VI.Veni.212.047

LVK Detector Status October 2023

Anna Green

Belgian-Dutch Gravitational Wave Meeting 2023

2023.10.23

Ground-Based Gravitational Wave Detector Network

LIGO

Since* 1994

"2G" detectors
ground-based
room temperature

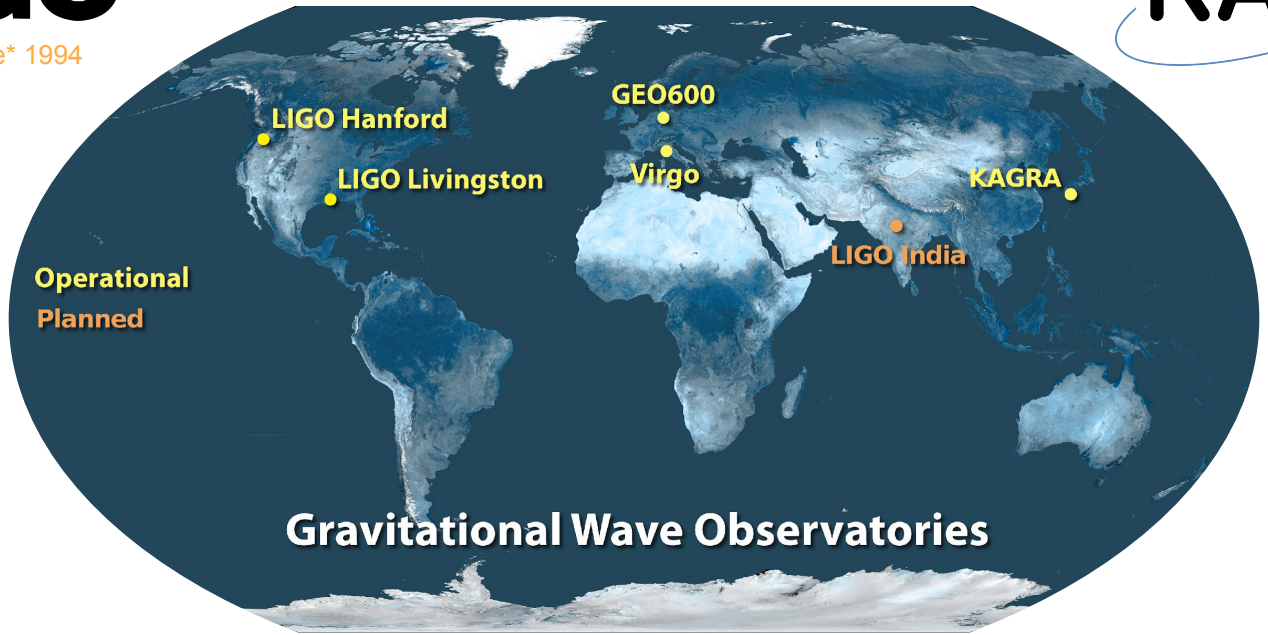
VIRGO

Since 1997

KAGRA

Since 2012

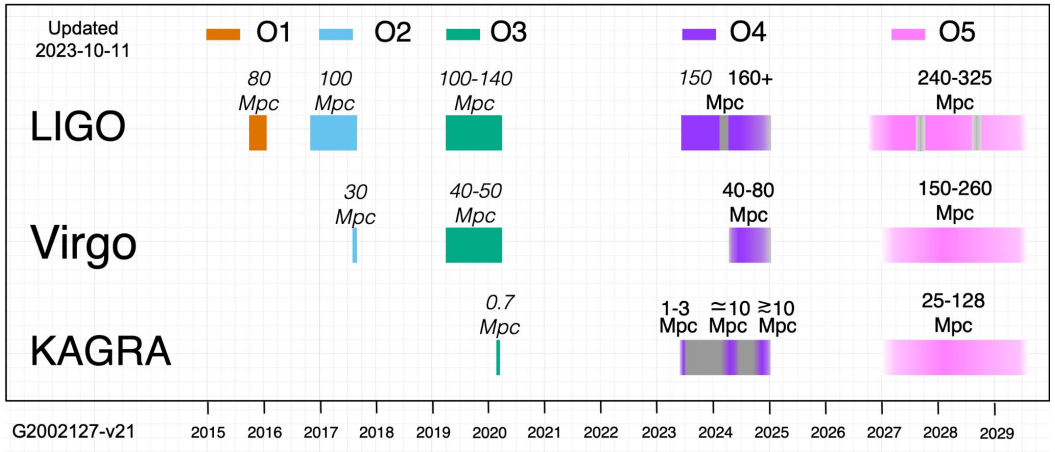
"2.5G" detector
underground
cryogenic



*site construction began

In brief: Latest schedule announcement (15th Oct)

observing.docs.ligo.org/plan/ (next news likely ~15 Nov)



O4 start: 24 May 2023
Total run: 20 mo. including ≲2 mo. commissioning breaks

- LIGO Livingston and Hanford ~ continuous running at 140-165 Mpc; duty cycles 69% LHO / 77% LLO
