

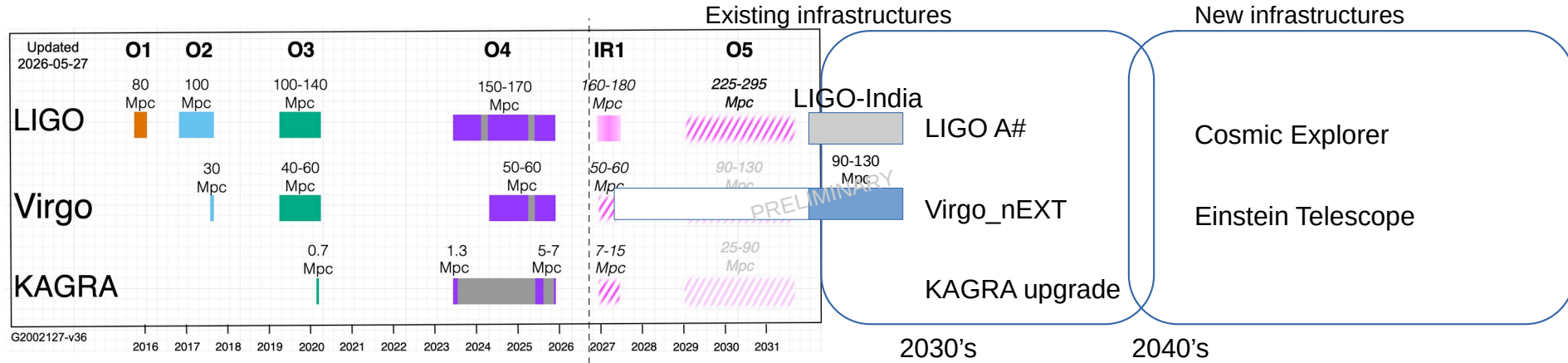
Current status and future perspectives of Virgo in the worldwide GW network

L. Rolland



- Timeline overview
- Some results from the O4 run
- Main noise limitation during the O4 run
- Plans for the run IR1
- Preparation of the upgrade with stable recycling cavities
- Longer term perspectives and links with ET

The general landscape of ground-based interferometers



EGO legal entity
Virgo Collaboration

EGO legal entity with VirgoLab structure
Virgo Collaboration

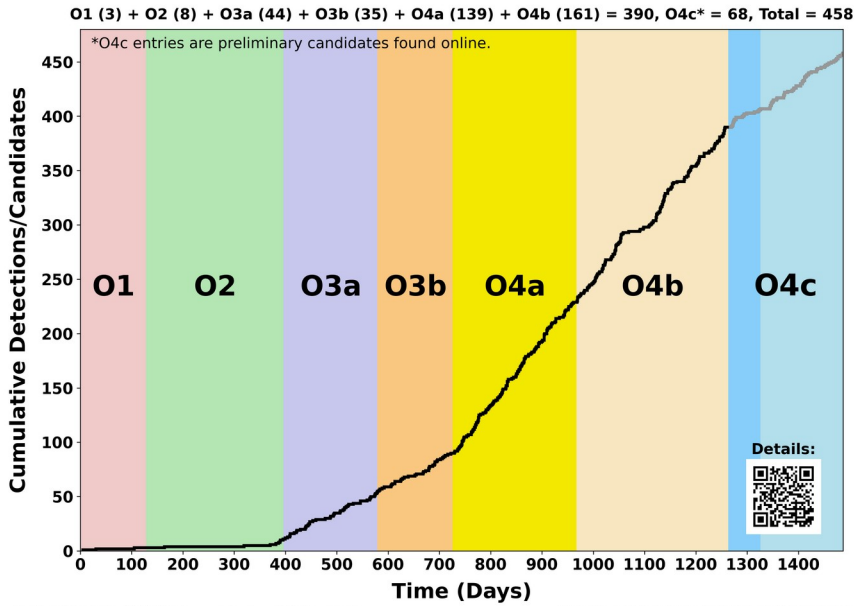
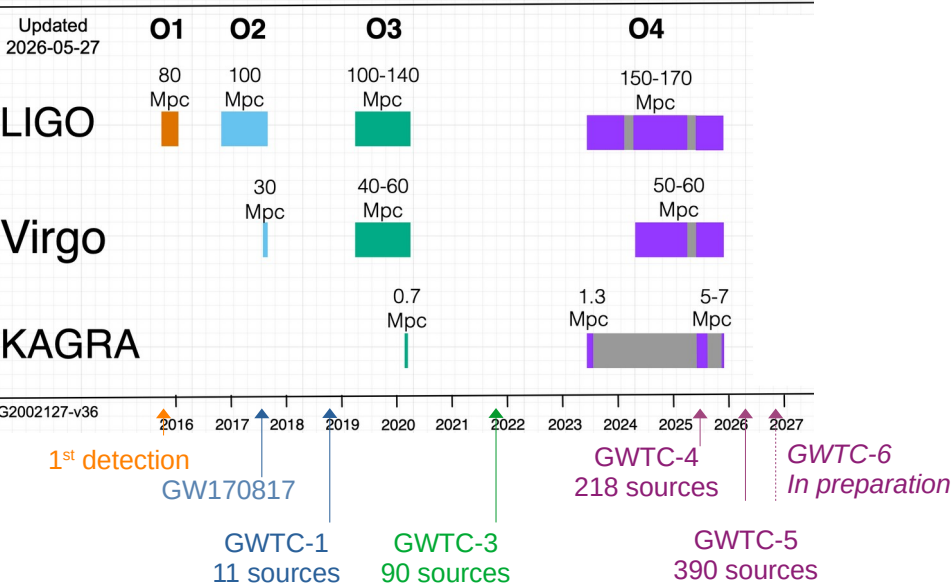
LVK: a cooperation agreement of three independent collaborations:
LIGO, Virgo and KAGRA

