The Gravitational-Wave Universe: Recent Results from LIGO-Virgo-KAGRA

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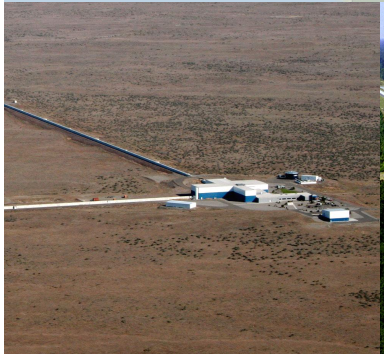
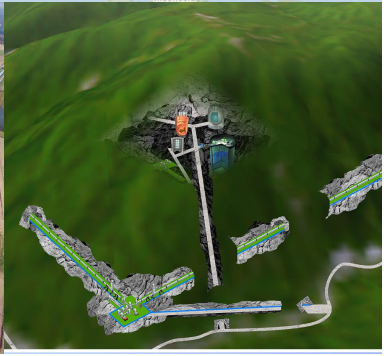
IP2I Lyon
30 March 2026

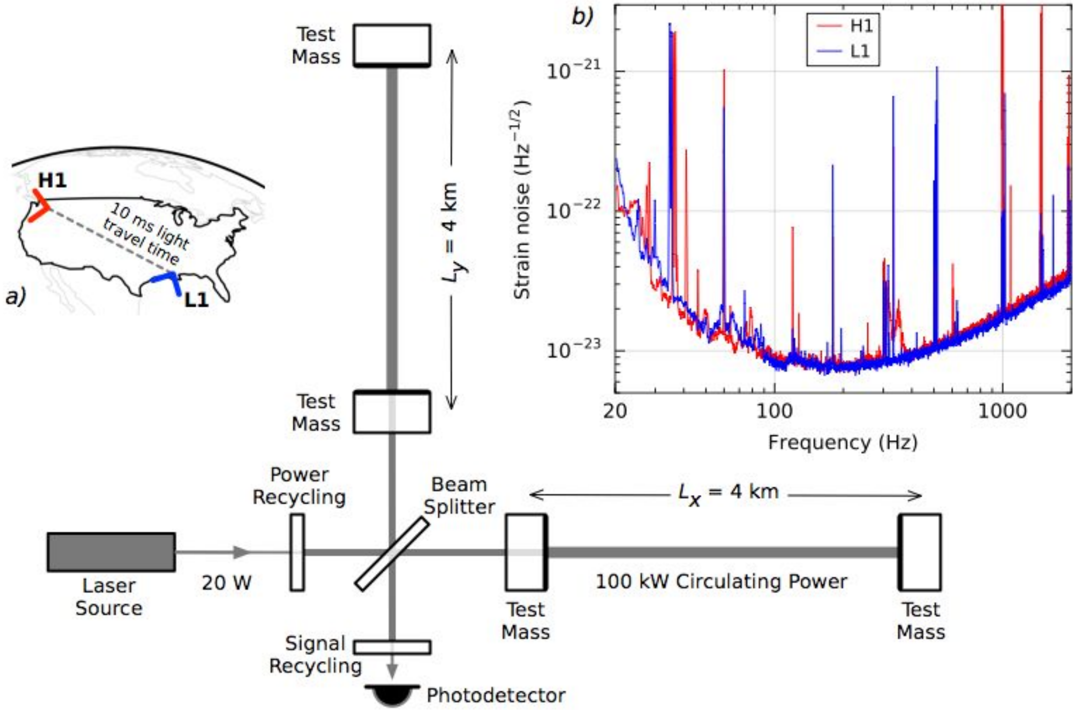
https://dcc.ligo.org/G2600921

International Gravitational-Wave Observatory Network (IGWN)





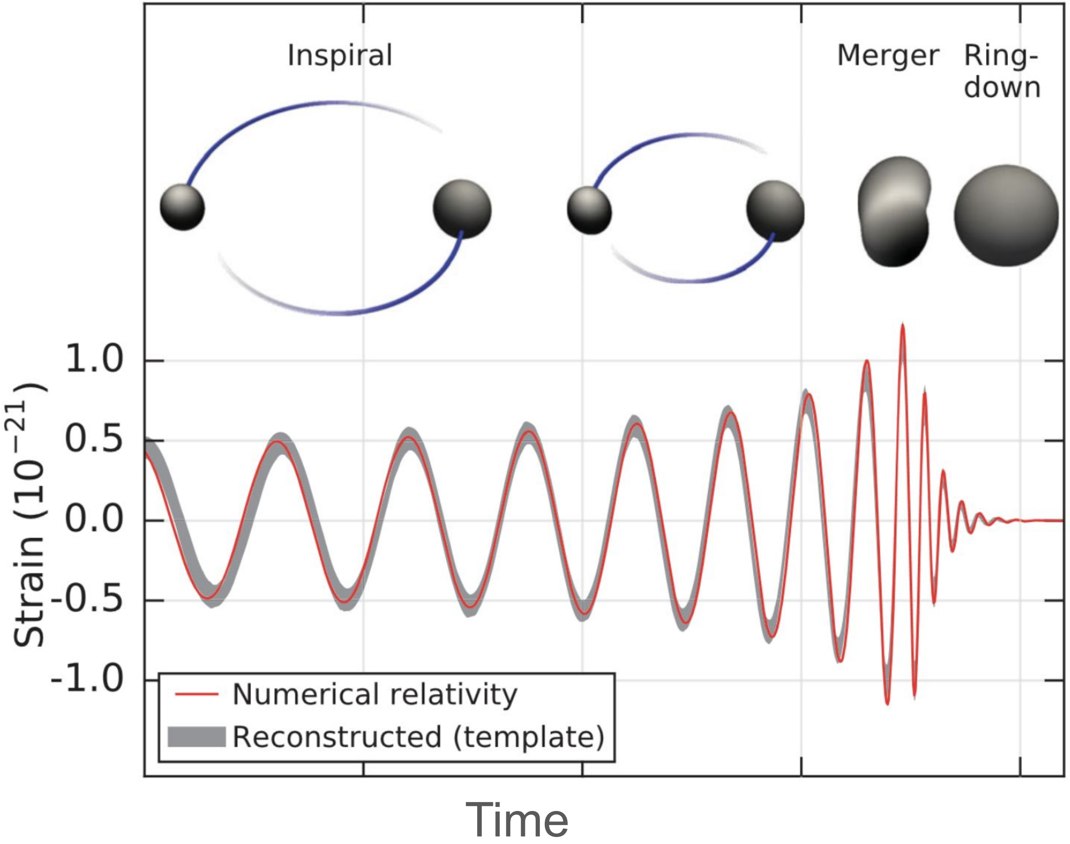
Ground-based Gravitational-Wave Detector



LIGO proposed by Ron Drever, Kip Thorne, and Rai Weiss in 80's.
First funding in 1992; civil construction ended 2000; Initial LIGO 2002-2010

Compact object mergers

Pairs of stellar-mass black holes, neutron stars, or a stellar-mass black hole and neutron star



B.P. Abbott et al. Phys. Rev. Lett. 116, 061102

Strain (quadrupole) at the detector

$$h(t) = \frac{\mathcal{M}'\Theta(i,\lambda,\delta,\psi)}{d_L}\left[\pi\mathcal{M}' f(\mathcal{M}', t - t_0)\right]^{2/3} \cos\left[\Phi(t_0 - t) + \Psi\right]$$

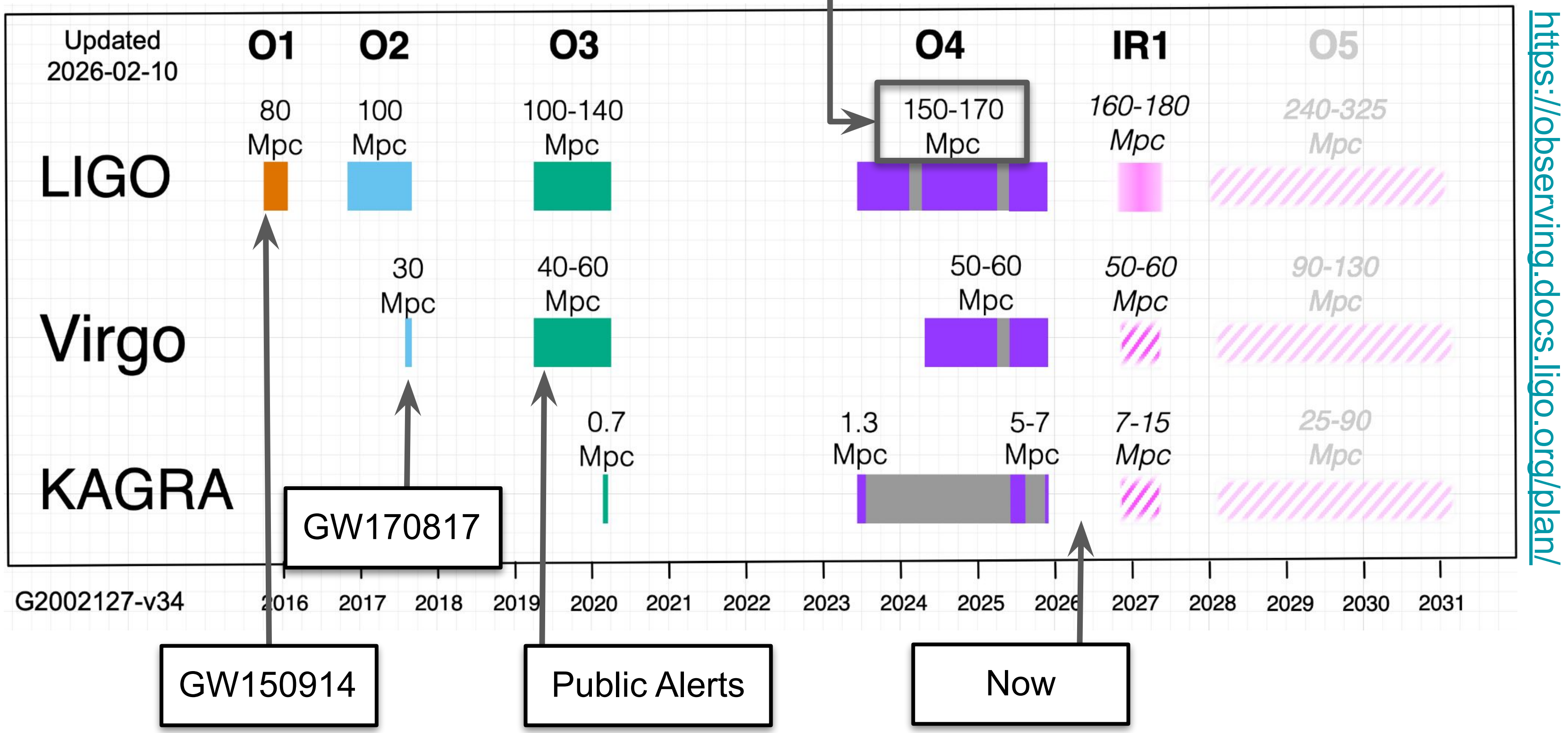
$$\Phi = -2\left(\frac{t_0 - t}{\mathcal{M}'}\right)^{5/8}$$

$$\mathcal{M}' = (1+z)\frac{(m_1 m_2)^{3/5}}{(m_1 + m_2)^{1/5}}$$

$$f = \frac{1}{2\pi}\frac{\partial\Phi}{\partial t} = \frac{1}{\pi\mathcal{M}'}\left(\frac{5}{256}\frac{\mathcal{M}'}{t_0 - t}\right)^{3/8}$$

