Status of Virgo

The 14th KAGRA International Workshop
Perugia May 15-16 2026

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Artemis CNRS / OCA / UniCA

Outline

Virgo collaboration

VirgoLab

Virgo in O4

Commissioning after O4

Preparation for IR1

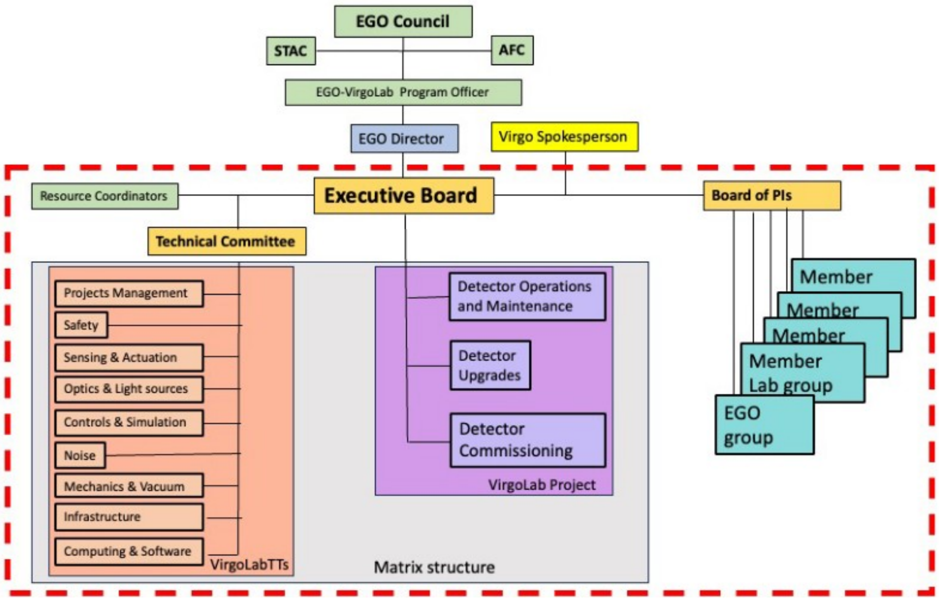
O5 upgrade

The Virgo collaboration

- 1000+ members, 500+ authors, 175 institutions, 21 countries.
- 41 groups:
  - 36 full members
  - 5 in probationary period
  - New group from Marietta Blau Institute, Vienna
- New by-laws adopted in 2022.
- Yearly pledge for activities.
- Bi-yearly group MoA review.
- The Virgo collaboration is part of IGWN.

VirgoLab

- New organizational structure mandated by EGO Council.
- Distributed laboratory: member groups are also member groups of Virgo.
- VirgoLab **in charge of commissioning, operation and upgrade** of the Virgo detector for O5.
- The Virgo collaboration remains in charge of the **data analysis and R&D for future upgrades and contributes to operation**.
- VirgoLab officially started on January 2026. The EGO director is the director of the VirgoLab.
- Framework agreement signed by all parties.

