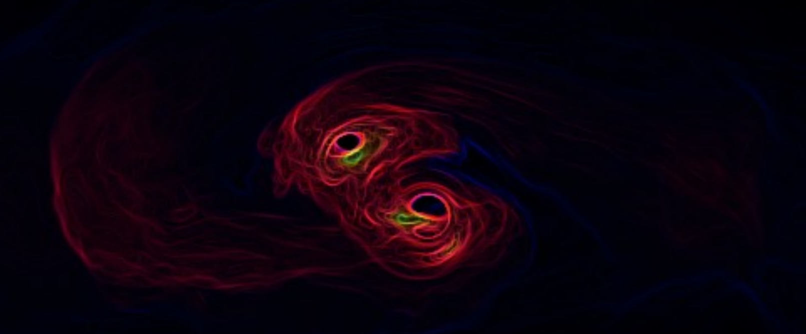
Hunting for intermediate-mass black hole with IGWN



Koustav Chandra
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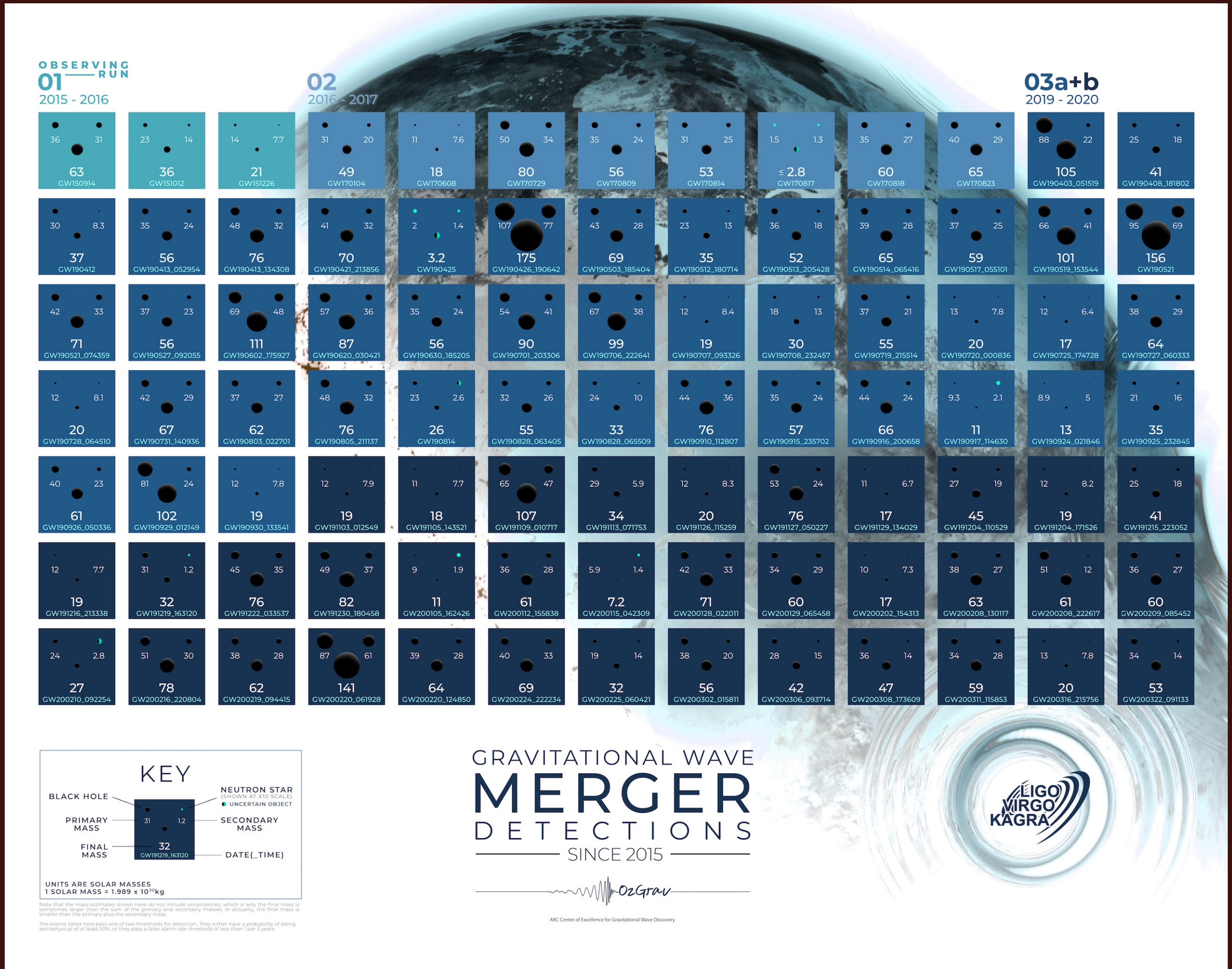
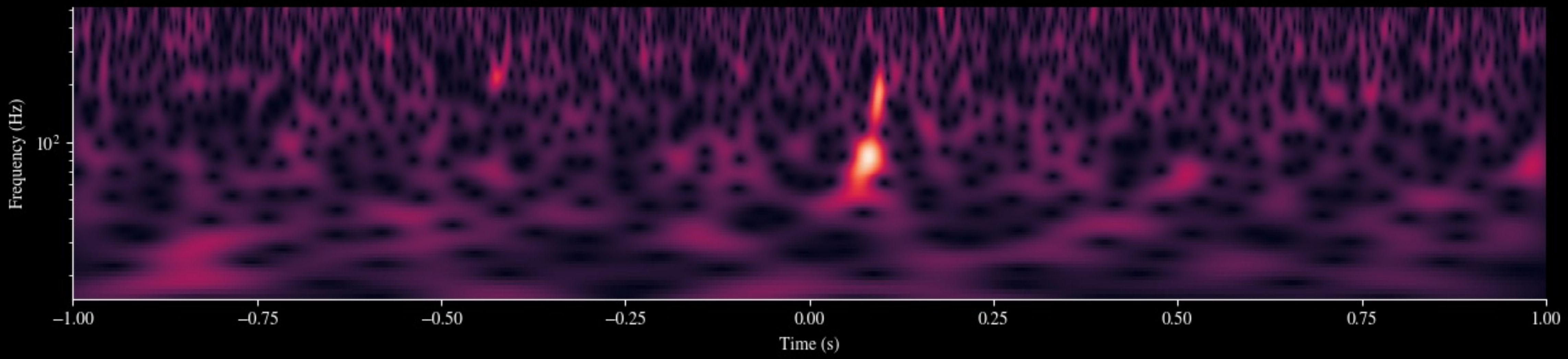
Observing Runs