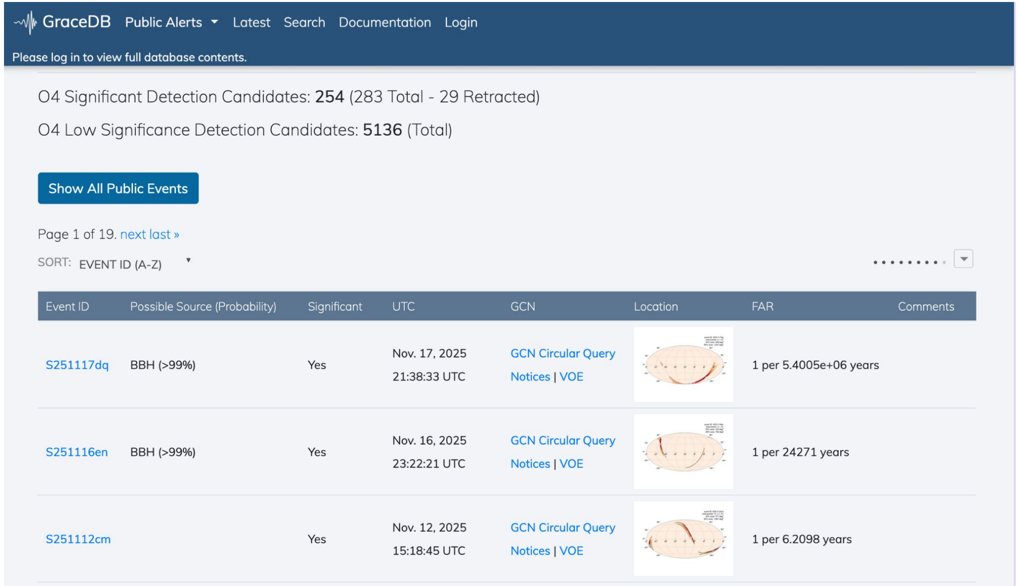
Observing runs

Angle Averaged
Binary Neutron Star (BNS) Inspiral Range



The fourth observing run (O4)

- O4 started 24 May 2023: will continue until 18 November 2025
  - Virgo delayed due to damage to optics; KAGRA had extended commissioning.
- Binary detection rates
  - O3 ~ 1 / 5 days
  - O4 ~ 1 / (2.8 days)
- Improved public alerts
  - Localization
  - Classification
  - Latency
  - Early-warning alerts
  - Low-significance alerts
- Best sensitivity
  - 150-170 Mpc BNS range



GraceDB Public Alerts Latest Search Documentation Login

Please log in to view full database contents.

O4 Significant Detection Candidates: **254** (283 Total - 29 Retracted)

O4 Low Significance Detection Candidates: **5136** (Total)

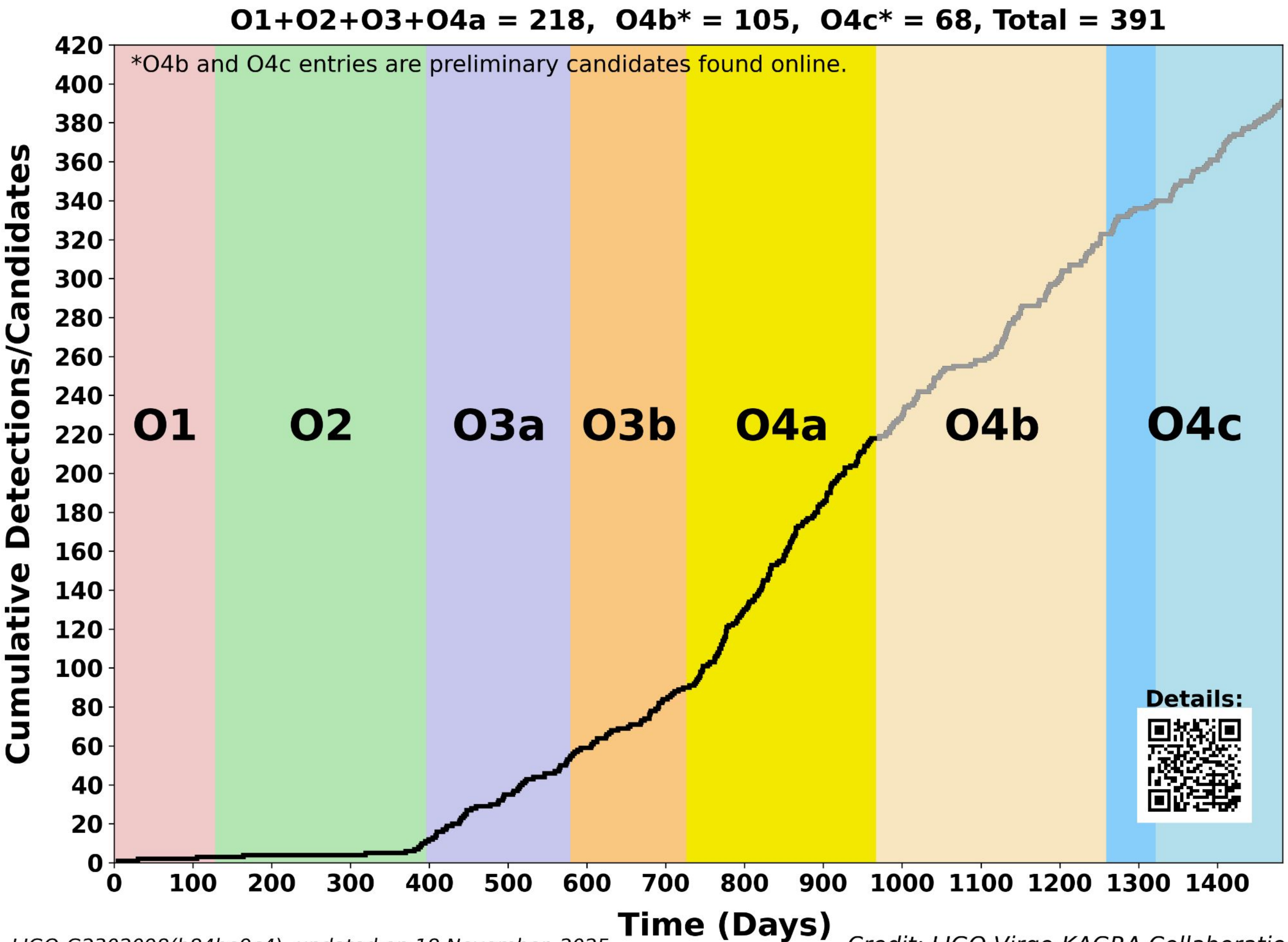
Show All Public Events

Page 1 of 19. next last »

SORT: EVENT ID (A-Z)

Event ID	Possible Source (Probability)	Significant	UTC	GCN	Location	FAR	Comments
S251117dq	BBH (>99%)	Yes	Nov. 17, 2025 21:38:33 UTC	GCN Circular Query Notices | VOE		1 per 5.4005e+06 years	
S251116en	BBH (>99%)	Yes	Nov. 16, 2025 23:22:21 UTC	GCN Circular Query Notices | VOE		1 per 24271 years	
S251112cm		Yes	Nov. 12, 2025 15:18:45 UTC	GCN Circular Query Notices | VOE		1 per 6.2098 years	

LIGO
VIRGO
KAGRA



LIGO-G2302098(b84be9c4), updated on 18 November, 2025

Credit: LIGO-Virgo-KAGRA Collaboration

GWTC-4

- GWTC-4.0: An Introduction
  - https://arxiv.org/abs/2508.18080
- GWTC-4.0: Methods
  - https://arxiv.org/abs/2508.18081
- GWTC-4.0: Update
  - https://arxiv.org/abs/2508.18082
  - 86 new binary candidates with false alarm rate < 1/yr
- GWTC-4.0: Population
  - https://arxiv.org/abs/2508.18083
- Open Data from O4a
  - https://arxiv.org/abs/2508.18079