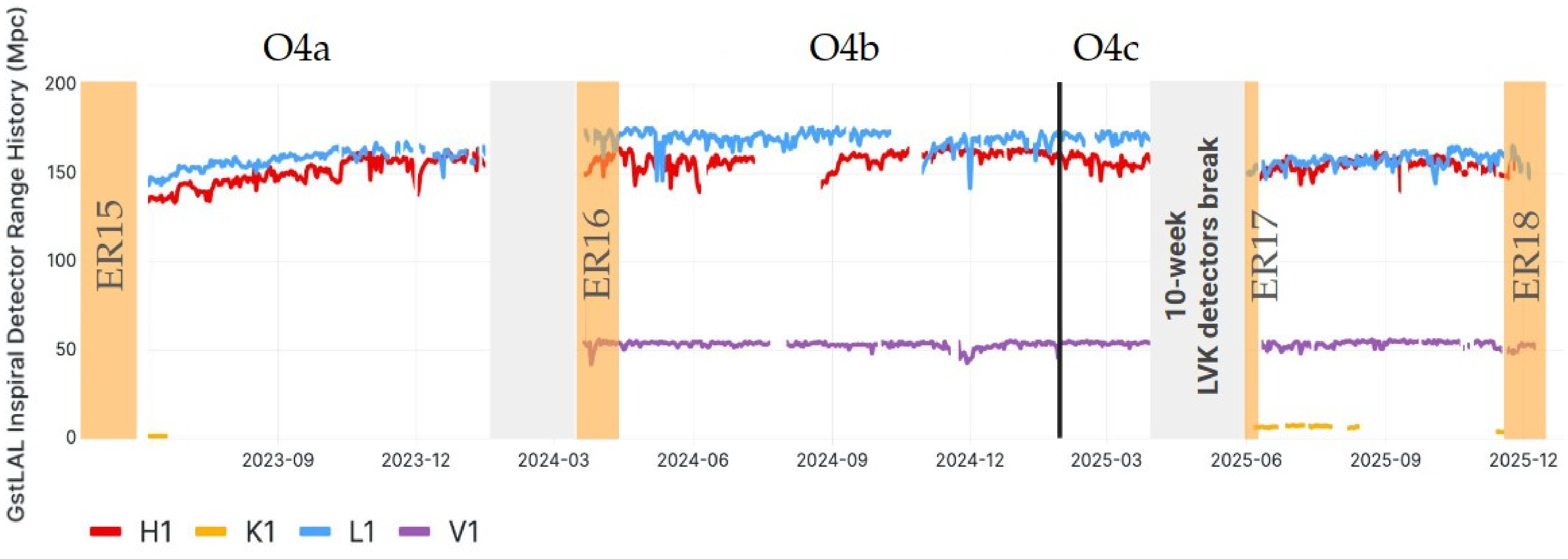


VirgoLab

Main bodies established

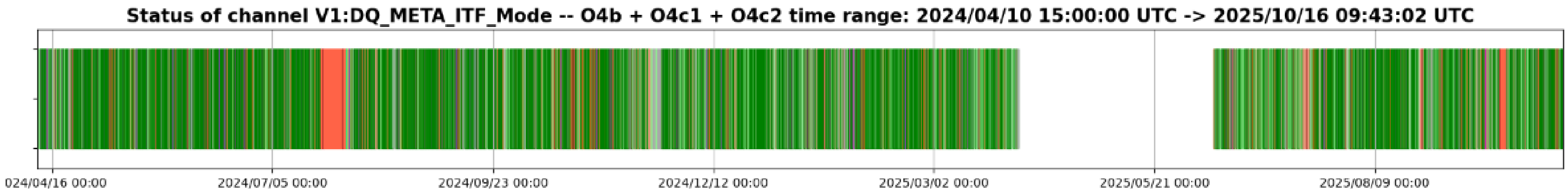
- Executive Board operational
- Board of Pis
  - First meeting held
  - Threshold for labs to be represented by a PI on the Board of PIs being tuned.
- Technical Teams and technical committee
  - Almost all TT Leaders has been appointed (Infrastructure and Safety to be appointed soon).
  - The Technical Committee started to meet regularly, every two weeks.
  - Detailed definitions of the TT, their roles and Interaction with the Projects are under definition.
- Collection of the IT services required by VirgoLab has started as long as the implantation/creation of the most urgent services (VirgoLab mailing list, changes in VMD, etc.).
- The invitation to the VirgoLab members to join the TTs is planned to be distributed soon

Virgo in O4



Virgo could not join O4a - issues with running laser high power with marginally stable recycling cavities

Virgo in O4 – duty cycle



Hanford: 63%

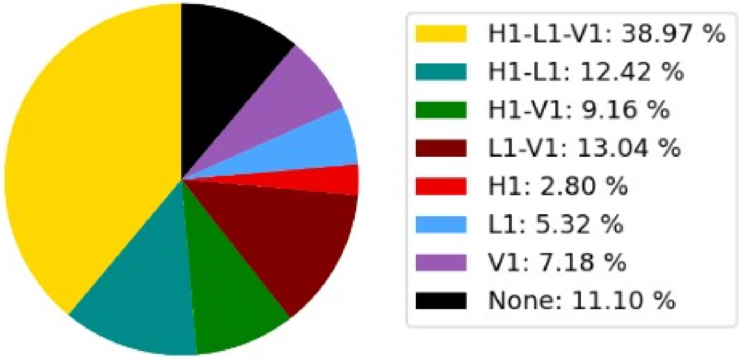
LIGO Hanford
Duty cycle = 63.35%
[120d:0h:58m:39s]

Livingston: 70%

LIGO Livingston
Duty cycle = 69.75%
[132d:4h:20m:44s]