- Virgo currently at ~35 MPc, did not join.
- KAGRA joined for ~5 weeks at ~ 1.3 Mpc; restarted commissioning 3 July

LIGO commissioning break: 16 Jan 2024 for ~2 months
→ O4 resumes in spring 2024

- LIGO expects similar sensitivity
- Virgo targets 40-45 MPc, expects to join from March 2024
- KAGRA joins for 3 months target 10 MPc, then continues commissioning

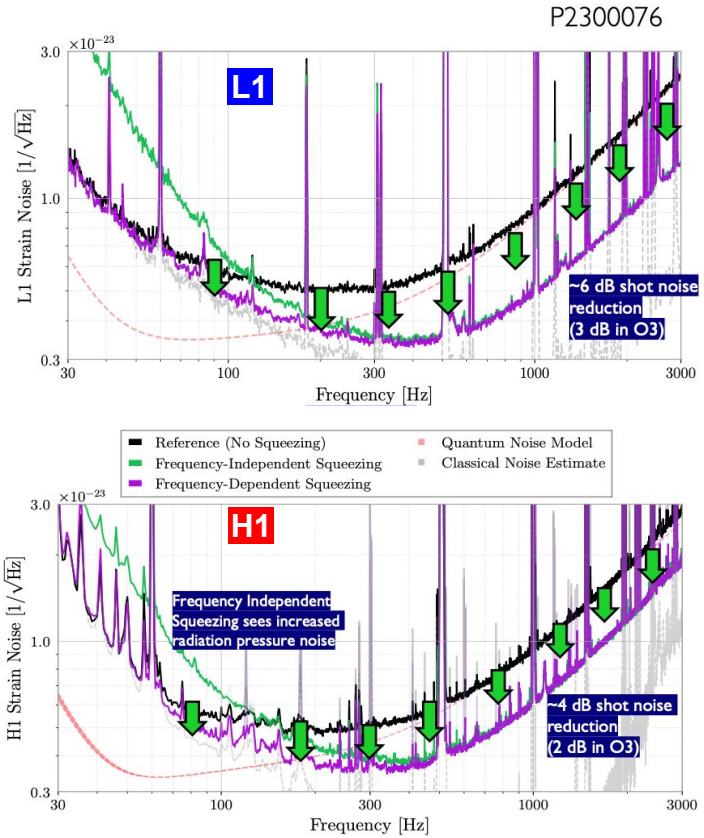
What’s changed since O3?

LIGO

O4 optical configuration:

4km dual-recycled Fabry-Perot Michelson Interferometer with **Frequency-Dependent Squeezing**

- Significant infrastructure & hardware changes: 300m filter cavity
- Broadband squeezing + more than O3
- Range boost: + ~20-30 Mpc
- Unresolved: why H1 gets less squeezing than L1