- 3 observing runs of IGWN
  - Last one = O3
  - Lasted from April '19 to the day before the Corona outbreak in US
  - Commissioning break in October '19

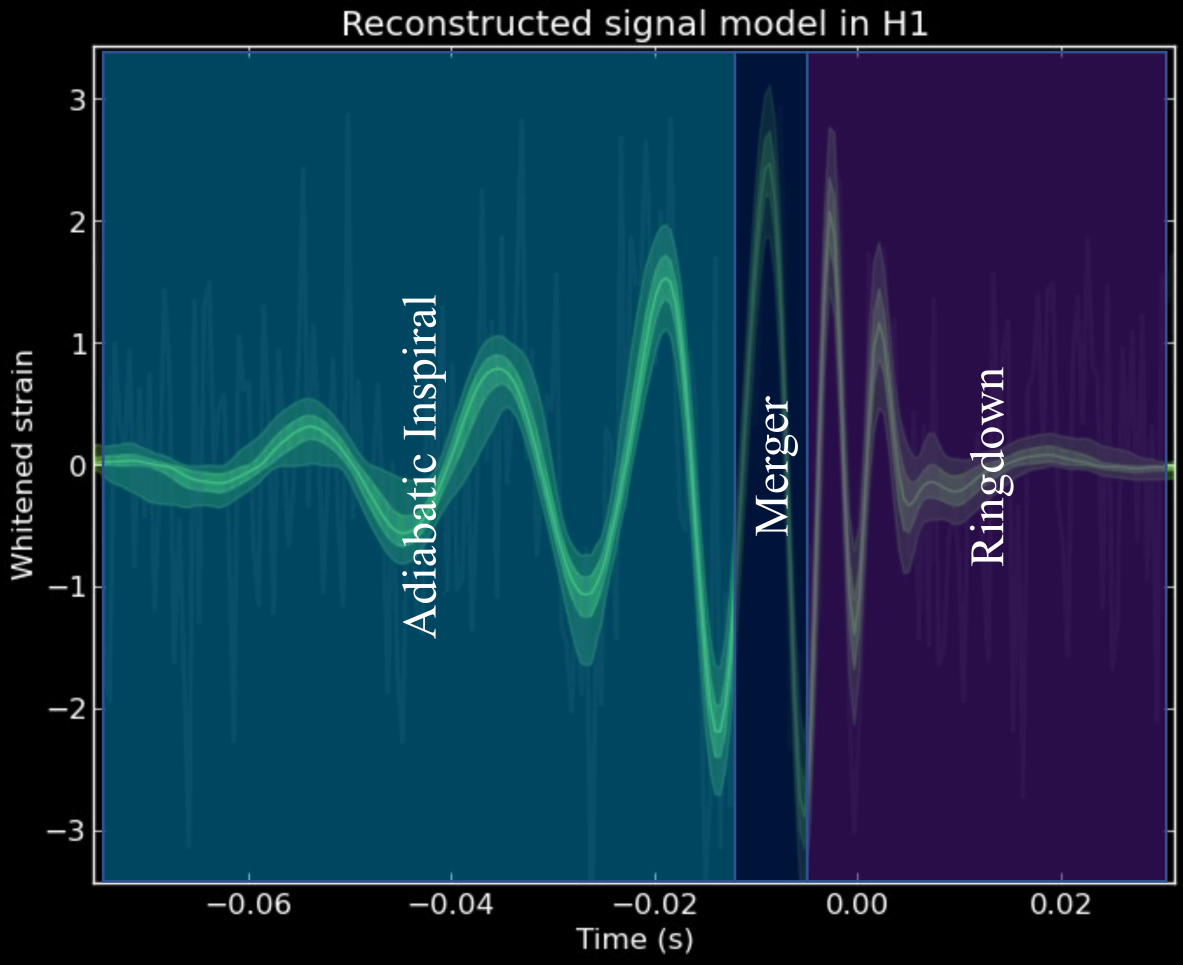


“Canonical” mergers

GW200311_115853



“Canonical” mergers



→ Relatively easier to detect

GW190521

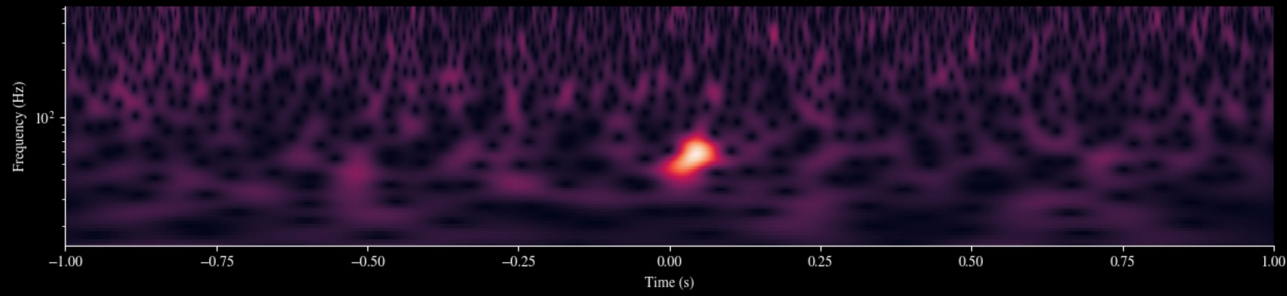
SNR: 14.7 FAR: **1 in 4900 years**

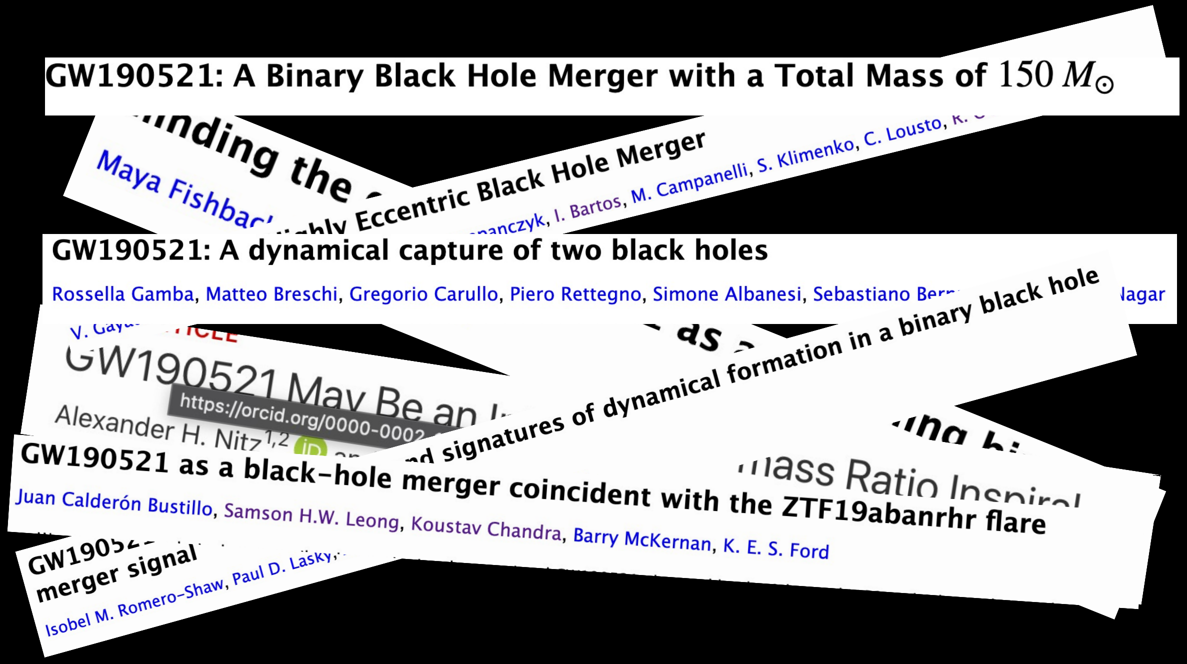
Almost no pre-merger dynamics → Who are the parents?

Definitely an IMBH remnant

How do we detect these elusive giant corpses?

IMBH: $M_{BH} \in [100, 10^5] M_\odot$





Basic Principle

$h(t)$

mimic

Residual ← $r(t) = d(t) - s(t) = n(t)$

For BBH Hunting
Deterministic
Or
Modelled

Stochastic Process

Future values are not uniquely determined by initial data! Rather samples from some probabilistic model

