

# STATUS OF THE VIRGO DETECTOR IN VIEW OF 04

Alessio Rocchi on behalf of the Virgo Collaboration

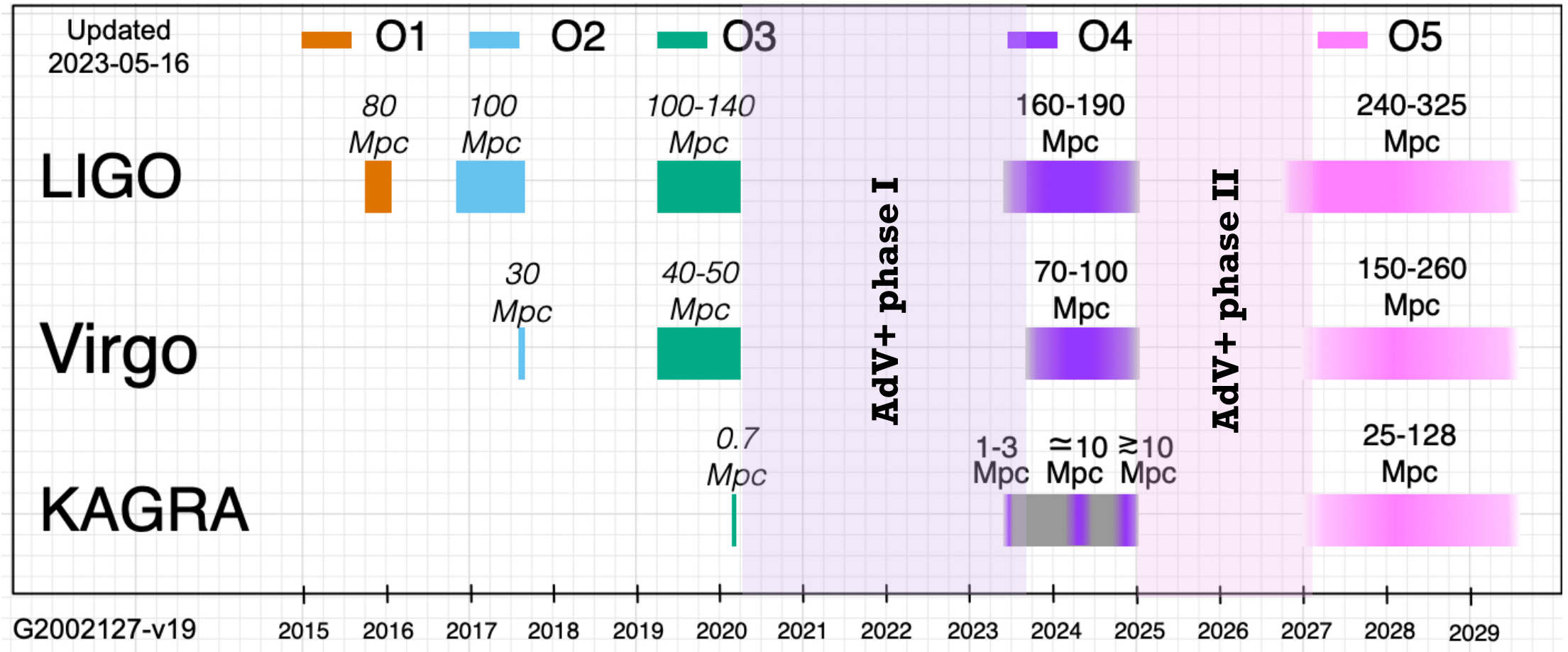
INFN Roma Tor Vergata

XVIII International Conference on Topics in Astoparticle and Underground  
Physics

28-08/01-09-2023 University of Vienna



# LVK OBSERVING TIMELINE



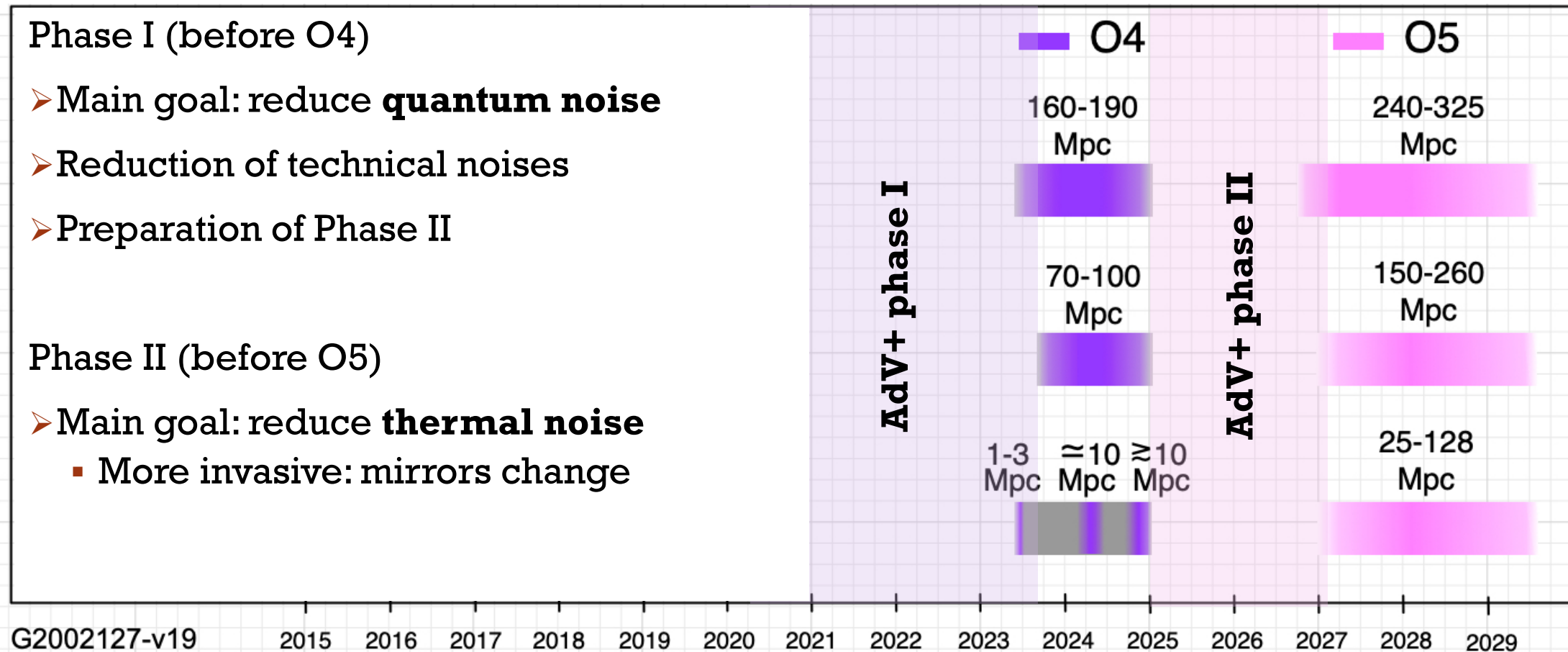
# 2-PHASES PROJECT

## Phase I (before O4)

- Main goal: reduce **quantum noise**
- Reduction of technical noises
- Preparation of Phase II

