Status of Virgo

Yuhang Zhao (APC, CNRS and Univ Paris Cité)
On behalf of the Virgo collaboration

LIGO and Virgo detectors restart gravitational wave observation

April 3, 2024

O4b (The second part of the fourth observation run) has started on April 10th

Virgo Collaboration

The Virgo collaboration builds, develops and operates the gravitational wave detector Virgo, hosted by the European Gravitational Observatory in Cacina near Pisa, Italy

VMD

Virgo Collaboration Members

This section provides information relating to the Members that constitute the Virgo Collaboration.

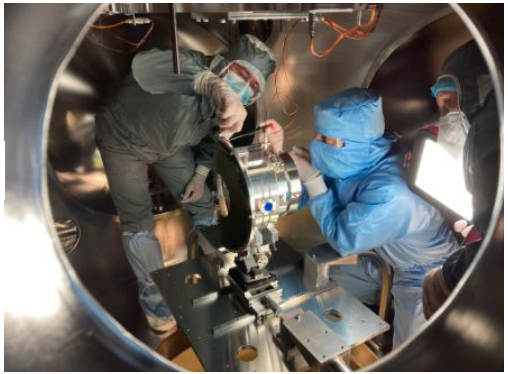
There are currently **890** Members in the Virgo Collaboration, representing **152** Institutions in **17** different countries.

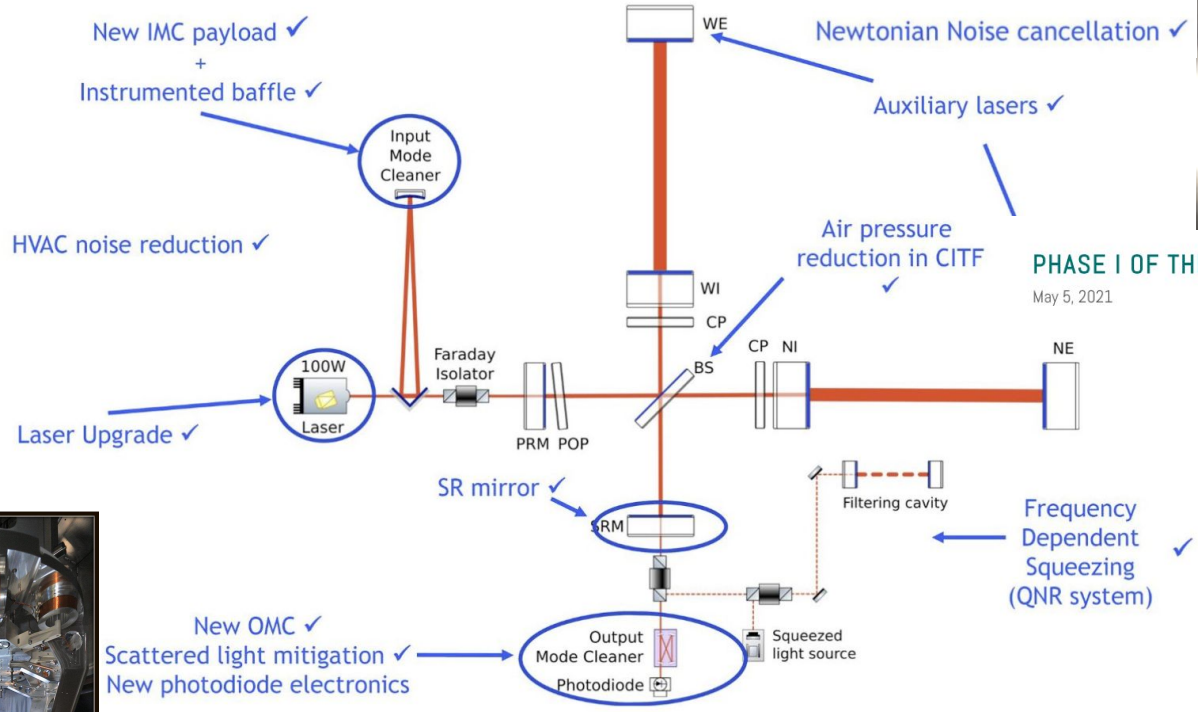
Approved by French CNRS and Italian INFN	Construction of Virgo began	Virgo Inauguration	Advanced Virgo approved	Advanced Virgo+ start
Early 1990s	1997	2003	2009	2020

