

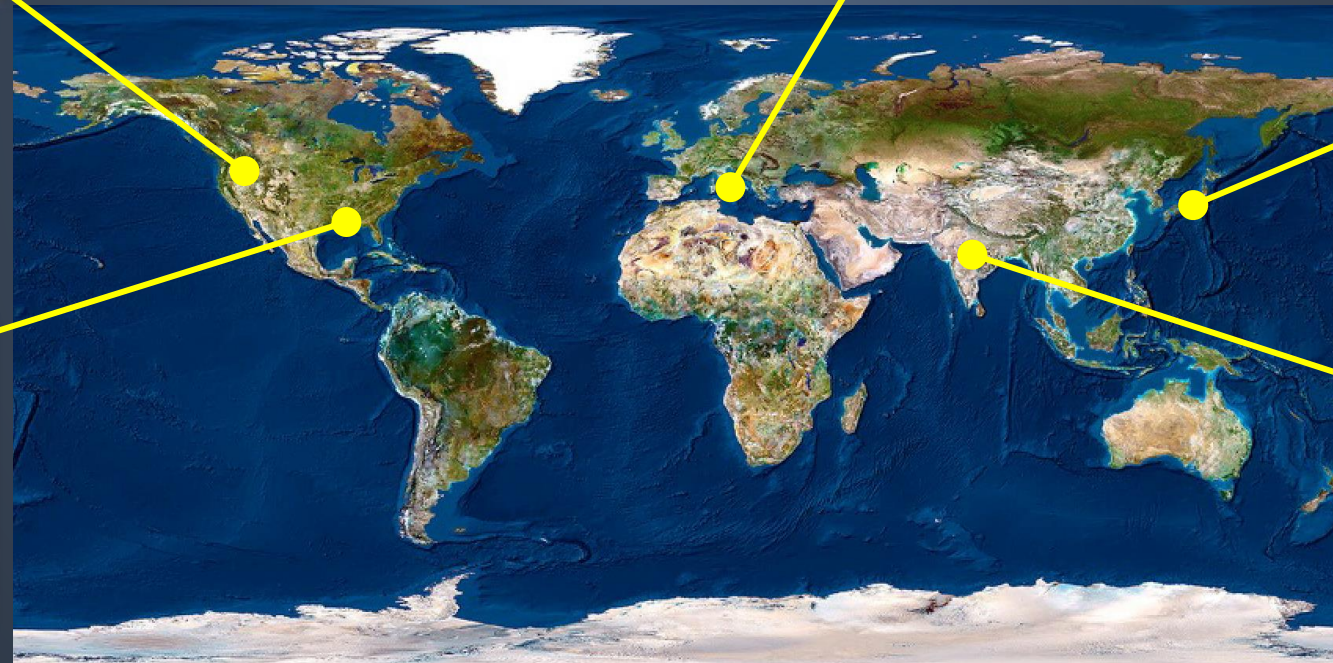


# ***Prospects for Current-Generation Ground-based GW Detectors***

**Dave Reitze**  
**LIGO Laboratory**  
**California Institute of Technology**  
**(for the LVK Collaboration)**



# The Global Ground-based GW Observatory Network



The International Gravitational-Wave Observatory Network

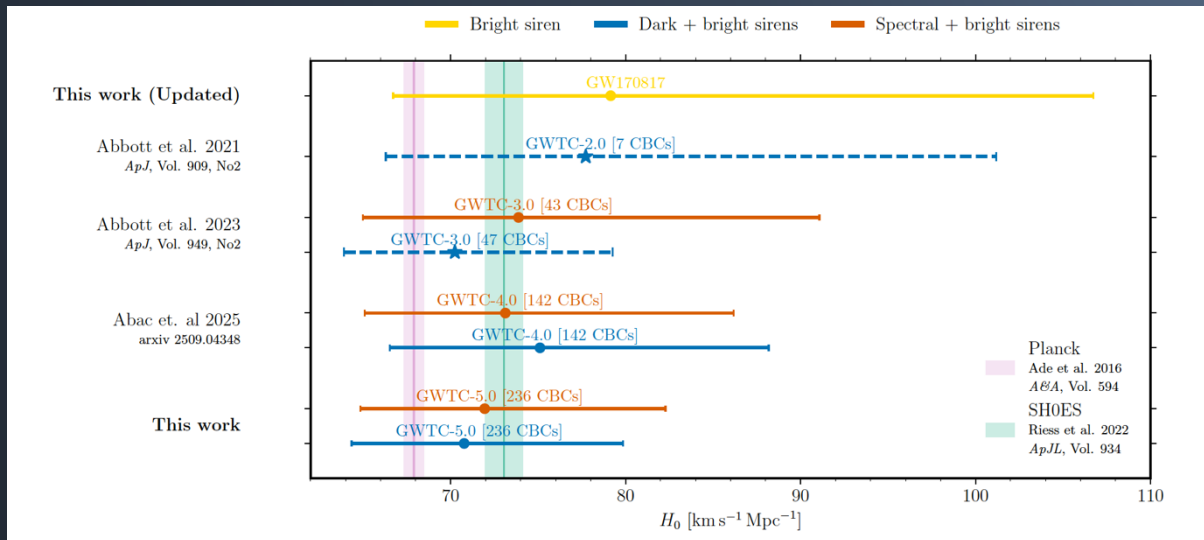
# LVK Recent Science Highlights from O4

## Gravitational-Wave Transient Catalog 'GWTC-5'

- Cumulative catalog of transient GW events from O1 to O4b observing runs
- 389 total GW events; one event very 3 days!

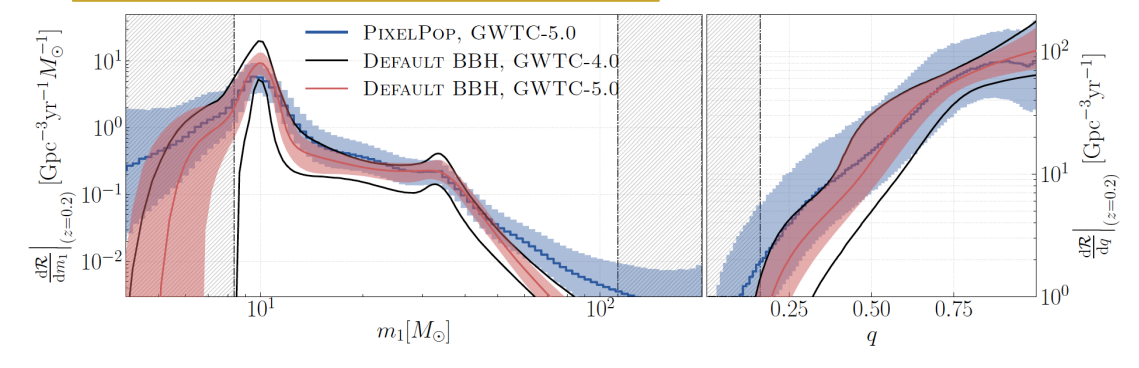
## GWTC-6 catalog planned for release in December 2026