## Phase II (before O5)

- Main goal: reduce **thermal noise**
  - More invasive: mirrors change



# DESIGN SENSITIVITY

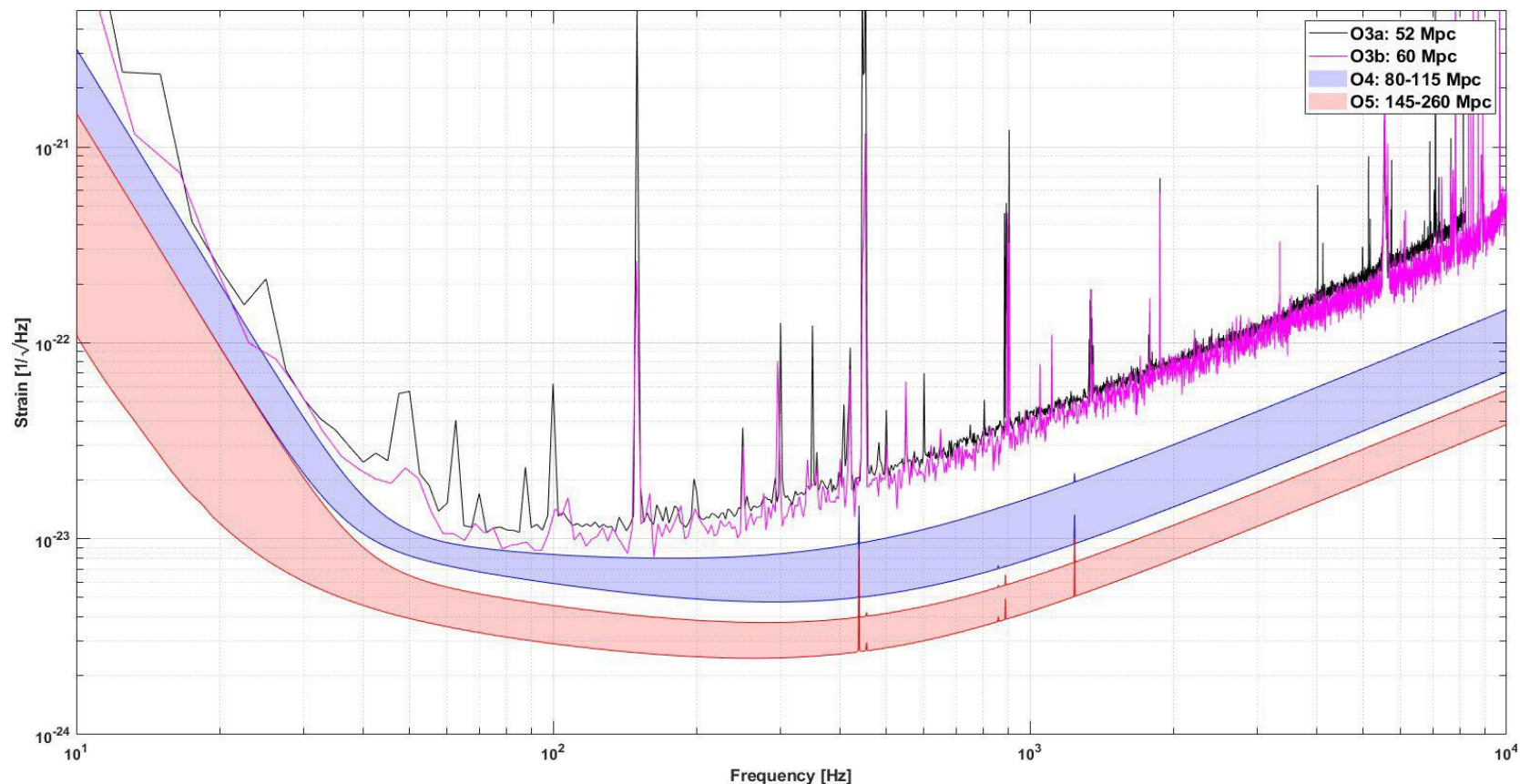
[VIR-0596A-19, VIR-0501C-22]