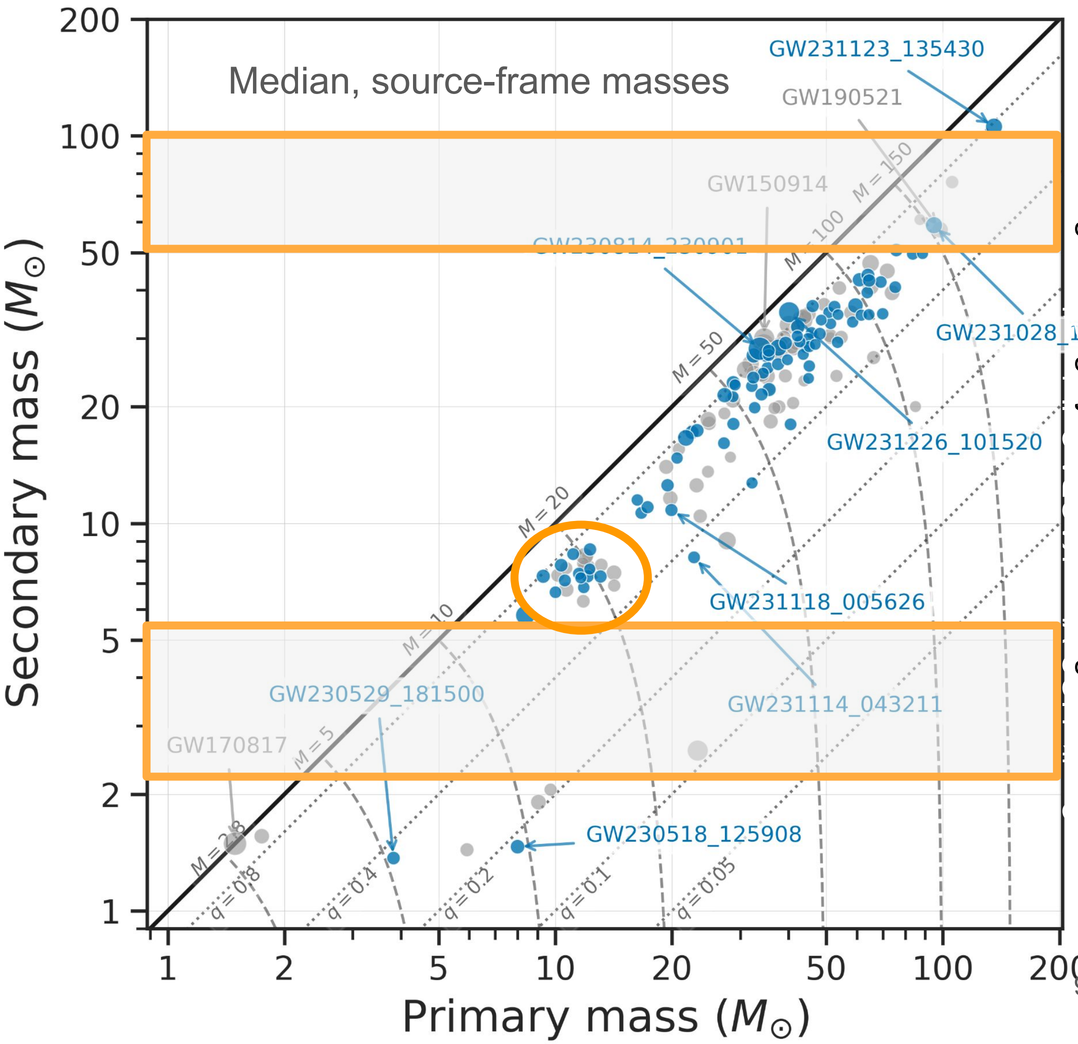
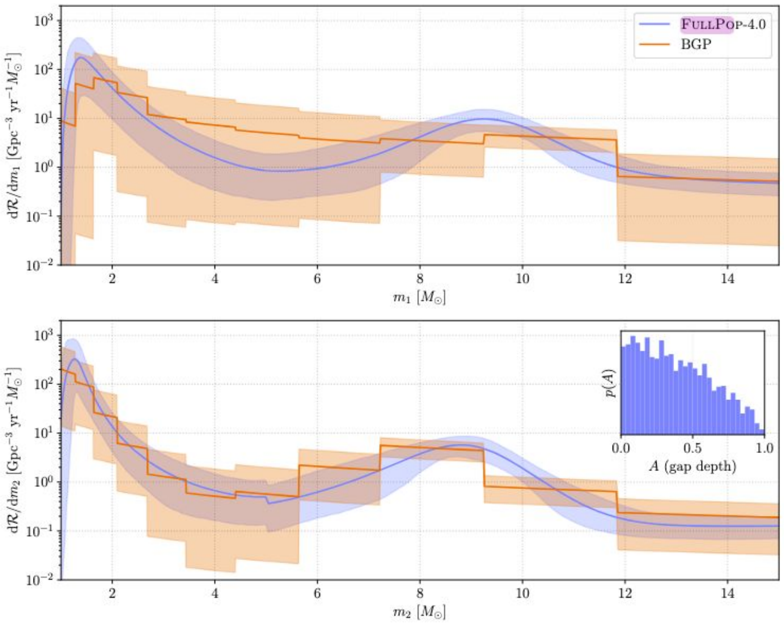


Figure: Gregory Ashton/LIGO-Virgo-KAGRA

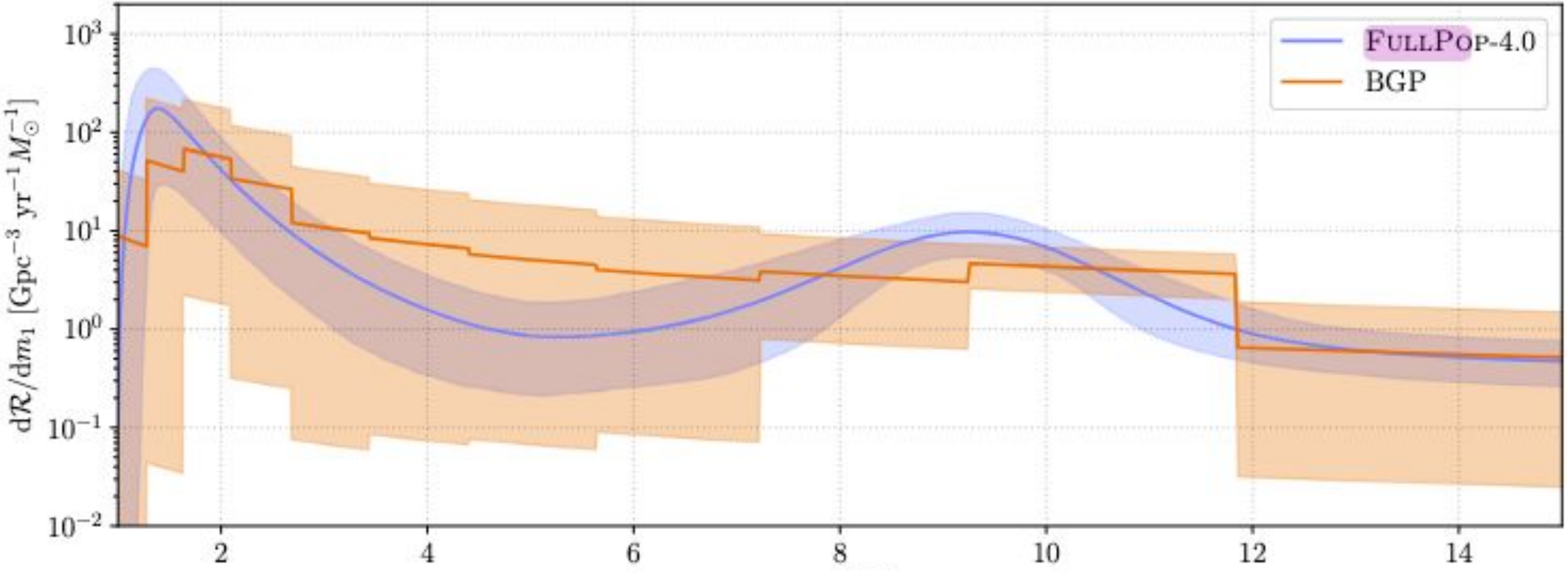
Inferring the astrophysical population

Figure 2 from LIGO-Virgo-KAGRA Collaboration, arXiv:2508.18083



- Deconvolve selection effects to infer astrophysics
- FULLPOP-4.0:
  - Example of strong modelling
  - Models the full mass spectrum with power-laws, peaks, and gaps.
- BGP:
  - Example of weak modelling.
  - Uses a binning scheme to infer the event rate within each bin, and a Gaussian process prior imposing smooth covariance across bins.

Populations with neutron stars



Primary Mass

Figure 2 from LIGO-Virgo-KAGRA Collaboration, arXiv:2508.18083

Populations with neutron stars

Evidence for a prominent pair of peaks at NS masses ~1.5Msun and at BH masses ~9 Msun on each side of the lower-mass gap. A completely empty gap between NSs and BHs is disfavored.

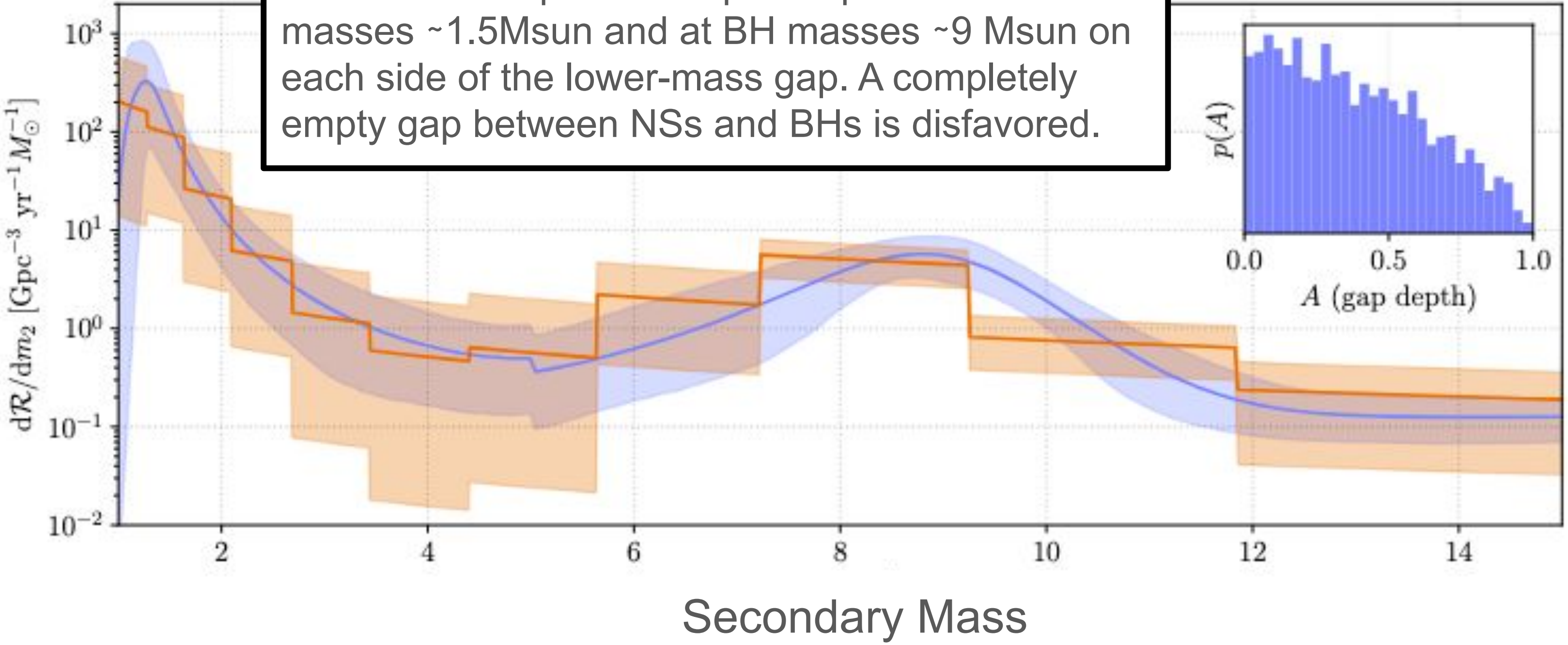
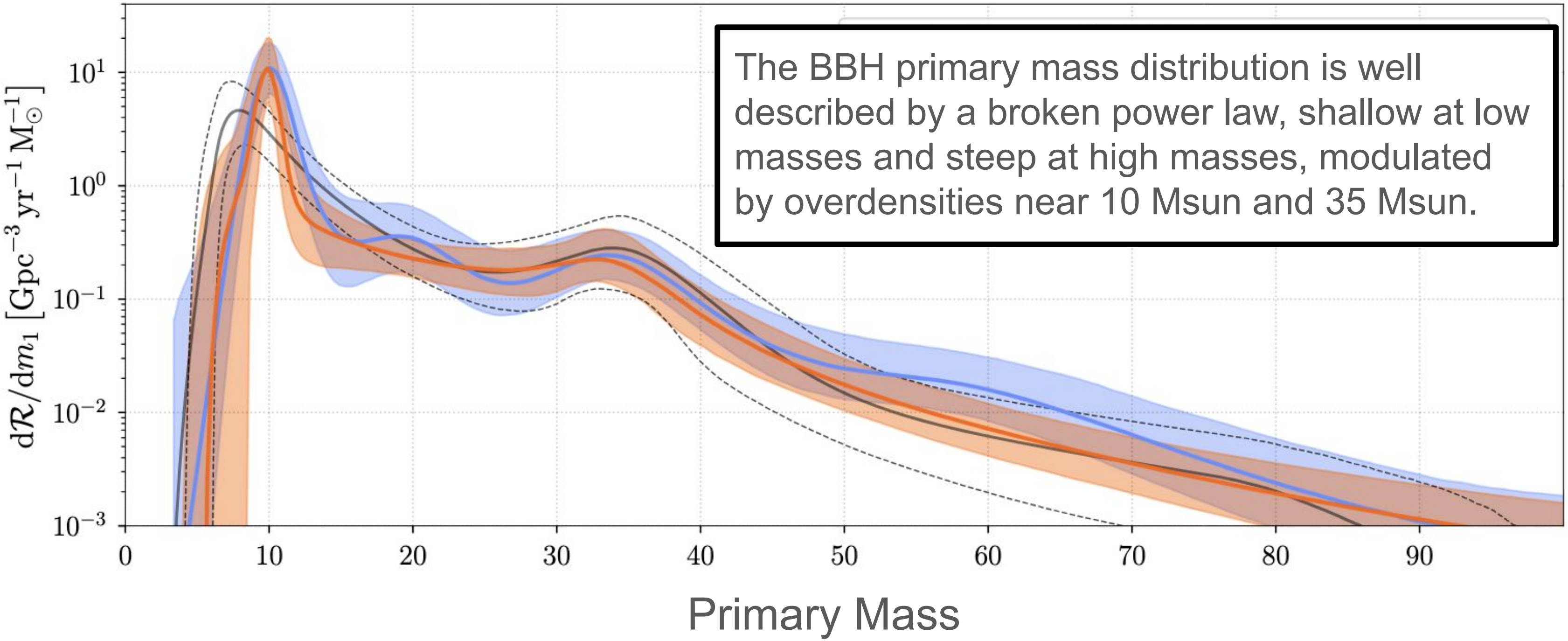