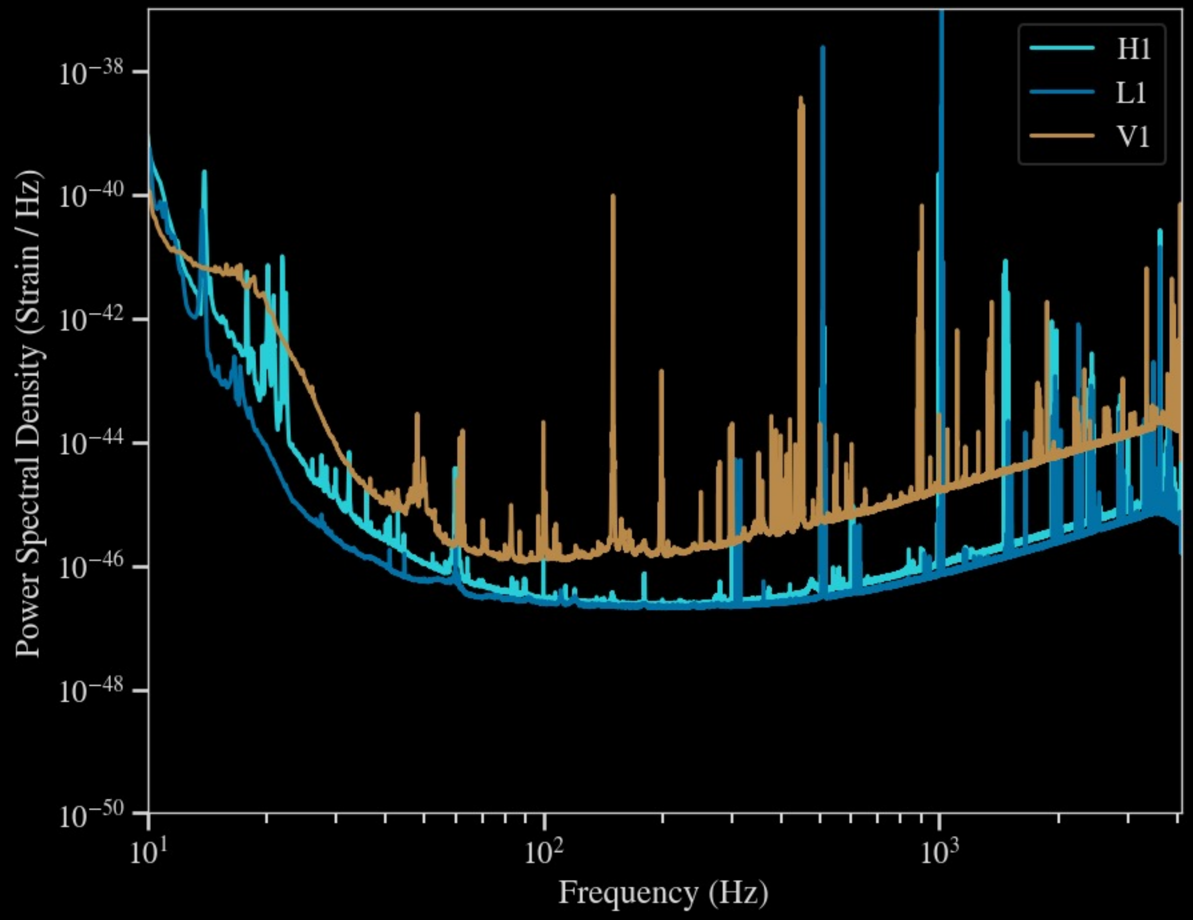
Romano+16

Noise Model

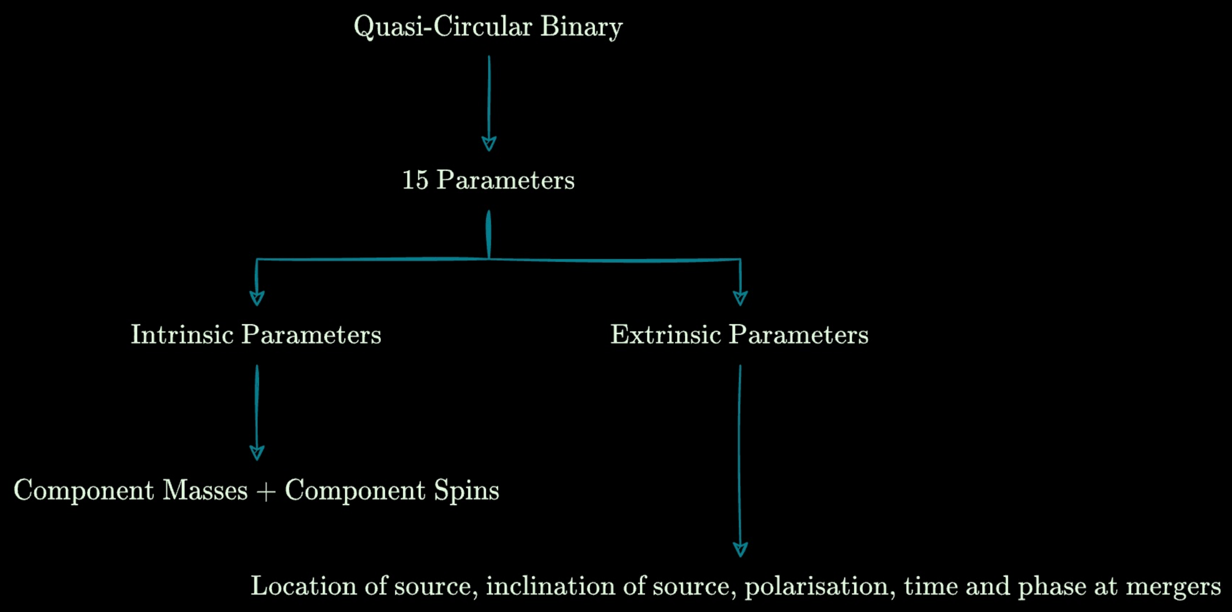
Noise is an ergodic, wide-sense stationary, Gaussian process.

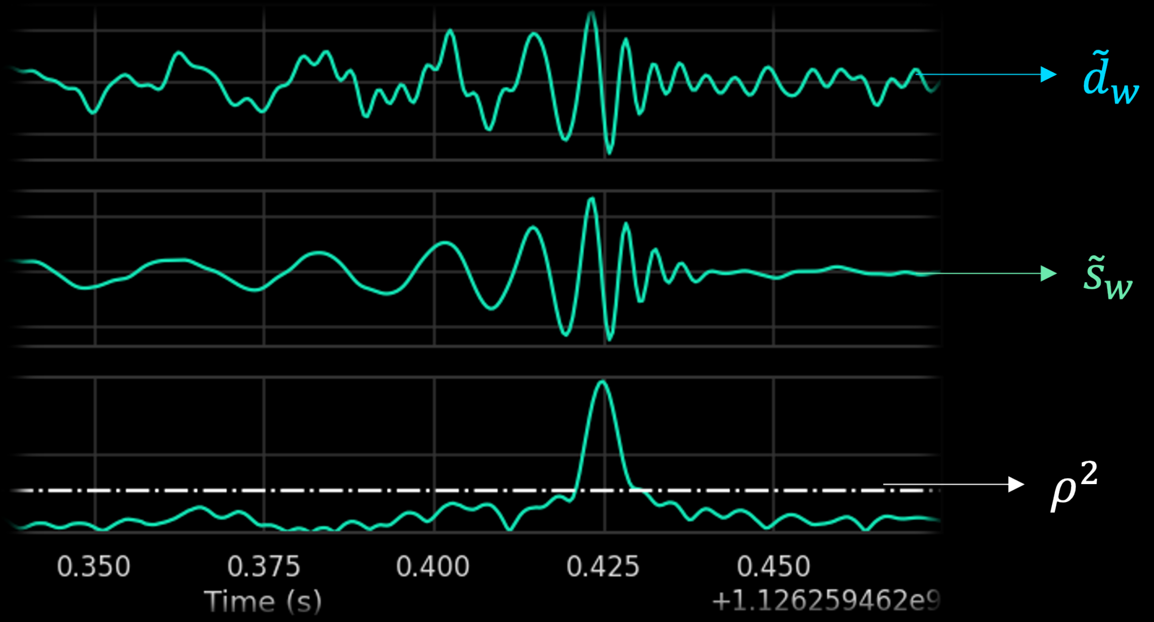
↓

Power spectrum conveys all the required information about the statistical properties of the noise!



Signal Model + Match Filtering





Problem:

- Don't know the parameters of the signal we are hunting for → Create template bank
- Searching over 15 dimensional parameter space is computationally prohibitive

Solution:

- Assume that the signal can be well described by dominant modes of a quasi-circular non-precessing binary
- Sufficient to search over the component masses and z-component dimensionless spin.

Sathya+'91, Allen+05

Multi-detector Candidates

Demand: Astrophysical triggers must share the same best-matched template & must be observed within a given time-lag difference.

Rank coincident triggers by using quadrature sum of SNRs

Statistical Significance

Generate background & compare the rank of a candidate against them.