**Phase I:** reduce quantum noise, hit against coating thermal noise

- BNS range  $\sim 100$  Mpc

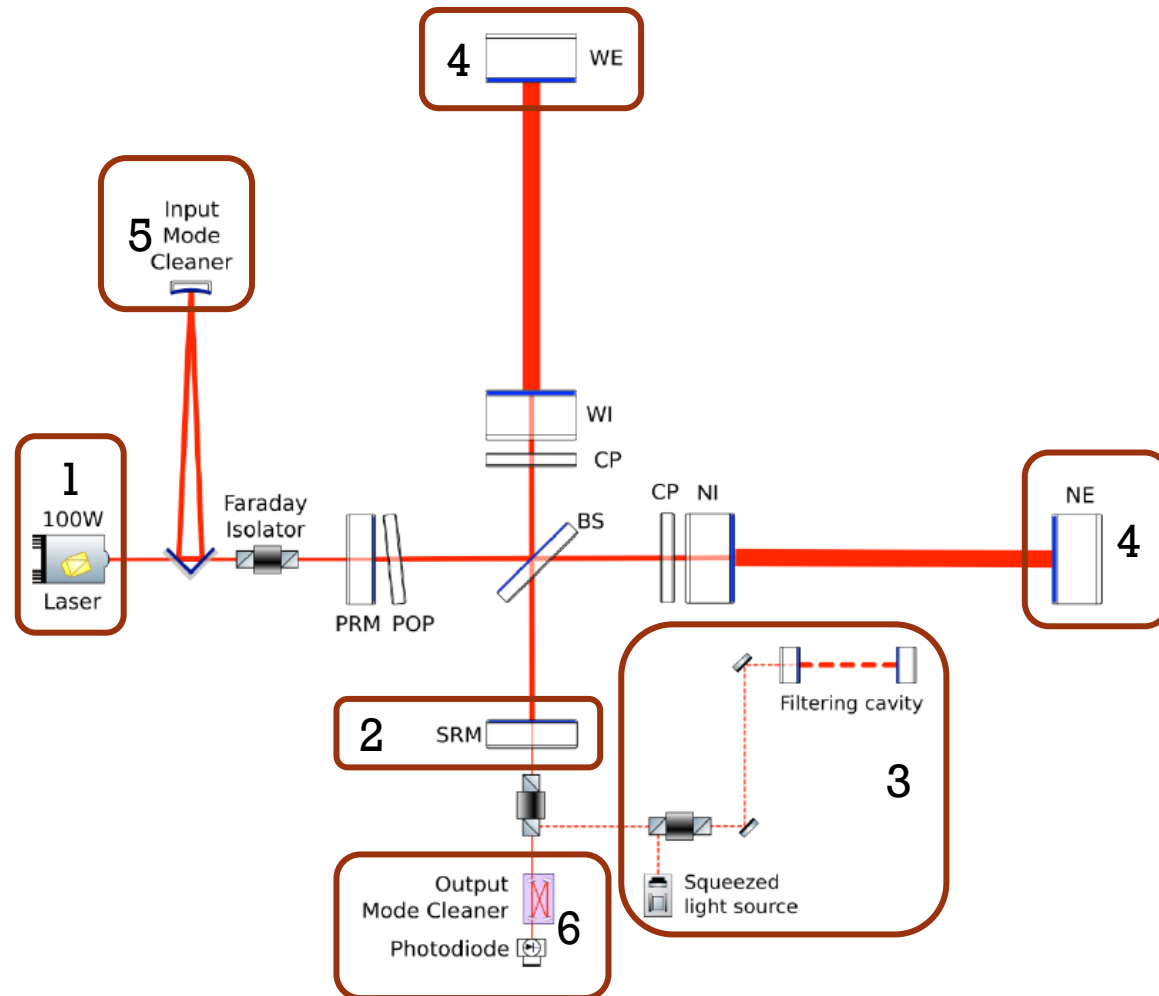
**Phase II:** lower thermal noise wall

- BNS range  $\sim 200$  Mpc



# ADV+ PHASE I

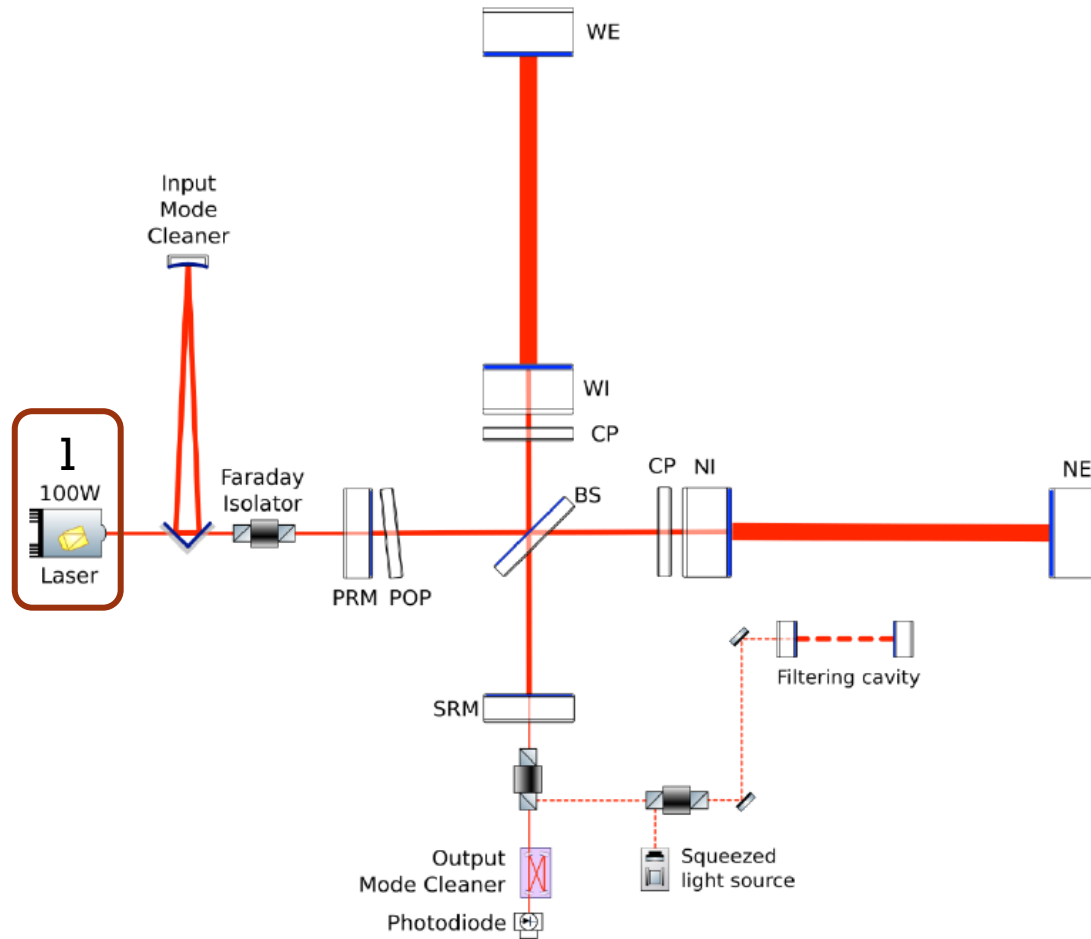
[VIR-0596A-19]



1. High-power fiber laser amplifier
2. Signal recycling mirror
3. Frequency dependent squeezing
4. Green light auxiliary laser system
5. New Input mode Cleaner payload with an instrumented baffle
6. New high finesse output mode cleaner and new read-out photodiodes.
7. HVAC upgrades and reduction of environmental noise.
8. Deployment of accelerometer arrays for Newtonian Noise characterization

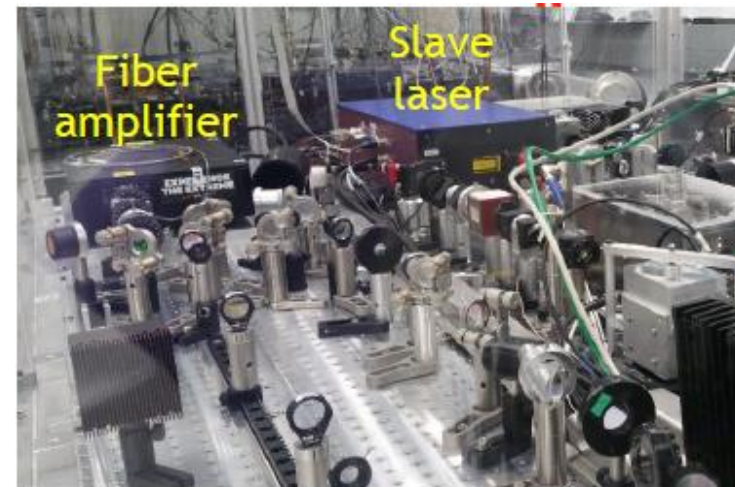
# HIGH-POWER FIBER LASER AMPLIFIER

[VIR-0951A-20]