Figure 2 from LIGO-Virgo-KAGRA Collaboration, arXiv:2508.18083

Binary black hole population

LIGO-Virgo-KAGRA Collaboration, arXiv:2508.18083

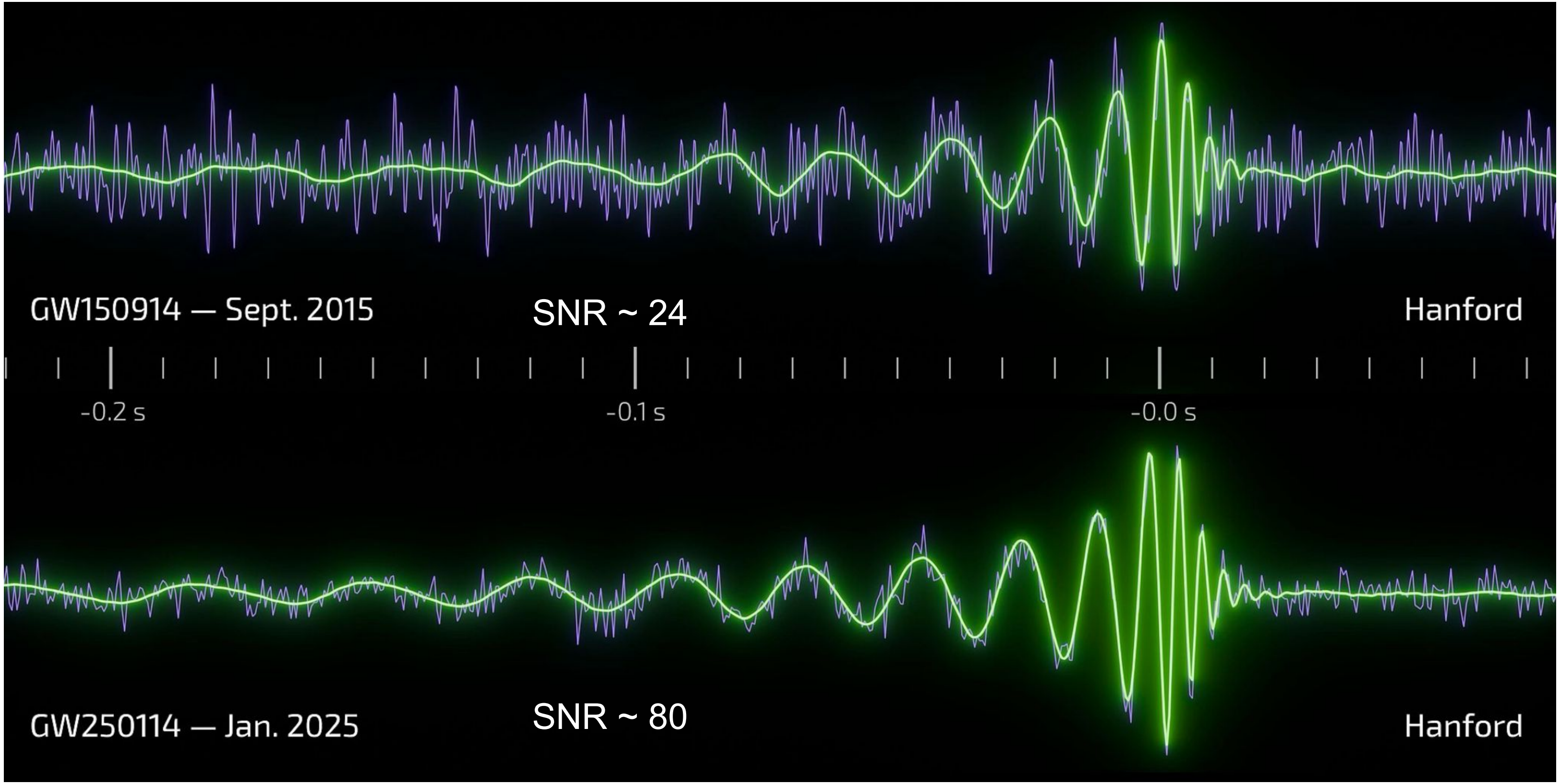


Summary

Many more detailed investigations in Arxiv in addition to papers about cosmology, testing GR, and searching for other sources!

- Effective inspiral spins are asymmetric about $\chi_{eff} = 0$, skewed toward positive values. Spin magnitudes span from 0 to 1, although ~90% of BHs have $\chi < 0.57$.
- Over abundances in the mass distribution at 1–2 Msun, around 10 Msun, and a feature near 35 Msun.
- The neutron star mass distribution remain consistent with previous results, favoring a broad distribution of neutron star masses between 1 Msun and 3 Msun.
- The redshift evolution of the binary black hole merger rate R(z) remains consistent with the cosmic star formation rate density.

GW250114 - testing general relativity

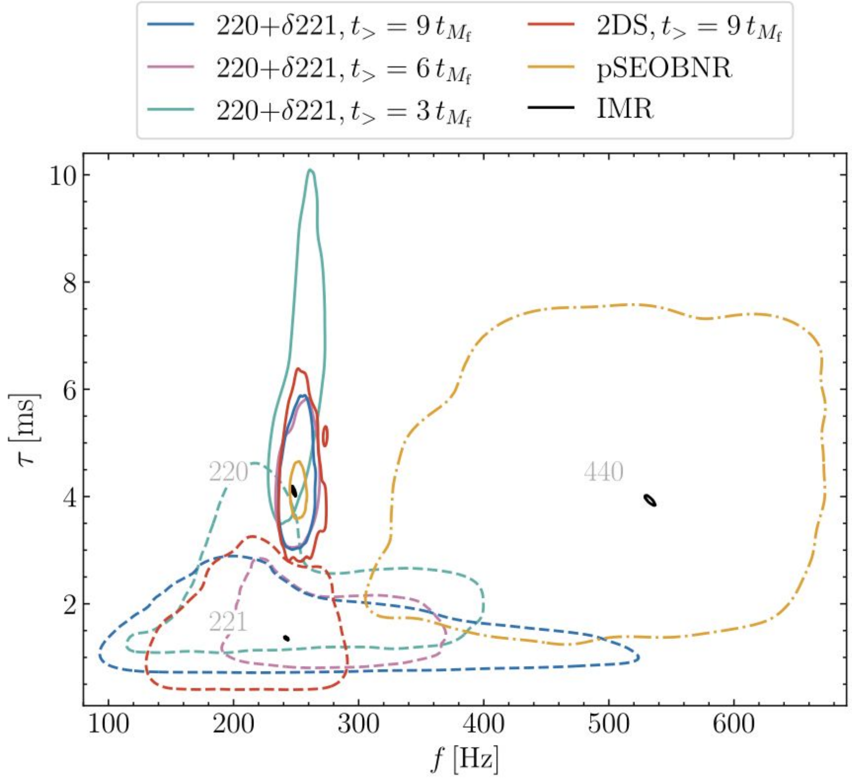


Abac et al, PRL 135, 111403 (2025)

Credit: Caltech/MIT/LIGO Laboratory

GW250114 - testing general relativity

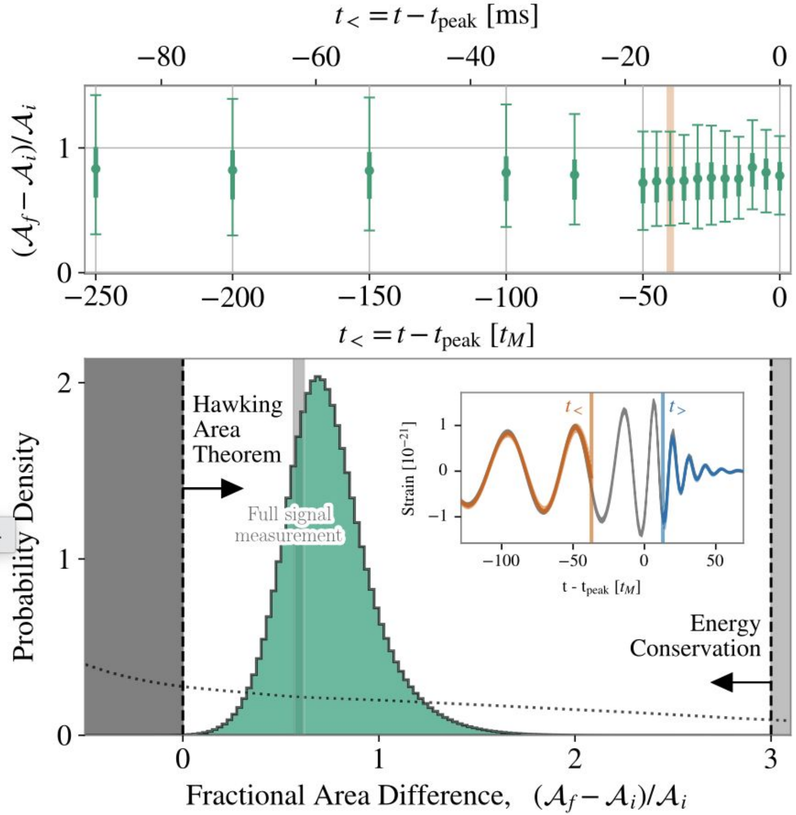
- Coalescence of two black holes with near-equal masses
  - m1 ~ 33.6 M⊙ & m2 ~ 32.2 M⊙, spins χ1;2 ≤ 0.26 (90% credibility) & eccentricity e ≤ 0.03
- Test the Kerr nature of remnant:
  - Decompose perturbations into spin-weighted spheroidal harmonics with angular indices (l, m).
  - For each (l, m), there are discrete complex frequencies ω_{lmn} indexed by n where $Re(\omega_{lmn})$ gives frequency and $Im(\omega_{lmn})$ is damping. n=0 is least damped, n=1 next, and so on.



