VIRGO: O4 and beyond

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ASTROPHYSICS AND COSMOLOGY | FEATURE

Gravitational waves: a golden era

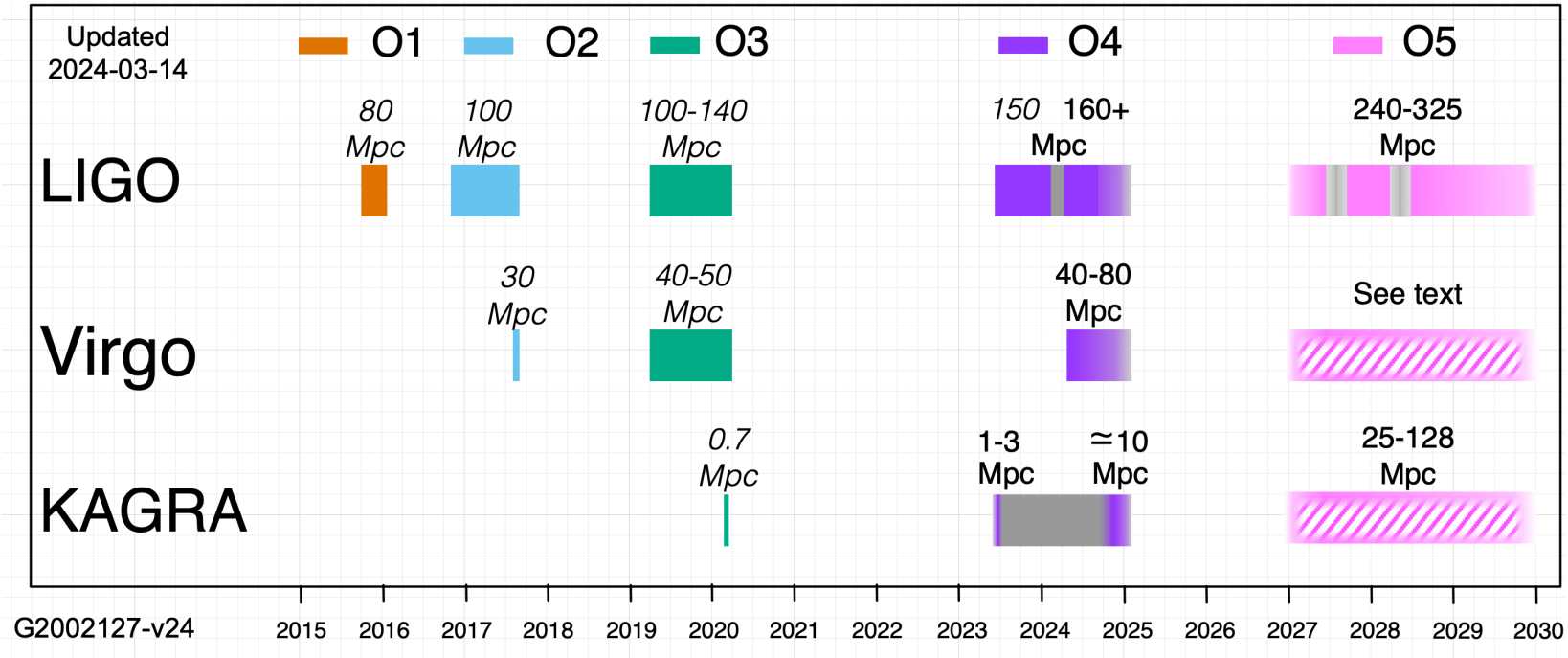
23 August 2023

A Maleknejad, F Rompineve

Outlook

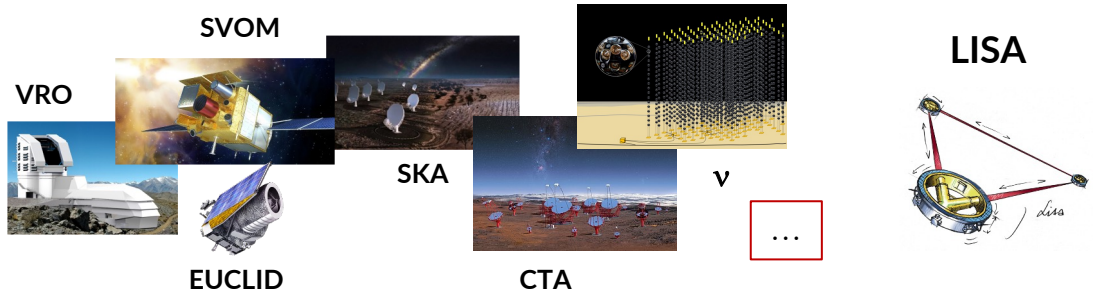
Precision detection of the gravitational-wave spectrum is essential to explore particle physics beyond the reach of particle colliders, as well as for understanding astrophysical phenomena in extreme regimes. Several projects are planned and proposed to detect GWs across more than 20 decades of frequency. Such a wealth of data will provide a great opportunity to explore the universe in new ways during the next decades and open a wide window on possible physics beyond the SM.