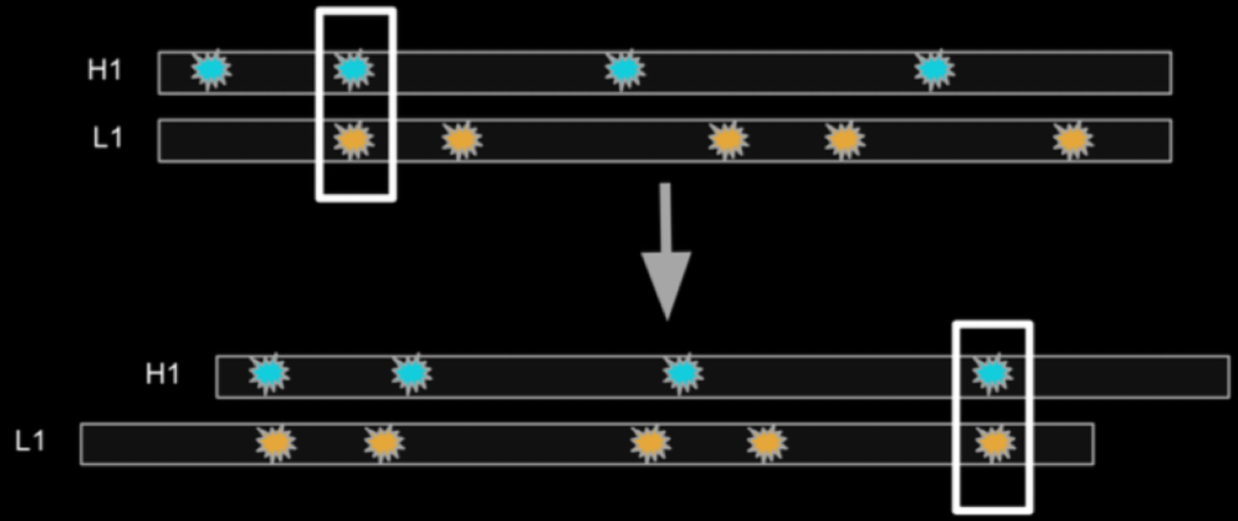
Quoted in terms of FAR = $\frac{n_b(R>R^*)}{T_b}$

# of bkg triggers with ranks $R > R^*$

Background time

$$T_b = \frac{T_a^2}{T_{shift}}$$

IFAR = 1/FAR

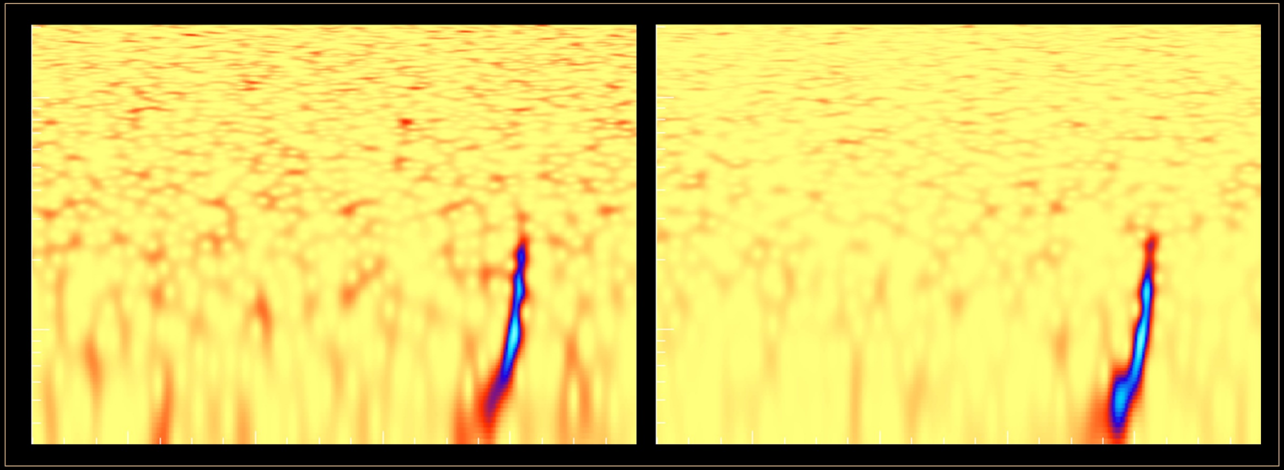


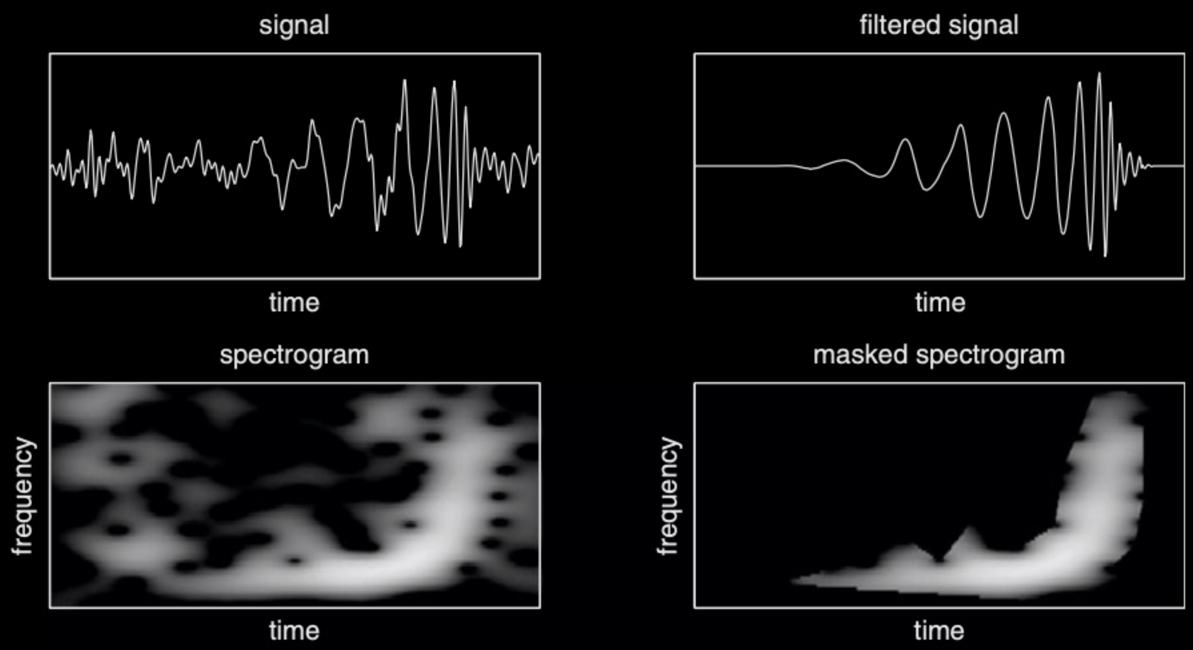
Usman+15

Burst Searches

- Rationale: GW signal are transient waveform → Create localised excess of energy in TF plane coherently across the detector.
- TF maps are created by wavelet transform of time domain data.
- Ranking statistics = f(Clustered TF Pixels)
- Assign FAR by method of time slides