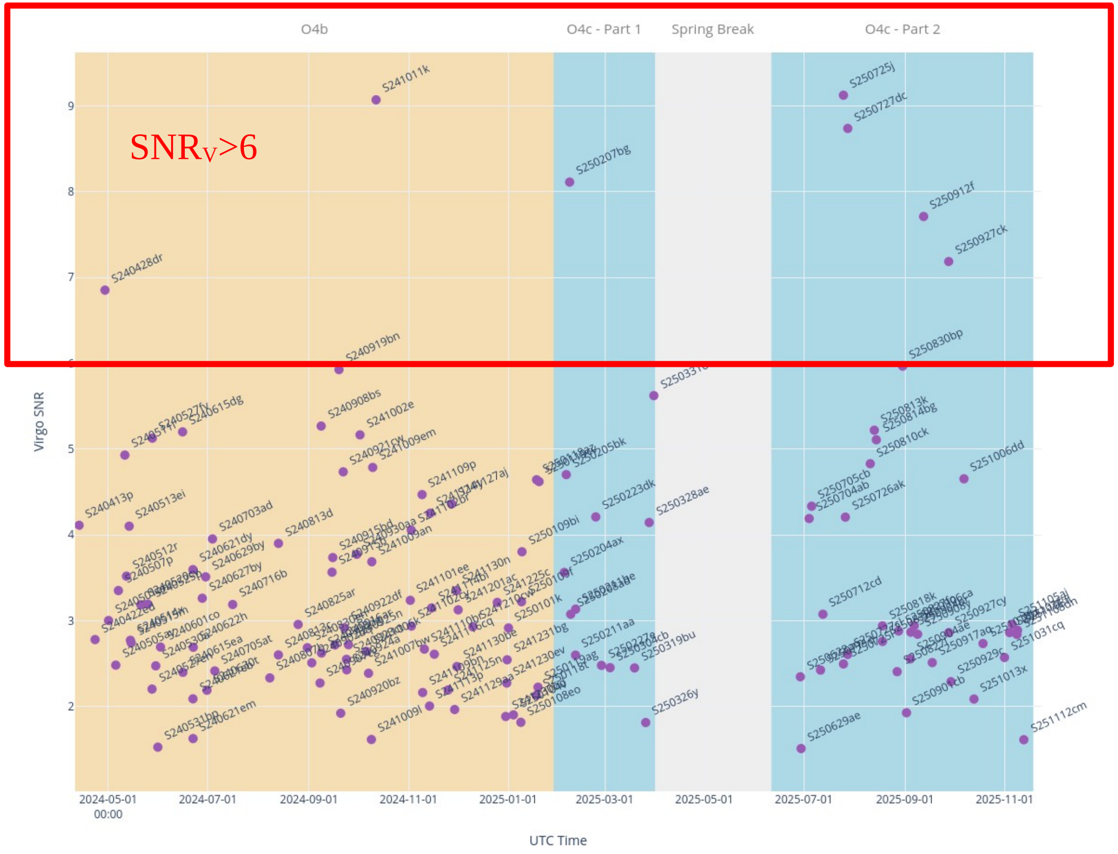
Virgo: 69%

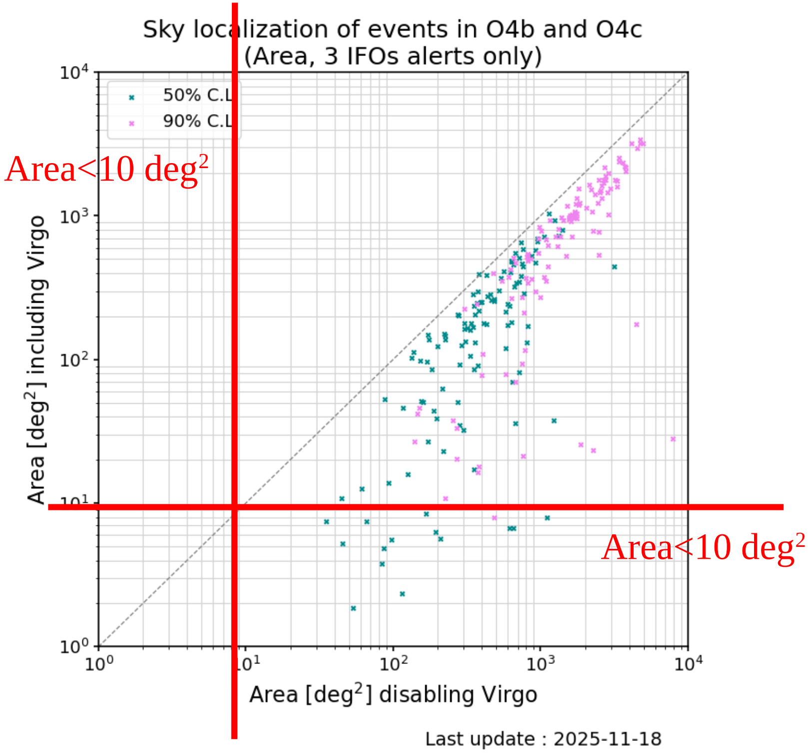
Virgo
Duty cycle = 68.35%
[129d:12h:29m:14s]