### Hubble-Lemaître Constant

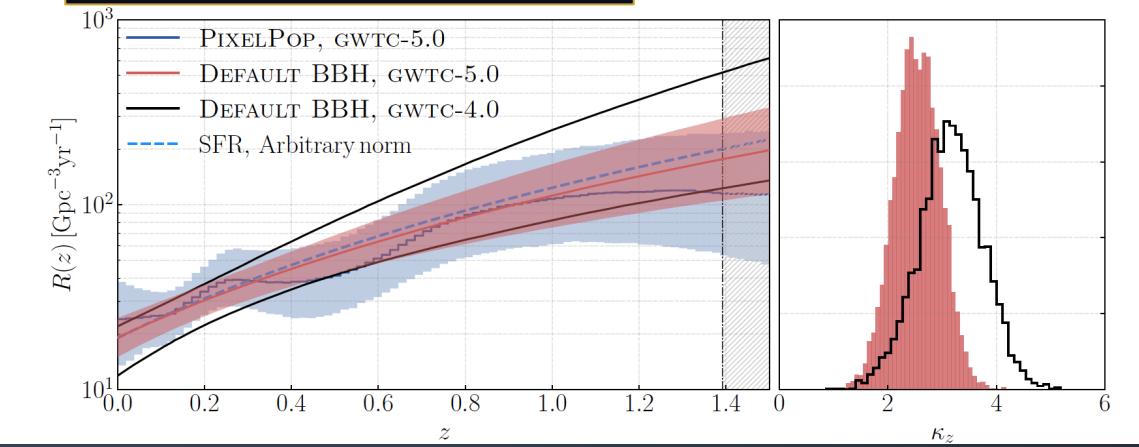


## GWTC-5 Highlights

### Binary Black Hole Populations/Mass Ratios

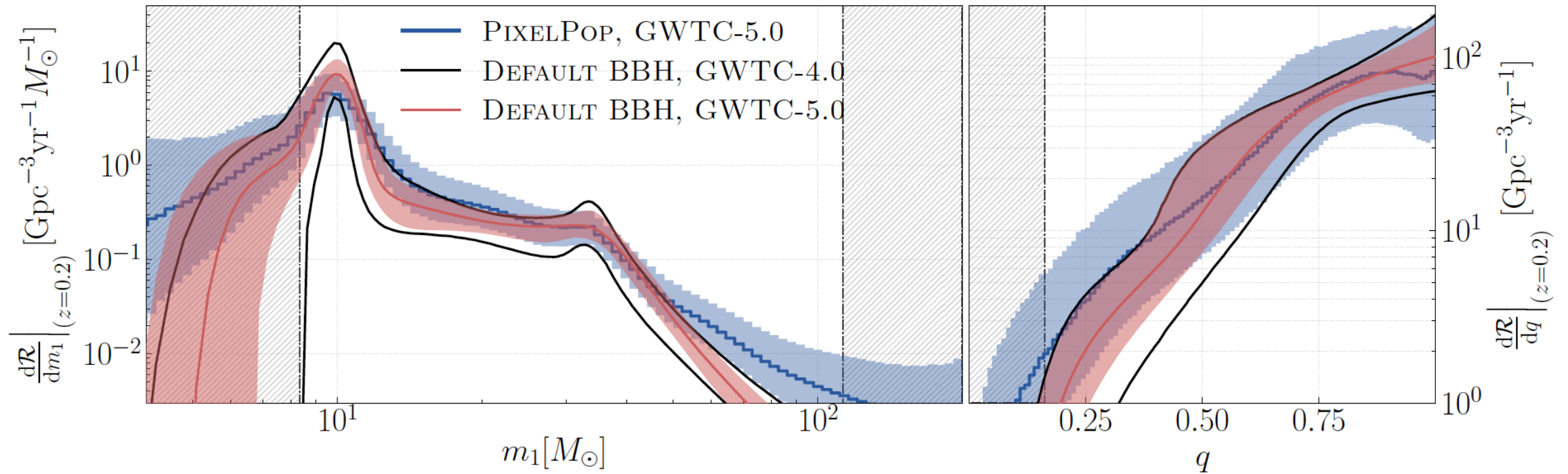


### Binary Black Hole Red Shift Dependence



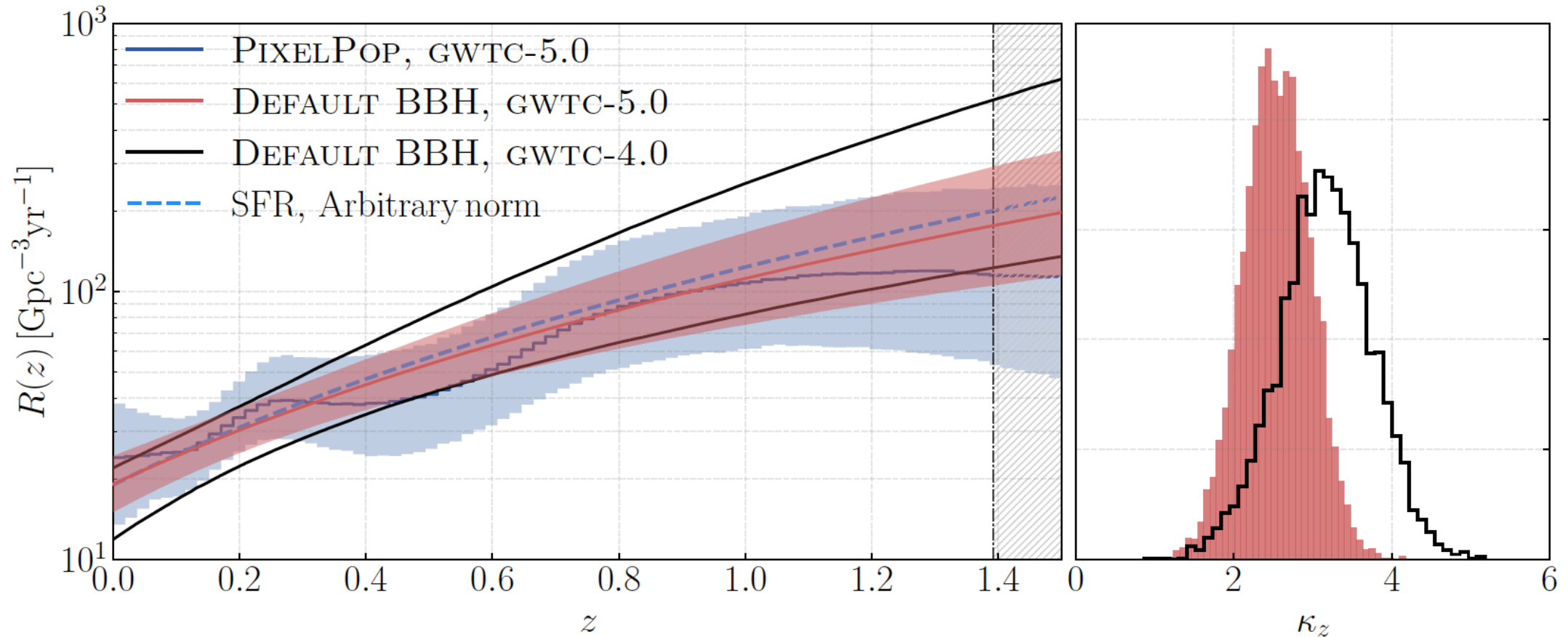
# LVK Recent Science Highlights from O4

## Binary Black Hole Populations/Mass Ratios



# LVK Recent Science Highlights from O4

## Binary Black Hole Red Shift Dependence

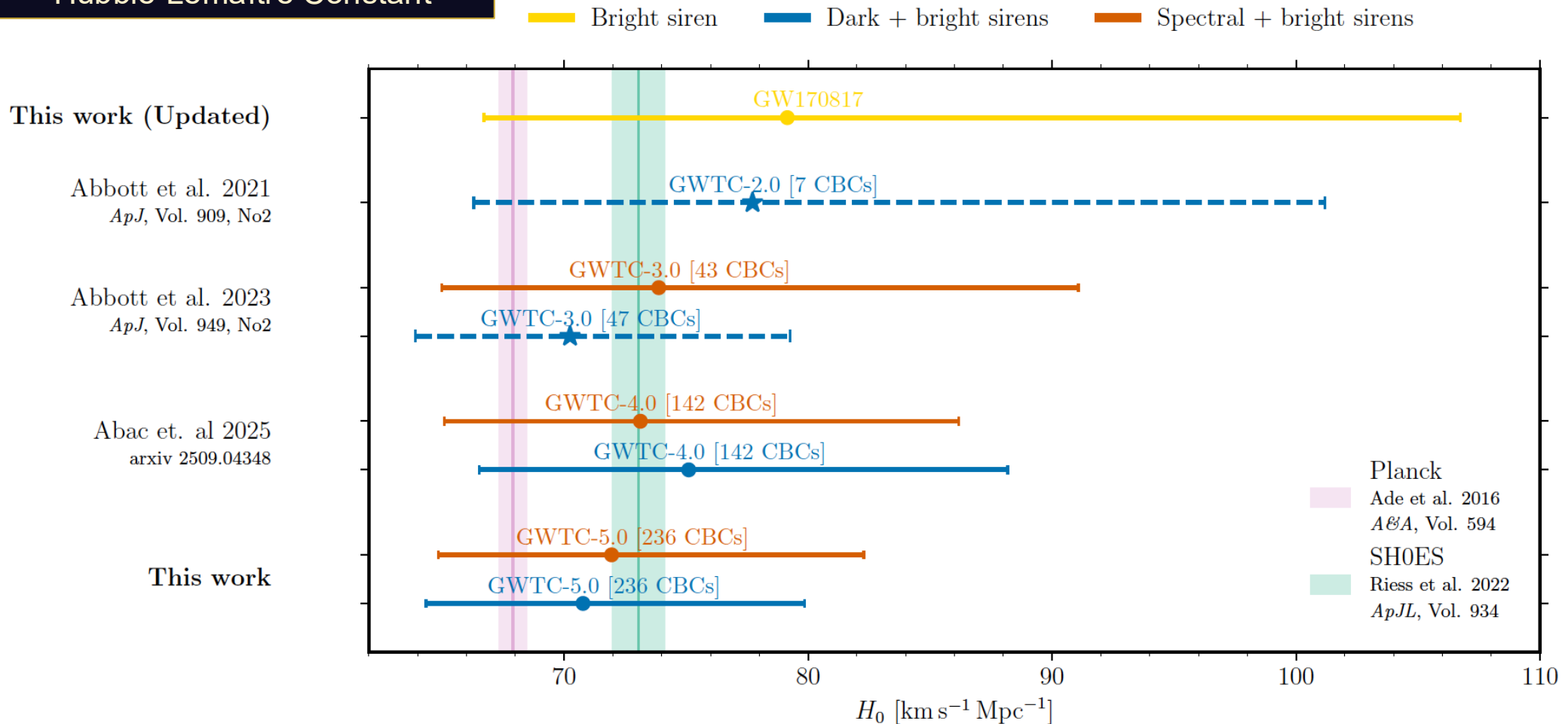


LVK Collaboration, "GWTC-5.0: Population Properties of Merging Compact Binaries", <https://arxiv.org/pdf/2605.27226>