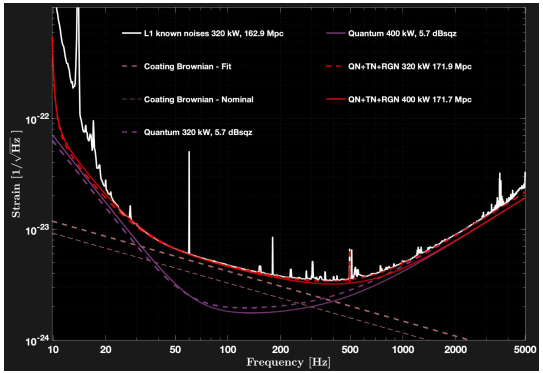


LVK presentation by Dhruva Ganapathy: LIGO-G2301680;
Paper LIGO-P2300076 (accepted PRX)

LIGO

Key theme: **high power** & its consequences

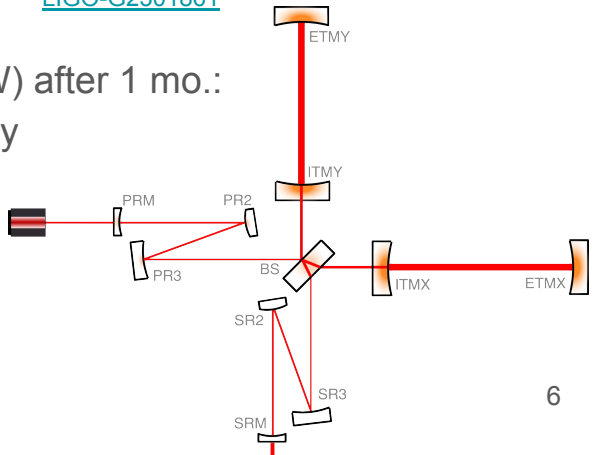
- Test mass replacement
  - To remove **point absorbers**
  - LHO: ITMY; LLO: both ETMs
- Increased input power
  - To improve shot noise
  - Upgraded laser source: 110W pre-stabilized laser output



LIGO-G2301861

LHO started O4 @ 75W input (430kW circulating), reduced to 60W (370kW) after 1 mo.:
thermalisation, parametric instabilities, unknown excess noise, less stability
- overall *increased* range by ~10Mpc

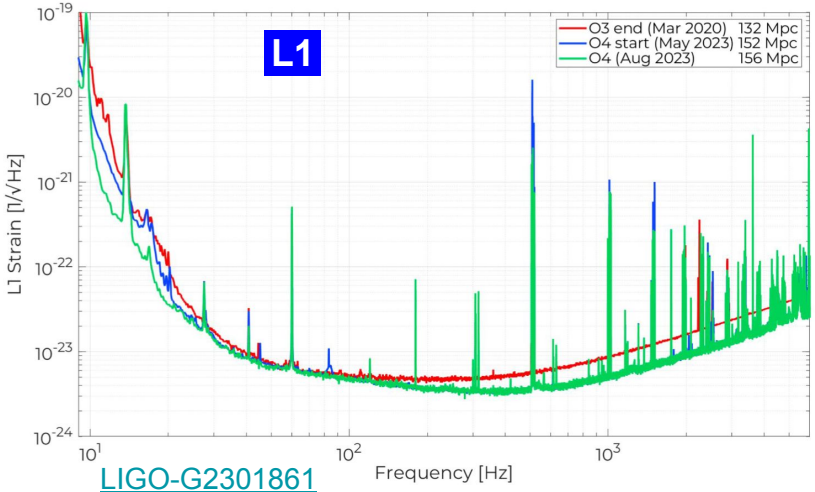
LLO operating with ~320kW circulating power;
increased mid-band noise (thermal?) means little to gain from going higher
(plus similar challenges of high power as LHO)



LIGO

Key Theme: **Technical noise** reduction

- Huge effort in many categories:
  - Improved length and alignment controls, scatter noise from environmental couplings (e.g. dehumidifier fans), electromagnetic interference, laser frequency noise, …
  - Chipping away at all the small contributions
    Including ‘making lemonade’ by commissioning during logging @ LLO May 30 - July 17
- Online noise subtraction e.g. calibration lines



LIGO-G2301861

Current noise budget is limited by:

- High freq: quantum, laser frequency
- Mid: coating thermal, quantum, jitter
- Low: alignment & length controls