- sharing of the data
- common data analysis working groups and papers
- joint run planning
- ...

a single "IGWN"
Collaboration

Governance of 3G detectors
still to be defined

Detections with the LVK GW detector network



LIGO-G2302098 (f244d4f6), updated on 25 May, 2026

Credit: LIGO-Virgo-KAGRA Collaboration

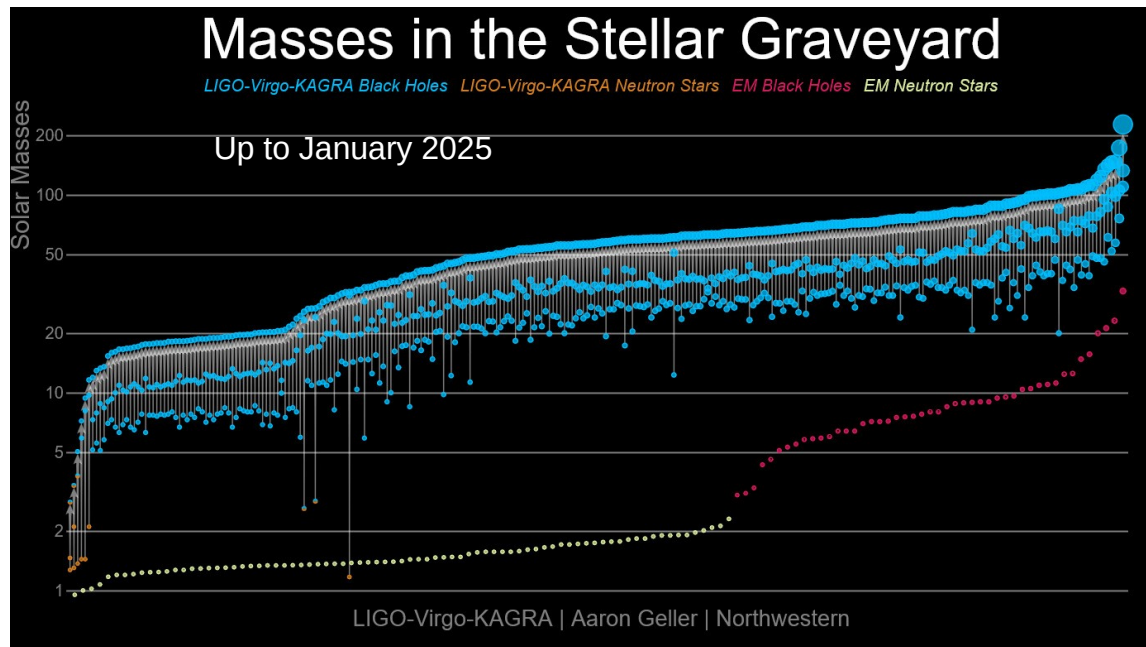
Online alerts generated for multi-messenger astronomy

Publication of particular events, and of catalogs and companion papers

Strain data and uncertainties released to the public : GW Open Science Center (GWOSC)

O4 in brief

- **30 months**
- **4 detectors**
- **177 Mpc: record BNS range**
- **283 online LVK alerts**
- **~380 offline events (~470 since O1)**
- **>70 collaboration papers**
- **3 catalog updates:**
 - GWTC-4, GWTC-5, GWTC-6
- **SNR = 80**
 - Record amplitude for GW250114
- **$M_{\text{tot}} > 200 M_{\text{sun}}$**
 - Record total mass for GW231123
- **6 deg²**
 - Record sky localization for GW240615