# LVK Recent Science Highlights from O4



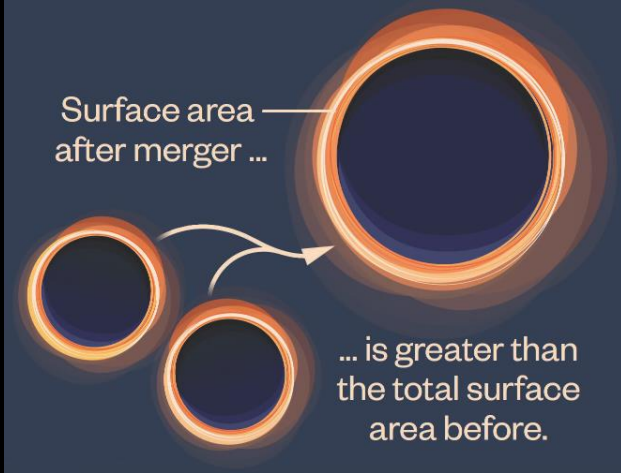
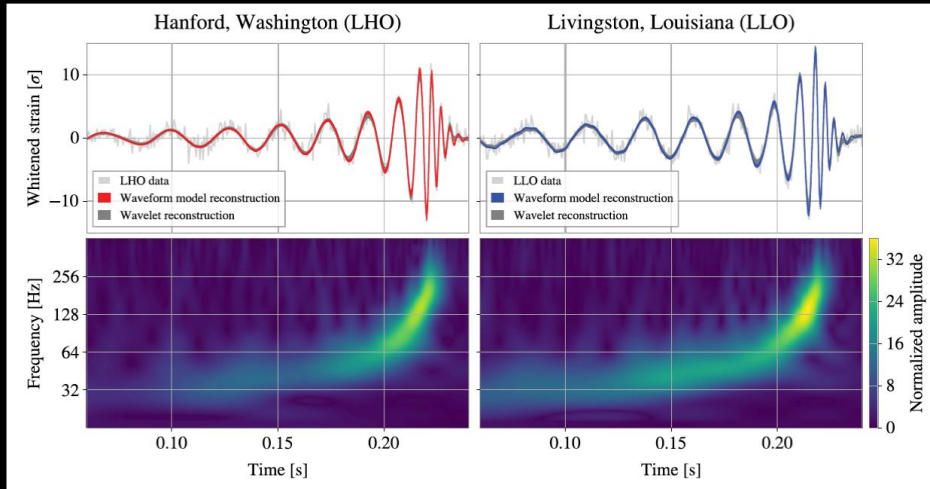
## Hubble-Lemaître Constant



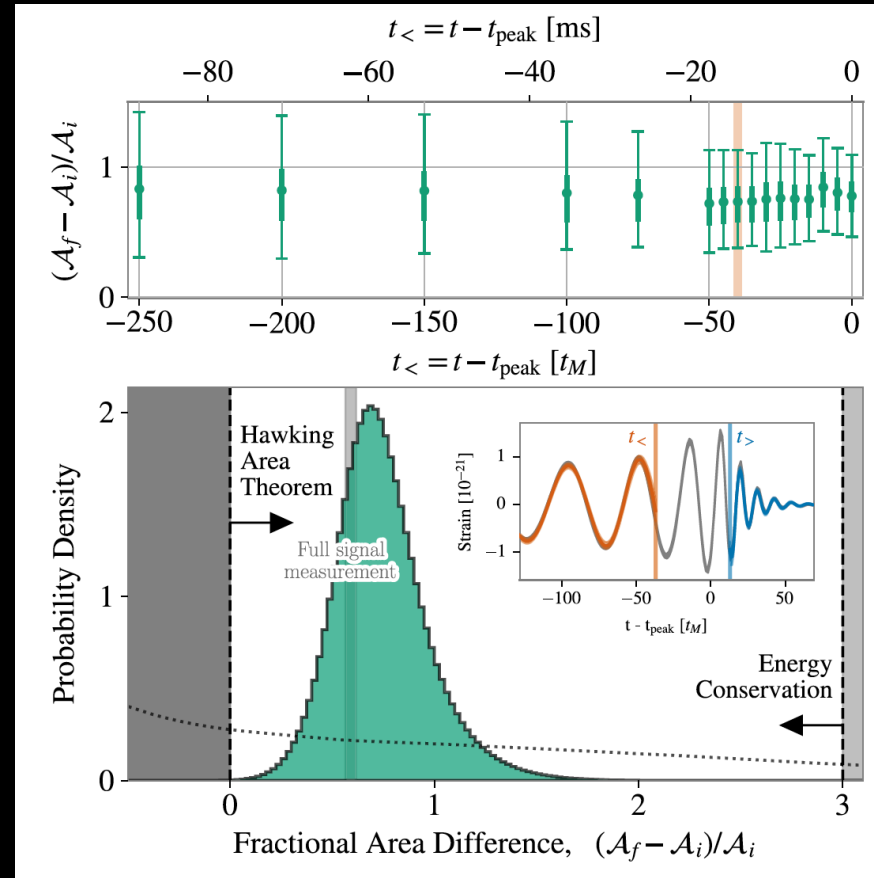
# GW250114: Verifying the ‘Kerr-ness’ of Black Holes and the Hawking Area Law



GW250114: ‘Loudest’ Event To Date, SNR ~ 80



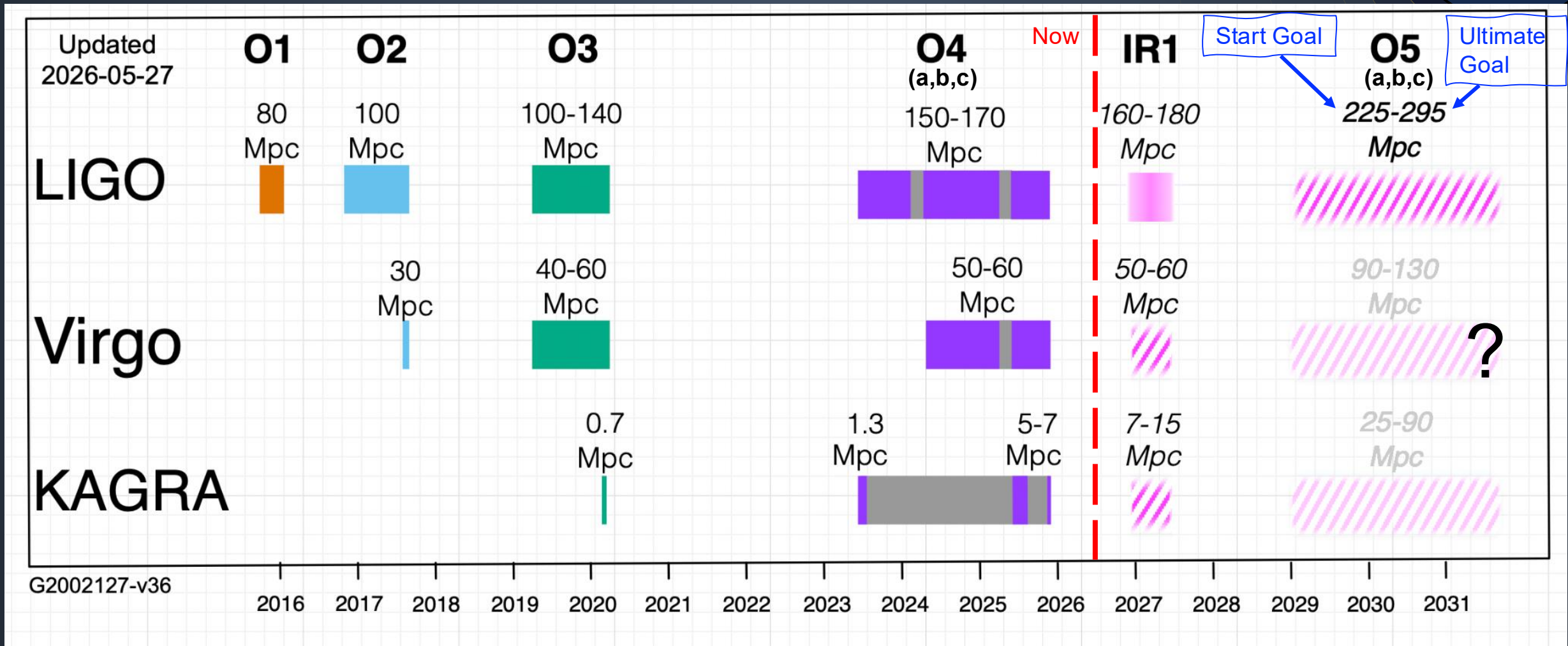
$$\mathcal{A}(m, \chi) = 8\pi \left( \frac{Gm}{c^2} \right)^2 \left( 1 + \sqrt{1 - \chi^2} \right)$$