Abac et al, PRL 136, 041403 (2026)

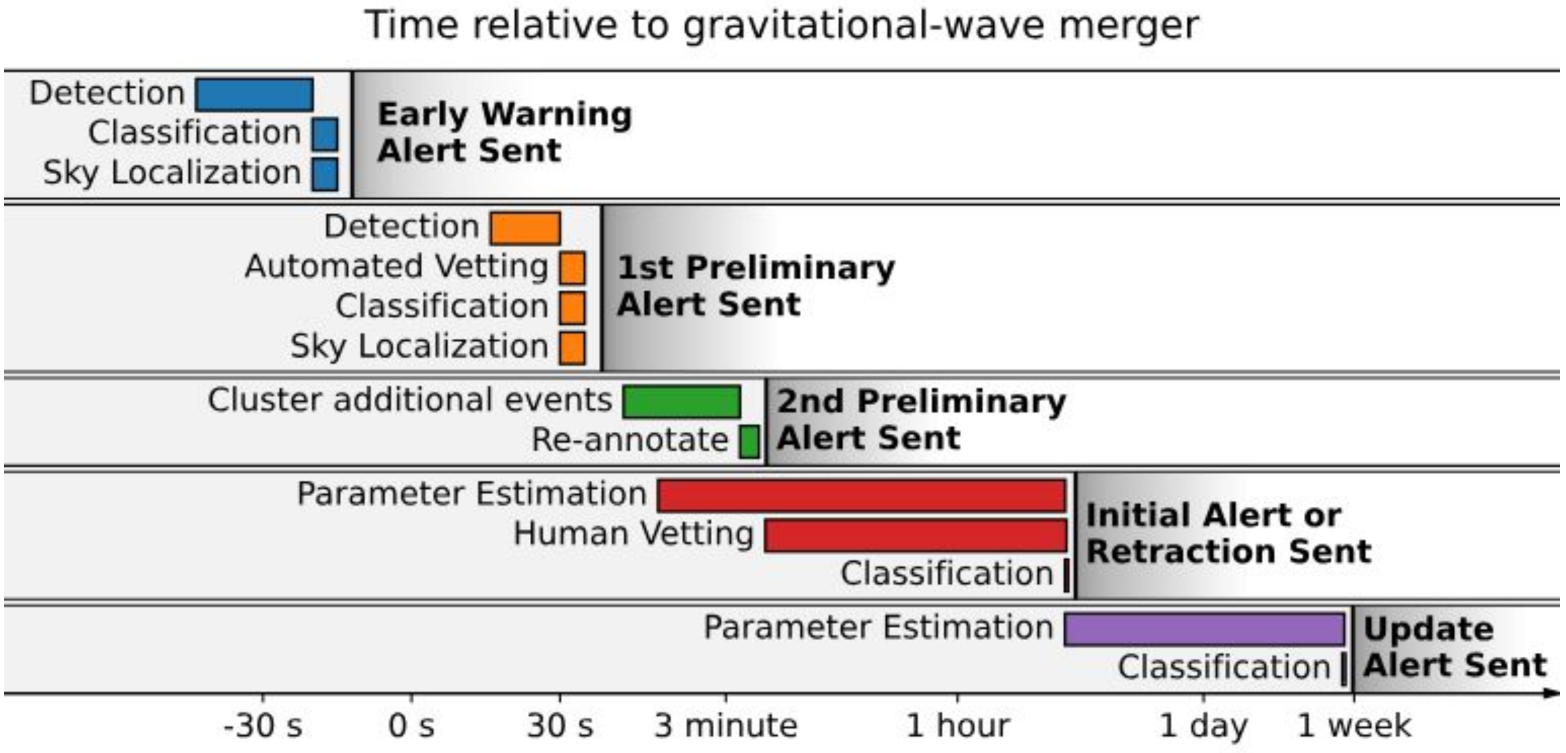
Confirming area increase

- Model the signal with GR waveform, up to a preselected time, t<, and measure the initial masses and spins.
  - $A_i = A_1 + A_2$
- Single l = |m| = 2, n = 0 at its earliest time of applicability when the overtone significance is < 1σ
  - A_f



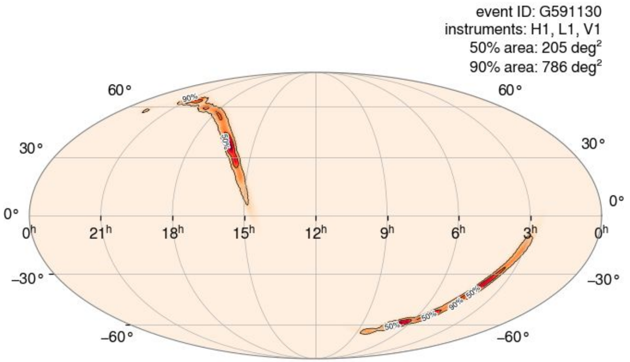
Abac et al, PRL 135, 111403 (2025)

Low-latency Alerts & EM follow-up



Preliminary alerts in ~30 sec latency in O4 distributed via SCiMMA and GCN

S250818k - subthreshold candidate

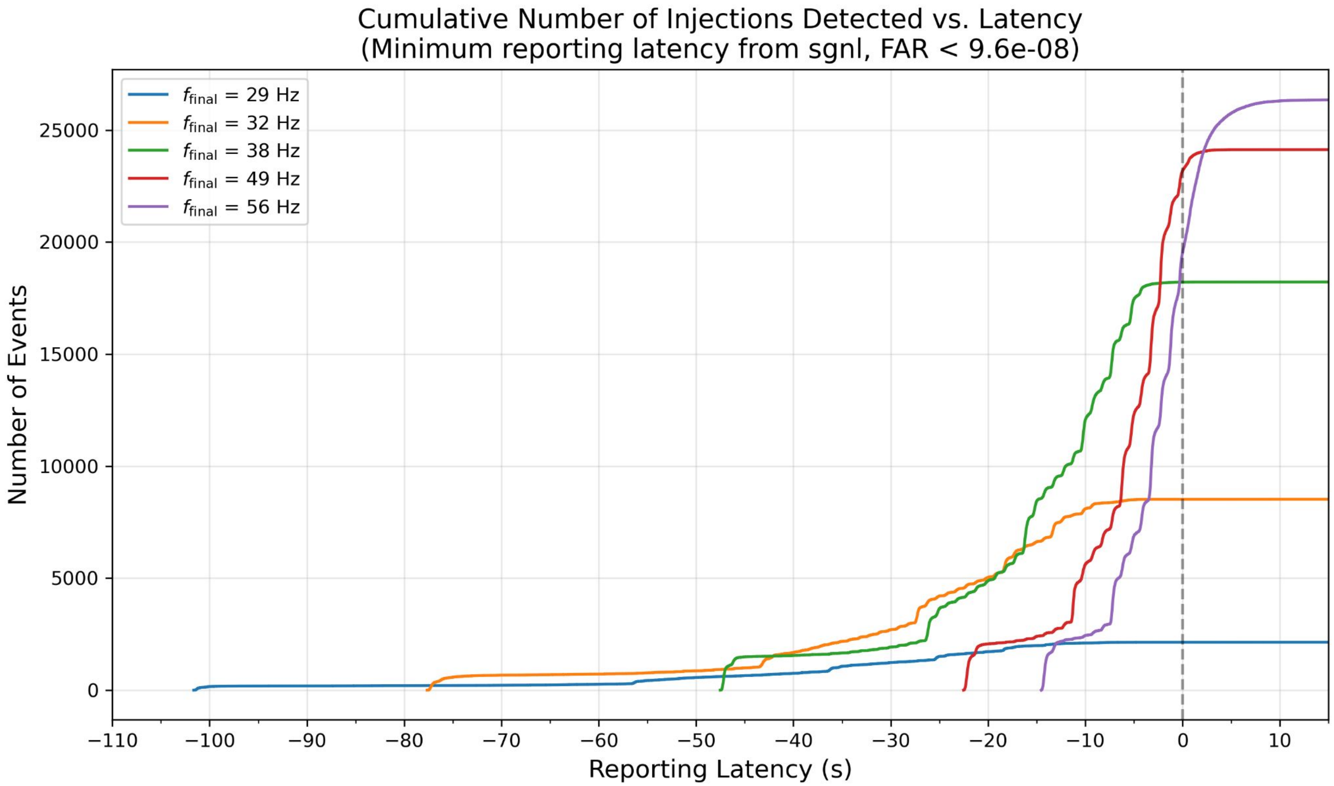


False alarm rate = 2.1/yr

- 2025-08-18 01:20:06 UTC - LVK candidate time
- +30 s - LVK preliminary alert
- +2.7 hrs - Zwicky Transient Facility begins observing
- +16 hrs - GCN 41414, Stein et al report optical transient ZTF25abjmnps/AT2025ulz
- +2.2 days - GCN 41436, Karambelkar et al report spectral observations consistent with a kilonova
- +2.3 days - GCN 41437, LVK reports updated properties of the low-significance candidate
- +6.5 days - GCN 41532, Banerjee et al report ENGRAVE observations of AT2025ulz as a type II supernova
- ….. Ongoing observations to confirm classification
- ….. GCN Circulars related to S250818k

Early Warning Mock Data Challenge

Preliminary (provided by Amanda Baylor)