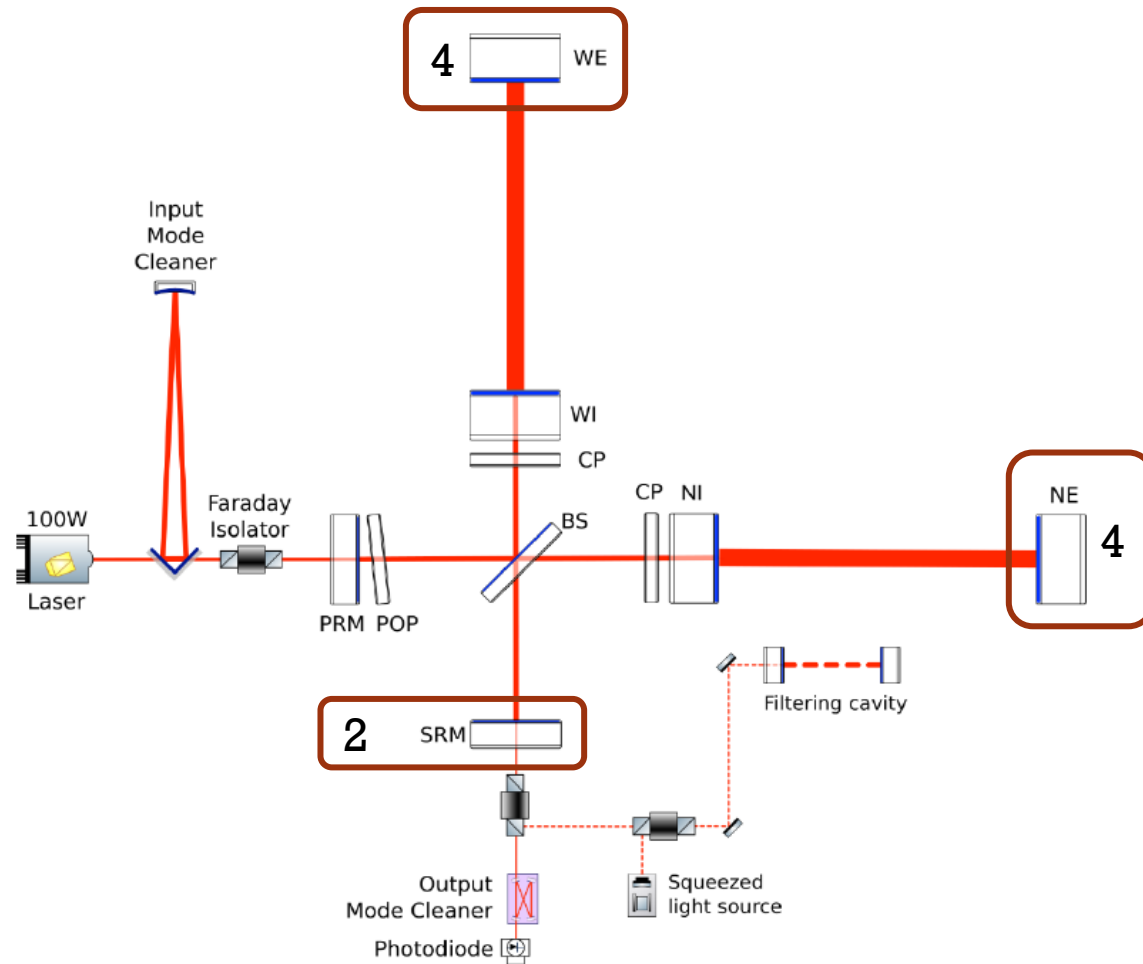
Delivers up to 100 W, in order to be able to inject up to 40 W in the ITF

- Leads to improvement of the shot noise, but also to:
  - Higher radiation pressure
  - Stronger thermal lensing

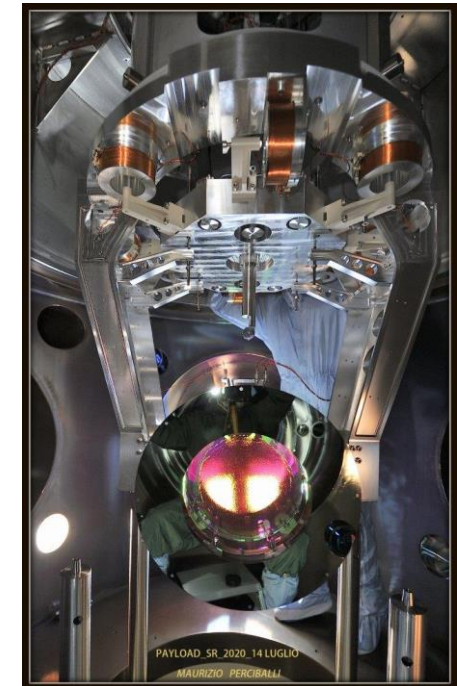


# SIGNAL RECYCLING MIRROR

[VIR-0596A-19]