600 authors 34 full members

37 groups 8 countries represented in the VSC

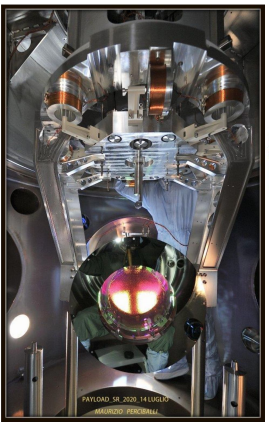
The advanced Virgo+ upgrades

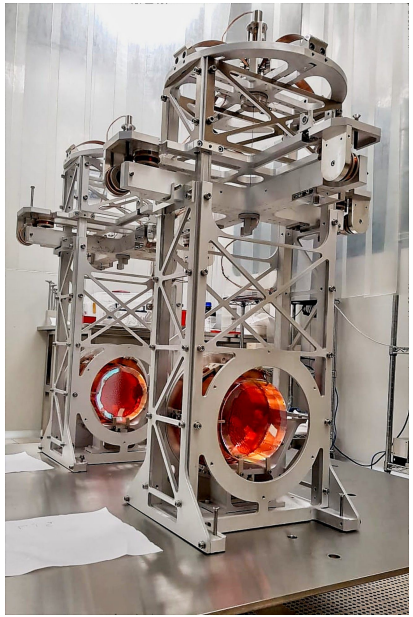




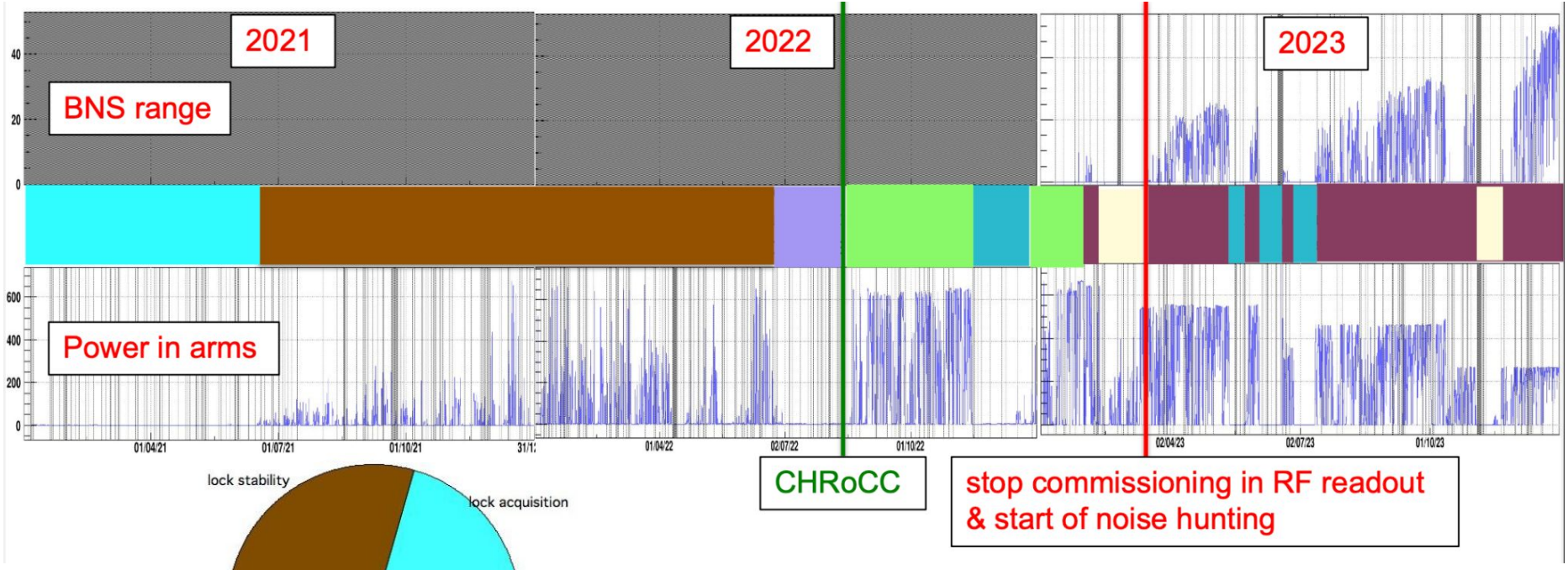
PHASE I OF THE UPGRADES TO ADVANCED VIRGO + COMPLETED

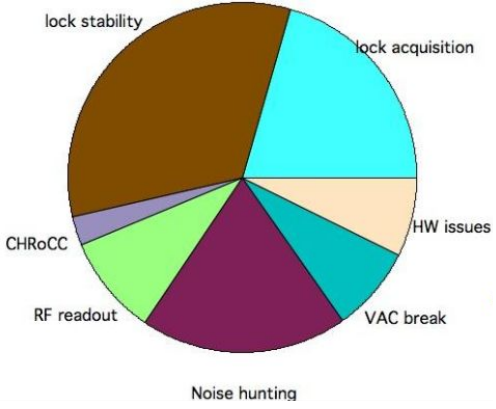
May 5, 2021





AdV+ commissioning from O3 to O4

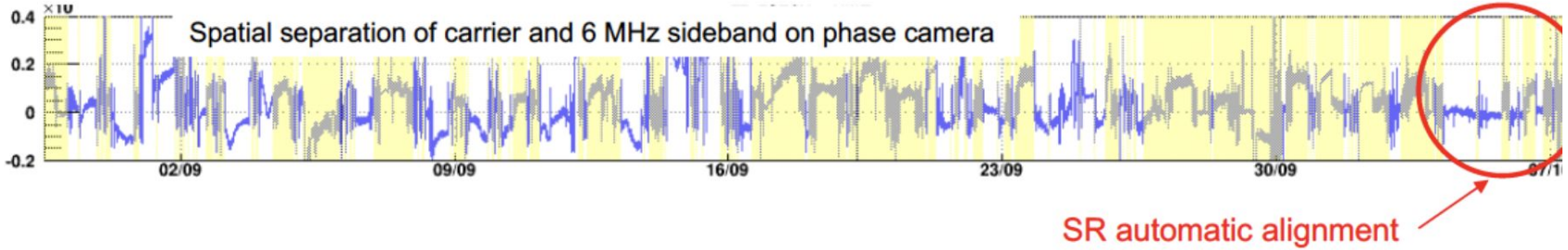




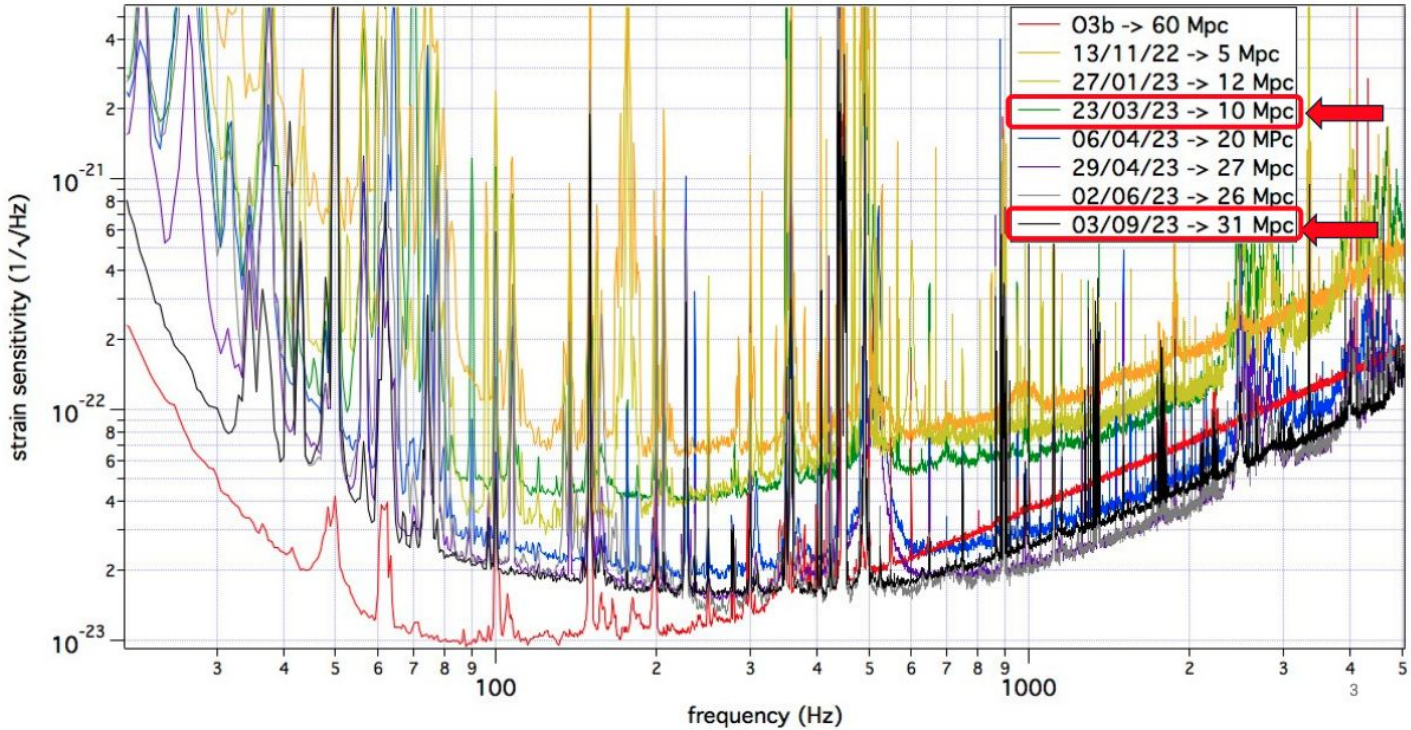
- About 10 net months for noise hunting
- Improved sensitivity by ~50 Mpc