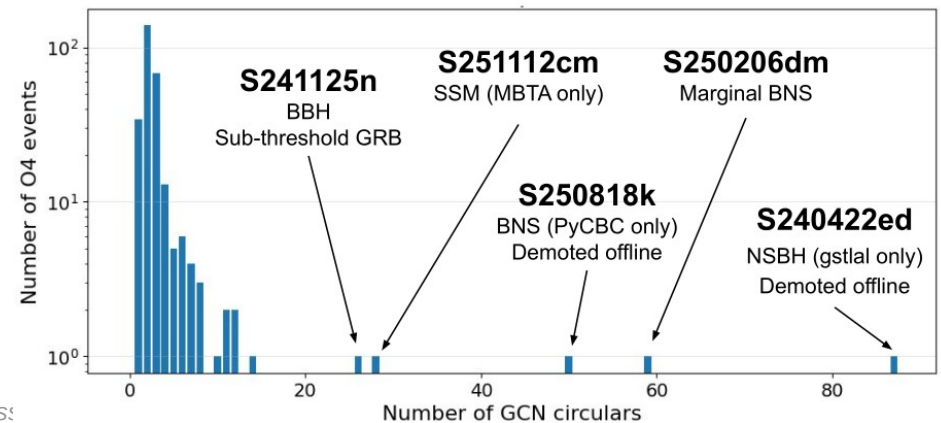
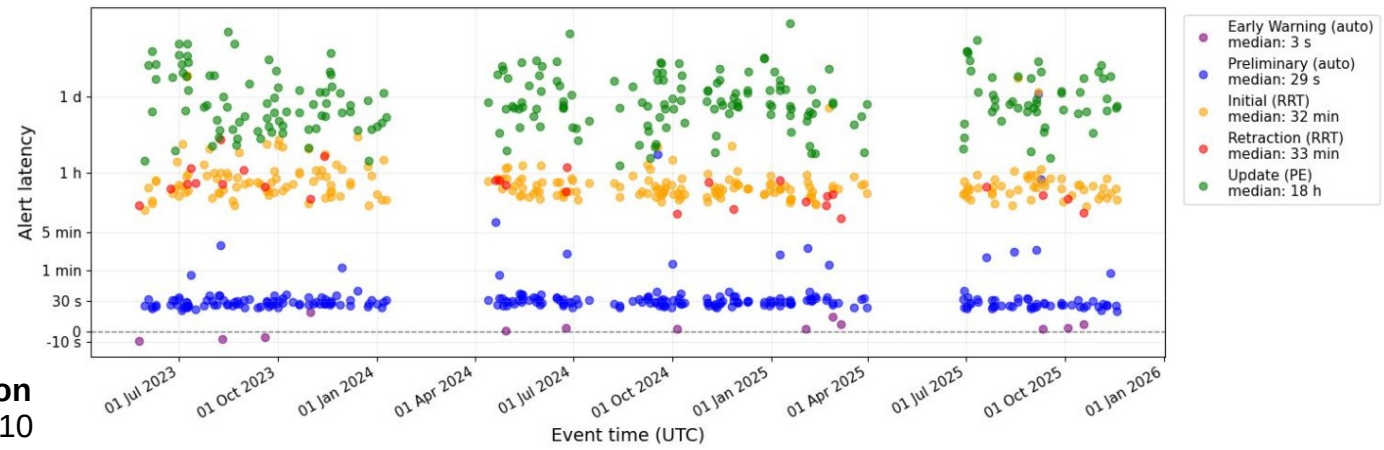
GW alerts during O4

Automatic alerts

283 online LVK alerts
254 confirmed
718 follow-up GCNs

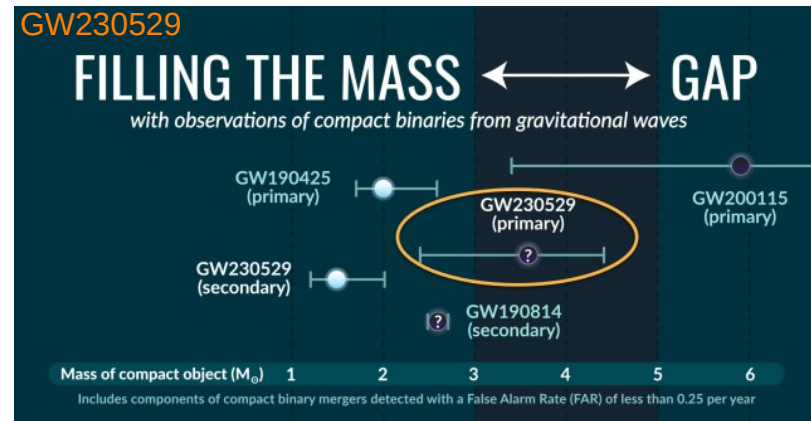
Virgo improves the **sky localization** by a factor 2 on average, a factor 10 for 10% of the alerts