# LIGO-Virgo-KAGRA Run Schedule: Next ~5 Years

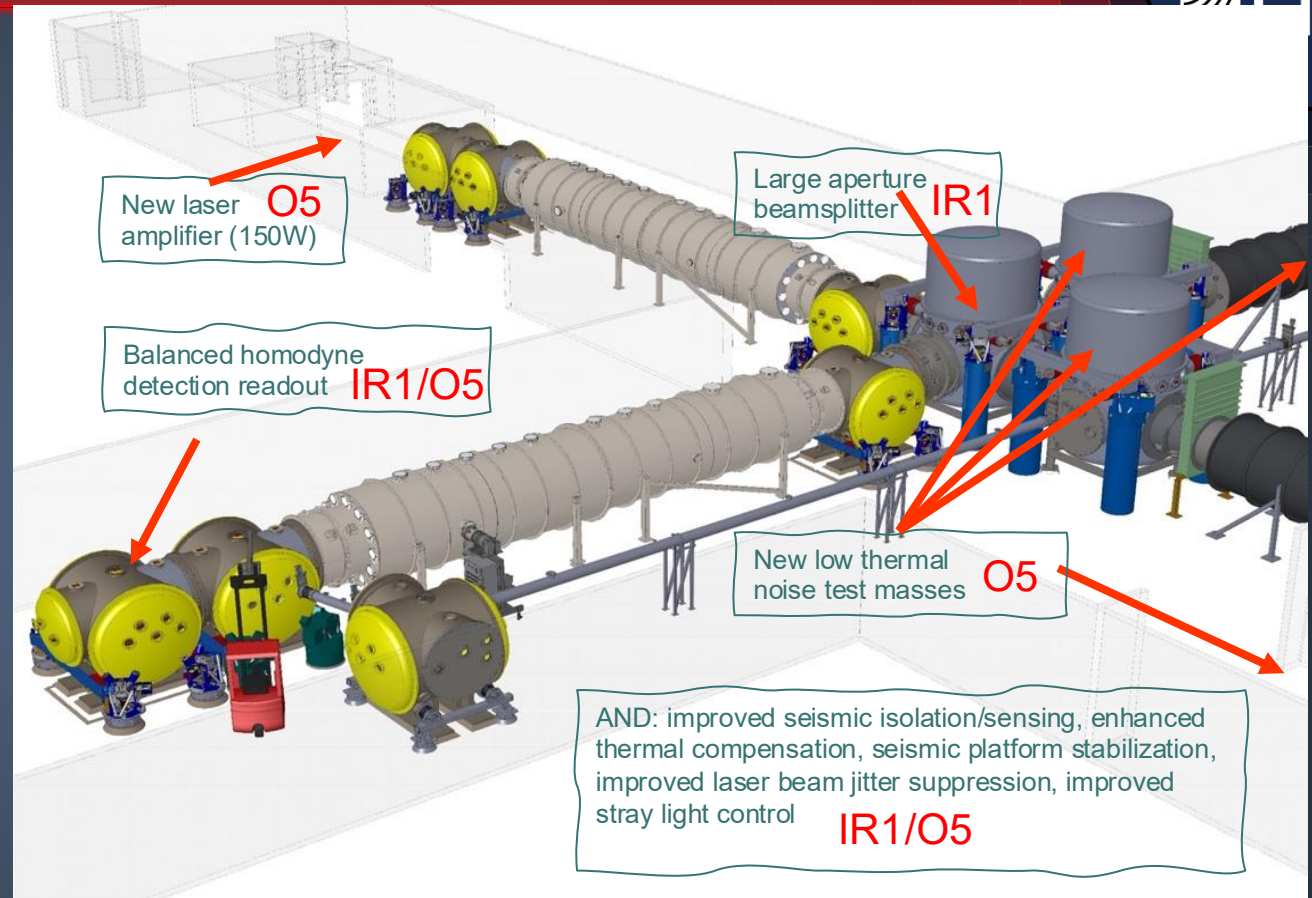


Latest run schedule information: <https://observing.docs.ligo.org/plan/#>



# LIGO Plans for IR1 and O5

- ❑ IR1: November 2026 – May 2026
- ❑ A+ Project includes detector improvements for IR1 and O5 runs:  
225 – 295 Mpc
  - Improved test mass mirrors, beamsplitter, scattered light suppression, squeezing, GW readout, higher laser power
- ❑ And improvements are needed! Rates for EM-bright events have diminished:
  - Binary neutron star (BNS)
    - ❑ GWTC-3:  $10 - 1700 \text{ Gpc}^{-3} \text{ yr}^{-1}$
    - ❑ GWTC-5:  $5.1 - 154.7 \text{ Gpc}^{-3} \text{ yr}^{-1}$
  - Neutron star – black hole (NSBH)
    - ❑ GWTC-4:  $9.1 - 84 \text{ Gpc}^{-3} \text{ yr}^{-1}$
    - ❑ GWTC-5:  $6.7 - 32.8 \text{ Gpc}^{-3} \text{ yr}^{-1}$
- ❑ BNS detections in O5 @ 295 Mpc:  $\sim 2 - 61$  per year



*We are not expecting significant sensitivity improvements in IR1 relative to O4; sensitivity improvements will be realized after the O5 upgrades are done.*

# Virgo Plans for IR1 and O5

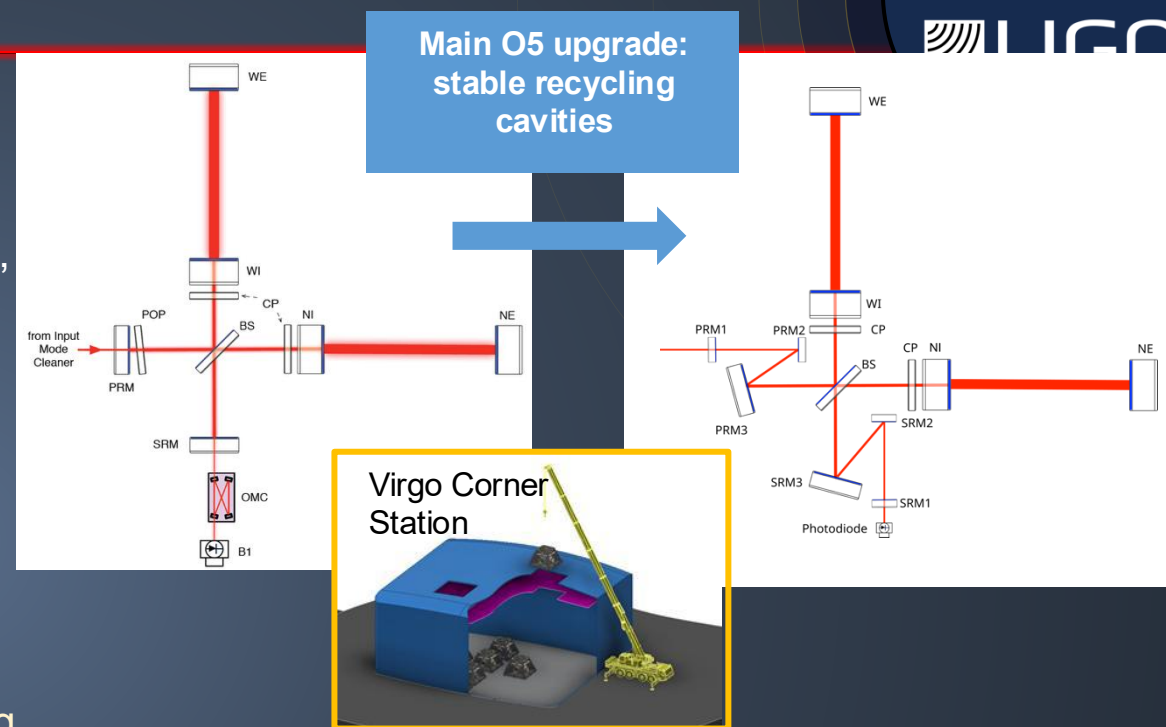
## IR1: 90-130 Mpc

- Higher order mode suppressor, replace highly absorbing test mass mirror, implement point absorber compensation, laser amplifier repair, improved controls

## O5 (two stage upgrade\*): 120 – 160 Mpc

- Stage 1: install stable recycling cavities (major infrastructure project), new input test mass mirrors, new beamsplitter frequency-dependent squeezing
- Stage 2: new end test masses, increased laser power, improved squeezing