Commissioning challenges with singal recycling mirror

- The challenge of degenerate recycling cavities
  - Make mode matching and alignment extremely critical
  - Difficult to measure cavity mismatch, as most HOMs resonante simultaneously
- Signal recycling alignment
  - Correct SR alignment should maximize dark fringe power
- Optical spring control
  - Optical simulations predict that HOMs in the central cavities generate offsets in longitudinal control signals, in particular for signal recycling cavity length (SRCL)
- Thermal compensation system (TCS) tuning:
  - Good tuning should have lower dark fringe power, higher power in the arm, lower SRCL offset
  - Tuning leads to lock bistability which does't allow a good locking state



Sensitivity evolution until september 2023



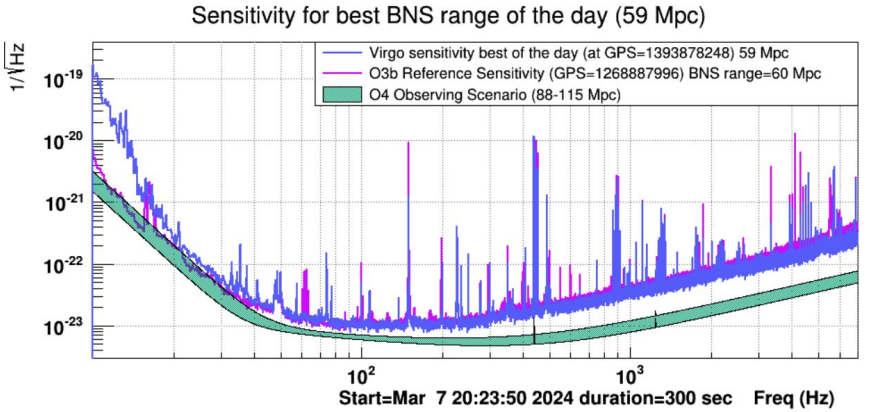
Progress on sensitivity mostly from

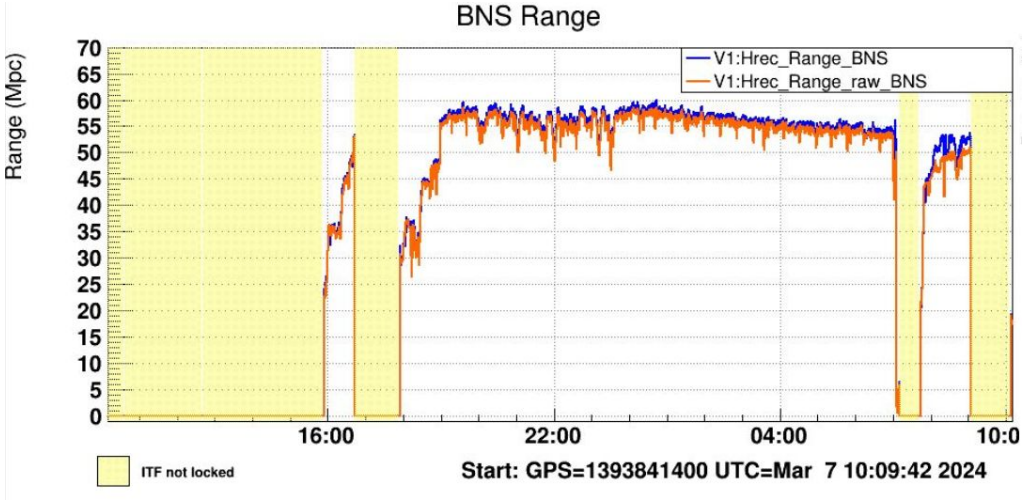
- Longitudinal control noise mitigation
- calibration&noise subtraction
- Relative intensity noise coupling mitigation

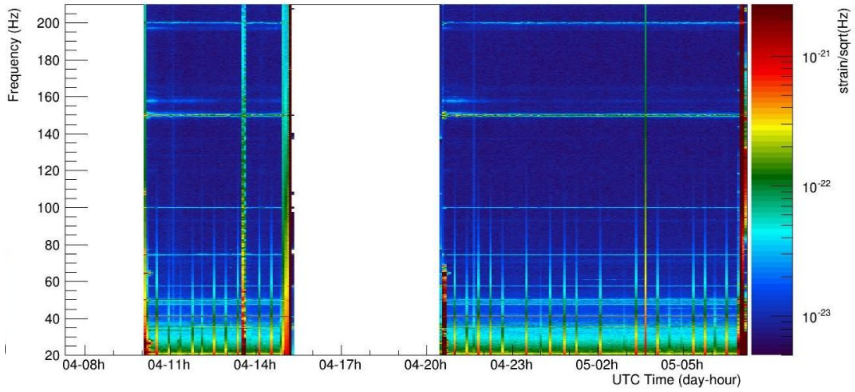
- Main limitation from unmodeled noise (resembling thermal noise)
- Noise unchanged after north end mirror replacement

Current status

- Sensitivity
  - Best BNS range ~60Mpc
    - SRC misaligned to increase optical gain
- Data quality
  - Glitch rate sensibly lower than in O3
    - Loud periodic glitches (25min period, <1s duration)
  - Spectral lines similar to O3