- Excluding the 10 weeks break during O4c
- O3 duty cycle : 76%
- O4c duty cycle reduced because of hardware pbs and bad weather conditions

Virgo in O4 in a nutshell



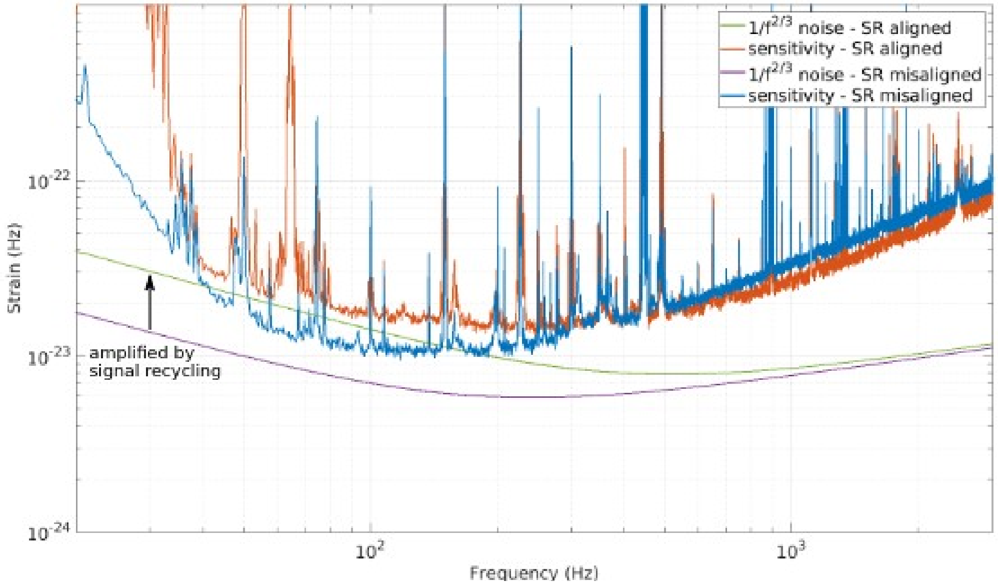


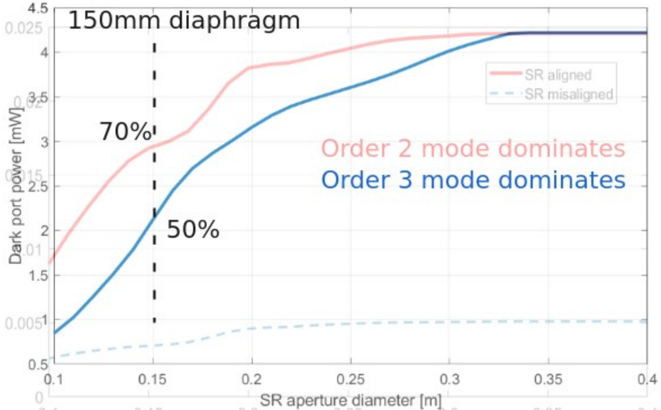
Virgo improves the accuracy of the sky localisation of GW sources: strenghten the network

Commissioning after O4

Understanding excess noise $1/f^{2/3}$

- Cause identified: carrier higher-order modes (HOMs) are amplified by the Signal Recycling (SR) cavity due to its marginal stability.
- SR misalignement improves sensitivity but makes squeezing useless.
- Test: install diaphragms in front of SR mirror to screen partly the HOMs