OBSERVING PLANS



The O5 start dates, duration, and sensitivities are current best guesses, and will likely be adjusted as we approach that run for all the detectors

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



events 1/5 days ~250/yr ~10^3/yr ~10^5/yr

O3 O4 O5

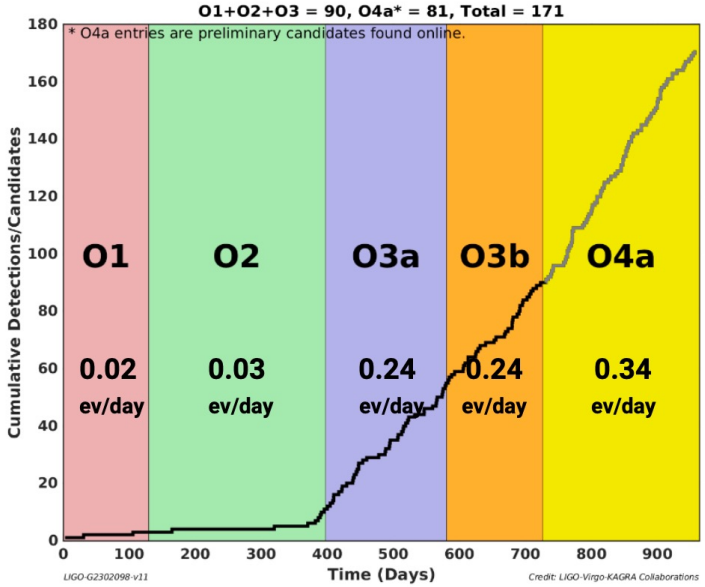
A#,Virgo_nEXT

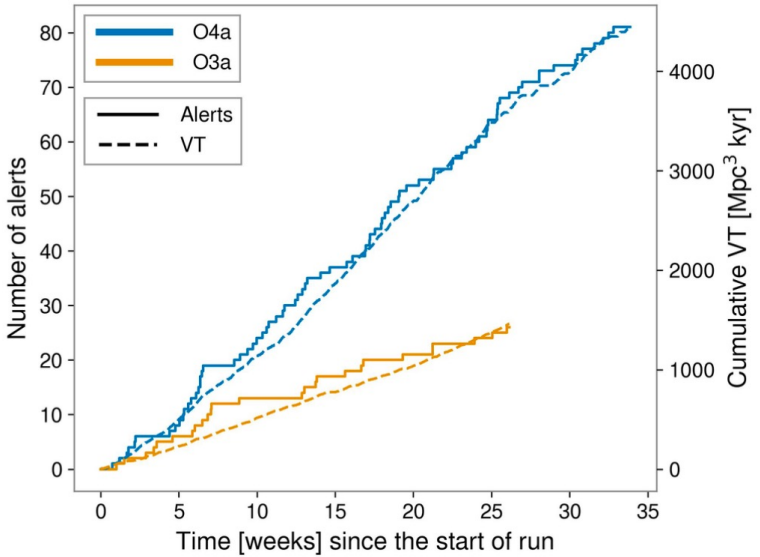
ET/CE

May 24, 2023 2030 ~2035

QUASI-CONTINUOUS DATA FLOW AT PROGRESSIVELY BETTER SENSITIVITY