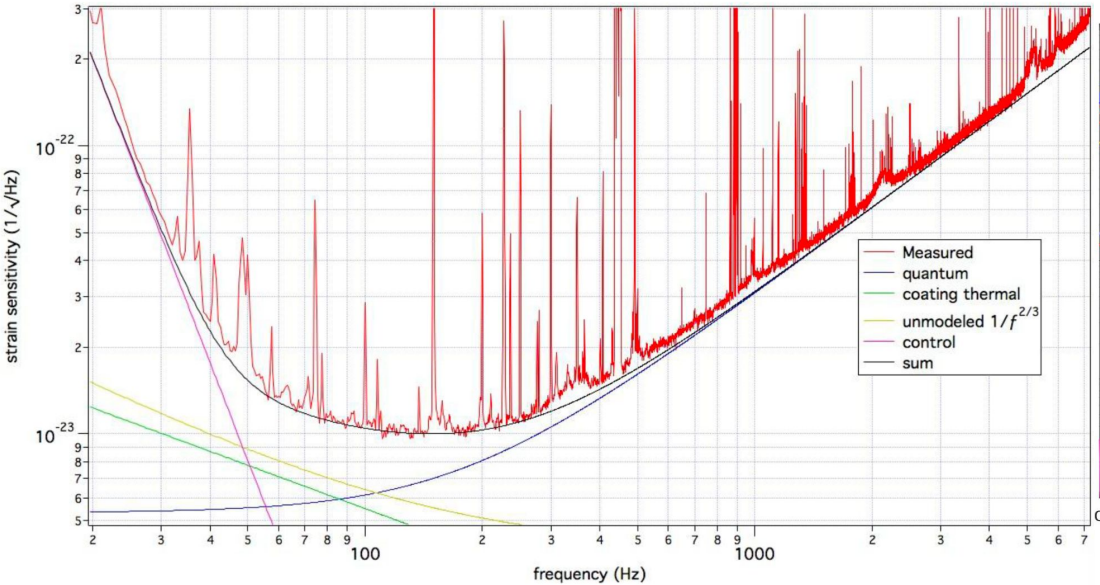


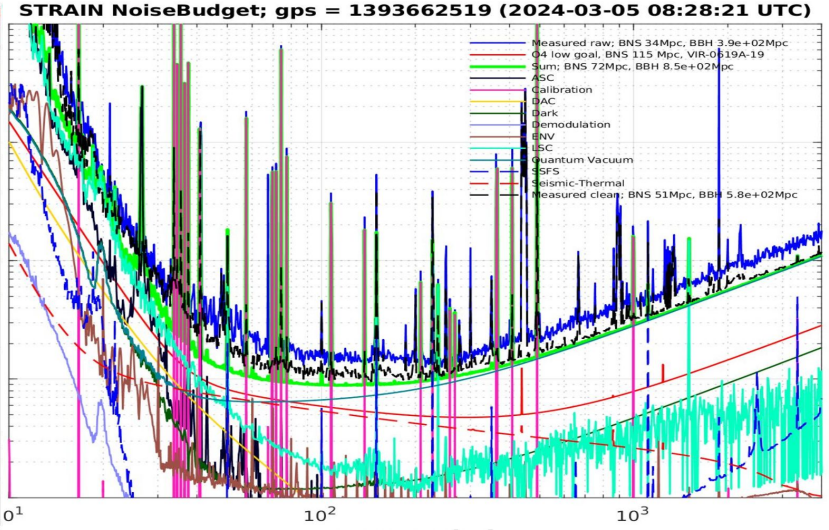




Noise budget

- Sensitivity explained by Quantum noise+coating thermal noise+control noise+unmodeled noise
- Current budget of modeled noise would explain sensitivity up to >70 Mpc

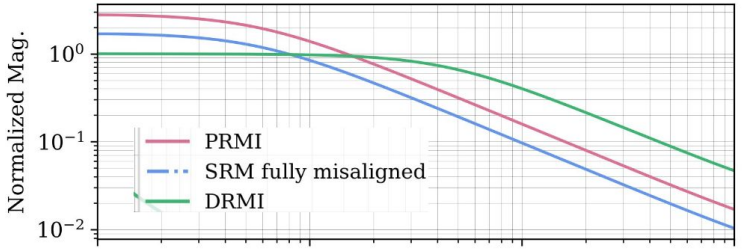




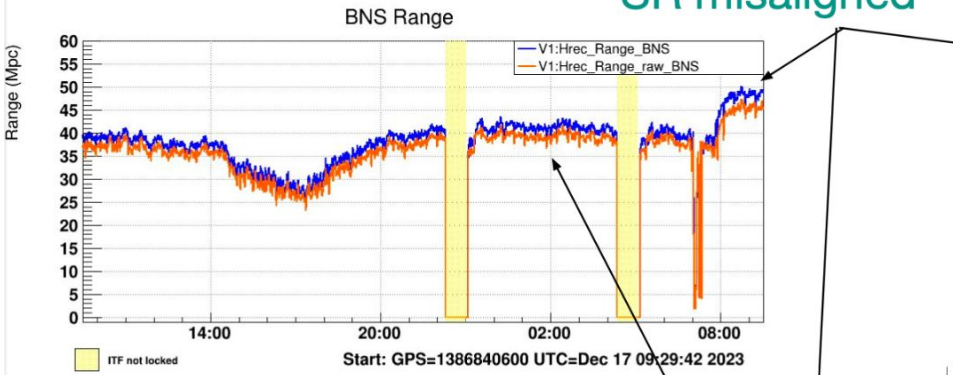
- Unmodeled noise is correlated on the two detection photodiodes
- By removing shot noise by anti-correlation, the slope of unmodeled noise is found to be 1/f^(2/3)

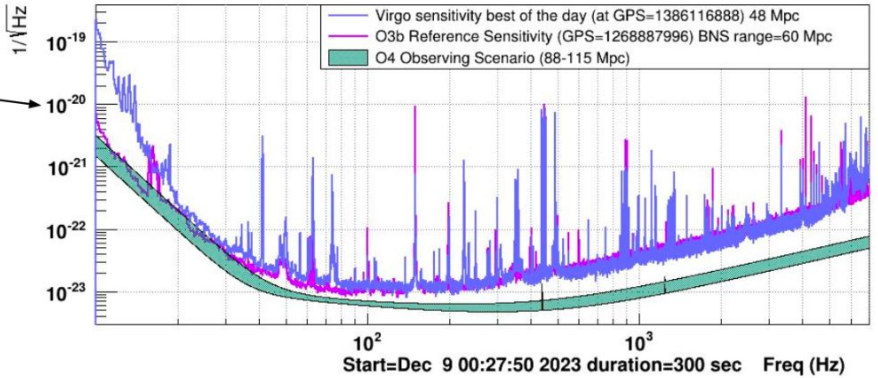
Signal recycling cavity alignment

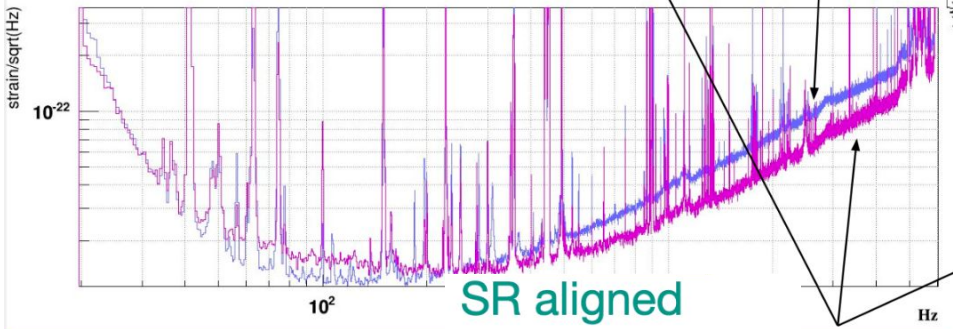
The signal gain is modified by choosing different signal recycling cavity alignment condition



SR misaligned

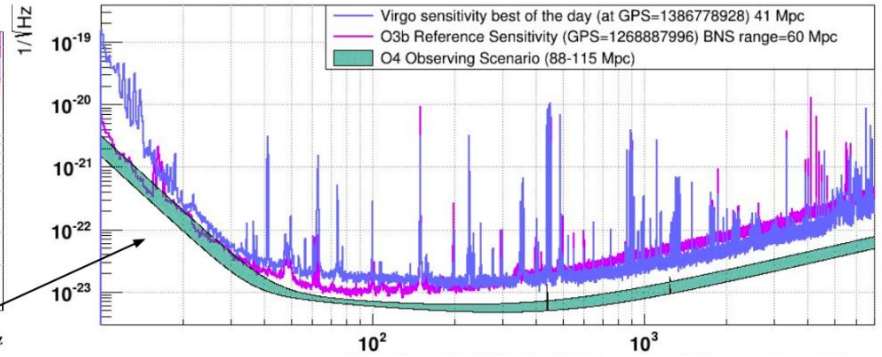






SR aligned

Sensitivity for best BNS range of the day (41 Mpc)