Follow-up of the GW alerts by the community

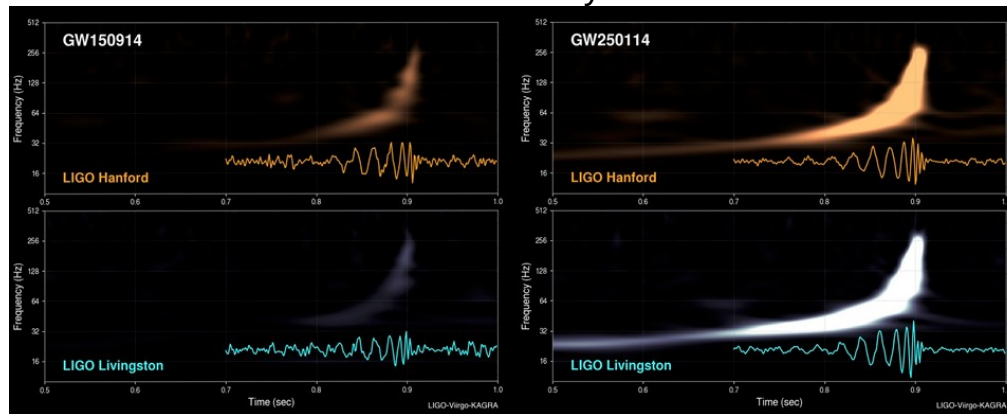


O4 special events

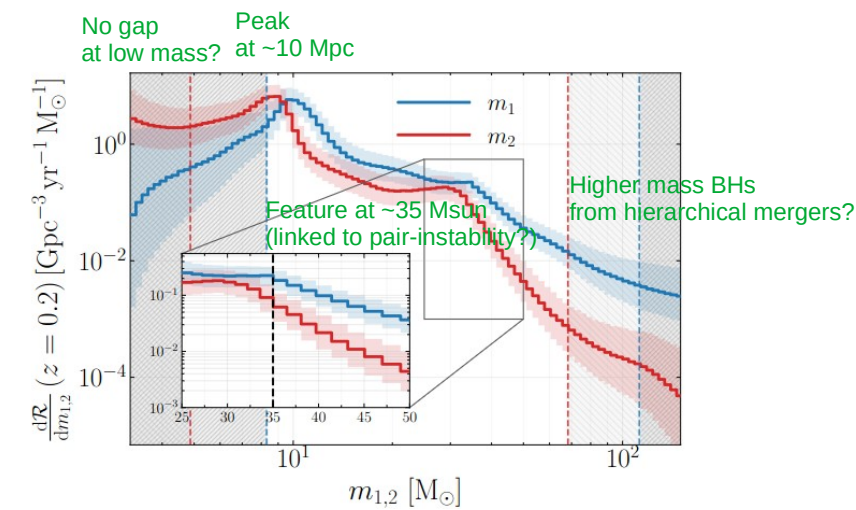
- GW230529 – NSBH candidate
 - BH in lower mass gap
- GW230814 – Tests of GR on high SNR BBH
- GW231123 – Heaviest BBH so far
 - $M_{\text{tot}} \sim 190$ to $260 M_{\text{Sun}}$
- GW241110 and GW241011 – Highly spinning BBHs
 - Likely of hierarchical origin
- GW250114 – Loudest event so far
 - SNR ~ 80 with HL detectors
- GW240915 and GW250207 – Astro calibration



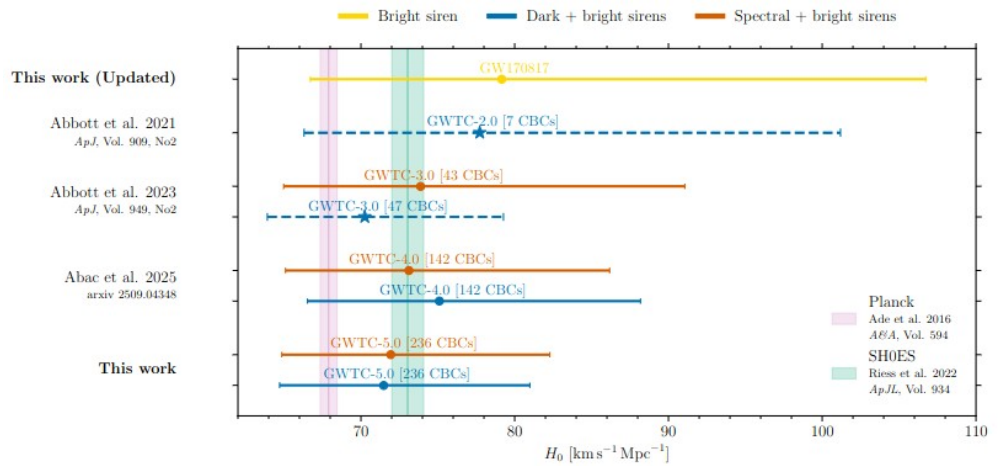
2 similar events... 10 years later



Some other results from O4



→ Growing evidence for multiple sub-populations of BH with distinct properties



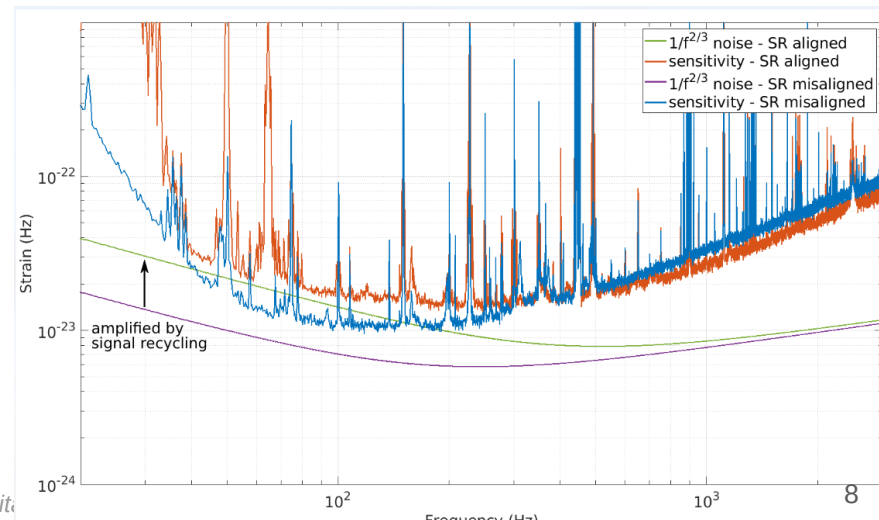
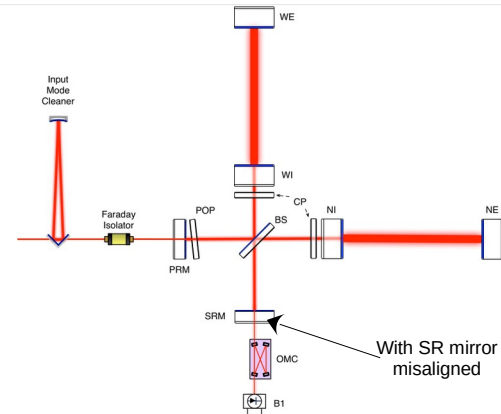
→ improved Hubble constant measurement.
Dark sirens (>200) now more precise than GW170817 alone.