\* Dependent upon available funding



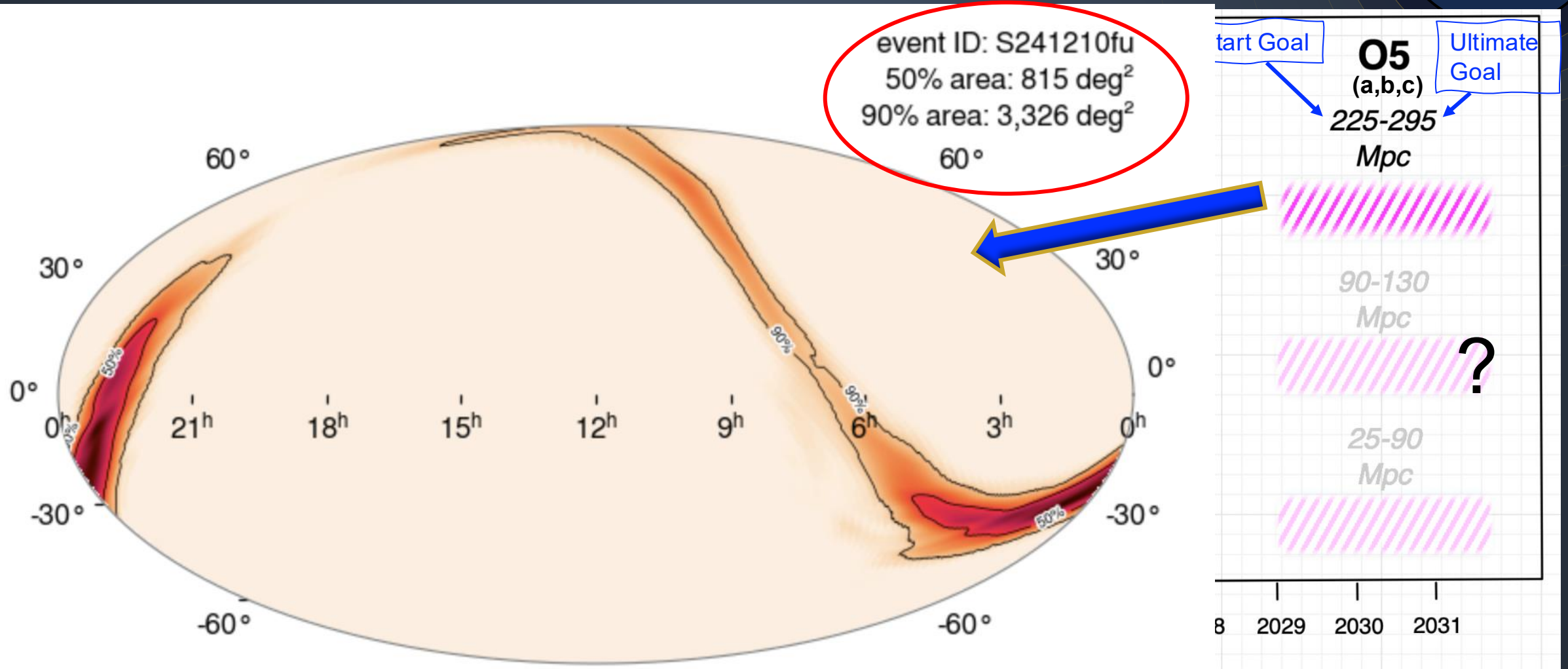
|                            | 2026 |    |    |    | 2027 |    |    |    | 2028 |    |    |    | 2029 |    |    |    | 2030 |    |    |    | 2031 |    |    |    | 2032 |    |    |    | 2033 |    |    |    |
|----------------------------|------|----|----|----|------|----|----|----|------|----|----|----|------|----|----|----|------|----|----|----|------|----|----|----|------|----|----|----|------|----|----|----|
|                            | q1   | q2 | q3 | q4 | q1   | q2 | q3 | q4 | q1   | q2 | q3 | q4 | q1   | q2 | q3 | q4 | q1   | q2 | q3 | q4 | q1   | q2 | q3 | q4 | q1   | q2 | q3 | q4 | q1   | q2 | q3 | q4 |
| Stage-0 (2026 Plans)       |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |
| Commissioning              |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |
| IR1                        |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |
| SCs preparatory activities |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |
| Stage-1 construction       |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |
| Stage-1 installation       |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |
| Commissioning              |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |
| Observing Run (O5?)        |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |
| Stage-2 construction       |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |
| Stage-2 installation       |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |      |    |    |    |

Beyond O5: Virgo\_nEXT

# LIGO-Virgo-KAGRA Run Schedule: Next ~5 Years



Latest run schedule information: <https://observing.docs.ligo.org/plan/#>



# KAGRA Plans for IR1 and O5

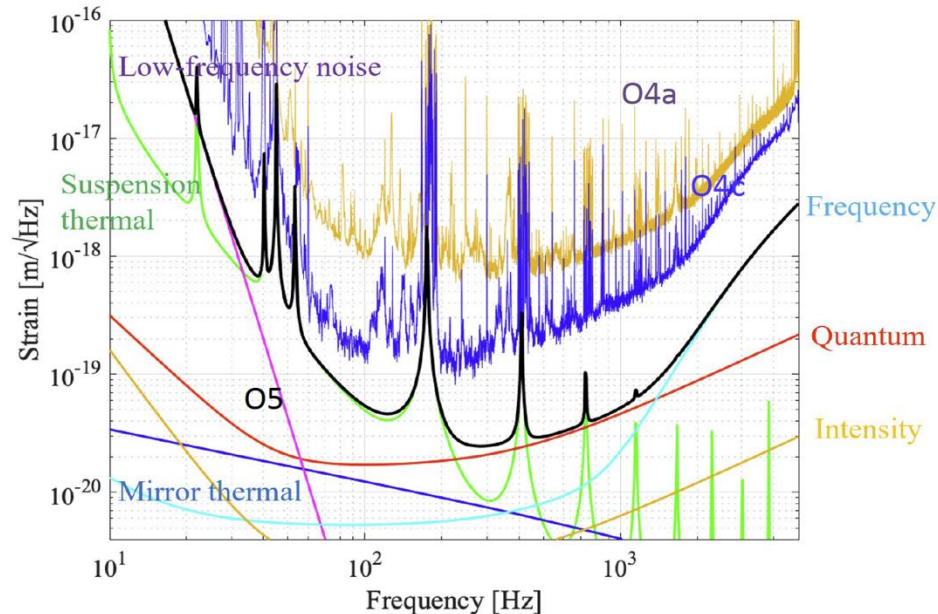
- IR1: KAGRA will run for at least part of IR1

➤ BNS range:  $\sim 10$  Mpc

- O5: KAGRA is planning on participating in most of O5

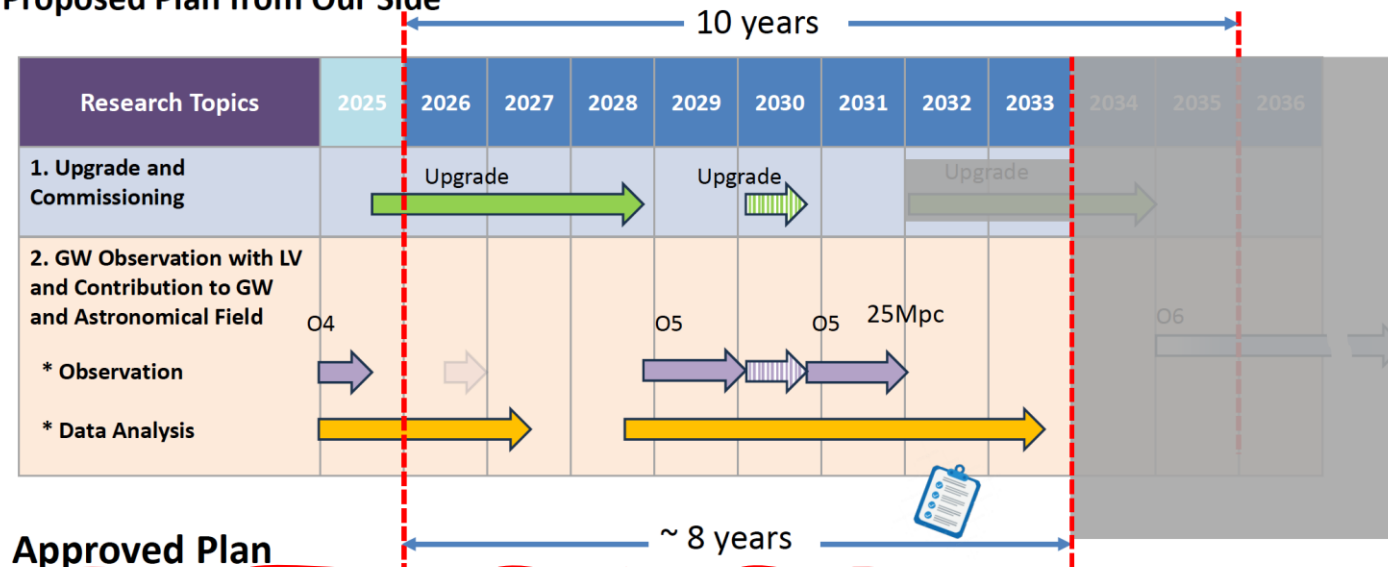
➤ BNS range:  $33 - 74$  Mpc

BNS Range = 33Mpc



## KAGRA Next Plan

- KAGRA next plan was also proposed in the MEXT review in November 2025.
- Proposed Plan from Our Side



- Approved Plan

- Until the end of data analysis for O5 (FY2033 if the schedule is perfectly performed).
- Evaluation is necessary in FY2032 for O6.

Plans/configuration beyond O5 are under development

# The International Gravitational-Wave Observatory Network (IGWN)



## Three Collaborations → One Global Network

IGWN is being established as a self-governing consortium — evolving the LSC, Virgo, and KAGRA collaborations into a single unified global baseline. It advances the frontiers of gravitational-wave astronomy, astrophysics, and fundamental physics, targeting full operation by mid-2028.