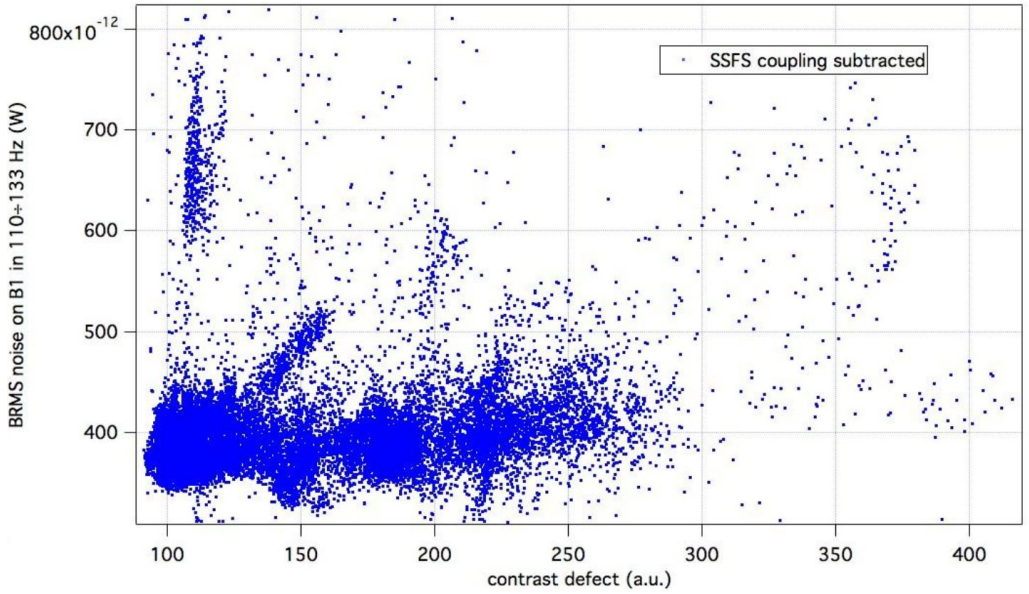


1/f^(2/3) unmodeled noise

It is independent on contrast defect. This means that HOMs do not contribute

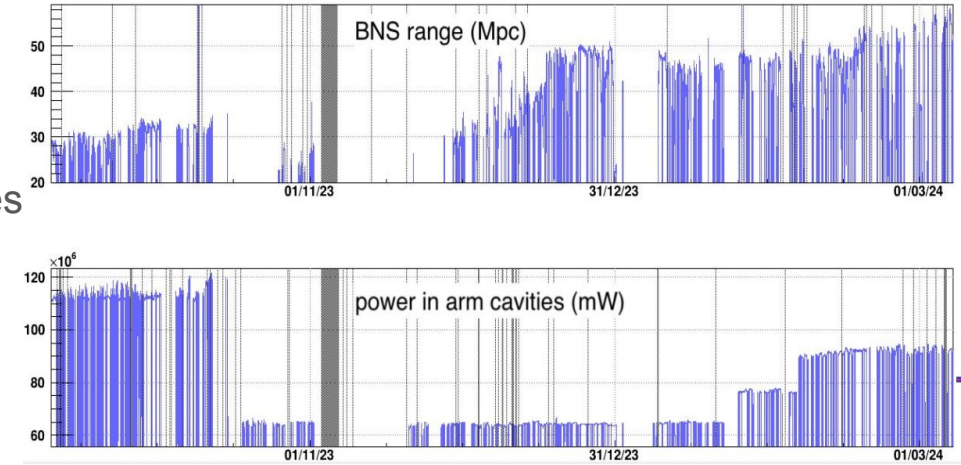
It is independent on DARM offset

Many investigations have been done, yet the source of the noise remains unknown



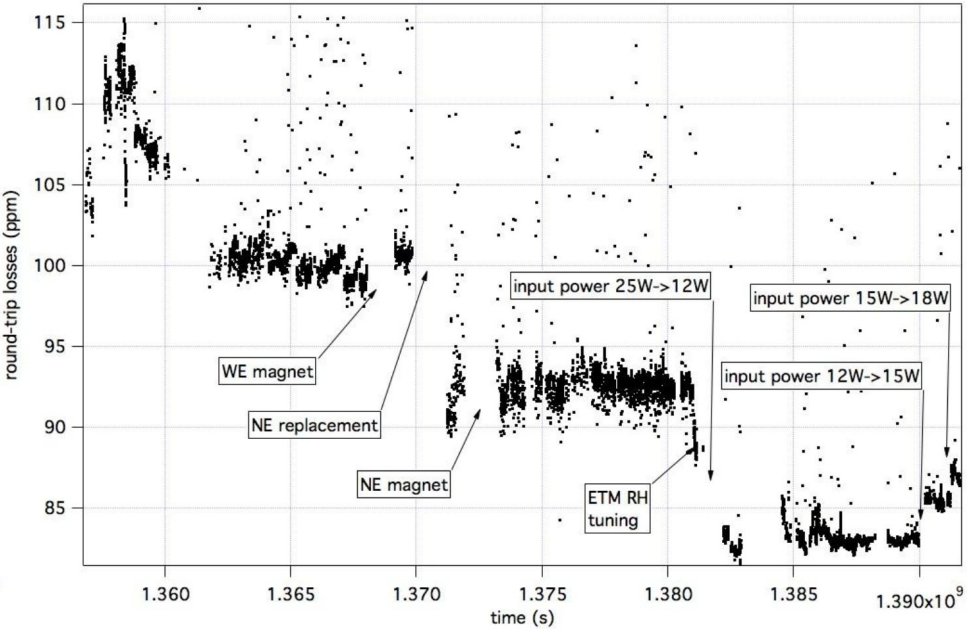
Input power tuning

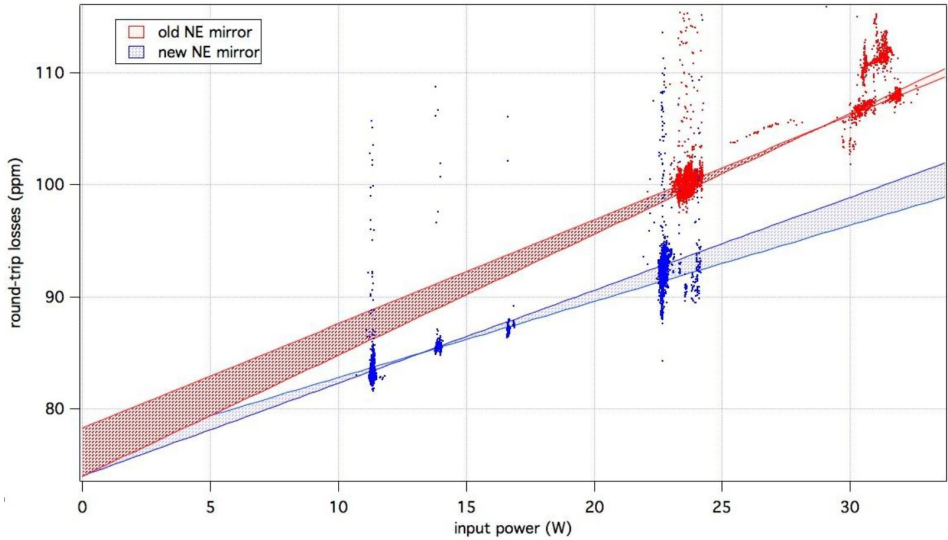
- 23W -> 11W
  - To verify unmodeled noise vs HOMs content
  - To simplify optical tuning by separating cold effects from thermal effects
- 11W -> 14W -> 17W
  - Small sensitivity improvement due to shot noise reduction
- No effect on 1/f^(2/3) noise
- No further steps planned until O4b
  - Time constraints
  - 1/f^(2/3) noise dominating sensitivity
  - Power-dependent losses in arm cavities



