates [$\mathcal{O}$(year)]

$\sim 10^5$ triggers →

Rank triggers based on coherence of detectors

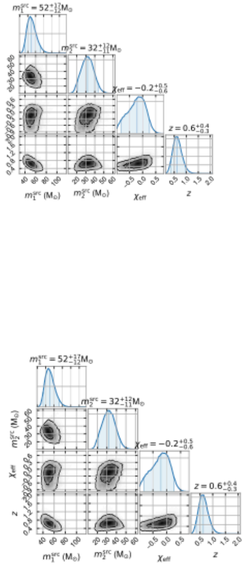


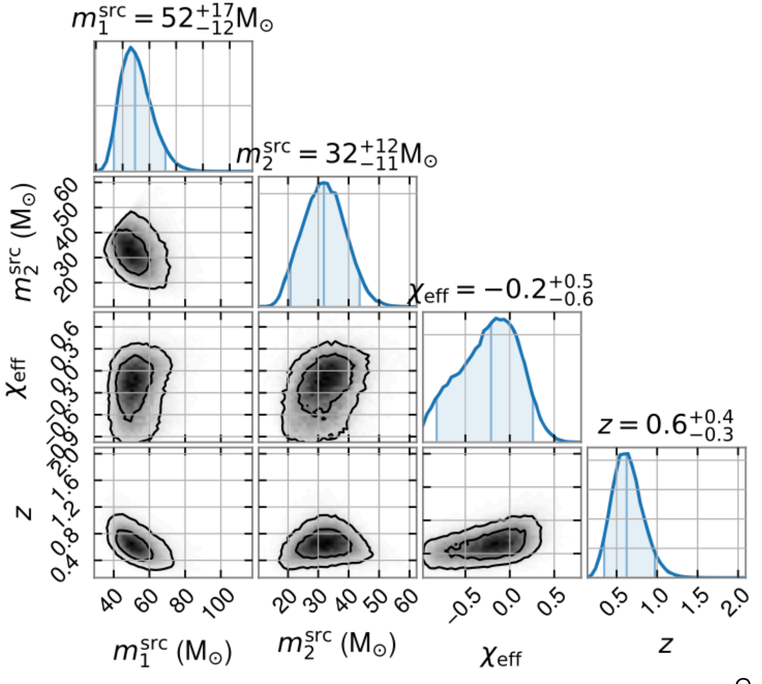
~ 100 triggers

[each $\mathcal{O}$(100) ms] →

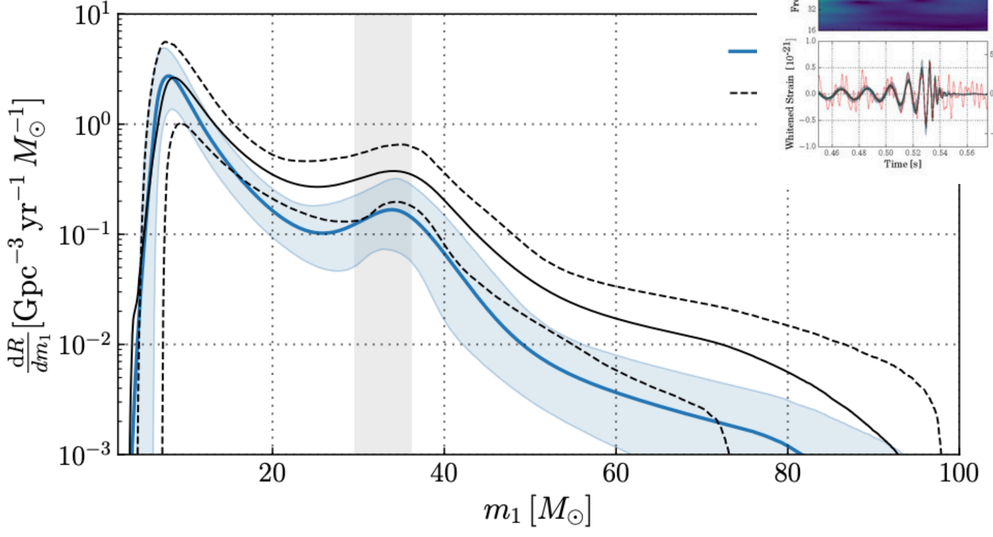
Perform PE (param. estimation)