**IGWN**

International Gravitational-Wave  
Observatory Network

**3,000+**

SCIENTISTS  
WORLDWIDE

**4 + 1**

DETECTORS  
(ACTIVE + CONSTRUCTION)

**5**

CONTINENTS  
COVERED

Sources: IGWN Transition Timetable V4 (Feb 2026); LVK cumulative events chart LIGO-G2302098, 18 Nov 2025

# Transition to IGWN

IGWN CONSORTIUM — UNIFIED GLOBAL BASELINE



## What IGWN is — and the road to 2028

# IGWN

### International Gravitational-Wave Observatory Network

- A global consortium with a unified governance structure and set of policies
- Consolidates experience from LSC, Virgo & KAGRA while removing redundancies and inconsistencies between current collaborations
- Overseen by the International Joint Oversight Group of funders

3,000+

SCIENTISTS

4 + 1

DETECTORS

5

CONTINENTS

LHO — Hanford

LLO — Livingston

Virgo — Cascina

KAGRA — Kamioka

LIGO-India — Aundha (under construction)

#### SCIENCE GAINS

- ✓ Greater coordination of upgrades and observing runs
- ✓ Improved localization when LIGO-India joins
- ✓ Coordination of all aspects of science program

#### OPERATIONAL EFFICIENCY

- ✓ Shared computing & digital infrastructure
- ✓ Improved ability to direct person-power to under-resourced tasks

#### COLLABORATION MODEL

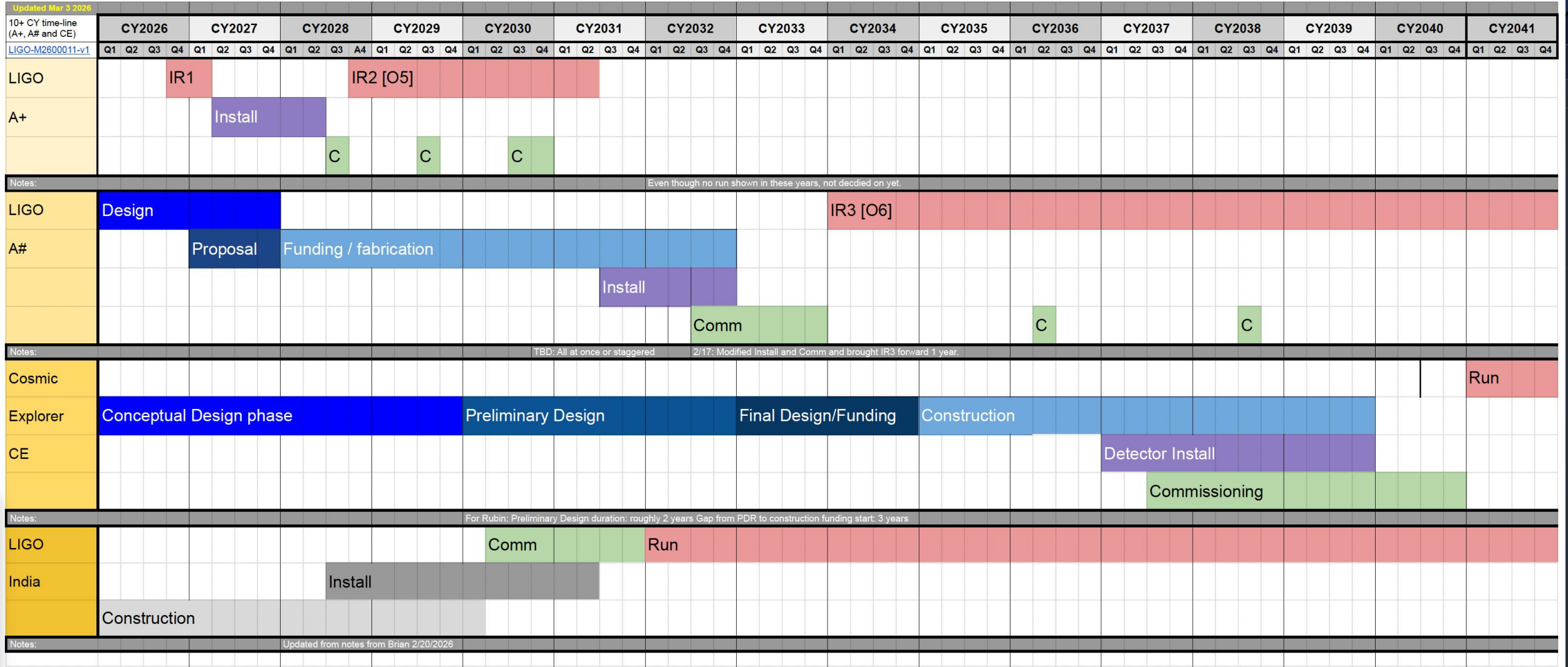
- ✓ Streamlined decision-making authority
- ✓ Closer coordination with global funding agencies
- ✓ Common cost model for all observatories and groups

### IGWN TRANSITION TIMETABLE (V4, FEB 2026) — TARGET: Q2 2028



Source: IGWN Transition Timetable V4 (Feb 2026). Milestones represent current planning.

# Longer Term Horizon for LIGO/A#/Cosmic Explorer: Working Plan

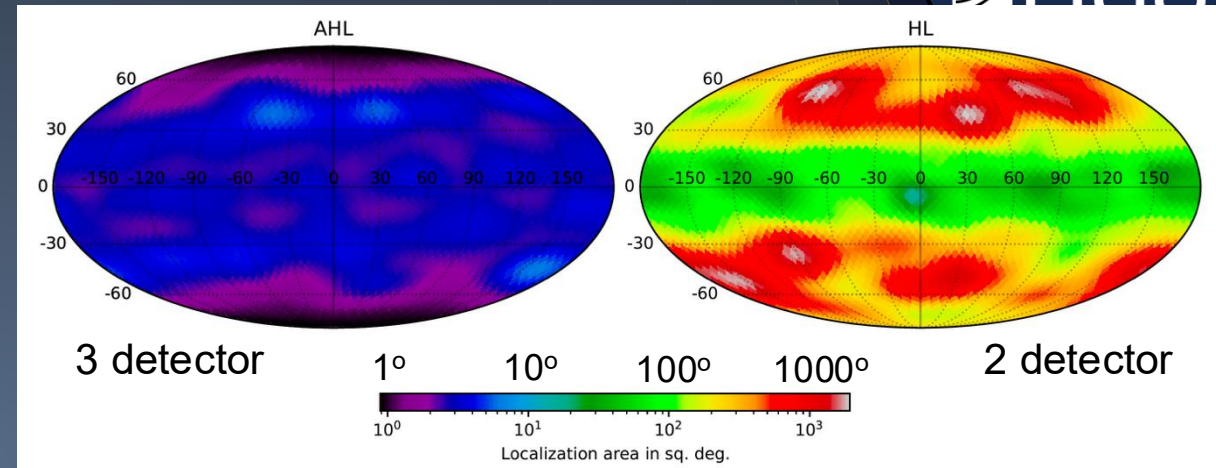


# LIGO-India



## LIGO Only Sky Localization

- ❑ LIGO-India is a 'clone' of the LIGO USA observatories
  - US supplies detector components for LIGO-India
  - Project was formally sanctioned in April 2023
- ❑ Primary scientific motivation: **GW event localization**
- ❑ Observatory construction began in March 2026; expected to complete by in early 2031
- ❑ LIGO-India expected to be operational in 2032
  - Expected BNS Sensitivity: **100-150 Mpc**



# A# Upgrade Program

## Post-O5 Upgrade to the existing LIGO interferometers

- Installation starting in ~2031\*
- Within the framework of existing technologies
  - ▶ 1  $\mu$ m laser wavelength (350 kW  $\rightarrow$  1.5 MW arm power)
  - ▶ Room temperature operation (no change)
  - ▶ Fused silica test masses (40 kg  $\rightarrow$  105 kg masses)
  - ▶ Quantum frequency-dependent squeezing (6 dB  $\rightarrow$  10 dB)
- *A# pushes the design as far as we believe is feasible in the LIGO facilities*
- While also serving as a pathfinder for Cosmic Explorer detector technology

\* Pending available funding

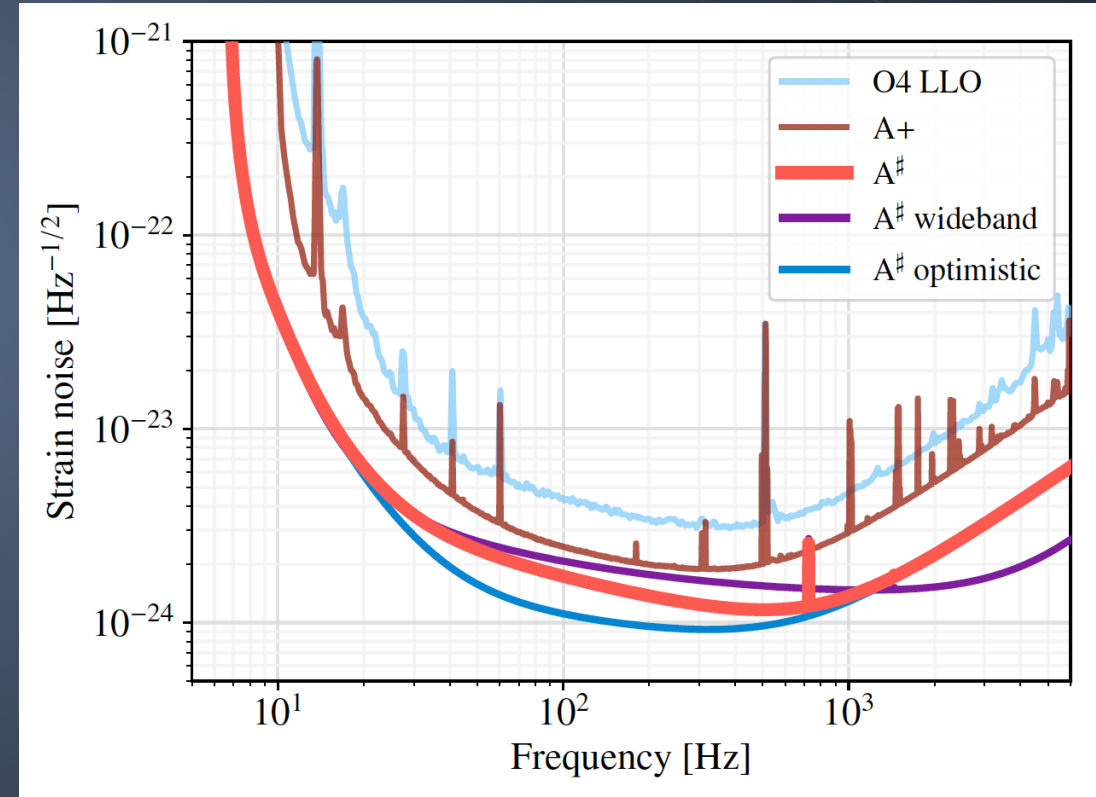
### A# BNS/BBH Range

| Configuration | Range [Mpc] |      |            |
|---------------|-------------|------|------------|
|               | BNS         | BBH  | $z_{\max}$ |
| O4            | 160         | 1400 | 1.6        |
| A+ (O5c)      | 280         | 2200 | 2.6        |
| A#            | 440         | 3000 | 4.7        |
| A# wideband   | 400         | 2900 | 4.8        |
| A# optimistic | 610         | 3700 | 5.6        |