Power-dependent losses in arm cavities

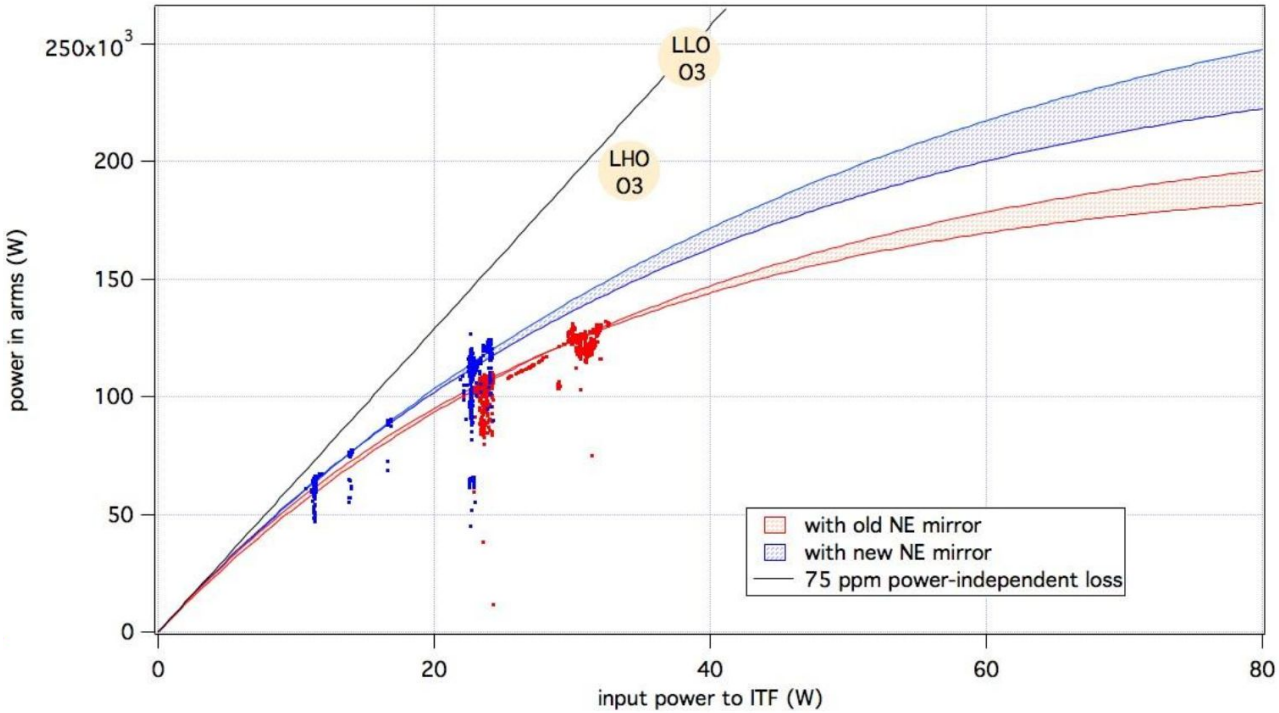
- Large change of arm cavity round-trip-losses with input power
- Power-dependent losses were reduced by ~¼ after replacing ¼ mirrors (north end)





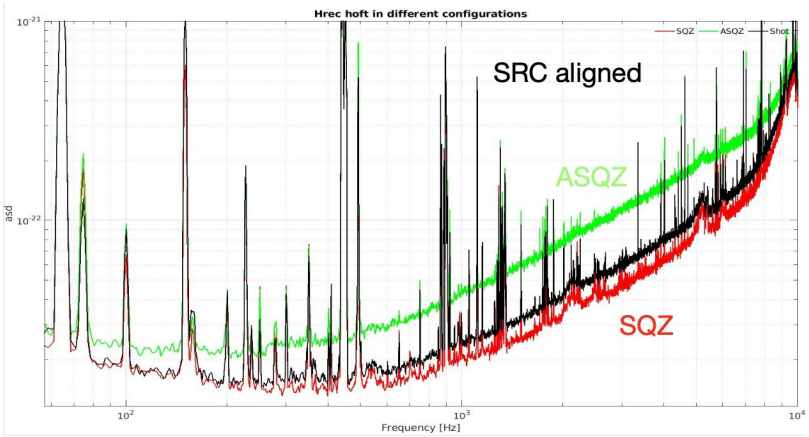
Power-dependent losses in arm cavities

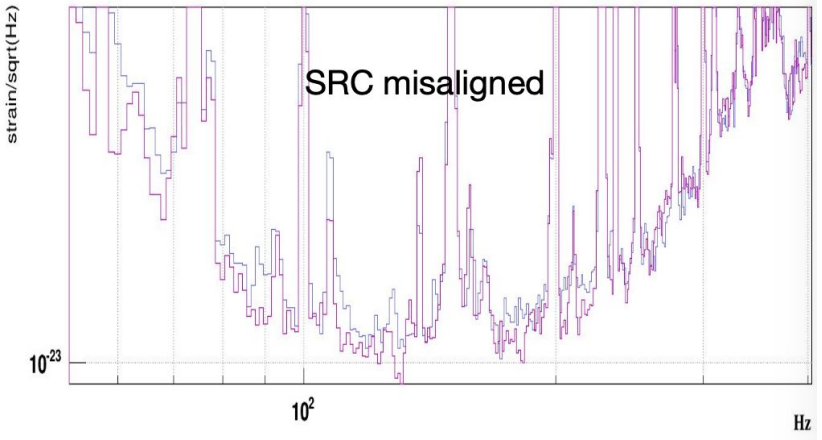
It is possible to reach the nominal power of 200kW in the arms with the new North-end mirror but this requires 60W input power