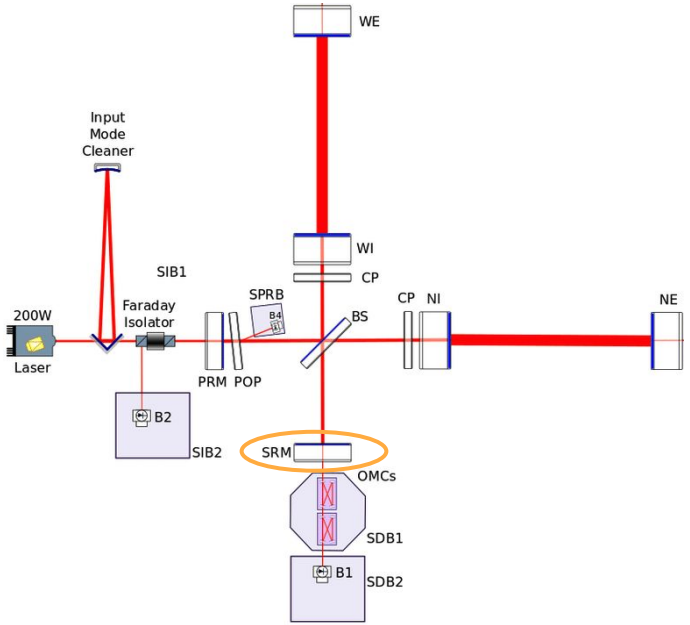
LVK presentations by Dave Reitze (LIGO Lab): LIGO-G2301691,
Naoki Aritomi (LHO): LIGO-G2301748 and Anamaria Effler (LLO): LIGO-G2301861

VIRGO

O4 Optical configuration:

3km dual-recycled Fabry-Perot Michelson Interferometer with Frequency-Dependent Squeezing

- Installed **SR mirror** for broadband operation
- Significant change in core optical configuration: more resonant cavities; new control scheme needed
- introduced **many new challenges** as both recycling cavities are **marginally stable**
  e.g. difficulty acquiring lock (low arm build up), lock 'jumps' (bistability - recycling cavity mode matching), offsets in control signals, excess power at dark port (resonant higher order mode light), ...
- Seriously considering installing stable cavities before joining O5, exploring 2 major infrastructure options



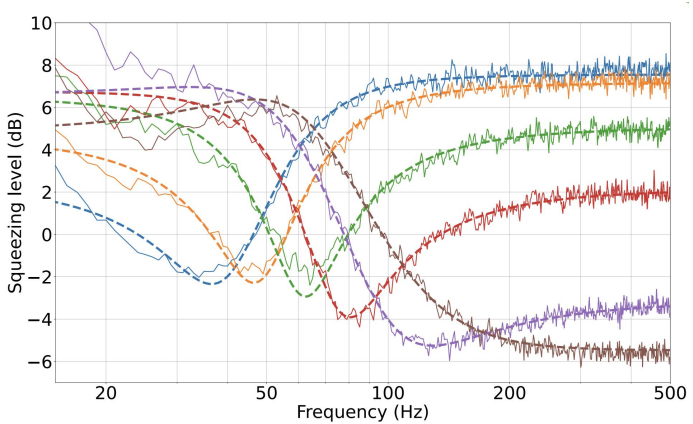
See Julia Casanueva and Piernicola Spinicelli's GWADW talks (VIR-0401A-23 and VIR-0402A-23) for a sense of the challenge

VIRGO

O4 Optical configuration:

3km dual-recycled Fabry-Perot Michelson Interferometer with **Frequency-Dependent Squeezing**

- Significant infrastructure & hardware changes: 285m filter cavity
- Broadband squeezing
- Independent testing successful; ready for injection (work in progress)