↓



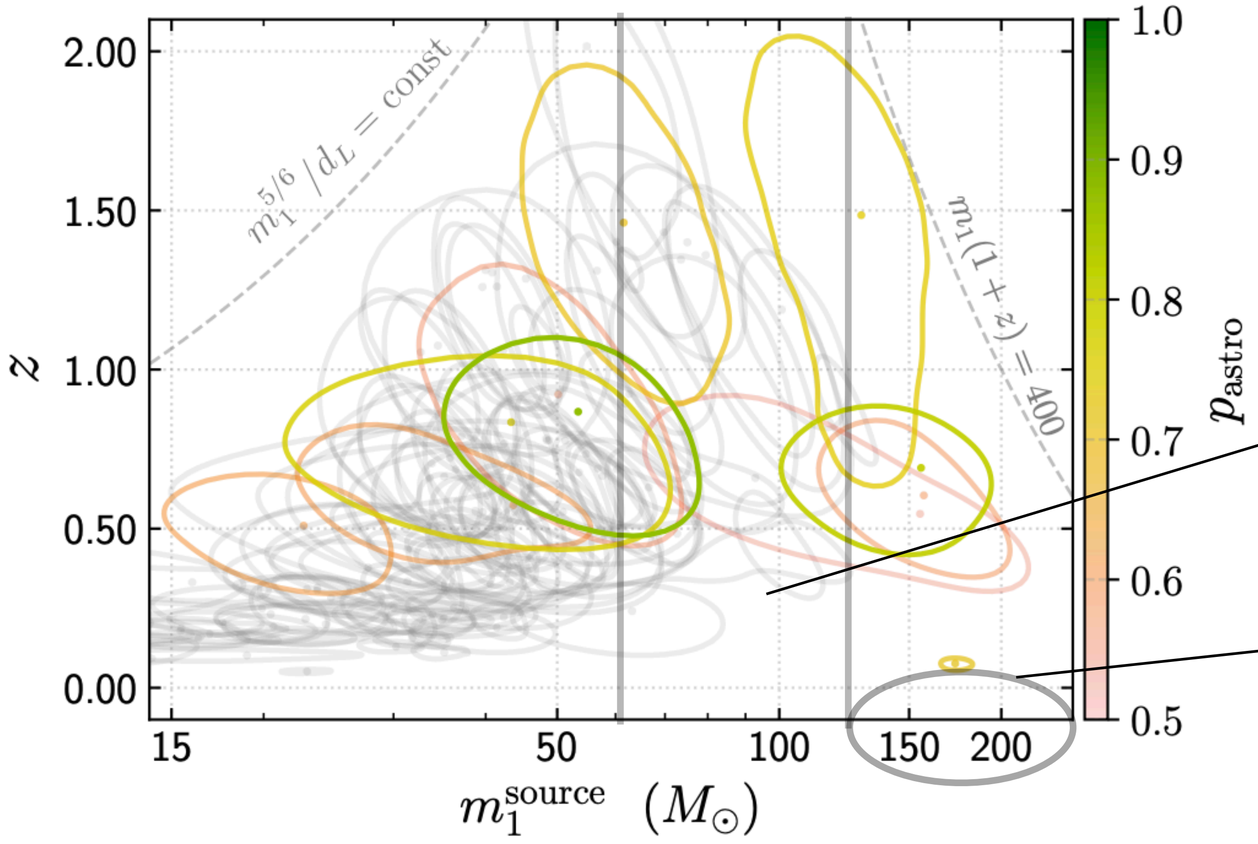


← **Pop. Inference**



New events from IAS-HM across O3

Colored: new detections Gray: LVK catalog + Other pipelines (IAS-22 + OGC)