O4a SUMMARY



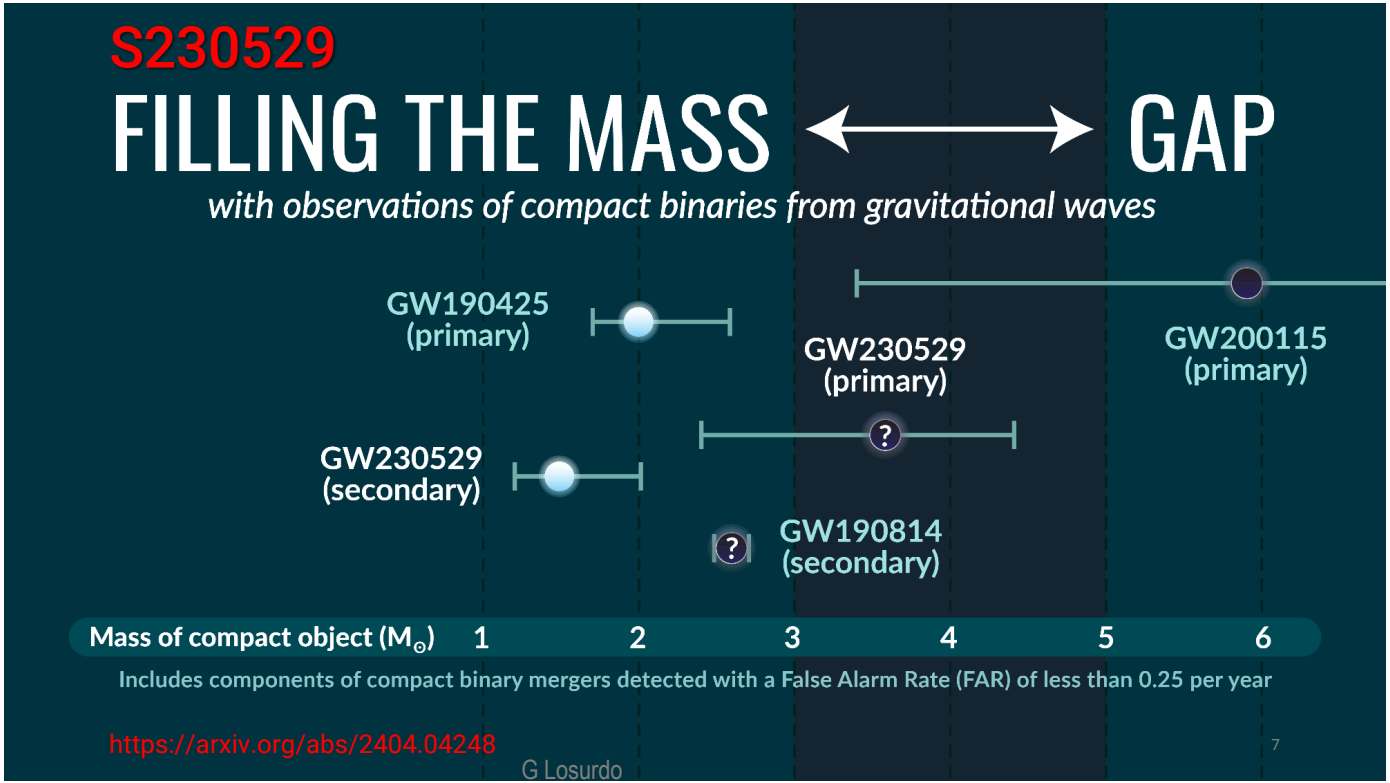


*O4 entries are preliminary candidates found online

Observation of Gravitational Waves from the Coalescence of a $2.5 - 4.5\ M_\odot$ Compact Object and a Neutron Star

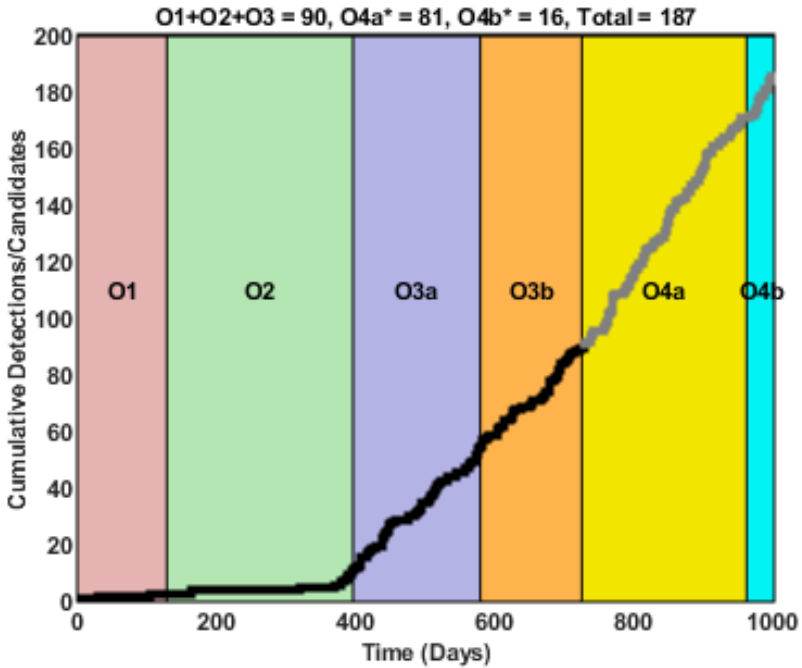
The LIGO Scientific Collaboration, the Virgo Collaboration, the KAGRA Collaboration

We report the observation of a coalescing compact binary with component masses $2.5 - 4.5\ M_\odot$ and $1.2 - 2.0\ M_\odot$