Main limiting noise in current Virgo optical configuration

The conclusions reached during the commissioning of O4

- Noise is coming from a noisy optical field interfering with the main read-out local oscillator
 - Not resonant in the 3-km arms
 - But resonant in the signal recycling cavity
- Laser light degrees of freedom that fit on the mirror surface
 - 2 polarizations, 2 quadratures and 120 high order modes

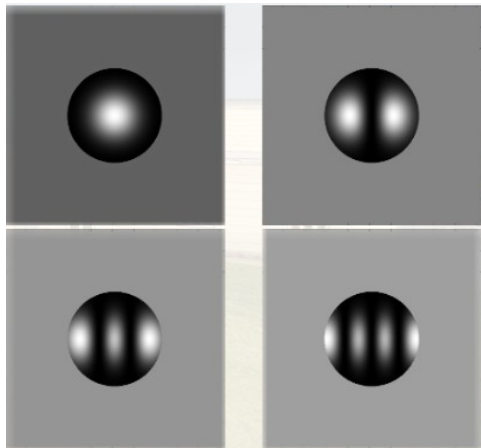
→ main suspects are some light high-order modes that resonate in the marginally stable recycling cavities



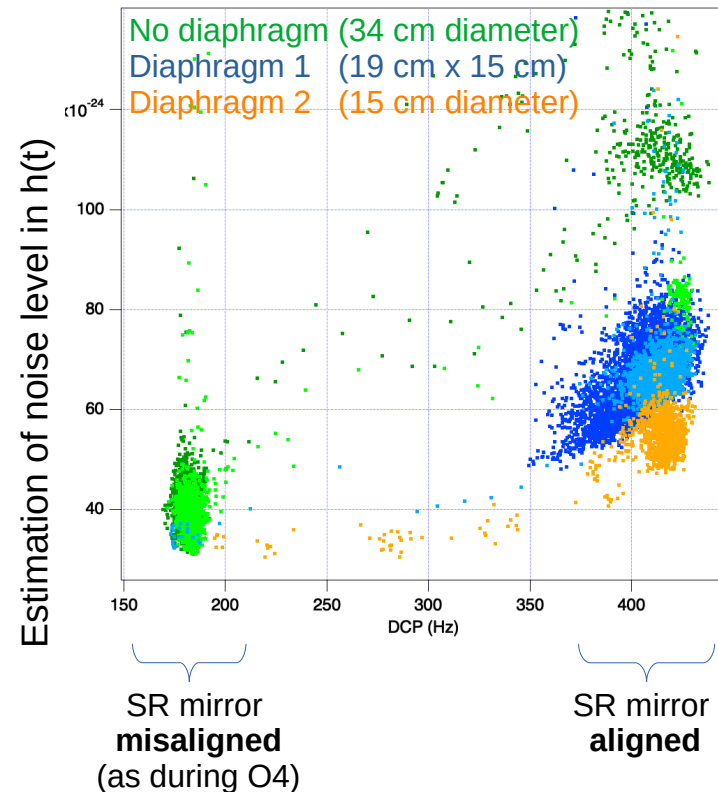
Main limiting noise in current Virgo optical configuration

After O4: installation of diaphragms on the signal-recycling mirror

- Goal: cut the (larger) high-order modes of the laser beam

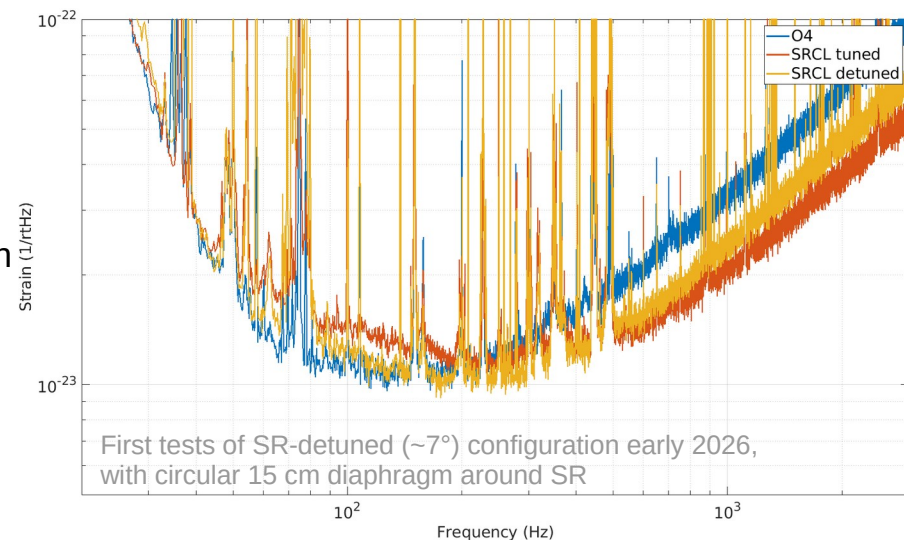


→ Strong confirmation that the extra-noise is carried by laser beam high-order modes in the marginally stable signal recycling cavity