11 new events

BHs in PISN: Crucial for understanding boundaries of mass gap

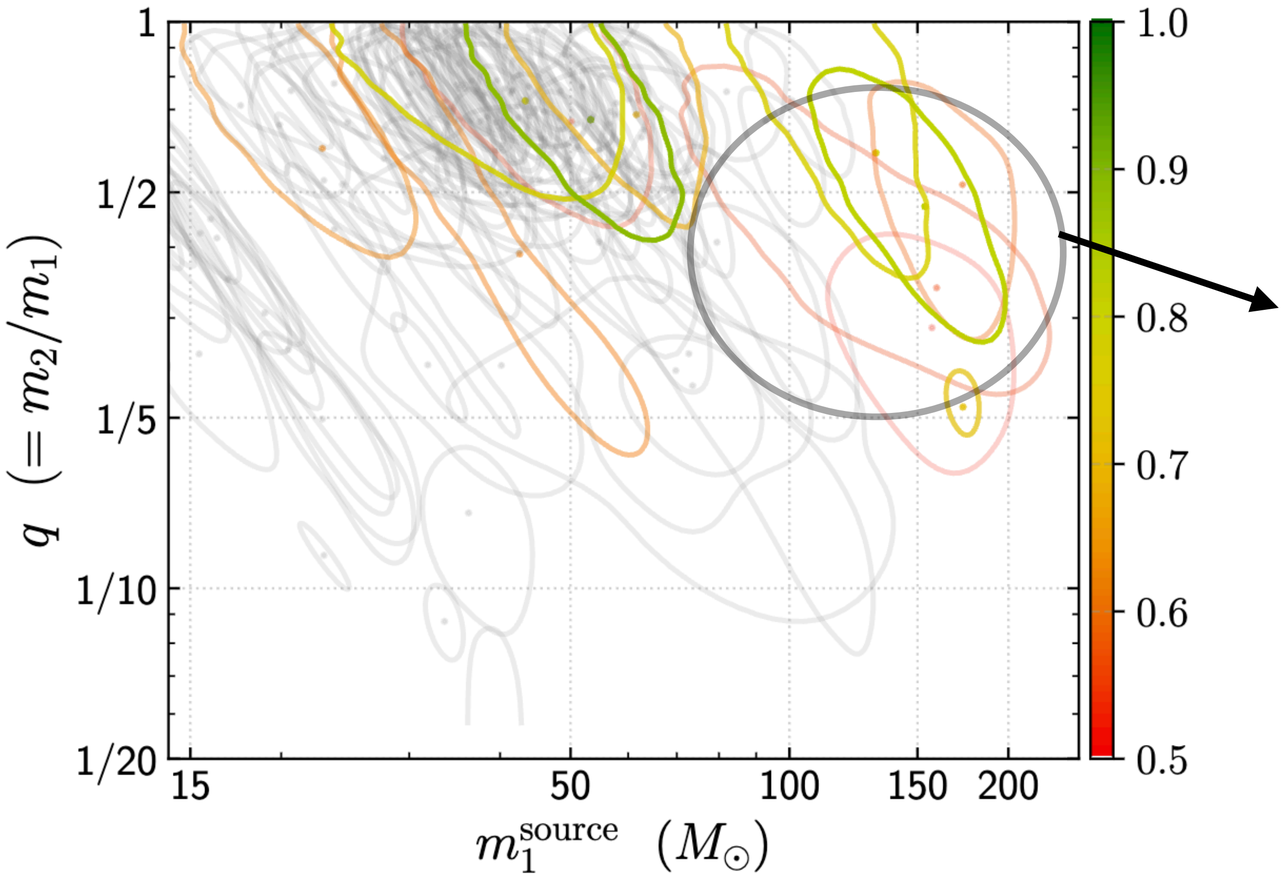
IMBH regime:

- Pop III stars??
- Primordial BHs??
- BHs formation in AGN disks??

Wadekar et al. 2312.06631

New events from IAS-HM across O3

Colored: new detections Gray: LVK catalog + Other pipelines (IAS-22 + OGC)



Mass ratio posteriors extend to lower values and fill the sparse regions.

Wadekar et al. 2312.06631

Mehta et al. 2311.06061

Population results

Astrophysical models of binary black hole mergers

- We fit the binary black hole merger population with simple parametric model for its parameters.

Primary mass,

$$\pi(m_1 \mid \alpha, m_{\min}, \delta_m, m_{\max}, \lambda_{\text{peak}}, \mu_m, \sigma_m) = \Big[(1-\lambda_{\text{peak}})\,\mathcal{P}(m_1 \mid -\alpha, m_{\max}) + \lambda_{\text{peak}}\,\mathcal{G}(m_1 \mid \mu_m, \sigma_m)\Big]\,S(m_1 \mid m_{\min}, \delta_m)$$