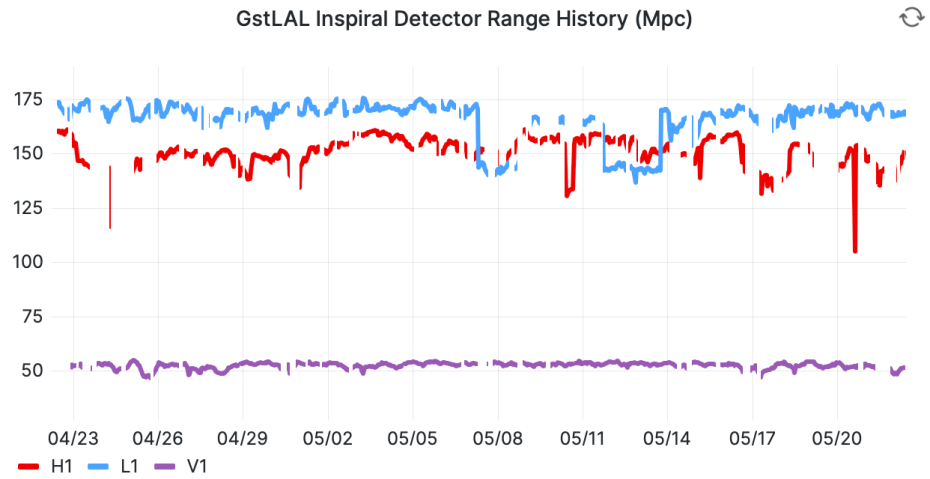


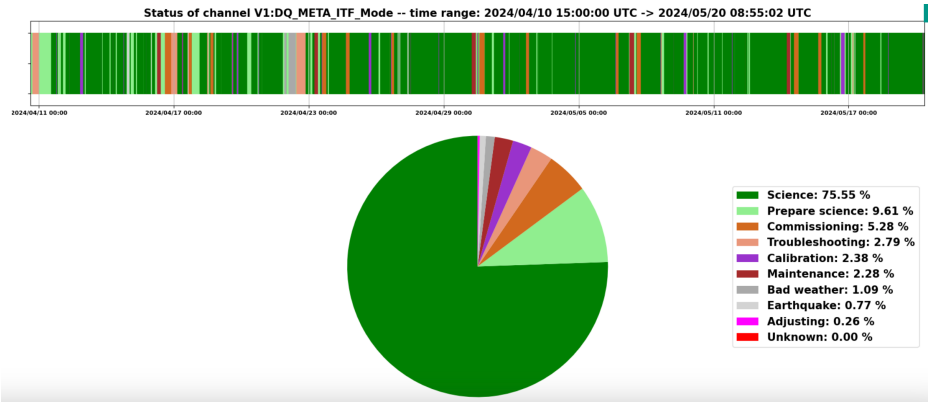
O4b

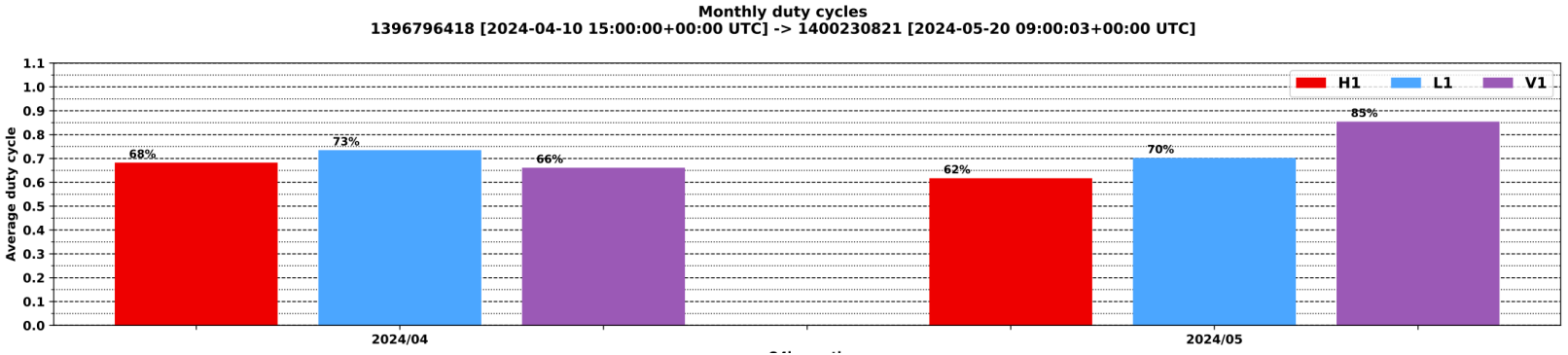
- O4b started on Apr. 10th
  - After 2+1 weeks of ER16
- O4b end date TBD
  - Likely not before mid-February 2025
- Virgo data used in low latency for sky localization – not for triggering