### A# Detection Rates

| Configuration | Annual Detections   |                     |                        |
|---------------|---------------------|---------------------|------------------------|
|               | BNS                 | NSBH                | BBH                    |
| A+ (O5c)      | $17^{+44}_{-14}$    | $26^{+31}_{-16}$    | $797^{+294}_{-217}$    |
| A#            | $69^{+164}_{-51}$   | $115^{+127}_{-62}$  | $2758^{+1005}_{-739}$  |
| A# wideband   | $54^{+129}_{-40}$   | $91^{+100}_{-50}$   | $2240^{+818}_{-601}$   |
| A# optimistic | $208^{+494}_{-148}$ | $305^{+330}_{-161}$ | $6571^{+2389}_{-1754}$ |

### A# target strain noise spectrum



# Summary



## ❑ O4 observing run completed

- Now detecting one event every three days 😎
- No BNS events in O4 😞
  - Interesting subsolar mass event

## ❑ IR1 and O5 runs coming into focus

- IR1 run November 2026-May 2027: all LVK detectors participating
- O5 run early 2029 – late 2031: LIGO and (possibly) KAGRA participating; Virgo is unlikely

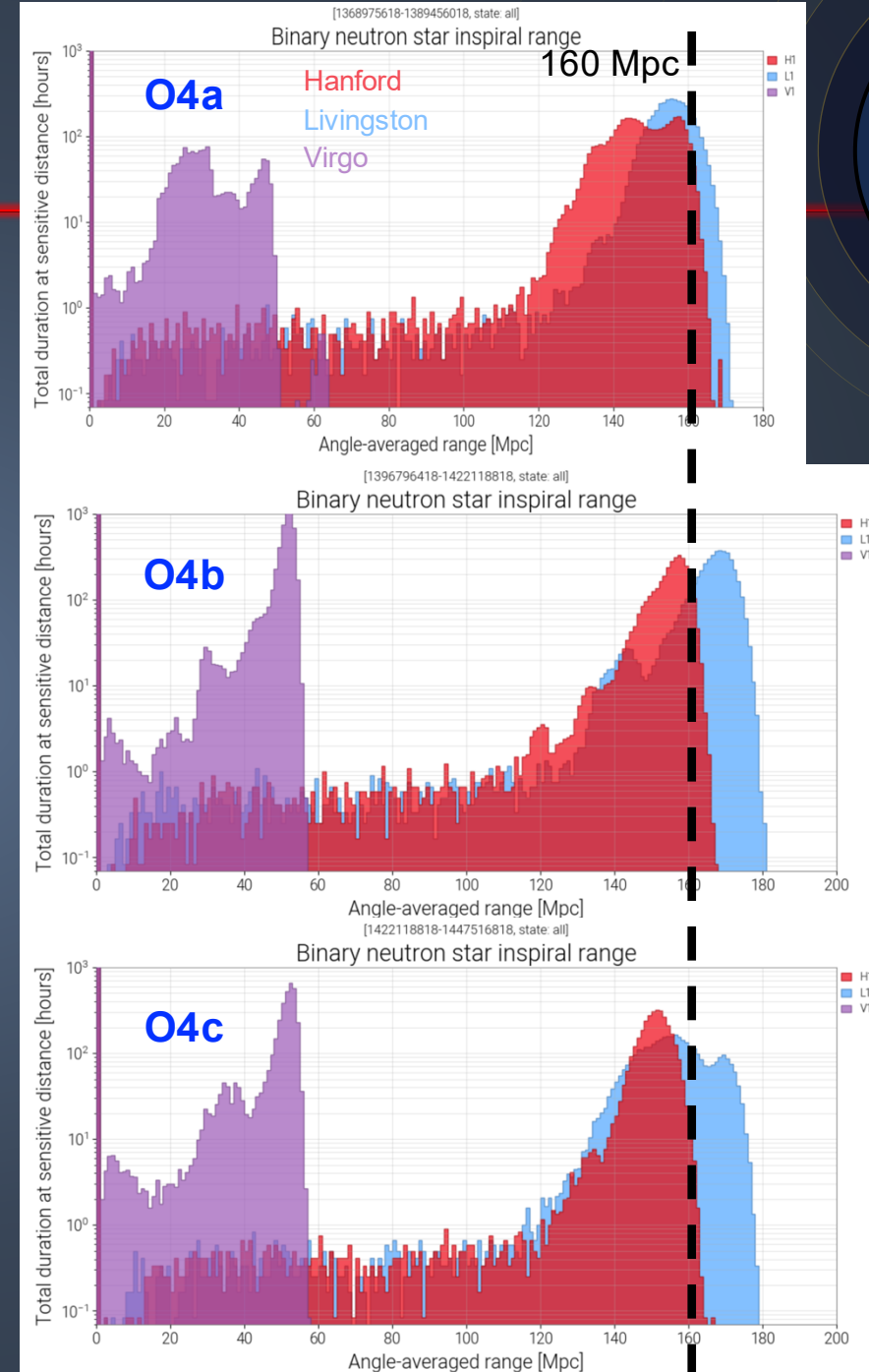
## ❑ O6 run 2033+: LIGO upgrading to A# configuration, LIGO-India coming online

Thanks to Alessio Rocchi, Shinji Miyoki, Peter Fritschel  
Funding: US National Science Foundation, UK STFC, Australian Research Council

# LIGO-Virgo-KAGRA O4 Observing Run

- Carried out from May 24, 2023 through November 18, 2025
- Longest observing run to date: 911 calendar days
  - 3 epochs: O4a, O4b, O4c
  - 755 observing days**; 156 days of commissioning periods
- Single detector performance goals:
  - BNS range: **> 160 Mpc**
  - Uptime observing fraction: **70%**
- LIGO O4 detector performance:
  - Average binary neutron star (BNS) sensitivity range:
    - LIGO Hanford: **152 Mpc**
    - LIGO Livingston: **162 Mpc**
  - Average uptime:
    - LIGO Hanford: **58.8%**
    - LIGO Livingston: **68.8%**

One detection every 3 days.  
LIGO's most successful run as measured by sensitivity and duration.





# Recent LVK Gravitational-Wave Open Science Highlights

- The LVK Collaborations release all gravitational-wave strain data to the broader research community through the Gravitational-Wave Open Science Center (GWOSC)

 <https://gwosc.org>

Gravitational Wave  
**Open Science Center**

Discover Gravitational-Wave Observatory Data, Tutorials, and Software Tools.

[Explore Data](#) [Learn](#)

[Event Catalog](#) [Open Data Workshop](#) [Tutorials](#)

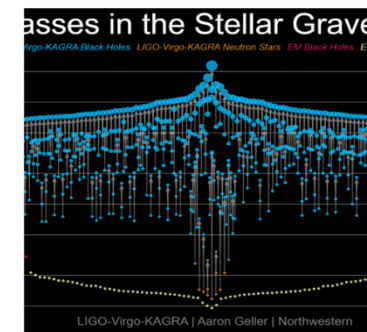
Starts With A Bang



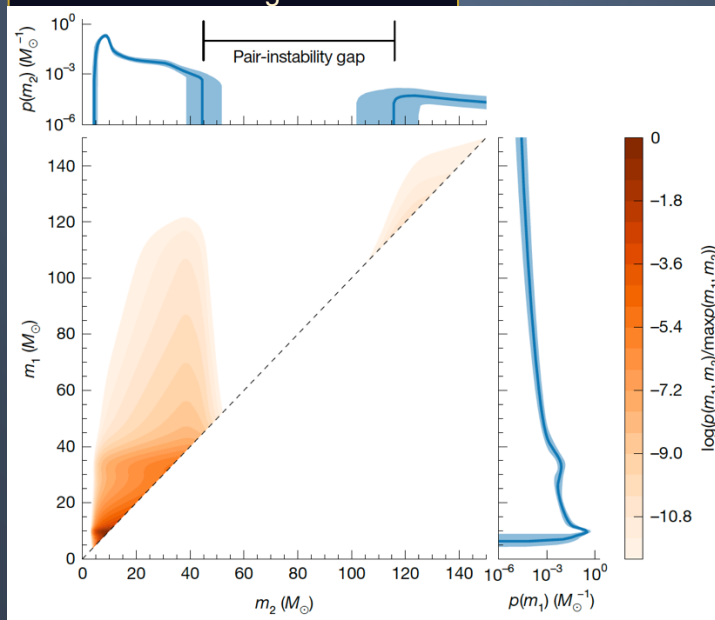
Gravitational wave astronomy is now a fully mature science