Power law distribution with slope $-\alpha$

Gaussian distribution with mean μ_m and variance σ_m

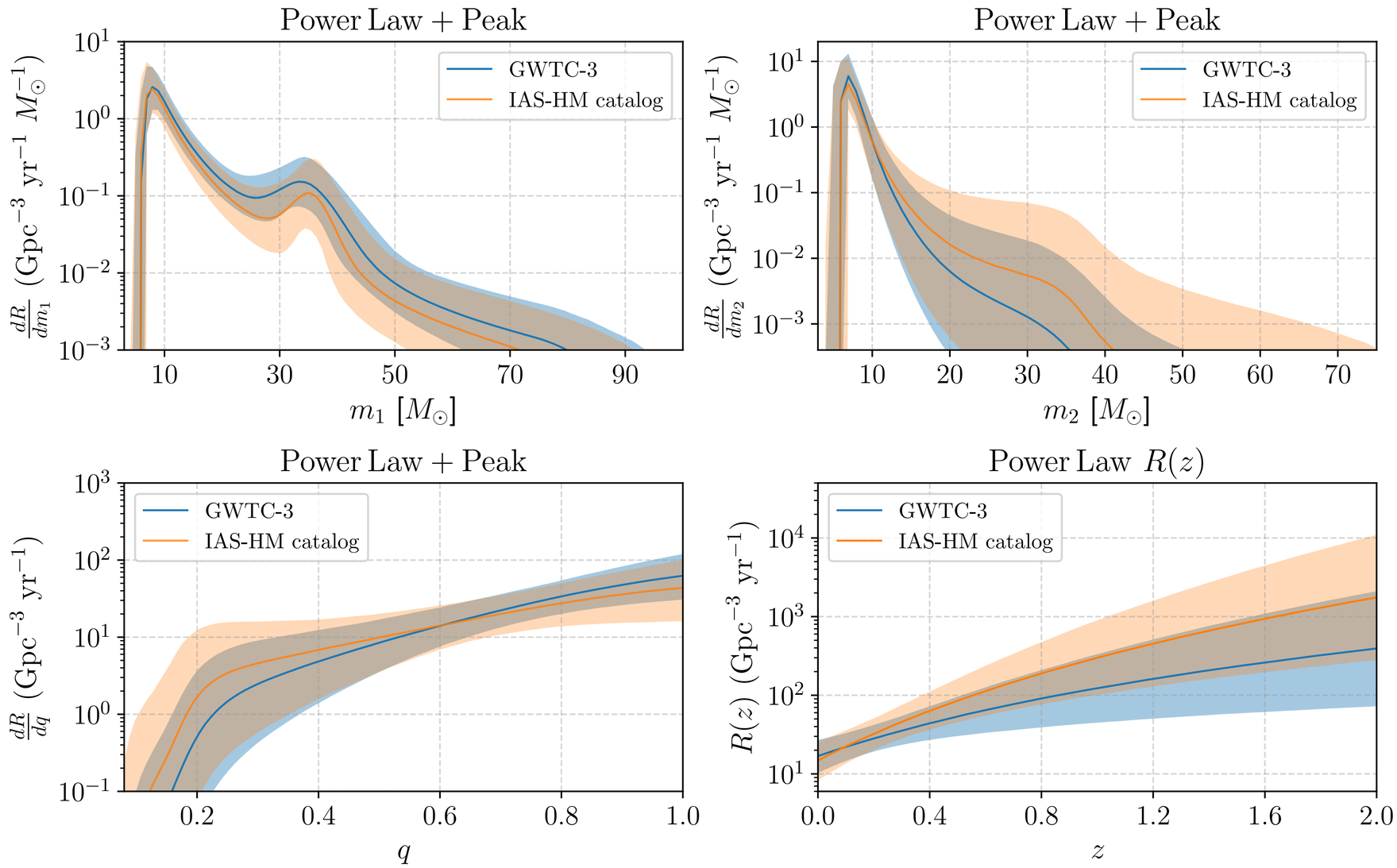
Mass ratio,

$$\pi(q \mid \beta_q, m_1, m_{\min}, \delta_m) \propto q^{\beta_q}\,S(qm_1 \mid m_{\min}, \delta_m)$$

Redshift evolution,

$$R(z) = \mathcal{R}_0\,(1+z)^{\kappa},$$

Measured Population Properties



Mehta et al. 2508.15350

Summary

- Different search pipelines, applied to the same dataset, can yield different results because they handle data complexities differently— for example, in dealing with power spectral density variations or signal-consistency tests.
- The IAS-HM pipeline identifies about 11 new events in the O3 data with astrophysical probability greater than 50%. These events tend to lie at higher redshifts and show lower mass ratios, pointing to more asymmetric mergers.
- A population analysis using the IAS-HM catalog suggests higher merger rates and a preference for asymmetric mergers compared to LVK's GWTC-3.
- With the O4a data now available, it will be exciting to see how these results evolve.