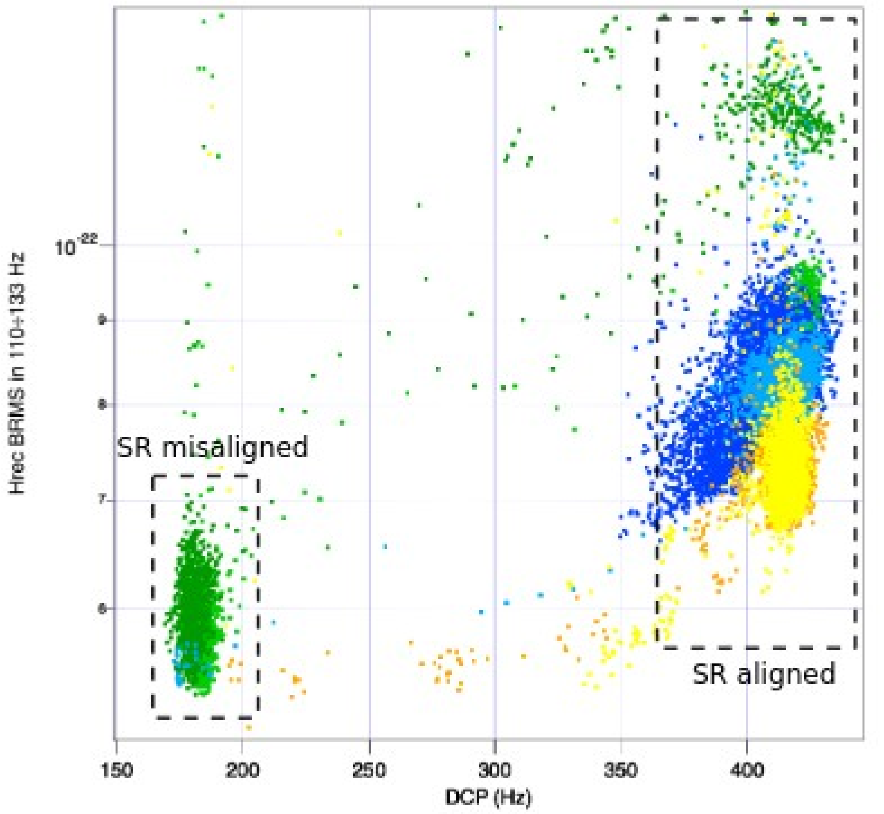




Commissioning after O4

Understanding excess noise 1/f$^{2/3}$

- Result: clear noise reduction confirmed with noise level now approaching O4 misaligned SR configuration.
- Long term solution: install recycling stable cavities to avoid HOMs resonating in SR cavity along with TEM00.



Green: 340 mm aperture (light green, 2025 Oct 2; dark green, 2025 Dec 8)
Blue: 190 mm × 150 mm aperture (dark blue, 2026 Jan 14; light blue, 2026 Jan 23)
Orange: 150 mm aperture (orange, 2026 Feb 10; yellow, 2026 Feb 16)

Preparation of IR1

- Virgo will participate to IR1 with the caveat that the upgrade is the priority
- Full commitment: aim for at least O4-level performance (sensitivity + duty cycle)
- Optical configuration: two solutions
  - Back to O4 configuration with misaligned SR
  - Detuned SR with squeezing
- SRC detuning achieved with almost no effort.
- Squeezing with detuned interferometer works.
- Hrec / calibration with detuned interformeter possible.
- Sensitivity: can detuning + squeezing work well enough to get us above 60 Mpc?