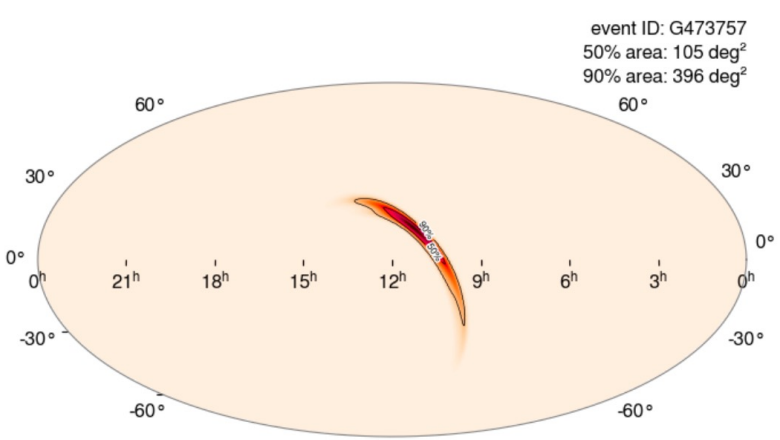
O4b statistics

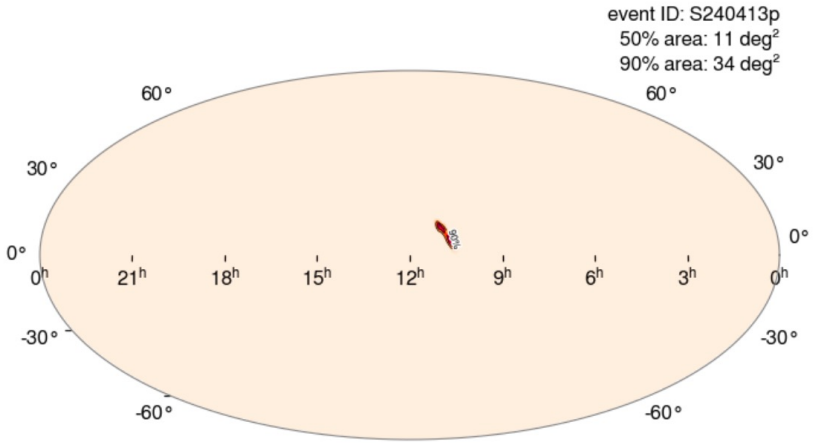






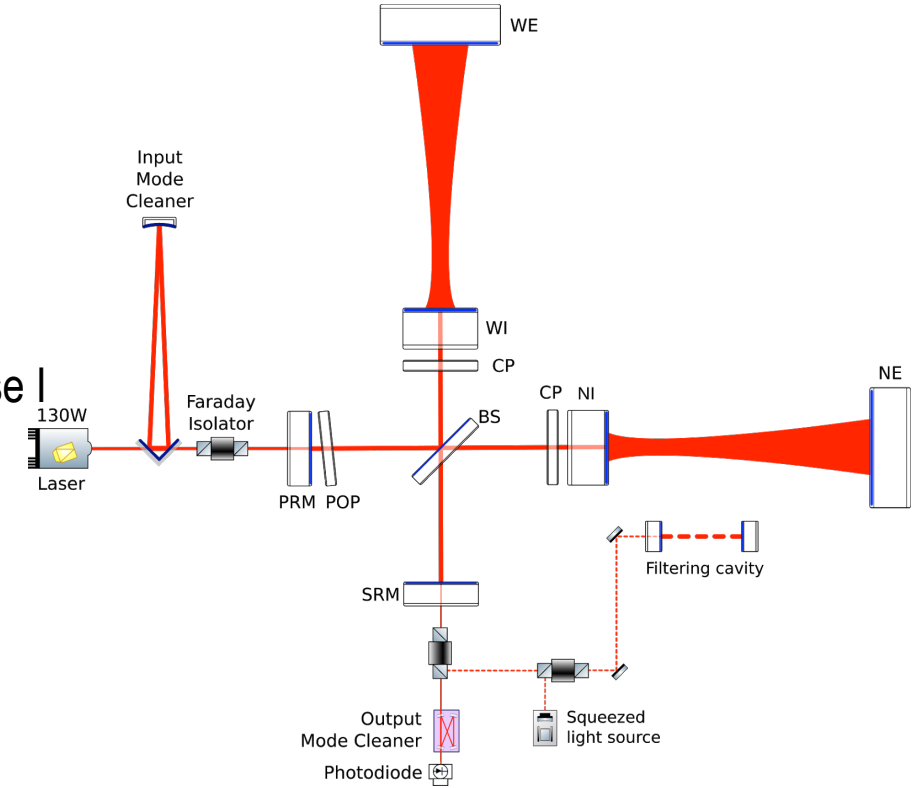
- Impact on localization capabilities
  - ~10 times better for BBH candidate S240413p