Early Warning Mock Data Challenge

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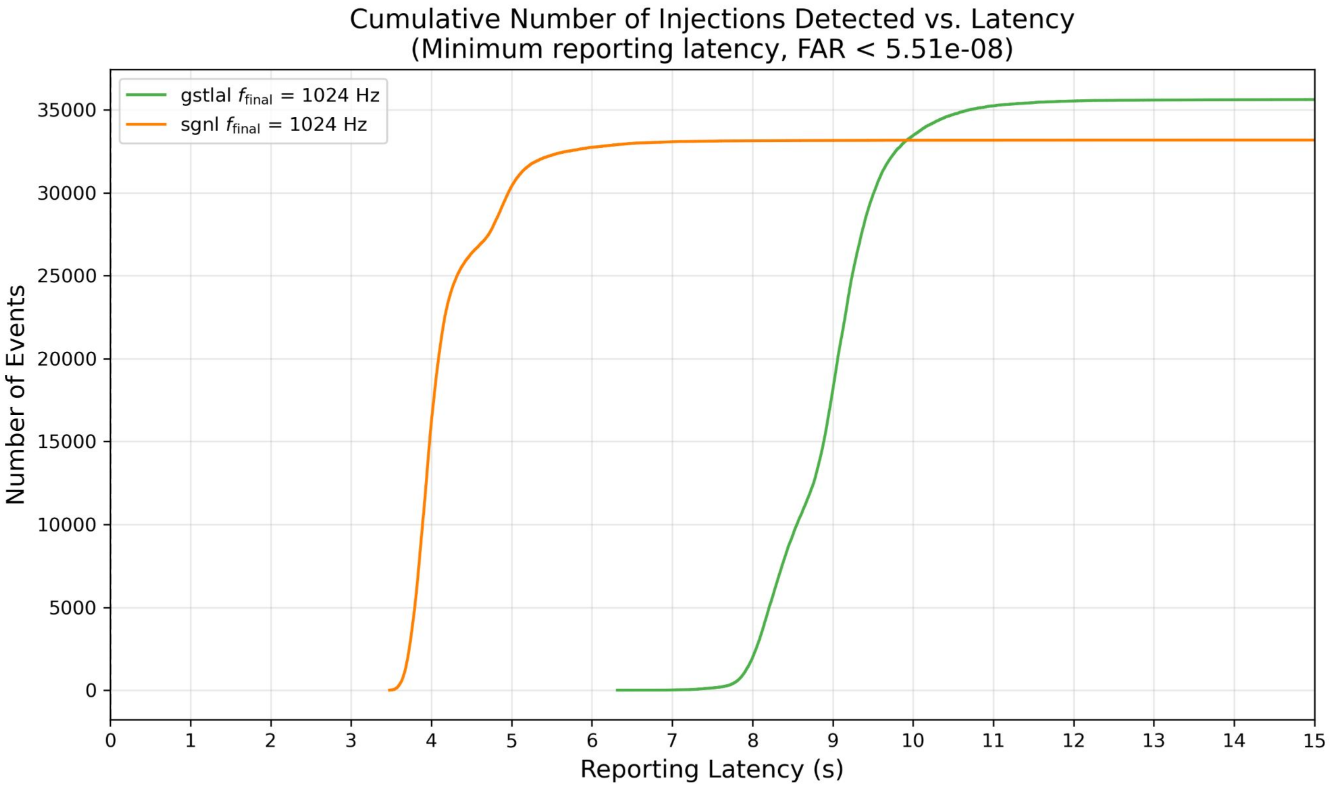
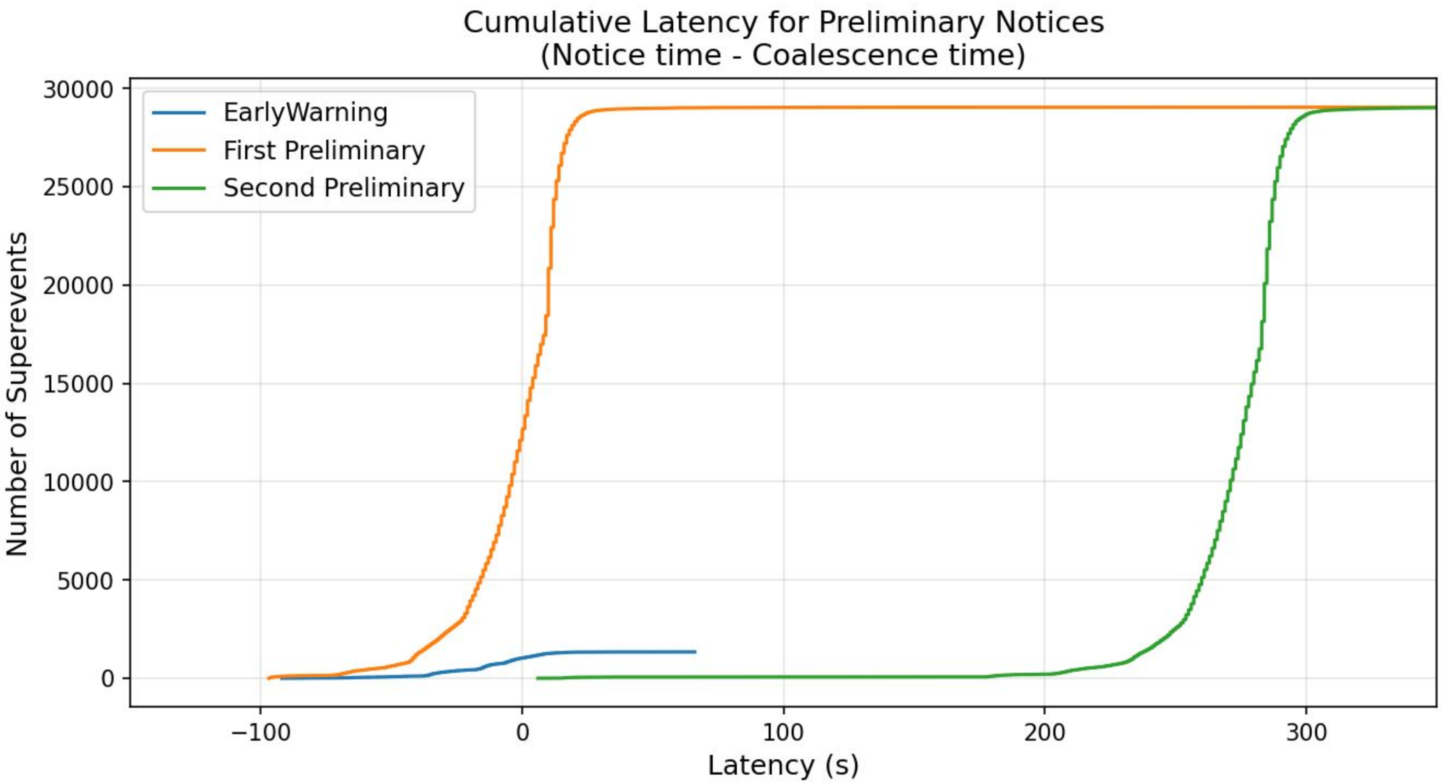


Early Warning Mock Data Challenge

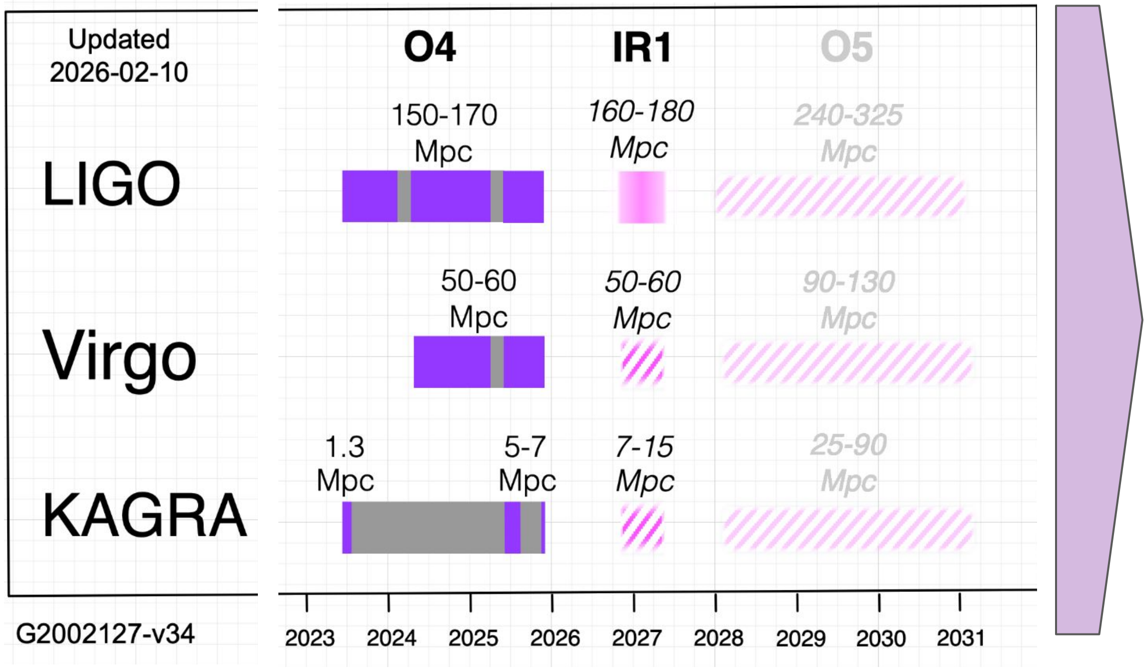


Preliminary (provided by Amanda Baylor)

Future Observing Runs

LIGO-Virgo-KAGRA anticipate observing to dovetail with next generation facilities

- Current thinking
  - Paced by upgrade paths.
  - Intersperse commissioning and observations
- Binary detection rates
  - O3 ~ 1 / 5 days
  - O4 ~ 1 / (2.8) days
  - IR1 ~ 1 / (2.8) days
  - IR2 (O5) ~ 3 / day
- Other science
  - Improved SNR
  - New sources?



https://observing.docs.ligo.org/plan/

IGWN 2025-2035

- Virgo faces challenges that require substantial modifications of the instrument and facilities to achieve the Advanced Virgo sensitivity.
    - Discussions are ongoing about the schedule for this multi-year detector improvement effort.
- KAGRA is focused on reaching its current target
- Construction of LIGO Aundha Observatory (LAO) in India is progressing
    - It will be operated under the LIGO umbrella in the 2030s.
- $A^{\#}$: targeted improvements to the LIGO detectors for post-O5
    - Report of LSC post-O5 study group [Fritschel et al, https://dcc.ligo.org/LIGO-T2200287/public]
    - Achieve close to a factor of 2 amplitude sensitivity improvement with larger test masses, better seismic isolation, improved mirror coatings, higher laser power, better squeezing …
    - $A^{\#}$ an engine for observational science and a pathfinder for next-generation technologies.
    - A network including LIGO A# detectors would be a cornerstone for multimessenger discovery.