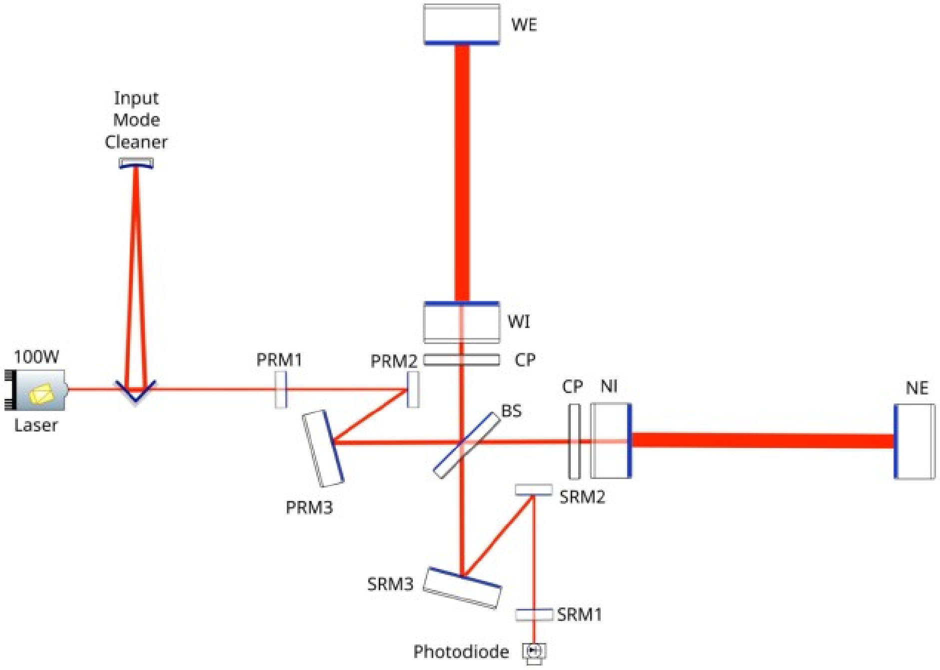
Preparation for IR1

- Coordinated infrastructure work
  - Replacement of control building UPS
  - Road resurfacing around central building and along north arm
  - Mode cleaner roof repair works → end mid-July
  - West End building roof repair works → delayed, end date TBD
- Main instrumental installation work - end planned June 20
  - New B1 photodiodes installed (lower electronic noise, needed for O5 squeezing)
  - Replacement of compensation plates by flatter spares
  - Installation of instrumented baffle
  - Point absorber mitigation system installation and alignment
  - Rebuilding green beam beating part of ALS with free space instead of fibered optics
  - Replacement of input mirrors by spares

Preparation for IR1

- Installation of ITM spare mirrors
  - Improved quality factor
  - A priori better localized point absorbers
  - Risks
    - No more spare
    - Failure during installations (mainly during venting)
- High power laser components replacement
  - Long procurement time, installation on site expected in December/January
- Virgo Operations working groups involved in current discussions and planning
  - Plan is to rely heavily on O4 framework
  - Human resources shortage remains: time & resources spent on IR1 preparation + operations not available elsewhere

O5 upgrade



[Virgo 2603.20342]

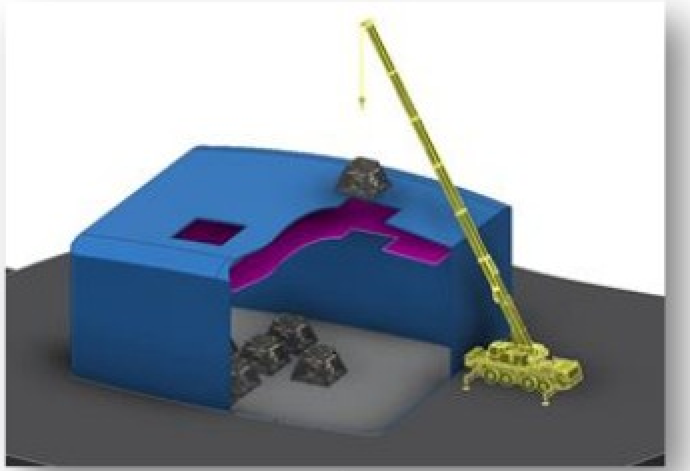
Stable recycling Cavities

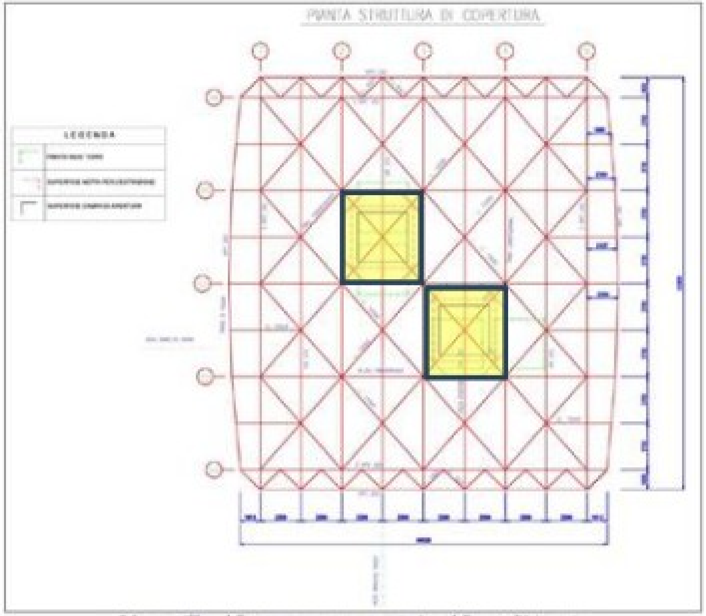
- Design based around solutions that allow for required stability (~20deg Gouy phase).
- Similar design already successfully implemented in LIGO and KAGRA (and planned for ET/CE)
- Stable cavities will filter out the higher order optical modes, reducing the impact of the noise they carry by more than a factor of ten.