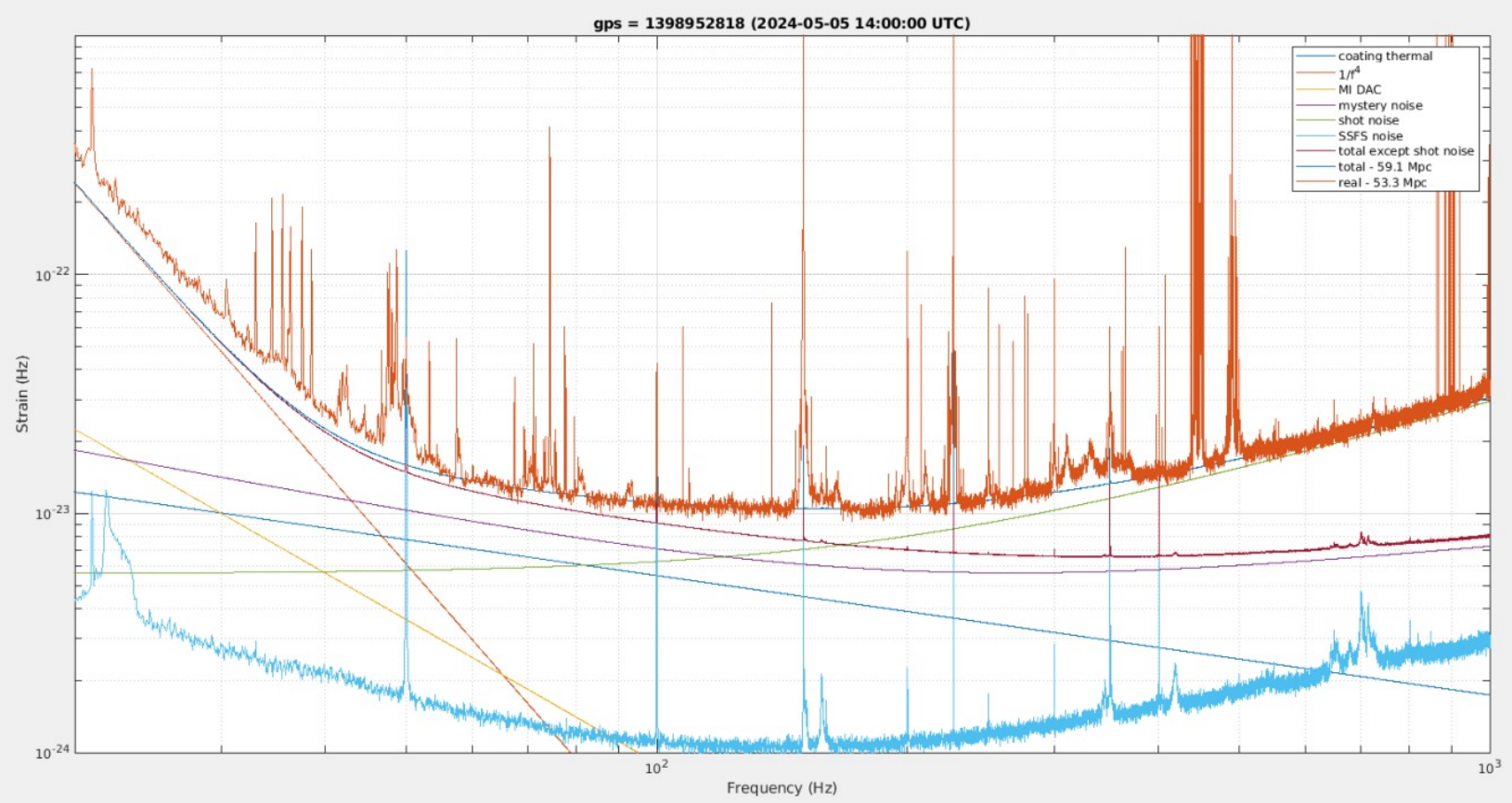


AdV+ Phase II (2019 PLAN)

- MAIN CHANGES:
  - Larger spot on ETM (6→10 cm)
  - Heavier mirrors (40→100 kg)
  - State of the art coatings
  - Higher laser power (40→60→80 W)
- Plan changed after difficulties with Phase I

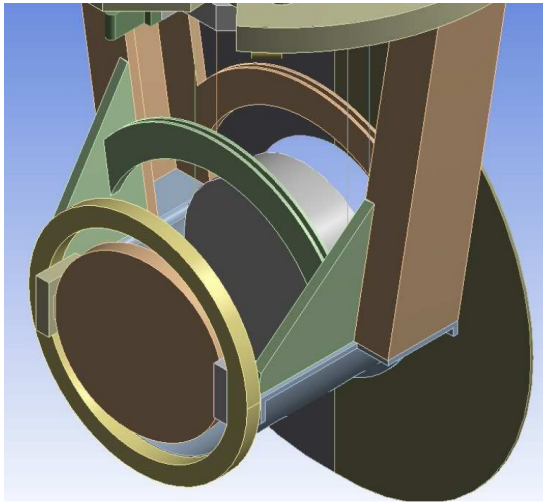


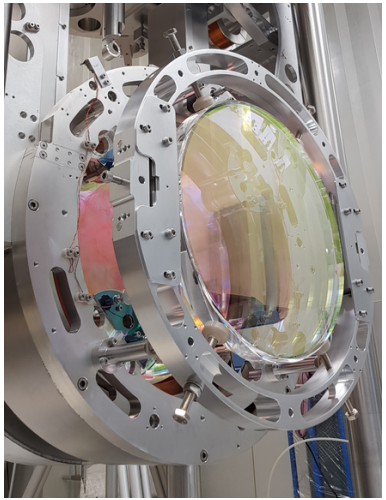
CURRENT SENSITIVITY



UNDERSTANDING THE MISTERY NOISE

Compenstation plate noise



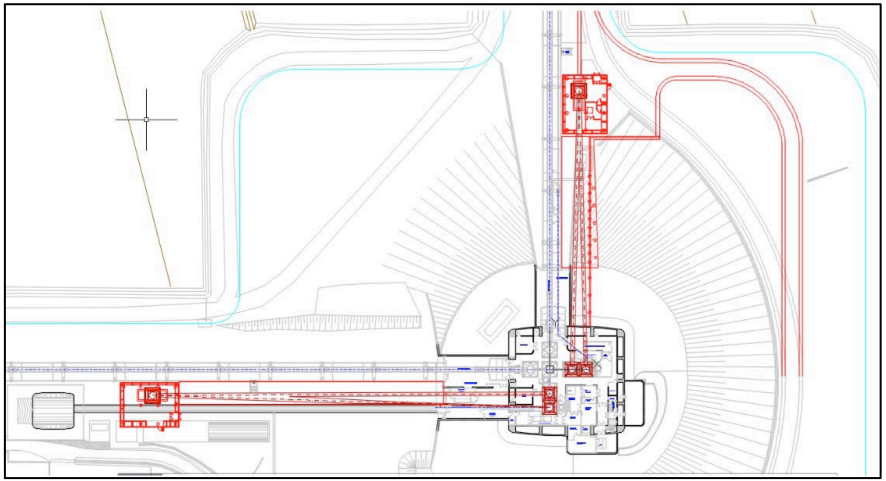


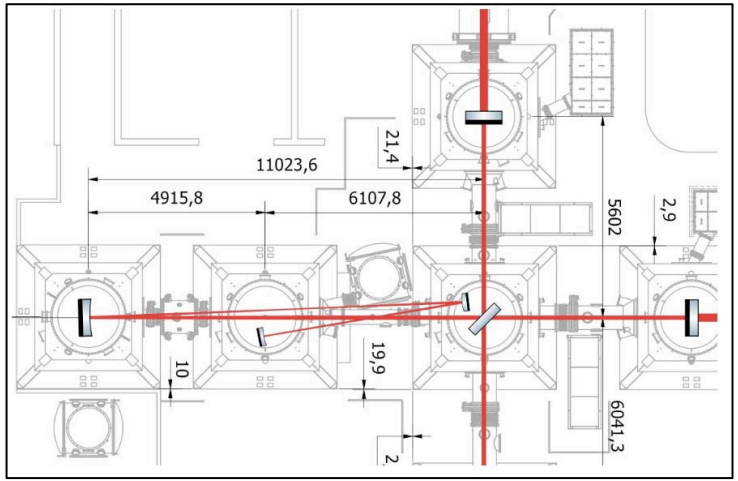
- CP are mounted rigidly
- Expected quality factor between 100 and 1000 → high thermal noise
  - Actual mounting did not correspond to design, quality factor may be even lower
- Metal can have additional noise due to creep
- Is there stress from lateral screws applied and creating birefrigence?