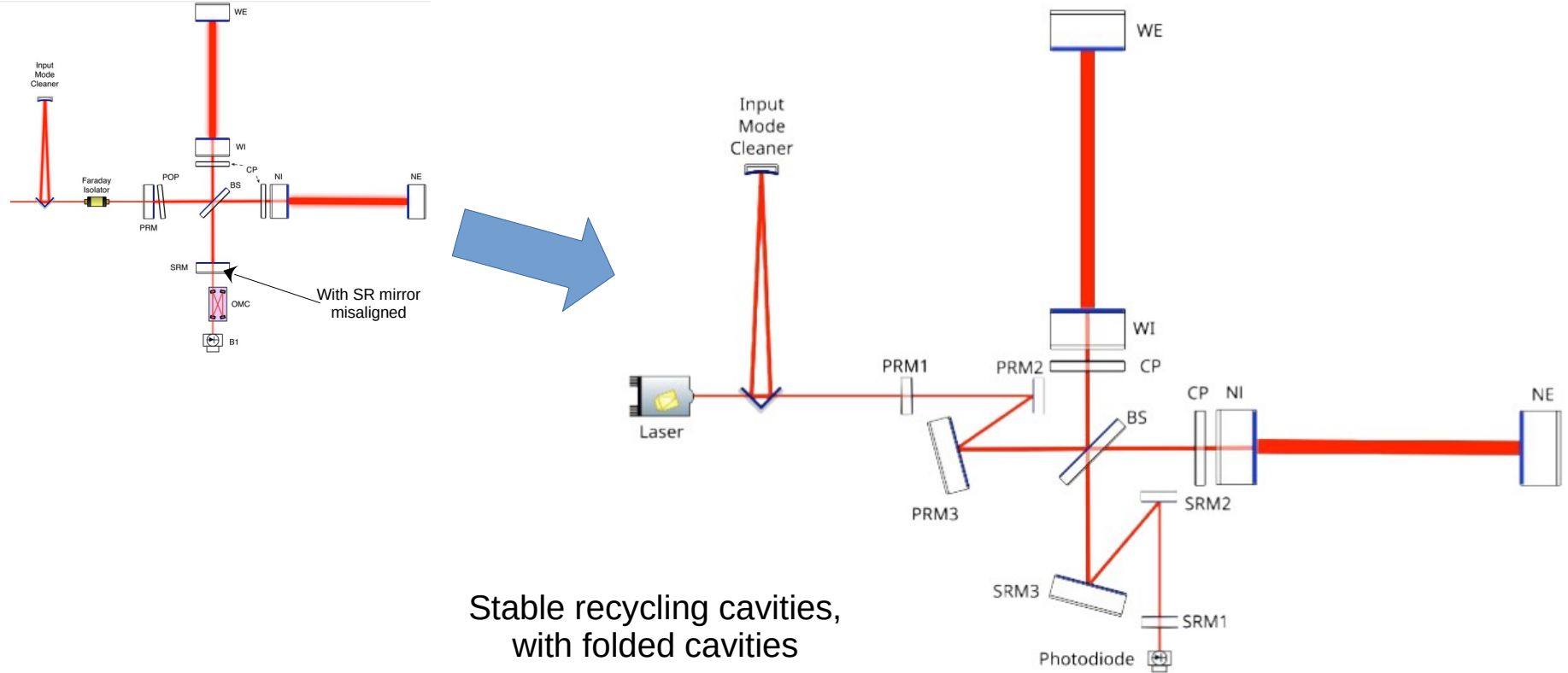
Plan for the run IR1 in 2026/2027

- Run with Vera-Rubin
- IR1 starting with at least two detectors: mid-November, or December, or January.
- Duration: nominally 6 months, may be extended up to 1 year.
- Detector sensitivities: similar to O4
- More about Virgo:
 - May run with a SR-detuned configuration
 - + squeezing system effective
 - Would be the 1st detector using this configuration
 - Also current ET-LF design
 - $h(t)$ strain reconstruction being adapted
 - Upgrading Virgo is the priority:
 - Virgo may stop running before the end of IR1