O5 upgrade

Old towers removal

- Reference solution: The four towers will be extracted from the roof
  - Significant dismantling work is foreseen, involving the injection, detection and squeezing labs
  - De-commissionig of four superattenuators with related electronics and cabling
- Preliminary design of the infrastructural intervention is available, together with estimates of the costs, the administrative procedure timeline and the works execution duration
- New less invasive solution (upgrade of the central building crane to 8-15 tons) being investigated: could reduce both costs and execution time.





Schema unifilare della copertura con rappresentazione delle aree di intervento

O5 upgrade

Core optics management

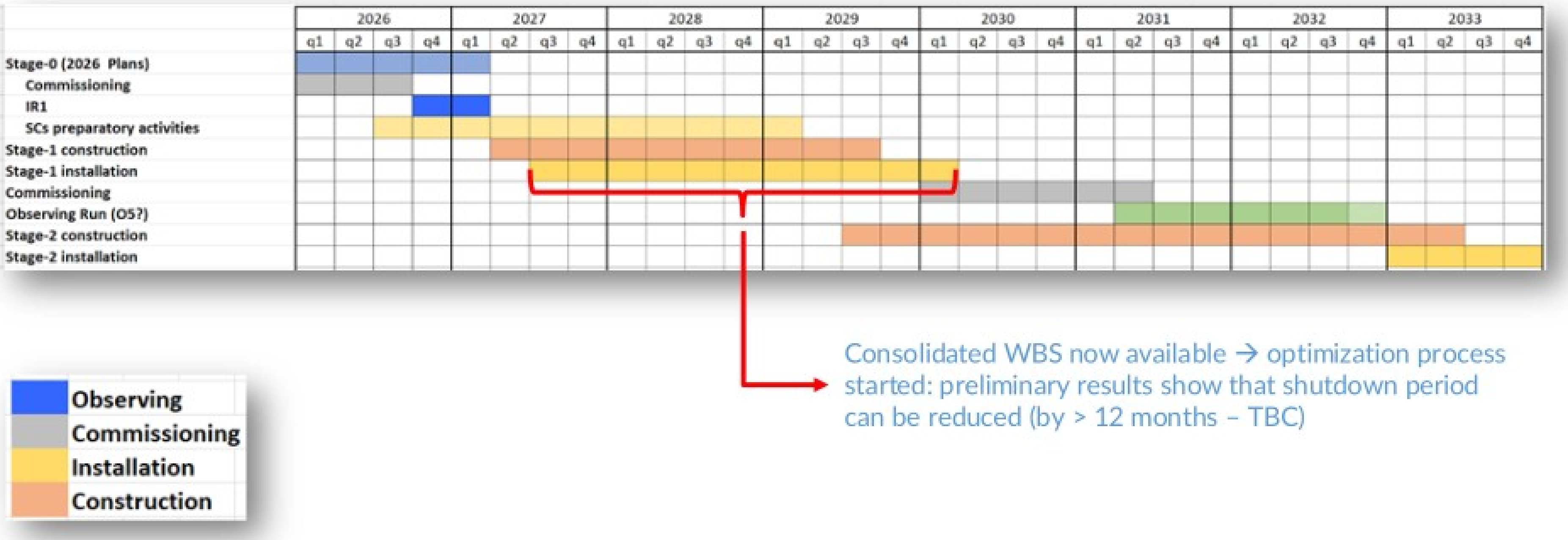
- New ITMs
  - In operation since 2016
  - Clear evidence for point absorbers; excess of thermal noise
- New ETMs
  - Recent installations of the spares coated in 2018 left the project without any spare
  - Clear evidence for point absorbers; possible source of excess of thermal noise
- New Beam Splitter
  - Current BS wedge is vertical, rather than horizontal → issue for future (post-O5) Balanced Homodyne Detection installation
  - Spare substrate available
- Due to extended timeline for Stable Cavities installation, coating optimization activities will go on for two more years