Observational Science with $A^{\#}$

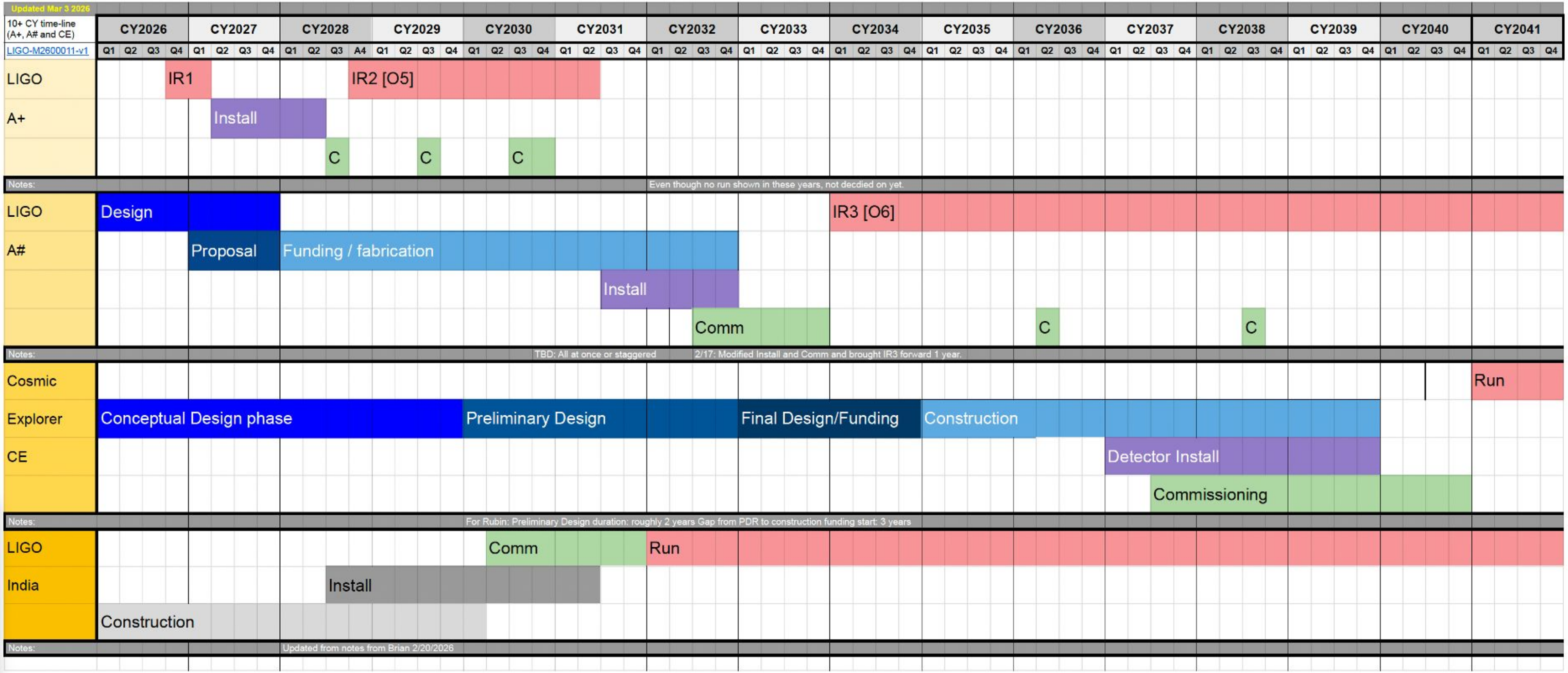
- Probe the compact object binary population with unprecedented precision
  - Masses, spins, sub-populations.
  - Clues about their formation and astrophysical environment.

- Hubble constant measurement to sub-percent levels
- Black hole spectroscopy via sub-dominant modes
- Neutron star radius measurements to sub-km
- Enlarge discovery space: nearby supernova, continuous wave sources, stochastic background

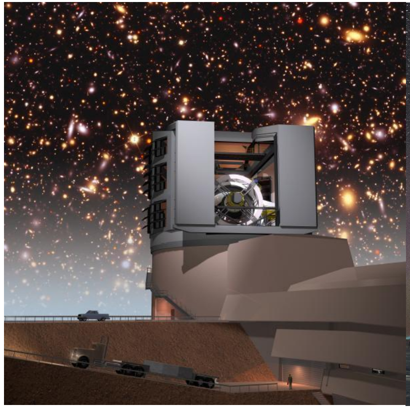
Configuration	Annual Detections		
	BNS	NSBH	BBH
A+	135^{+172}_{-78}	24^{+34}_{-16}	740^{+940}_{-420}
$A^\sharp$	630^{+790}_{-350}	100^{+128}_{-58}	2100^{+2600}_{-1100}
$A^\sharp$ (A+ coatings)	260^{+320}_{-140}	45^{+60}_{-27}	1150^{+1450}_{-640}
$A^\sharp$ Wideband (A+ coatings)	200^{+250}_{-110}	40^{+54}_{-25}	970^{+1220}_{-540}
Voyager Deep	1280^{+1610}_{-710}	190^{+240}_{-110}	3100^{+3900}_{-1700}
Voyager Wideband	730^{+920}_{-410}	129^{+165}_{-74}	2300^{+2900}_{-1300}

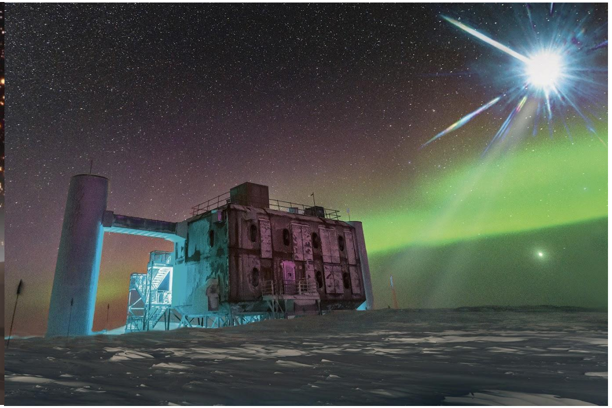
See Fritschel et al, https://dcc.ligo.org/LIGO-T2200287/public

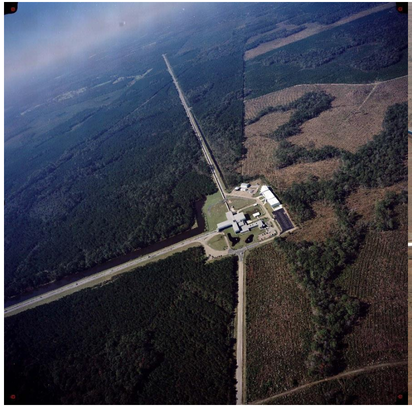
From now to Cosmic Explorer

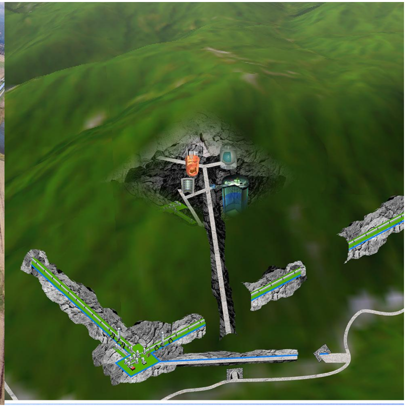


LIGO-Virgo-KAGRA: cornerstone of MMA









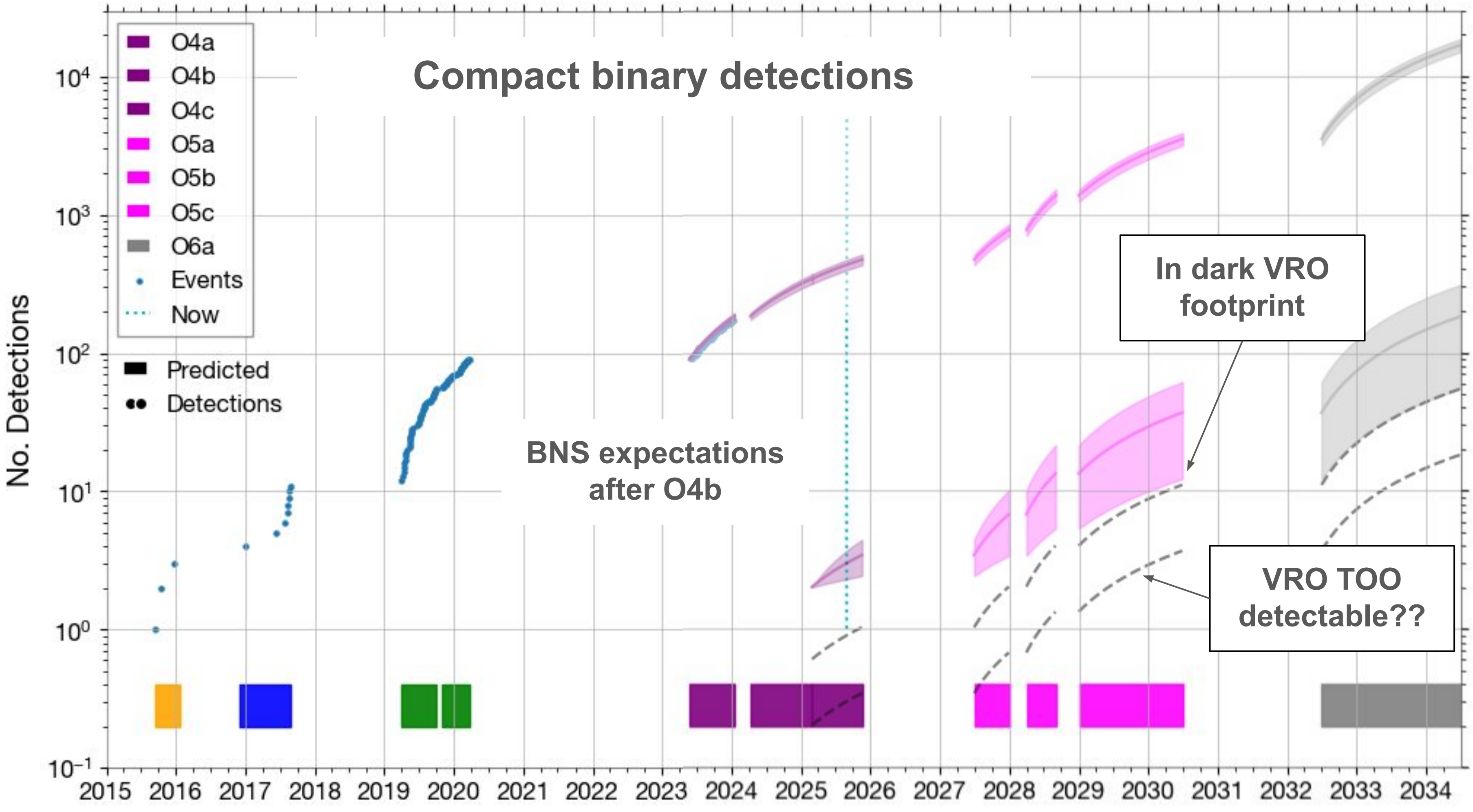
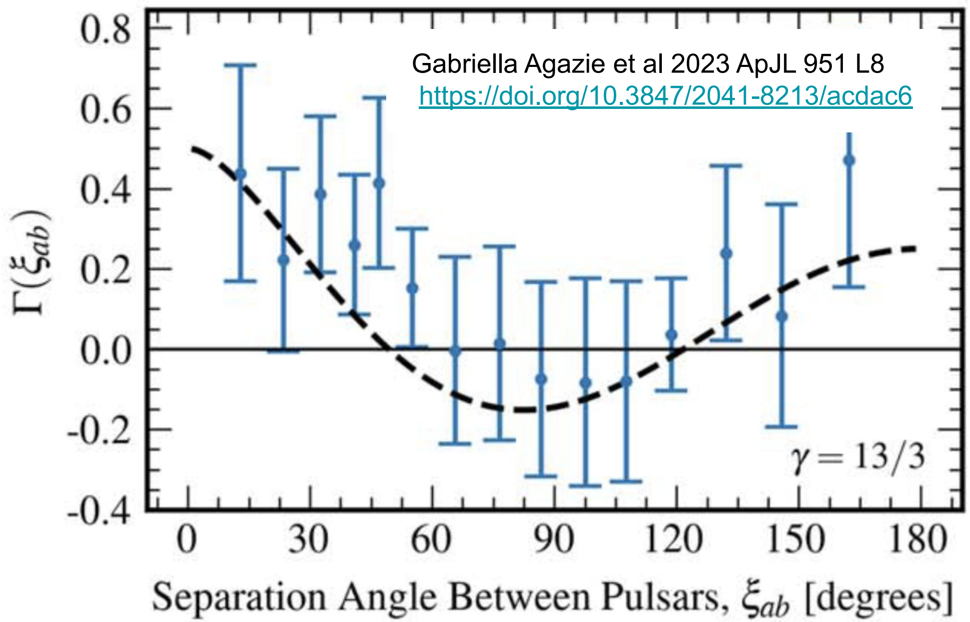