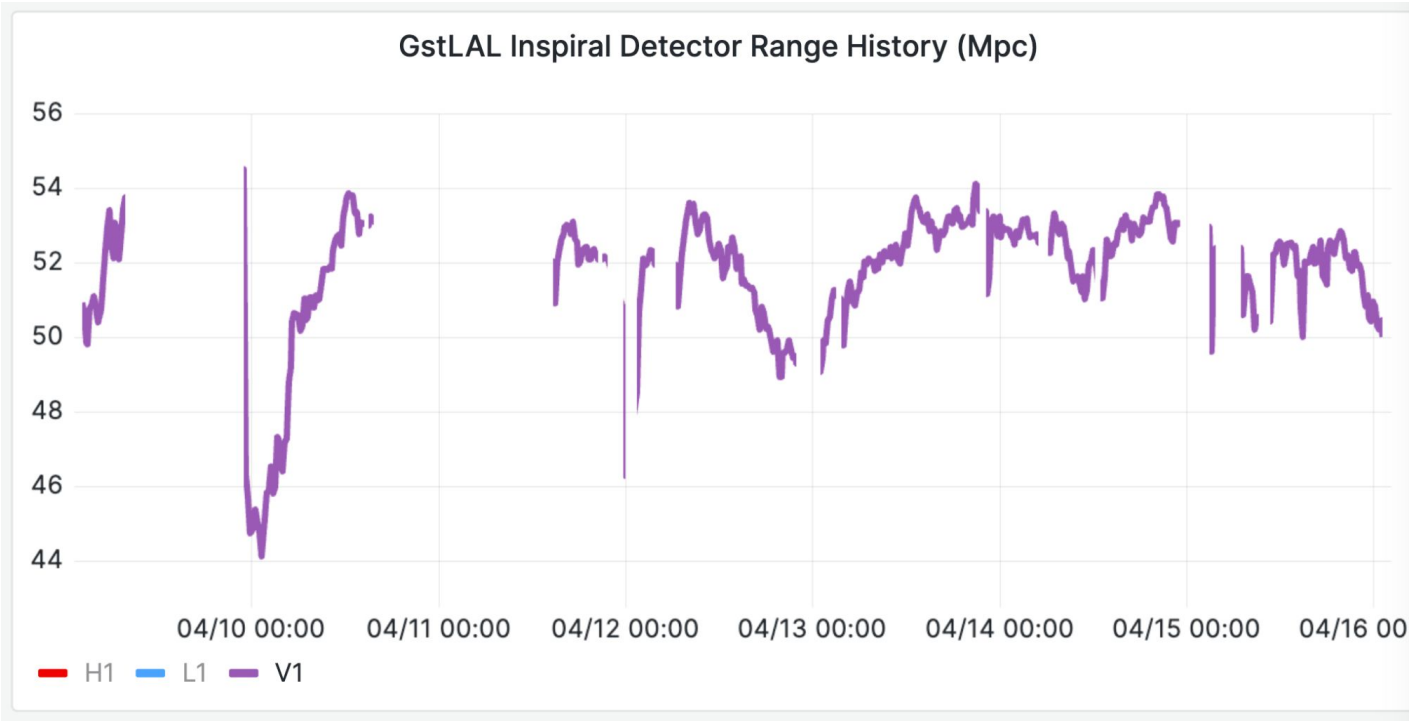
Quantum noise reduction with squeezing

- Frequency dependent squeezing not necessary (low power)
- With SRC aligned, squeezing efficiency is ~2.5dB (similar to O3)
  - Currently limited by mismatch, SRC & OMC losses
- With SRC misaligned, squeezing efficiency drops dramatically above DCP frequency
  - Limited by excess losses in SRC
  - But still helping in the bucket: 2Mpc increase in BNS range
- Possible further improvements by
  - Optical tuning to reduce losses
  - Alignment tuning to remove clipping losses



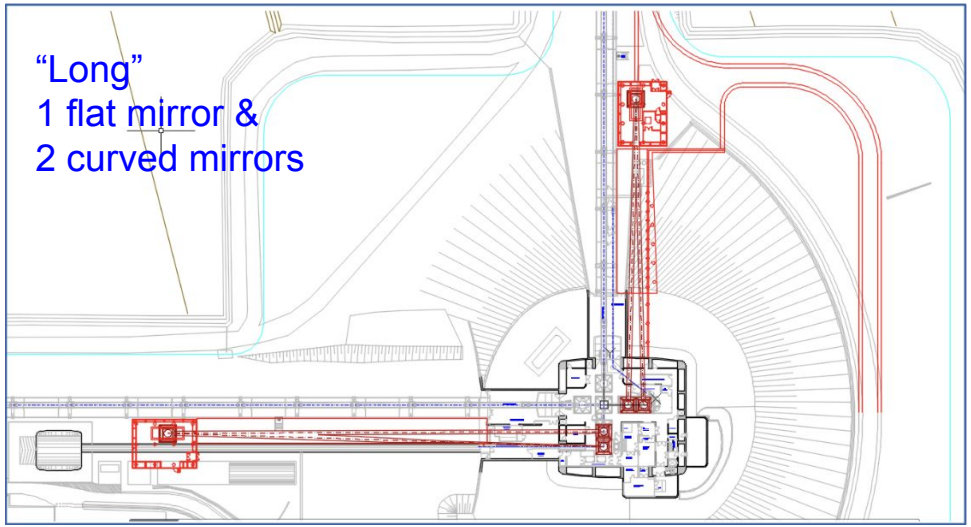


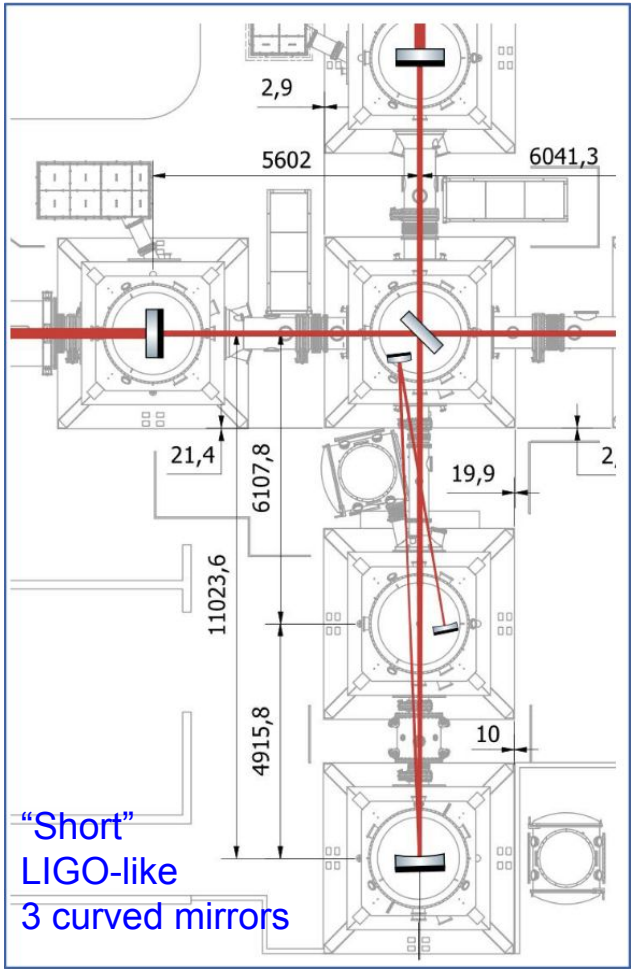
The first week of the Virgo run



AdV+ Phase 2

- The influence of marginally stable cavity on the thermal tuning and stability of the lock lead to a major plan change in Virgo — to introduce stable recycling cavities in AdV+ Phase 2
- There is a collaboration-wide agreement on introducing stable recycling cavities
- Now we are in a quite mature stage of the conceptual design phase for stable recycling cavities





Two configurations

- Two different viable configurations for stable recycling cavities have been studied
- Preliminary information on cost and schedule available:
  - Long option: about 20M euro and 3.5 years (excl. commissioning)
  - Short option: about 10M euro and 2.5 years (excl. commissioning)
- The criteria for comparing the two options have been defined and based on risk analysis:
  - Technical risks
  - Limitations for further upgrades
  - Schedule
  - Costs
- Following this analysis, the baseline configuration is the Short Option
- This conclusion has been internally reviewed

Report of the Internal Review Board for the choice of a baseline configuration for the stable recycling cavities of Advanced Virgo+

Matteo Barsuglia[1], Livia Conti[2], Giovanni Losurdo[3], Christophe Michel[4], Lluïsa-Maria Mir[5], Fulvio Ricci[6], Bas Swinkels[7], Maria C. Tringali[8]

Abstract

We present the results of the internal review on the choice of a baseline configuration to implement stable recycling cavities in Advanced Virgo+. The project management presented the conceptual study of two main configurations, defined “short” and “long” recycling cavities. At a later stage the “short” was put forward as the preferred solution. Here, we endorse the management decision and report the result of our analysis highlighting aspects asking for further investigations. We present a list of recommendations aimed to help the preparation of a robust Technical Design Report.