https://logbook.virgo-gw.eu/virgo/?r=57972

STABLE CAVITIES

- Two options investigated
  - Install recycling cavities in existing infrastructure: short cavities
  - Build additional infrastructure: long cavities
- Assessed in terms of cost, schedule, flexibility, technological readiness and risk





- Conceptual design studies document released in January (VIR-0026A-24)
  - Short cavities proposed by the upgrade coord. as preferred solution
- Reviewed by internal board
  - Report released in March
  - Endorses choice to favor short cavity solution (and highlights several aspects requiring further investigation)
- Outcome of review endorsed by Virgo steering committee in April
- Next: write TDR, review by external committee (Autumn)

MORE CHANGES BEFORE O5

- Skip the implementation of large end test masses
  - Keep current arm cavity geometry; defer installation of large mirrors to Virgo_nEXT
  - Change request approved
- Include additional upgrades based on Phase I commissioning experience
  - List being defined
  - Might include replacing (some) arm cavity mirrors to reduce power-dependent optical losses
- Next steps
  - Deliver technical design report
  - Consolidate WBS, deliverables, budget, planning, risk management
  - Overall budget approval expected after external review of TDR

A NEW UPGRADE: GOALS

- Continue/extend the Virgo/LIGO science program until the advent of 3G detectors
  - Existing detector will still play a crucial role for ~ a decade after O5
  - ~ x2 sensitivity improvement wrt AdV+
  - Ensures continuity in the flow of data
- Intermediate step in technology developments between 2G+ and 3G
  - Framework: same Virgo wavelength, room temperature, "same" infrastructure
  - Pathfinder and risk reducer for Einstein Telescope
  - Strong synergies on common R&Ds
- Keeps the community together, allows to form a new generation of GW interferometry experts

SOME FIGURES

	AdV+ best	V_next best	ET HF
Power inj.	125 W	277 W	500 W
Arm power	390 kW	1.5 MW	3 MW
FDS detected	6 dB	10 dB	10 dB
Mirror mass	42/105 kg	105 kg	200 kg
beam radius	49/91 mm	91 mm	120 mm
coating losses	5.4e-5	6e-6	1.25e-5
NN reduction	1/5	1/5	0-1/3

LF NOISE

- At 3 Hz ET is O(10^6) better than today's detectors
- Virgo_nEXT can be a key to understand/tackle LF noises
  - Sensing/controls
  - Environmental
  - Scattered light
  - …

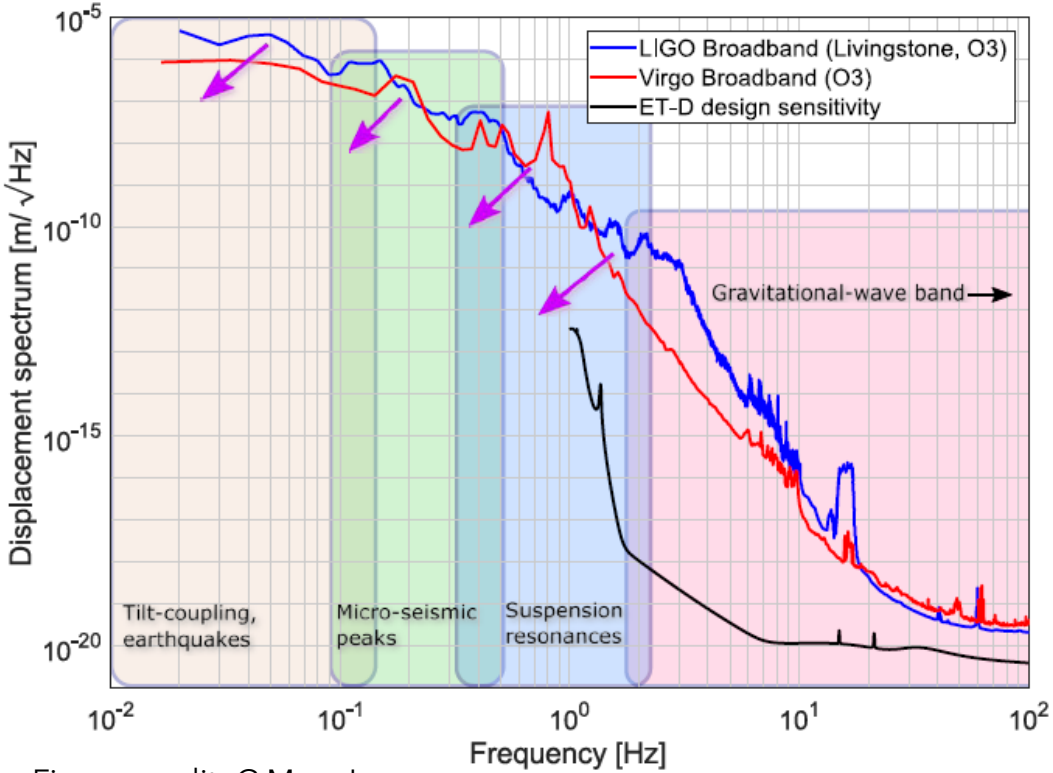
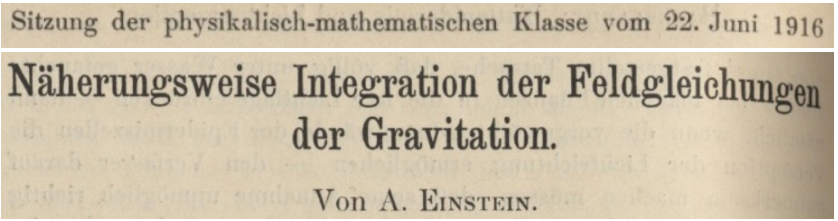