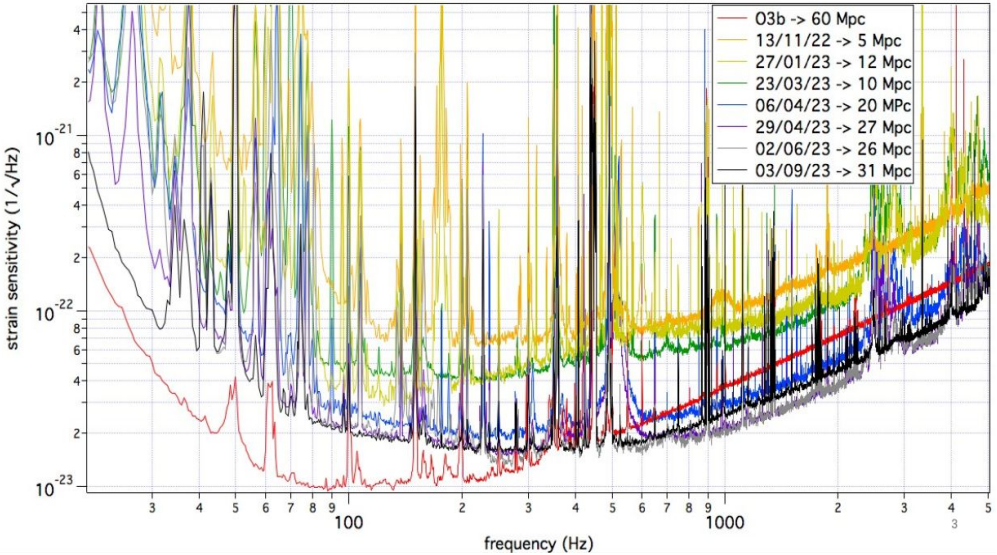
GWADW presentation by Luis Diego Bonavena (VIR-0400B-23)

VIRGO

Noise hunting

- Big mystery: ~1/√f noise 80~300Hz
- **Test mass replacement** (North End Mirror) due to thermal noise didn't solve it.
- Known noises predict ~50 MPc, getting ~35MPc (target was ~60MPc)
  - <30Hz limited by signal recycling cavity length control
  - high freq: quantum + sensor noise
  - Mid-band is as-yet unidentified.
- Extended commissioning time now to identify & mitigate the noise, but will anyway join O4 in March 2024 to contribute to detections

Sensitivity evolution Nov 22–Sept 23



VIR-0810B-23/LIGO-G2301925

KAGRA

O4 Optical configuration:

3km power-recycled Fabry-Perot Michelson Interferometer with **cryogenic test masses**

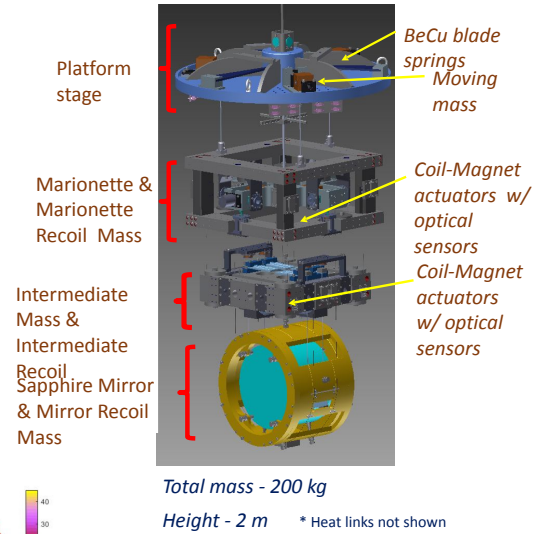
KAGRA's O4 schedule:

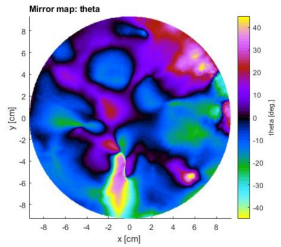
- O4a: 24th May – 21st June
  1 cryogenic test mass (~88K), ~1.3 MPc, ~80% duty cycle
  O4a summary: gwdet.icrr.u-tokyo.ac.jp/~controls/misc/html/
  - Resumed commissioning July 3rd
- O4b: 3 months, starting spring 2024
  all test masses cryogenic (~30 K), 10 MPc target
  - Then more commissioning
- O4c targets >10MPc, timing TBD