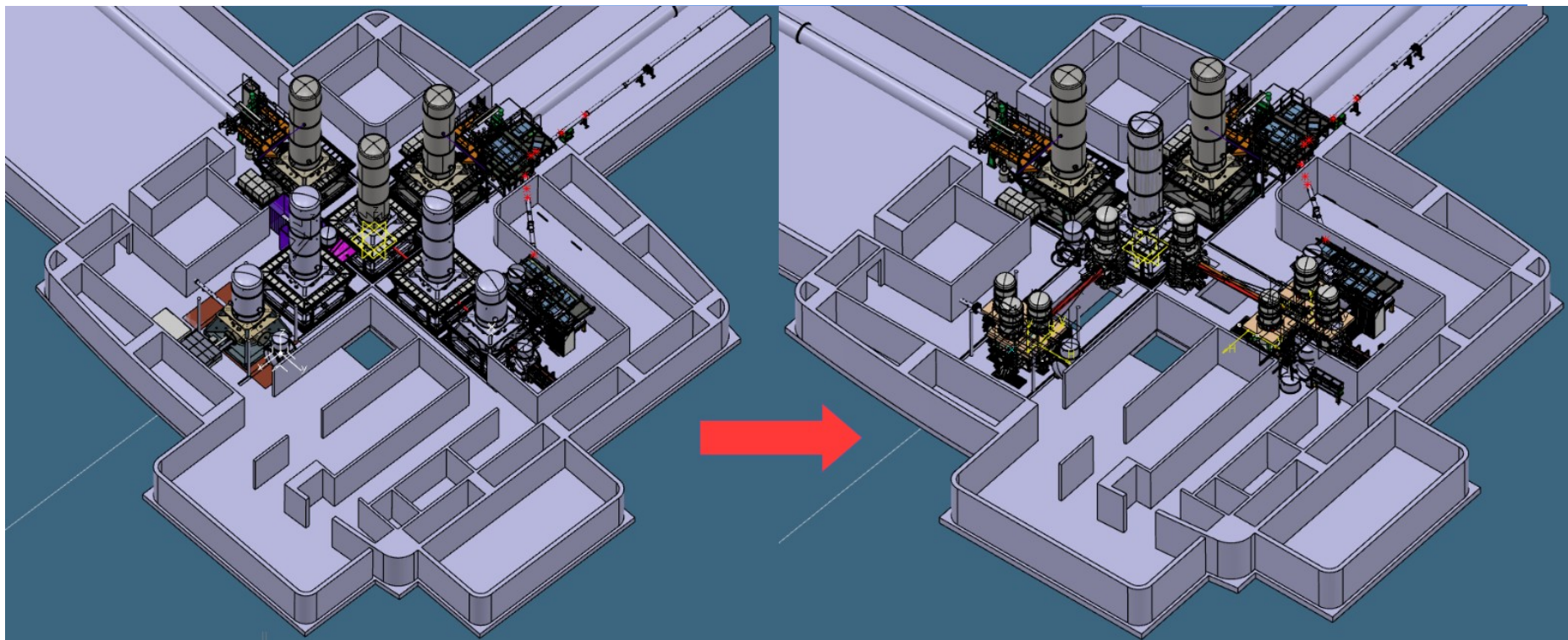


Virgo will be tested with such configurations in the coming weeks, to select the IR1 configuration
... **but configuration still not compliant with further upgrades**, in particular with laser power increase

The Virgo upgrade: a new optical configuration



The Virgo upgrade: important infrastructure works



4 big Virgo towers to be dismantled
8 new towers to be built and installed
Associated new and bigger clean rooms

...in a very space-constraint building

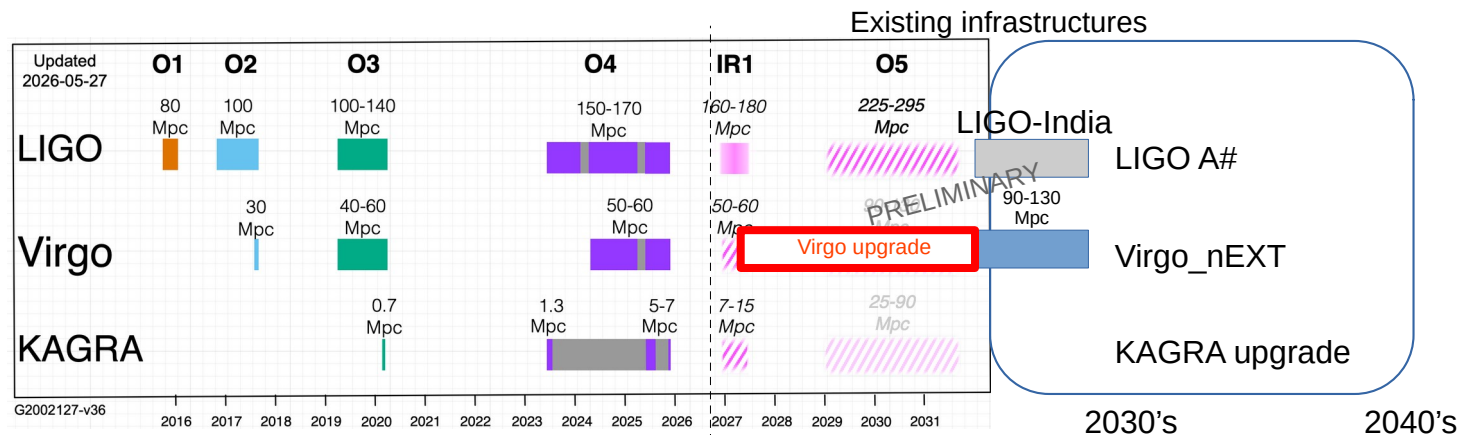
The Virgo upgrade: timeline

→ Replace the marginally stable recycling cavities by stable cavities

completely new plan since 2023/2024

new design and project organization ready

→ Green light and budget from the agencies expected for December/March!