O5 upgrade

Three Project Stages for two installation steps

- Stage-0 – funding approval March 2026
  - Preparatory activities for Stable Cavities: infrastructural works administrative procedures, recycling cavities suspensions prototypes, vacuum chambers and mirrors
  - Production of new electronics for suspension control
- Stage-1 – funding approval March 2027:
  - Main target: install stable cavities + replace Input Test Masses (and input payloads) and Beam Splitter
  - Input power ~25 W, 3-4 dB of Frequency Dependent Squeezing
  - Sensitivity range: 90-130 Mpc (depends mostly on low frequency noise)
- Stage-2 – funding approval March 2029:
  - Main target: replace End Test Masses (and end payloads), install high-power laser
  - Increase input power >40 W, 4-6 dB of frequency dependent squeezing
  - Sensitivity range: 120-160 Mpc (depends mostly on low frequency noise and coating thermal noise)

O5 upgrade



Consolidated WBS now available → optimization process started: preliminary results show that shutdown period can be reduced (by > 12 months – TBC)

Upgrade for O5

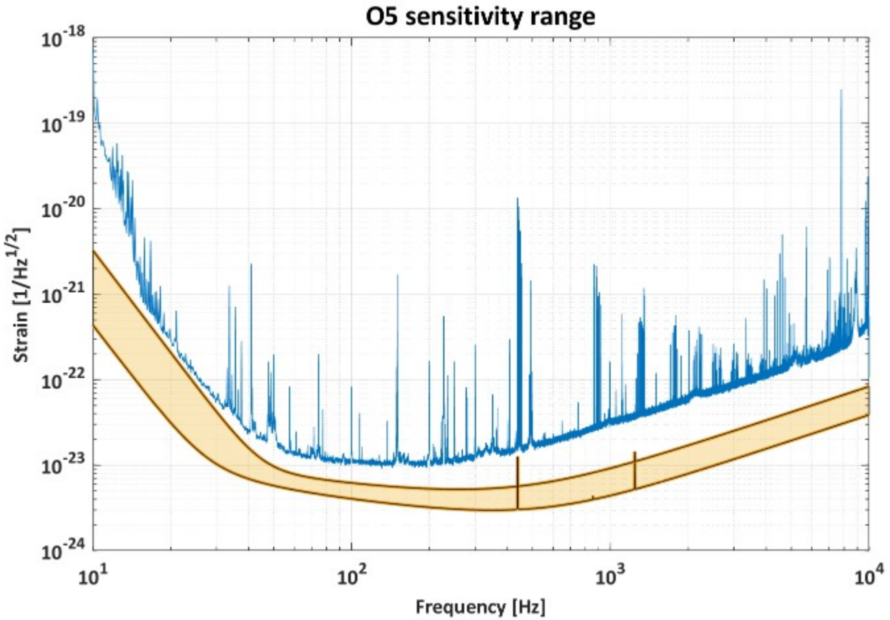


FIG. 4. Range of sensitivities expected for AdV+ O5 (orange band). Also shown is the sensitivity measured by AdV during O4b in blue.

- Full TDR (> 900 pages) released in May 2025
- Overview document recently uploaded on arXiv: https://arxiv.org/abs/2603.20342v2

[Virgo 2603.20342]

Parameter	O4b	Stage 1	Stage 2
Power injected	17 W	25 W	40–80 W
Signal recycling	Yes	Yes	Yes
Squeezing type	FIS	FDS	FDS
Squeezing detected level	0 dB [a]	4.5 dB	5.3 dB
Mirror thermal noise @ 100 Hz	$< 6 \times 10^{-24}/\sqrt{\text{Hz}}$ [17]	$4.8 \times 10^{-24}/\sqrt{\text{Hz}}$	$3.4 \times 10^{-24}/\sqrt{\text{Hz}}$
Technical noise @ 20 Hz	$3 \times 10^{-22}/\sqrt{\text{Hz}}$	$(2 \times 10^{-22}$–$2.6 \times 10^{-23})/\sqrt{\text{Hz}}$	$(2 \times 10^{-22}$–$2.6 \times 10^{-23})/\sqrt{\text{Hz}}$
BNS range	55 Mpc	90–130 Mpc	120–160 Mpc