KAGRA

Challenges of **cryogenics**

- **Frosting** on **test masses**
  - significantly impacted cavity finesse → “super-low” sensitivity
  - New cooling strategy, vacuum requirements, emergency heaters, cryostat monitors
  - ETMX: nitrogen frosting under 28K, recovered by heating to 30K
  - all other test masses now at ~88K
- **Frosting** on **windows**
  - used for alignment sensing (OpLev injection) → no ifo control → heaters added
- **material stiffness** increases at low temperature
  - shifts mirrors up, affecting alignment controls → New position estimation system
- **Birefringence** in crystalline sapphire optics
  - Feared effect on alignment signals so far not observed
  - Ongoing studies to mitigate future effects



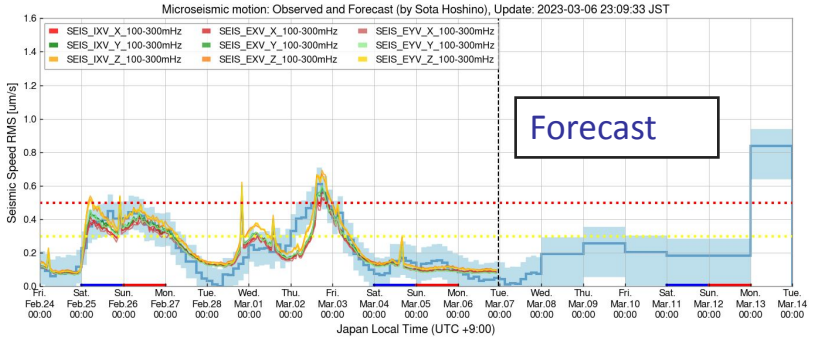


LVK presentation by Shinji Miyoki LIGO-G2301989

KAGRA

‘health check’ & repair of all **suspensions**

- Systematic characterisation of all suspension types (not done pre-O3) - opened all vacuum tanks
- can now stay locked through strong winter ocean waves
- + enhanced wave forecasting to determine daily work
- recovered full lock with DC readout Feb 8th 2023



LVK presentation by Jun'ichi Yokoyama [LIGO-G2300639]

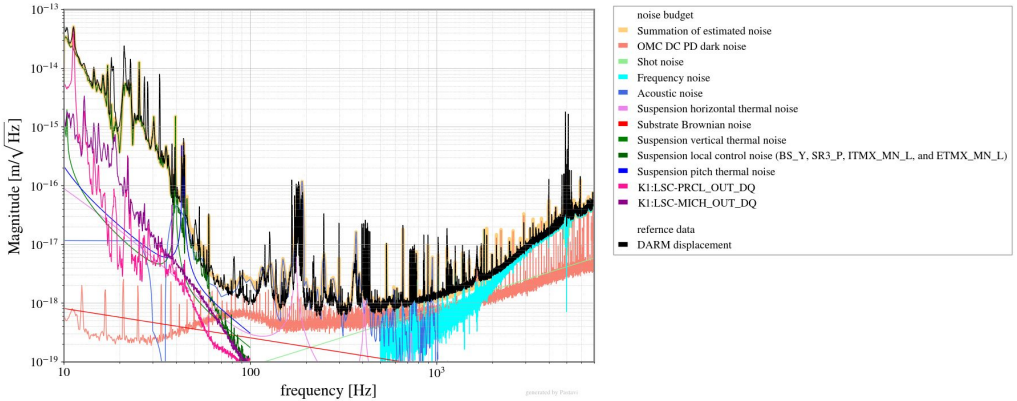
KAGRA

And also…

- Extensive stray light mitigation
  - baffles added around recycling cavity mirrors, beamsplitter and IMC
  - Additional beam dumps around input and output optics
- New OMC mirrors to reduce output losses
- Improved laser intensity stabilisation
- New laser source (up to 60W) prepared
- Alignment Sensing and Control implemented
  - Significantly improved circulating power and interferometer stability

Noise budget for O4a – klog 26086

- High: Shot noise and PD dark noise
- Mid: PD dark noise, acoustic noise.
- Low: ETMX, SRMs and BS control noises.