Klimenko+15





Headaches!

~~LIGO data can be modelled to be Gaussian~~

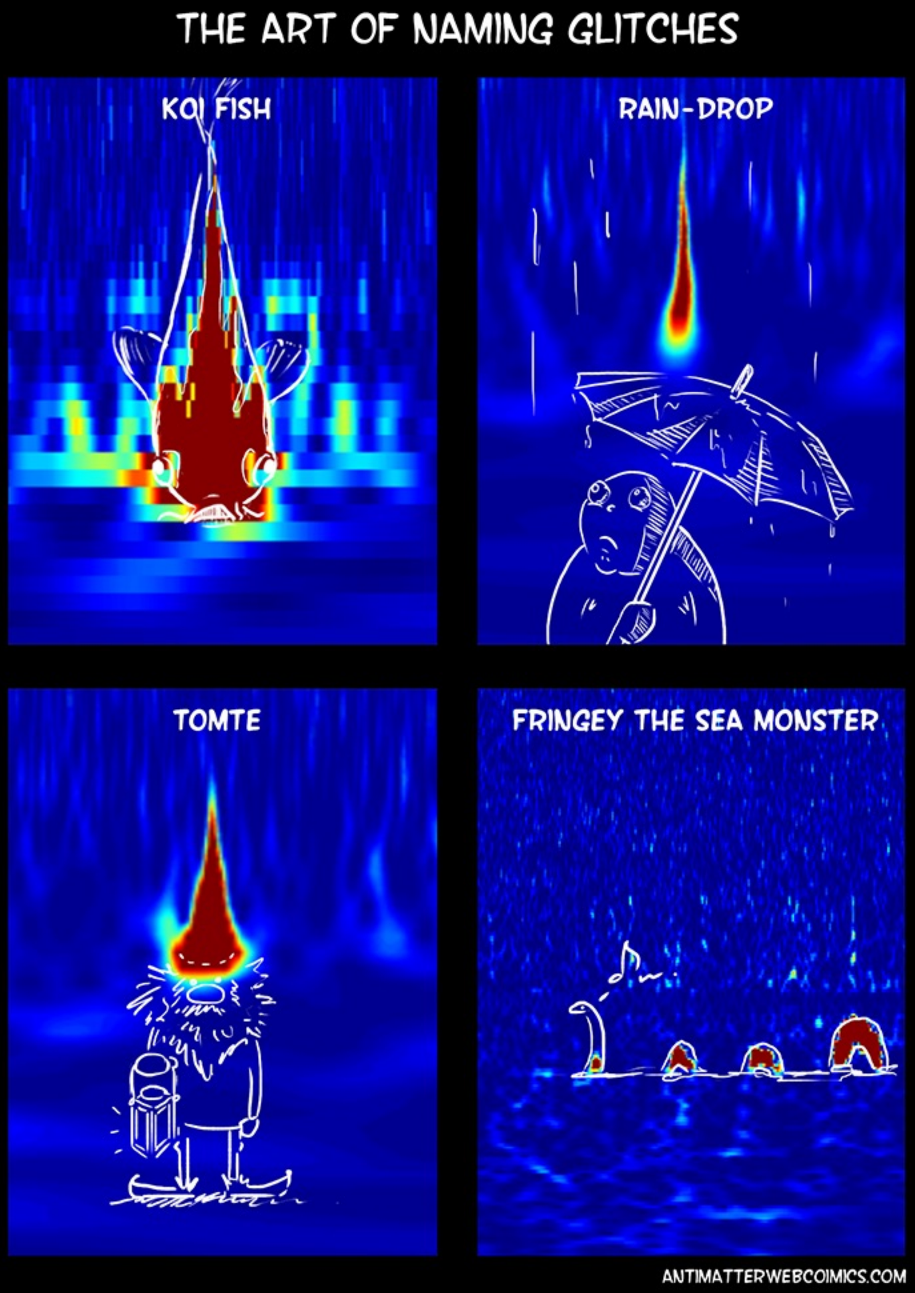
~~LIGO data can be modelled to be wide-sense stationary~~

Tackle

Perform signal consistency test

Use signal-noise discriminators

Allen ’04, Klimenko+15, . . .



O3 IMBH Search

No new confident detection in IMBH search other than GW190521

Coherent Burst Search

Coincident Matched-Filter Search

Meta Analysis

Events	cWB FAR(yr^{-1})	PyCBC FAR(yr^{-1})	GstLAL FAR (yr^{-1})	P-value
GW190521	2.0×10^{-4}	1.4×10^{-3}	1.9×10^{-3}	4.5×10^{-4}
200114_020818	5.8×10^{-2}	$8.6 \times 10^{+2}$	$3.6 \times 10^{+4}$	0.12
200214_224526	1.3×10^{-1}	-	-	0.25