→ Build Virgo as a robust detector, ready for further upgrades

→ stop losing sensitivity relative to LIGO detectors

→ have a future for Virgo until ET starts in the 2040's: laser power increase, improved squeezing, larger mirrors, ...

→ preserve experimented and trained people for ET commissioning (ET will have stable cavities)

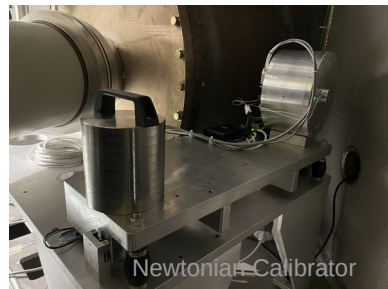
The Virgo upgrade: some of the French contributions

New laser

(Artemis)

Improvements of the calibration

(IPHC, LAPP)



Newtonian Calibrator

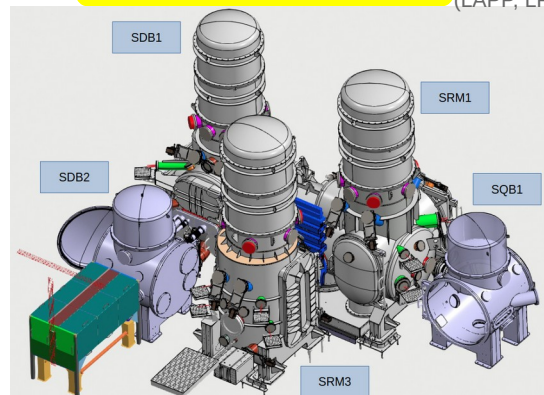
More and improved digital electronics for control loops and data acquisition

(IP2I, LAPP)



New vacuum tanks

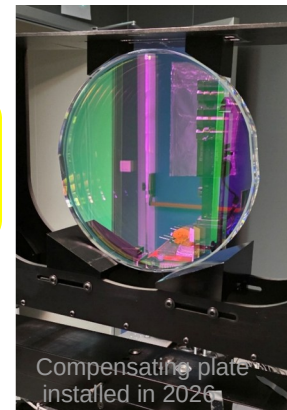
(LAPP, LPC)



Design of the vacuum tanks for the detection

New mirrors (recycling cavities, beam-splitter, ...)

(LMA)



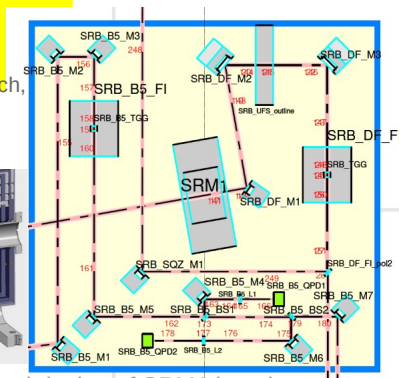
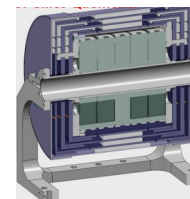
Compensating plate installed in 2026

New optical benches for detection and injection systems

(LAPP, APC, Subatech, LPC, Fresnel)

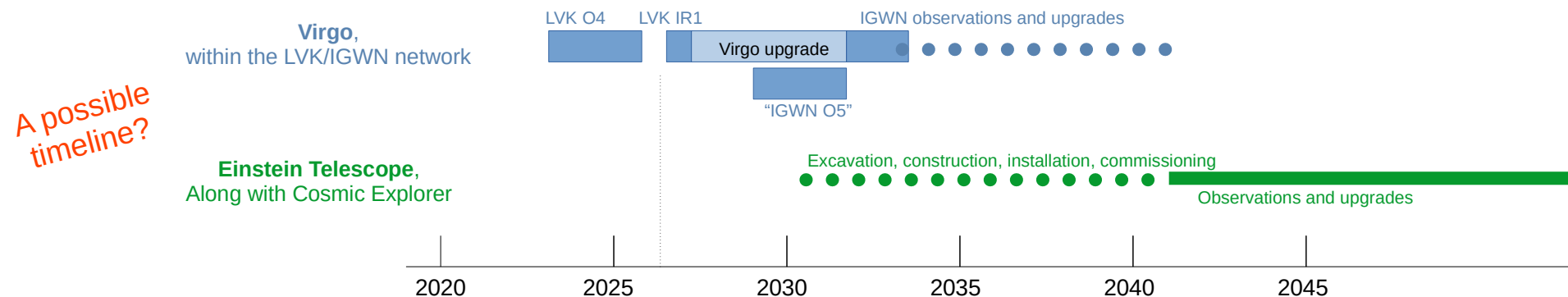
Scattered light

(Fresnel, Artemis)



Optical design of SRM1 bench and Faraday isolator magnetic shield

About future IGWN runs and links to Einstein Telescope



- **ET**
 - ~few Hz to 10 kHz range, to be operated for more than 50 years
 - geometry and site selection expected by 2027
 - ETO working on a more solid timeline
 - operation/observation expected around 2040+
- **Virgo/ET synergies (mainly with ET-HF)**
 - A lot of activities to participate/start, in ET, and possibly in Virgo: welcome!
 - Infrastructure (vacuum), system engineering and quality, detector, computing, environmental impact, data analysis, ...