LVK presentation by Shinji Miyoki LIGO-G2301989

Summary & Outlook

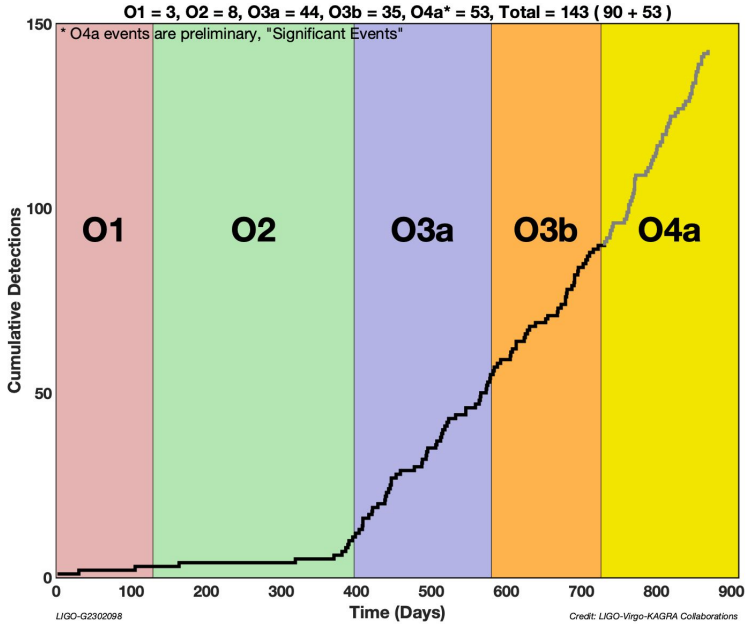
O4 will include an evolving network of detectors

- anchored by LIGO, with Virgo, KAGRA joining at different stages

Detector changes:
common themes, but different challenges

- Common: configuration changes, increasing power and lots of noise hunting
- LIGO: higher power
- Virgo: marginally stable cavities
- KAGRA: cryogenic technologies

Essential to solve for detectors now;
directly inform the choices we make for future detectors



Event rate now 1 BNS every ~3 days (~6 in O3)

Live status

gwistat → online.igwn.org

- Which detectors are observing
- Current detector ranges

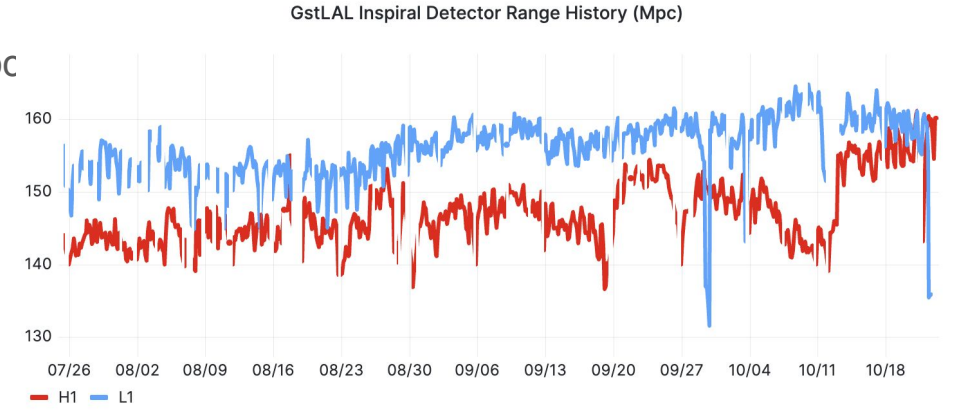
ldas-jobs.ligo.caltech.edu/~detchar/summary/O4a/
(with login)

- More details e.g. duty cycles, event triggers, loc
  durations,...

Gravitational Wave Detector Network

Operational Snapshot as of Oct. 19, 2023 11:25:35 UTC

Detector	Status	Duration [hh:mm]	Latency [s]
GEO600	Unlocked	04:07	16
LIGO Hanford	Observing	12:16	63
LIGO Livingston	Observing	12:16	40
Virgo	Down	>99:00	20
KAGRA	Down	>99:00	53



Last 90 days