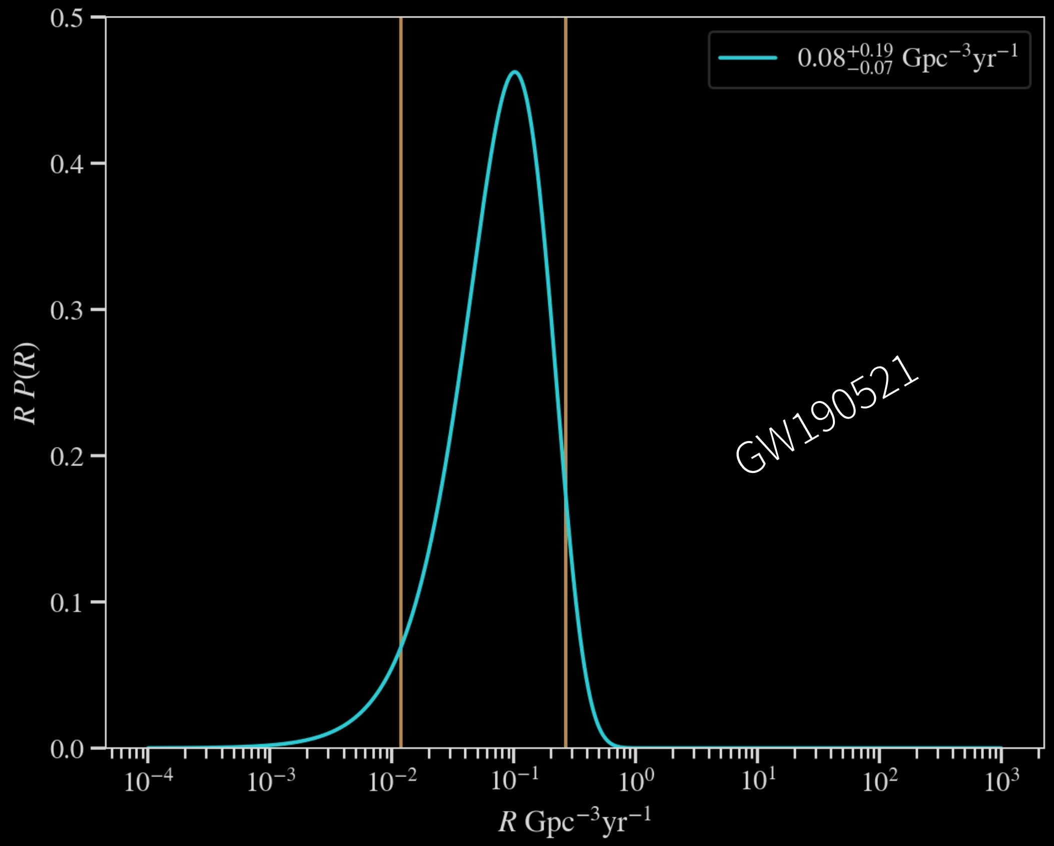
Dubious

Guaranteed Noise Trigger

Chandra+21, O3 IMBH

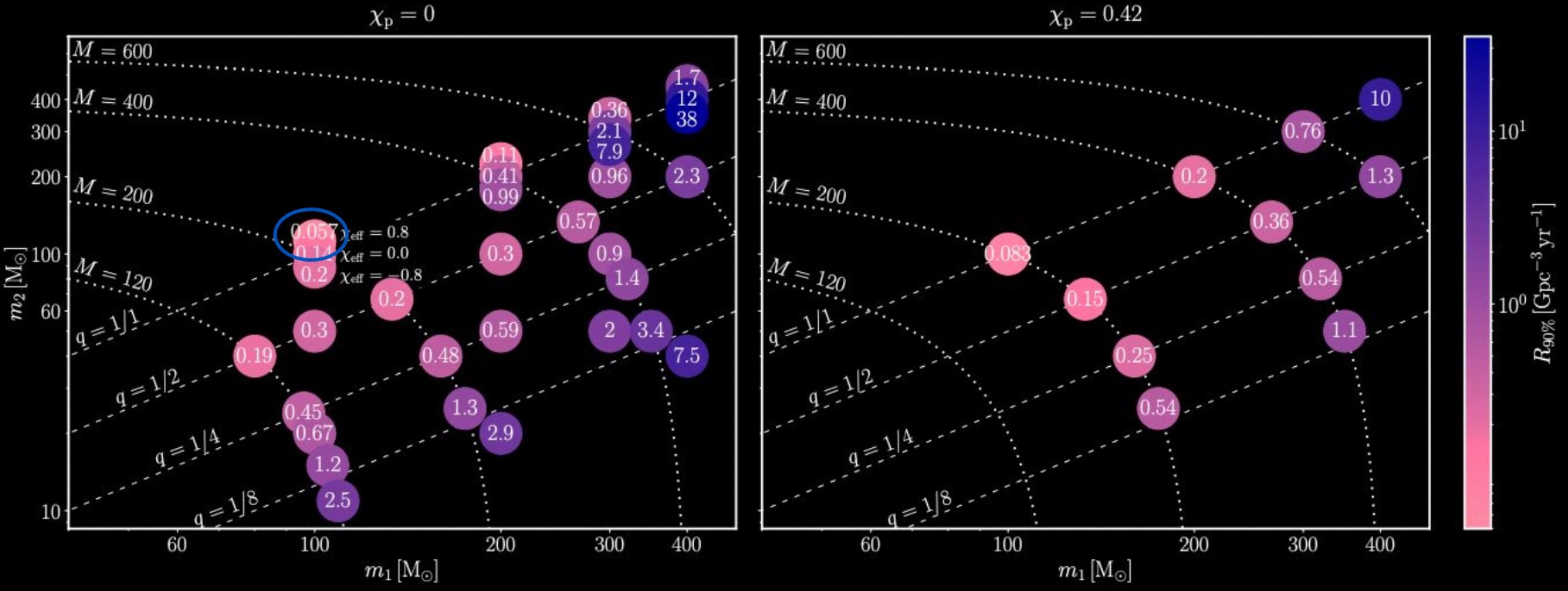
SINGLE-EVENT BASED MERGER RATE ESTIMATE

- Insufficient number of IMBHB detections = Cannot meaningfully estimate merger rate for the population of IMBHBs
- Treat each event as a sole representative of a new class of events with same intrinsic parameters
- Use o/p samples of intrinsic parameters to cook up a population
- Estimate merger rate based on it