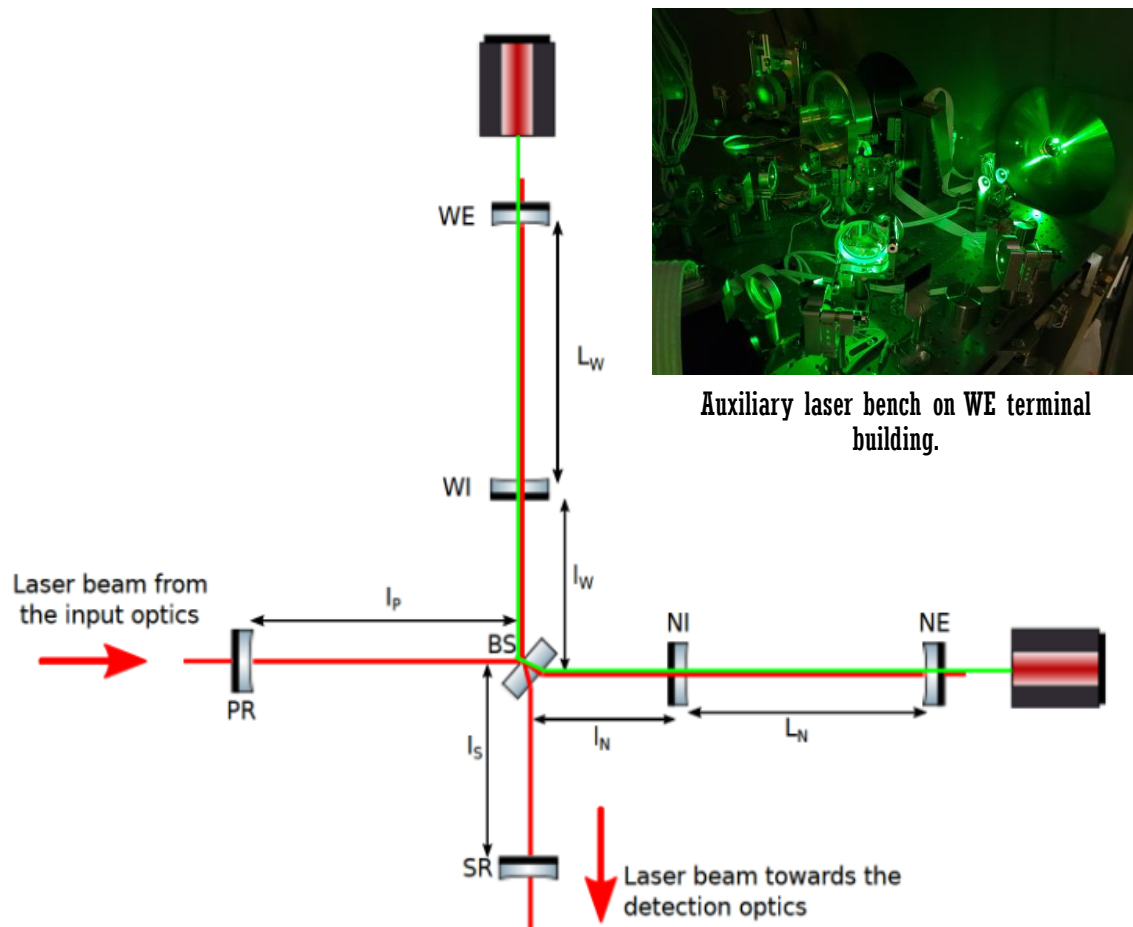


- The Signal recycling mirror enhances the detector sensitivity at high frequency.
- It creates a new resonant optical cavity to be controlled both in angular and longitudinal degrees of freedom
- Requires lock acquisition procedure to be reviewed due to new DoFs to be controlled.



# GREEN AUXILIARY LASER

[VIR-0596A-19]

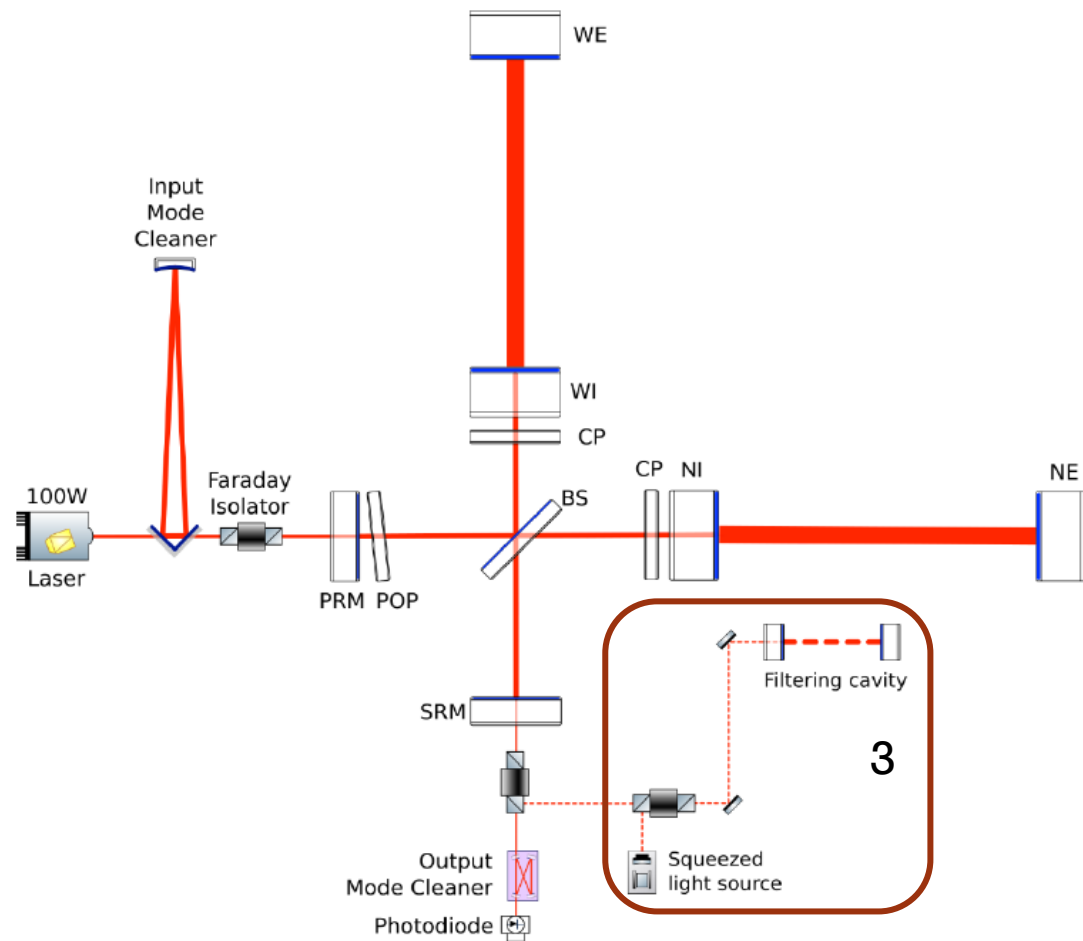


- The lock acquisition uses auxiliary green (half the wavelength of the main ITF laser) beams to control the arm cavities independently from the central area
- A common offset to the arm lengths is added, bringing the main laser source out of resonance
- After the central area DoFs are controlled, the offset on the common mode is slowly reduced, bringing the arm cavities to resonance on the IR.

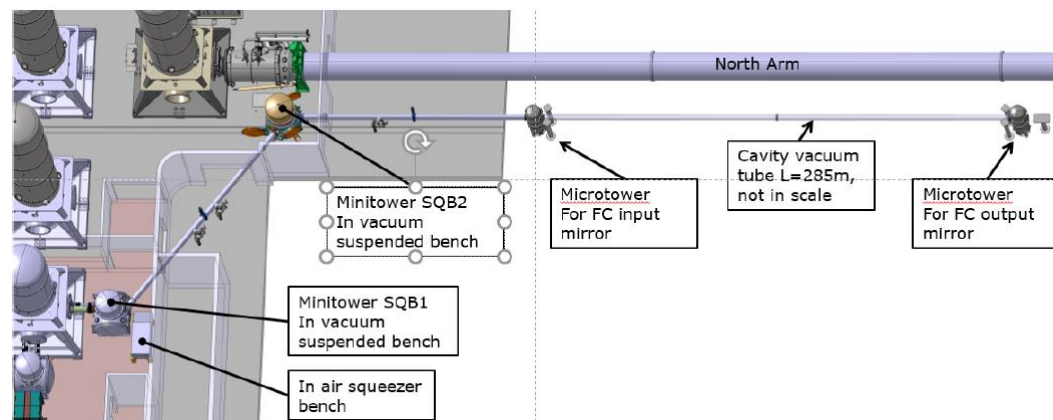


# FREQUENCY DEPENDENT SQUEEZING

[VIR-0596A-19]