Figure: Amanda Baylor, Cody Messick, PRB

Pulsar Timing Observations



Gabriella Agazie et al 2023 ApJL 951 L8
https://doi.org/10.3847/2041-8213/acdac6

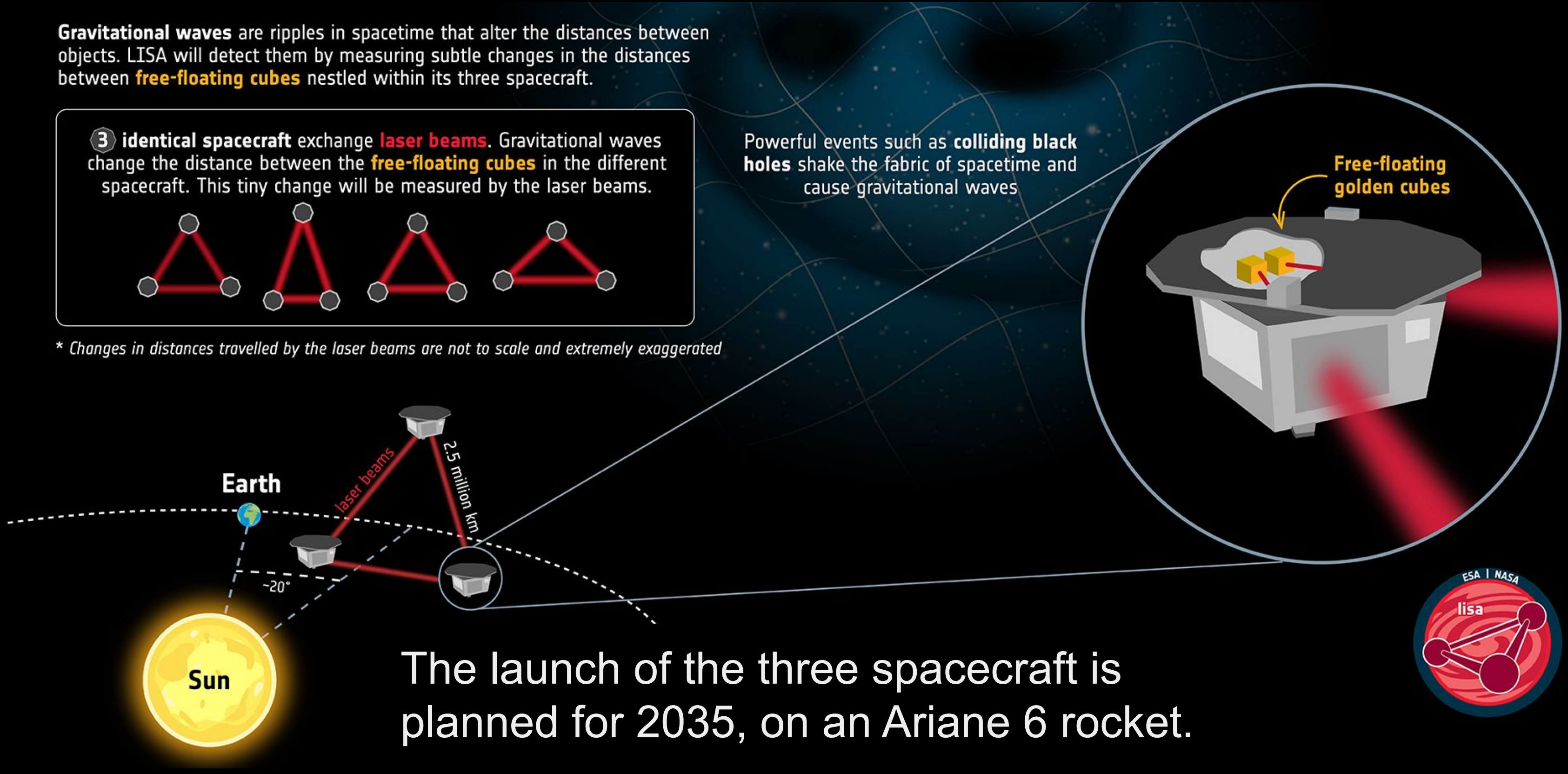
Hellings-Downs interpulsar correlations from a gravitational-wave background.

- Bayesian analysis ~ 3 sigma
- Frequentist analysis ~ 3.5 - 4 sigma

Possibly background from supermassive black hole binaries.

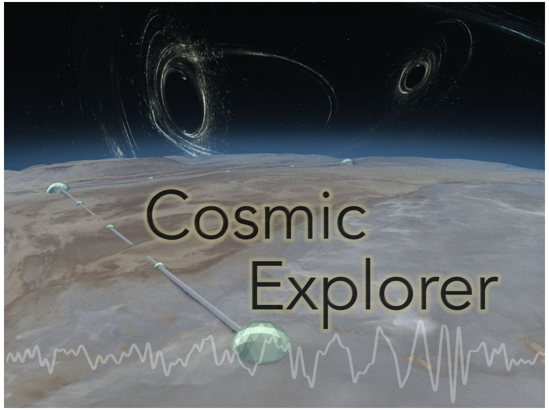
- NANOGrav - G. Agazie et al 2023 ApJL 951 L8
- PPTA - D. J. Reardon et al 2023 ApJL 951 L6
- EPTA and InPTA - J. Antoniadis et al. A&A, to appear
- CPTA - H. Xu et al 2023 Res. Astron. Astrophys. 23 075024

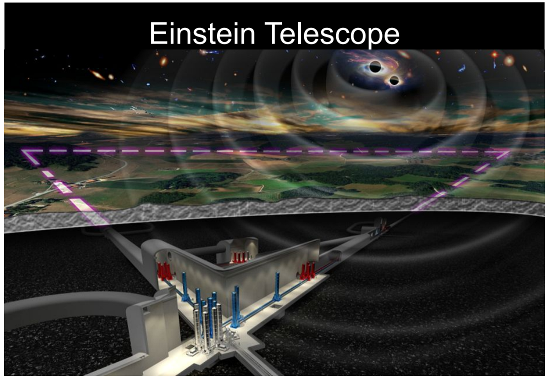
LISA mission

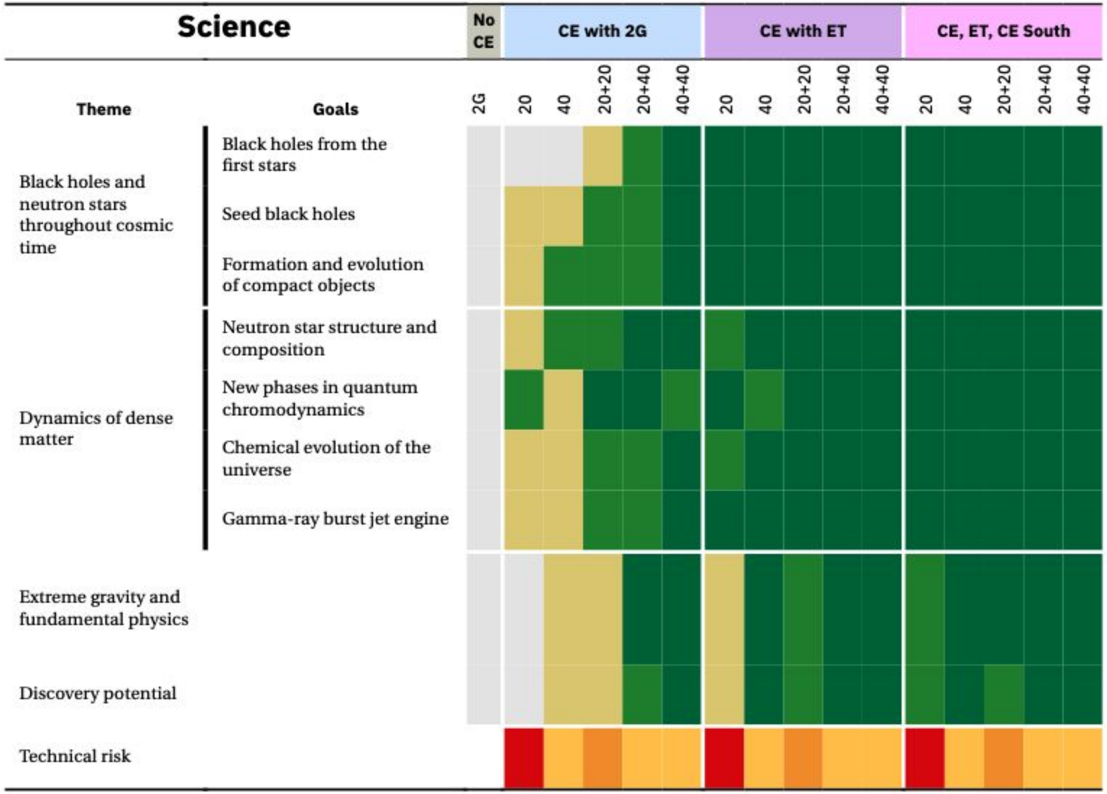


The launch of the three spacecraft is planned for 2035, on an Ariane 6 rocket.

Next Generation Detectors - late 2030s or early 2040s







A Horizon Study for Cosmic Explorer
https://arxiv.org/abs/2109.09882