Figure credit: C Mow-Lowry

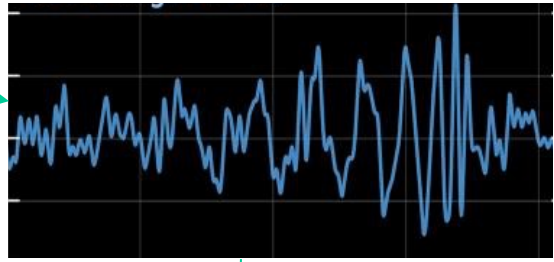
THE PATH


Sitzung der physikalisch-mathematischen Klasse vom 22. Juni 1916

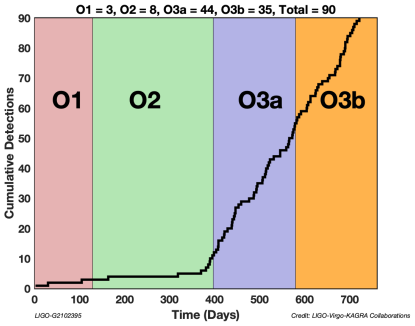
Näherungsweise Integration der Feldgleichungen der Gravitation.

Von A. Einstein.

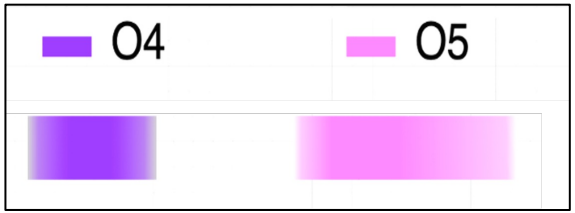
100 years



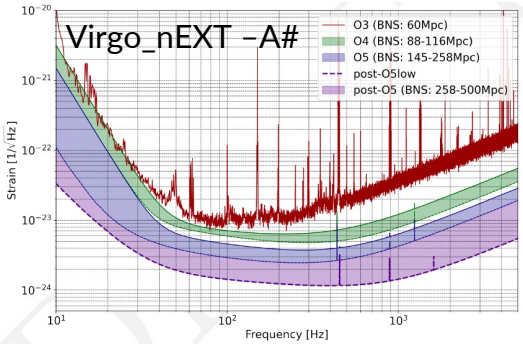
5 yrs



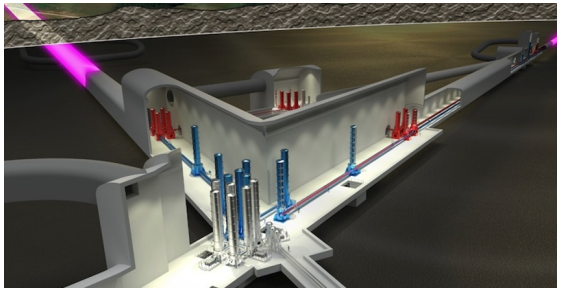
→ 2030



2030 →



>2035 →



EGO-VIRGO ORGANIZATION

Slide by G Gemme

- EGO Council set up a committee to review the current Virgo/EGO organization
- (Some) Recommendations
  - EGO must play a much stronger role in detector construction, operation and integration after acceptance of detector (sub)systems at the EGO site
  - Oversight by the EGO Council should be strengthened by appointing a program officer, who is the liaison between the EGO Council and the EGO Director
  - EGO and Virgo must adopt a rigorous project management structure […], similar to any large-scale (international) research infrastructure
  - Additional financial resources are essential for the future of EGO/Virgo
  - A careful assessment of the EGO staffing needs should be carried out as soon as possible
  - The Virgo Collaboration must have an increased engagement in (on-site) detector related activities and tasks of common interest
  - The impact of the prospect of Einstein Telescope on Virgo should be carefully managed
- EGO Council will install a team in close collaboration with the Virgo collaboration to define the implementation strategy

IGWN

Slide by G Gemme

- The International Gravitational Wave Network is a proposed single organization to coordinate the development, commissioning, and operations of the international network of ground-based, gravitational-wave detectors (L+V+K) and to carry out the scientific mission of that network
- The IGWN Design Committee is charged with developing a Charter (scope and purpose) and Bylaws for the organization
  - Secure individual groups contributions to detector-related activities
  - Sharing of financial resources and allocation of resources to IGWN activities
  - Avoid redundancies deriving from multiple venues where decisions are taken
  - Respect the specific needs and the necessary representativeness of regional realities
- The committee is not charged with the creation of IGWN
  - Formation and approval process will be dealt with separately
- Timeline: deliver a final recommendation by the end of the O4b run (with some flexibility)
- Meeting between representatives of the funding agencies in June