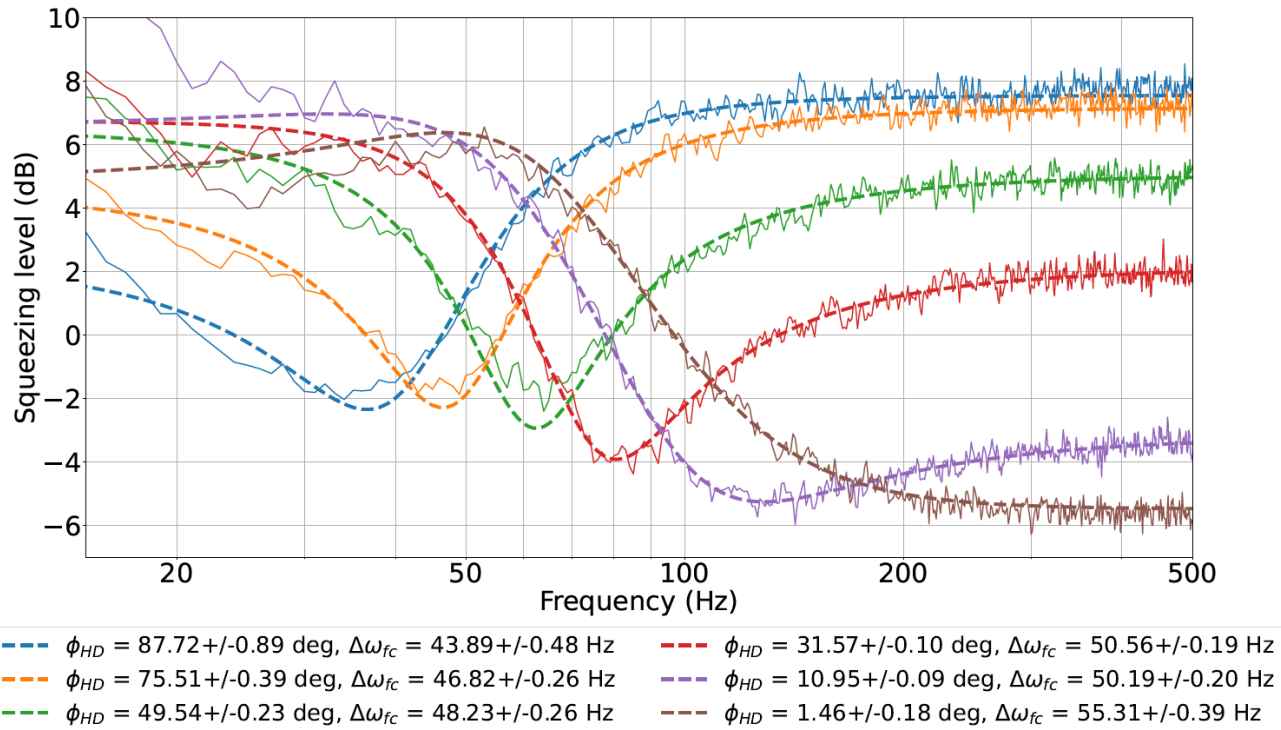


- Injection of frequency IN-dependent squeezing already performed in O3 (PRL, **123**, 231108 (2019))  
→ hints of radiation pressure at low frequency
- A 300m long high finesse filter cavity has been built for squeezing ellipse rotation below 50 Hz
- Frequency dependent squeezed to reduce shot noise at high frequencies and radiation pressure noise at low frequencies.



# FREQUENCY DEPENDENT SQUEEZING

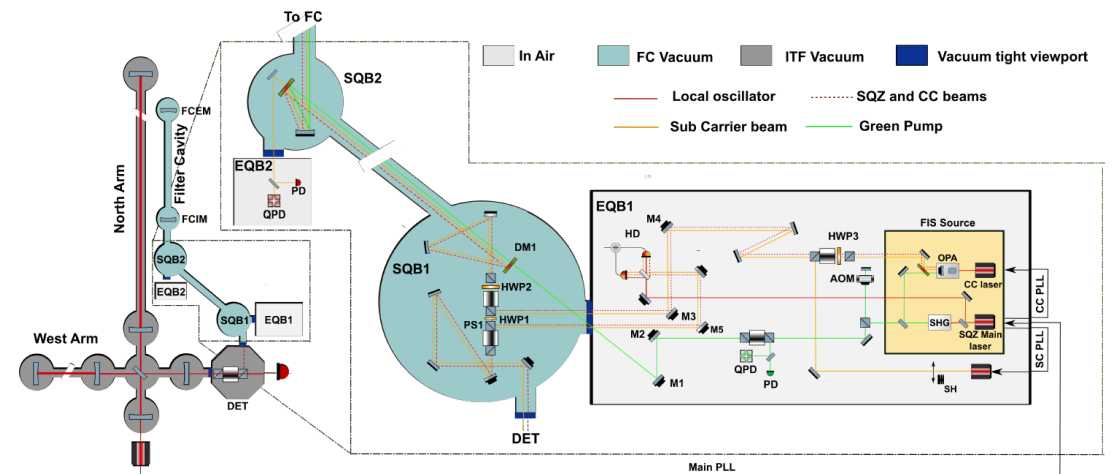
- Frequency dependent squeezing measured down to 25 Hz
- System ready, paper published (PRL, **131**, 041403 (2023))