O3 IMBH

Injection based Merger Rate Upper Limit

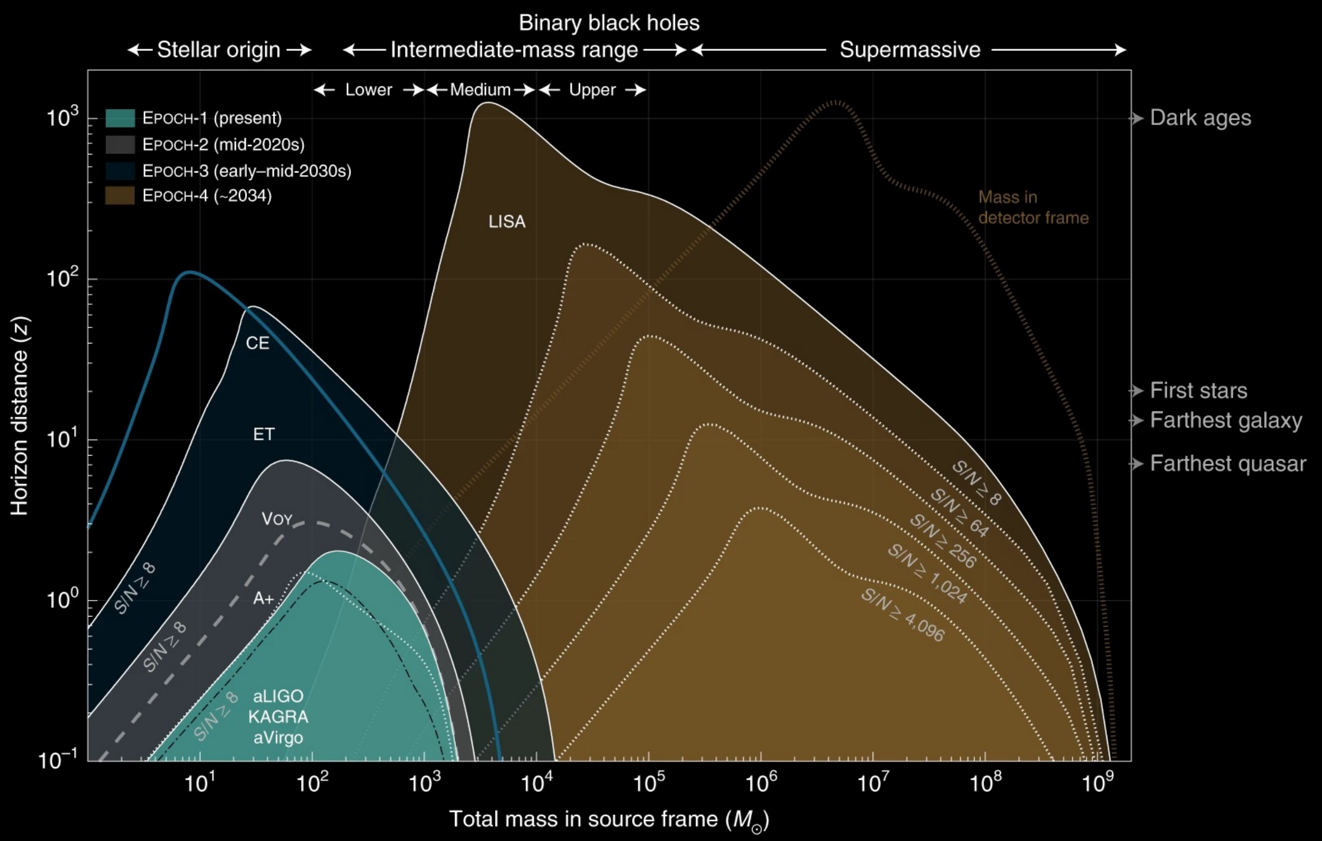


Chandra+20, O3 IMBH

Conclusion

With our current methods:

- We have reported the first unambiguous detection of IMBH.
- Lots of unanswered questions on their origin, population, etc..
- Bright future: 3G detectors, LISA



K. Jani+(2020)


Neutron Stars detected
Stellar Black Holes detected
Supermassive BHs detected
Intermediate-mass BHs detected

Backup

Comparison between searches

mass1_source	mass2_source	chi_eff	chi_p	PyCBC_VT	cWB_VT	GstLAL_VT
60	60	0	0	16.01	12.24	11.71
80	40	0	0	11.51	8.93	8.18
96	24	0	0	4.64	3.54	3.04
100	20	0	0	3.11	2.42	2.06
105	15	0	0	1.67	1.24	1.05
109.09	10.91	0	0	0.82	0.6	0.51
100	50	0	0	11.95	9.96	7.4
100	100	0	0	14.84	12.76	10.27
133.33	66.67	0	0	10.35	9.47	6.56
160	40	0	0	3.9	3.69	1.93
175	25	0	0	1.34	1.29	0.53
200	20	0	0	0.57	0.6	0.22
200	50	0	0	2.99	2.83	1.8
200	100	0	0	6.27	5.86	5.38
300	50	0	0	0.72	0.75	0.44
200	200	0	0	4.82	4.55	4.29
266.67	133.33	0	0	3.08	3.33	2.68
300	100	0	0	1.68	1.94	1.29
320	80	0	0	1.11	1.22	0.7
350	50	0	0	0.44	0.47	0.2
200	200	-0.8	0	1.9	1.86	1.66
300	300	-0.8	0	0.22	0.22	0.11
400	400	-0.8	0	0.04	0.05	0.03
100	100	0.51	0.42	26.38	20.88	19.42
133.33	66.67	0.14	0.42	13.97	12.36	9.01
160	40	0.26	0.42	7.67	7.65	4.13
175	25	0.32	0.42	3.35	3.59	1.44
200	200	0.51	0.42	10.53	9.38	9.19
266.67	133.33	0.14	0.42	4.96	5.42	4.24
320	80	0.26	0.42	2.58	3.63	1.88
350	50	0.32	0.42	1.11	1.79	0.65
300	300	0.51	0.42	2.44	2.49	1.72
400	200	0.14	0.42	1.12	1.45	0.58
400	400	0.51	0.42	0.1	0.18	0.01

K. Chandra +21