In 2016, humanity announced our first successful gravitational wave detection. 10 years and 389 events later, here's how far we've come.

by **ETHAN SIEGEL**

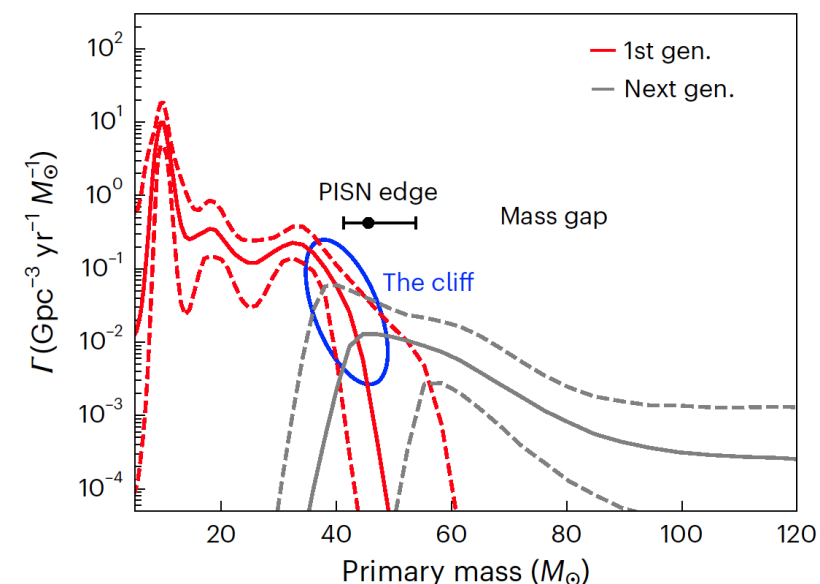


Evidence for Pair Instability Gap from LVK BBH Mergers



Hui Tong, et al., "Evidence of the pair-instability gap from black-hole masses", Nature **652**, 874 (2026)

Evidence for Mass-Dependent Black Hole Formation Channels



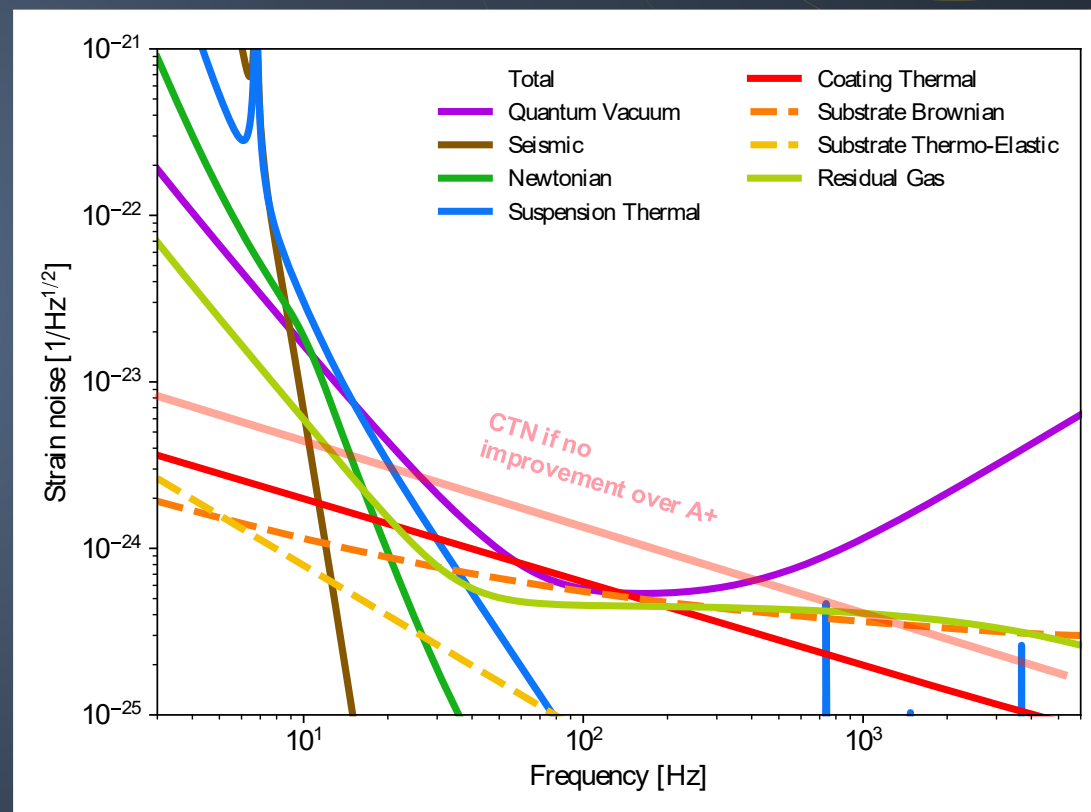
Fabio Antonini, et al., "Gravitational-wave constraints on the pair-instability mass gap and nuclear burning in massive stars", Nature Astronomy (2026)

# Technical Elements of A#

## All part of the Cosmic Explorer design

- Higher Power: **1.5 MW** in the arms (doubling+ from A+)
  - ▶ Involves upgrades to lasers, thermal compensation, parametric instability mitigation
- Higher level of squeezing: **10 dB** (7 dB for A+)
  - ▶ Involves reducing optical losses, improving mode-matching
- Larger Test Masses: **105 kg** (now 40 kg)
  - ▶ Beam sizes stay the same (w/ caveats)
- New Test Mass Suspension, with improvements
  - ▶ Ex.: higher stress silica fibers to lower the bounce & roll mode frequencies
- Seismic Isolation improvements: *key to low-frequency sensitivity*
  - ▶ Reduce optic motion in the 'control band' (below 10 Hz)
  - ▶ New and lower noise sensors for the Internal Seismic Isolators (ISI)
- A# targets another factor of ~2 reduction in coating thermal noise, to take full advantage of quantum noise reduction
  - ▶ This model uses parameters for **AlGaAs crystalline coatings**
  - ▶ AlGaAs challenges
    - Scaling up to the size required for test masses
    - Open technical questions regarding optical performance & noise

## A# target strain noise spectrum



# LIGO-Virgo-Kagra → IGWN



THE COLLABORATIONS — EACH WITH A DISTINCT IDENTITY

## Three collaborations

| LSC                                                                                                                                                                                                                                                                       | Virgo                                                                                                                                                                                                                                                          | KAGRA                                                                                                                                                                                                                                             |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| LIGO Scientific Collaboration                                                                                                                                                                                                                                             | Virgo Collaboration / EGO                                                                                                                                                                                                                                      | Kamioka Gravitational Wave Detector                                                                                                                                                                                                               |
| US                                                                                                                                                                                                                                                                        | EU                                                                                                                                                                                                                                                             | JP                                                                                                                                                                                                                                                |
| 1,600+                                                                                                                                                                                                                                                                    | ~1000                                                                                                                                                                                                                                                          | ~400                                                                                                                                                                                                                                              |
| MEMBERS                                                                                                                                                                                                                                                                   | MEMBERS                                                                                                                                                                                                                                                        | MEMBERS                                                                                                                                                                                                                                           |
| ~100                                                                                                                                                                                                                                                                      | ~160                                                                                                                                                                                                                                                           | ~100                                                                                                                                                                                                                                              |
| INSTITUTIONS                                                                                                                                                                                                                                                              | INSTITUTIONS                                                                                                                                                                                                                                                   | GROUPS                                                                                                                                                                                                                                            |
| 20+                                                                                                                                                                                                                                                                       | 10+                                                                                                                                                                                                                                                            | 15+                                                                                                                                                                                                                                               |
| COUNTRIES                                                                                                                                                                                                                                                                 | COUNTRIES                                                                                                                                                                                                                                                      | COUNTRIES                                                                                                                                                                                                                                         |
| LHO — Hanford, WA                                                                                                                                                                                                                                                         | Virgo — Cascina, Italy (EGO)                                                                                                                                                                                                                                   | KAGRA — Kamioka, Japan (underground)                                                                                                                                                                                                              |
| LLO — Livingston, LA                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                   |
| LIGO-India — Aundha (under construction)                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                   |
| <ul style="list-style-type: none"><li>▶ Founded in 1997</li><li>▶ First GW detection GW150914 (Sept 2015)</li><li>▶ Funded by NSF + international partners: STFC, DFG, ARC, NSERC, MPG, etc.</li><li>▶ Fellows Program: 122+ alumni, 6 now in faculty positions</li></ul> | <ul style="list-style-type: none"><li>▶ Joined three-detector network during O2 (August 2017)</li><li>▶ Critical role in sky-localization of GW170817 (BNS + EM counterpart)</li><li>▶ Funded by EGO member states — CNRS, INFN, NWO-I, FWO and FNRS</li></ul> | <ul style="list-style-type: none"><li>▶ World's first underground cryogenic GW detector</li><li>▶ Sapphire mirrors cooled to 20 K; seismic-suppressing site</li><li>▶ Joined LVK network in O3 (February 2020)</li><li>▶ Funded by MEXT</li></ul> |