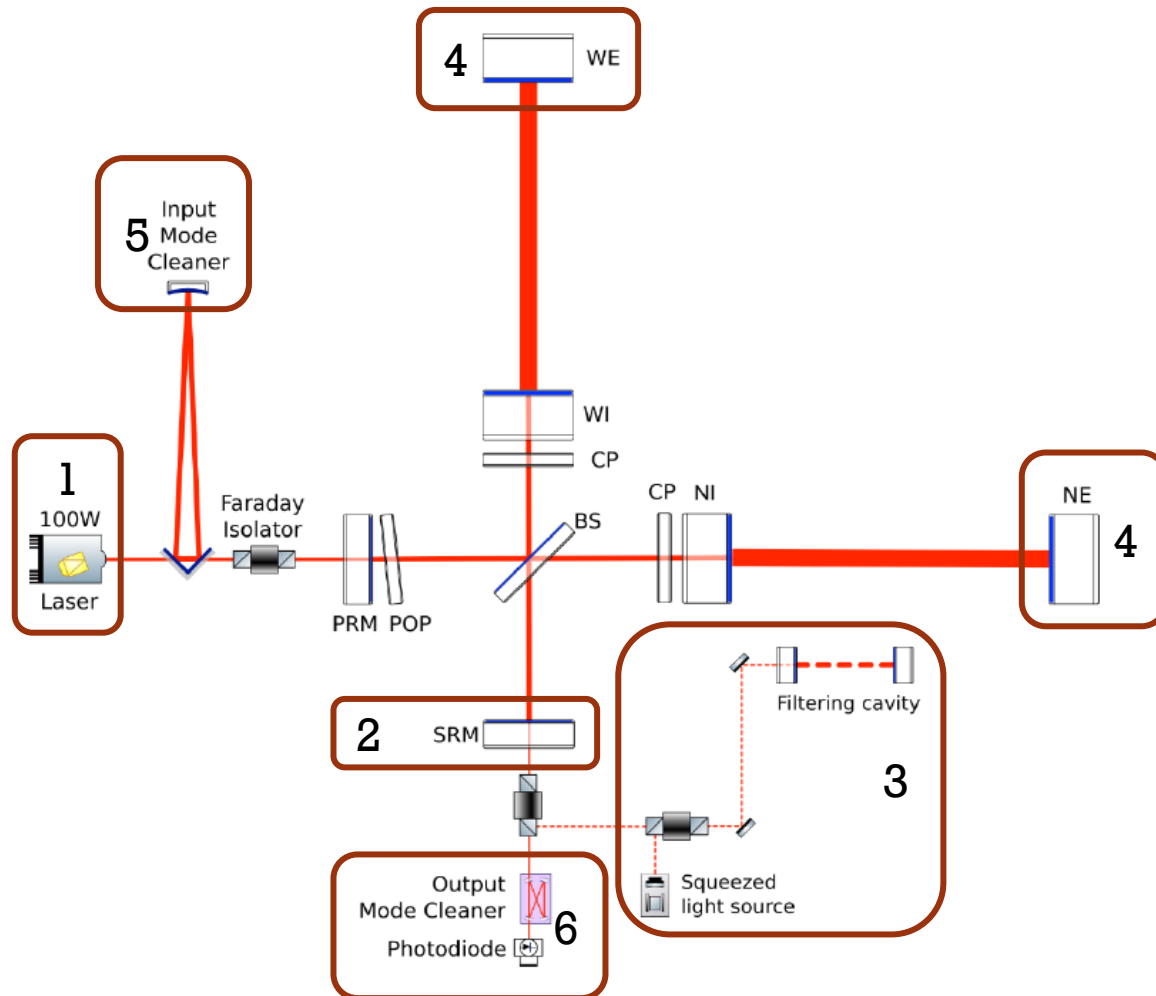
Frequency dependent squeezed vacuum source for the Advanced Virgo gravitational wave detector

F. Acernese *et al.* (the Virgo Collaboration),  
 H. Vahlbruch, M. Mehmet, H. Lück, and K. Danzmann  
 Institut für Gravitationsphysik, Leibniz Universität Hannover and Max-Planck-Institut für  
 Gravitationsphysik (Albert-Einstein-Institut), Callinstr. 38, 30167 Hannover, Germany  
 (Dated: May 4, 2023)

In this paper we present the design and performance of the frequency dependent squeezed vacuum source that will be used for the broadband quantum noise reduction of the Advanced Virgo Plus gravitational-wave detector in the upcoming observation run. The frequency dependent squeezed field is generated by a phase rotation of a frequency independent squeezed state through a 285 m long, high-finesse, near-detuned optical resonator. With about 8.5 dB of generated squeezing, up to 5.6 dB of quantum noise suppression has been measured at high frequency while close to the filter cavity resonance frequency, the intra-cavity losses limit this value to about 2 dB. Frequency dependent squeezing is produced with a rotation frequency stability of about 6 Hz RMS, which is maintained over the long term. The achieved results fulfill the frequency dependent squeezed source requirements for Advanced Virgo Plus. With the current squeezing source, considering also the estimated squeezing degradation induced by the interferometer, we expect a reduction of the quantum shot noise and radiation pressure noise of up to 4.5 dB and 2 dB, respectively.



# ADV+ PHASE I



- Installation within a year, despite pandemic
- Main interferometer completed in **December 2020**
  - Quantum Noise Reduction system completed in **April 2021**

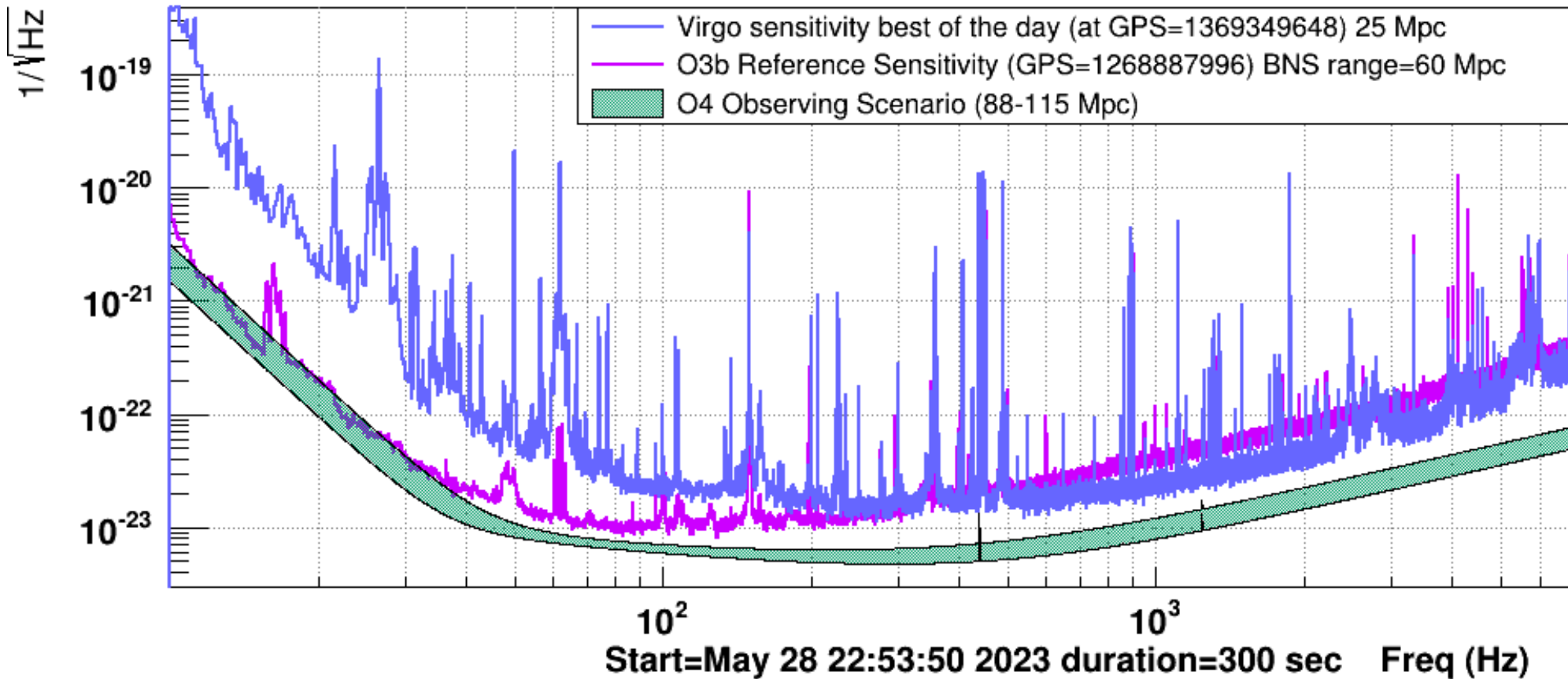
## Commissioning

- Started in **January/May 2021** for main ITF/QNR system

# DETECTOR SENSITIVITY

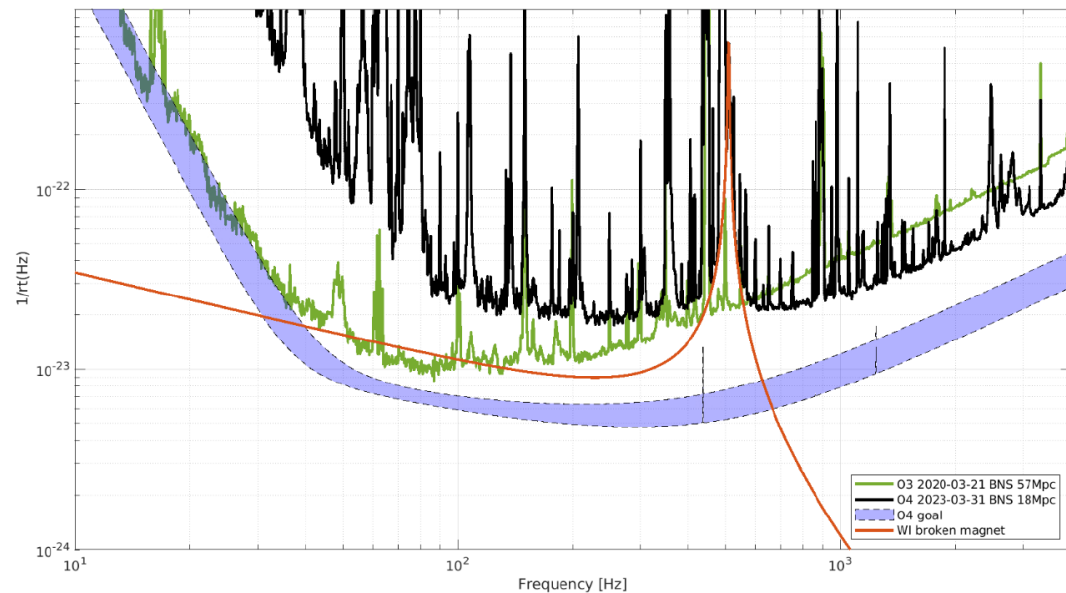
- Sensitivity at high frequency better than in O3
  - The signal recycling cavity does enlarge the detector bandwidth

Sensitivity for best BNS range of the day (25 Mpc)

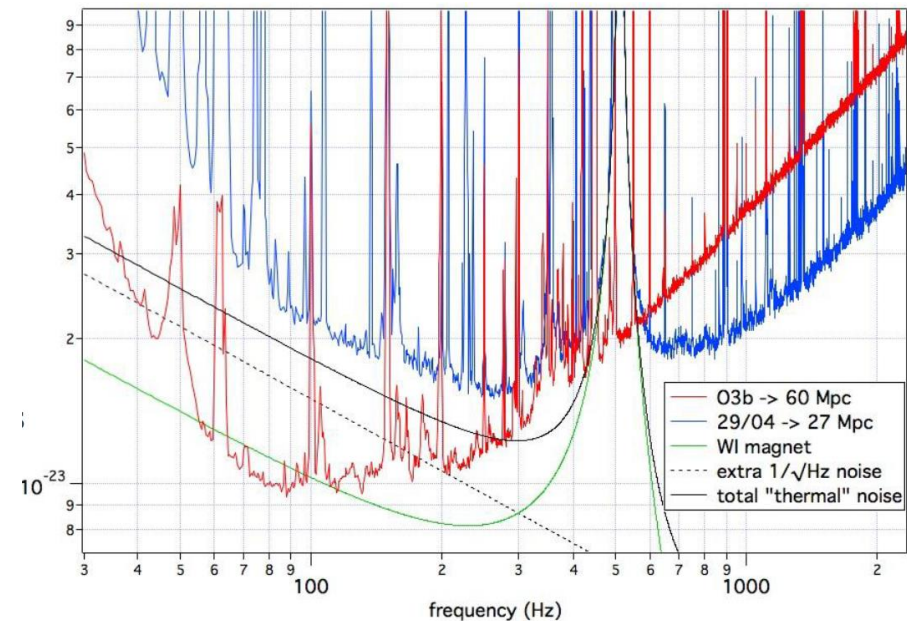


# DETECTOR SENSITIVITY

- Two main limitations spotted during the noise hunting:
  - Large peak around 500 Hz, due to a dangling magnet on the WI mirror following the suspension fibers break that occurred during the November venting;
  - A suspicious  $1/\sqrt{f}$  noise around 100 Hz, with the same shape as the thermal noise  $\rightarrow$  all data pointing to a degradation of the mechanical properties of the NE mirror;
- Both issues required invasive in-vacuum interventions to be solved (done in May-June);
- Sensitivity improved up to about 30 Mpc (for coalescing BNS).



A. Rocchi - TAUP 2023



# CONCLUSIONS

- Installation of AdV+ Phase I upgrades concluded in December 2020;
- Commissioning of the main interferometer ongoing since January 2021;
  - Stable ITF operation achieved;
  - Noise hunting started;
  - Frequency Dependent Squeezing demonstrated.
- O4 started on May 24<sup>th</sup>, 2023
  - It will last 18 months (instead of 12 months) to increase chances of multimessenger detections (O3 was a big success, but stingy on MM events);
- Virgo has not joined O4 yet, to address issues with two mirrors;
- The current plan is to:
  - Continue the commissioning activity to improve the sensitivity;
  - Join O4 in Fall.