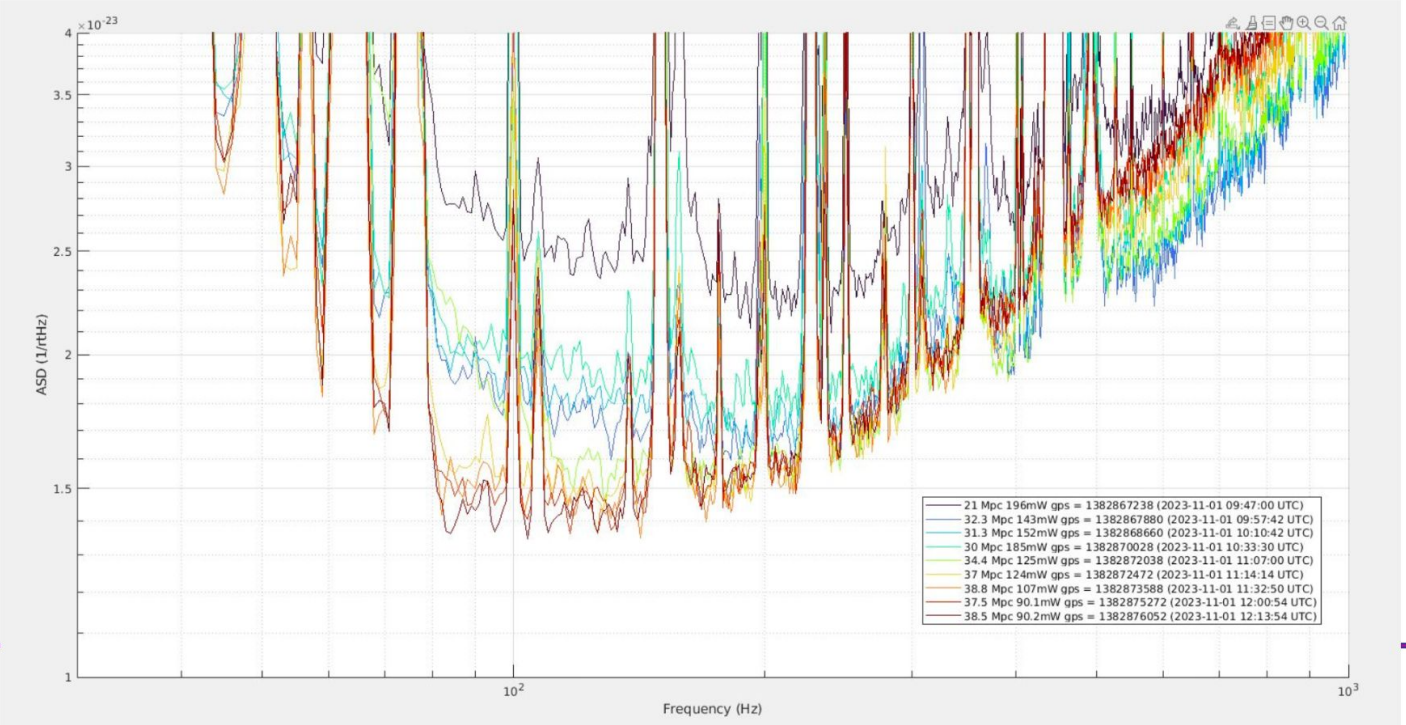
Conclusion

- Several AdV+ phase 1 upgrades ompleted
- Virgo has started the observation run with a sensitivity of ~60Mpc best achieved
  - Sensitivity same as O3b
  - Lower glitch rate than O3
- Several challenges have been encountered and solved, during 3 years of upgrade and commissioning
- Noise budget:
  - Known noises: quantum noise+coating thermal noise+control noise (amounts to ~70Mpc)
  - unmodeled noise with slope 1/f^(2/3)
- Stable cavities for AdV+ phase 2

Reference: VIR-0505A-23, VIR-0225A-24, VIR-1149A-23, VIR-0259B-24, VIR-1052A-23

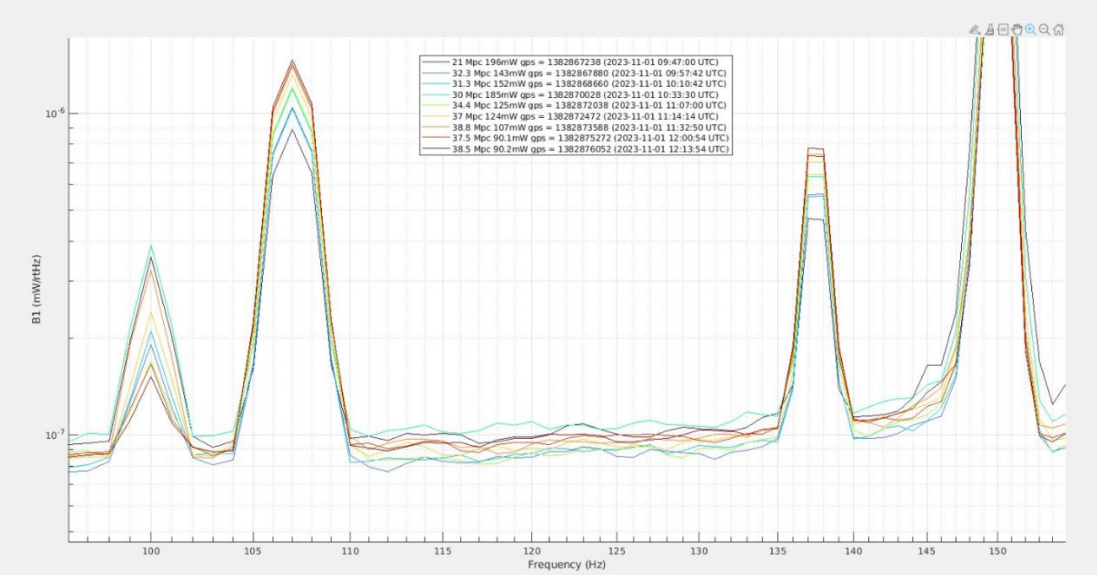
Hunting unmodeled $1/\sqrt{f}$ noise

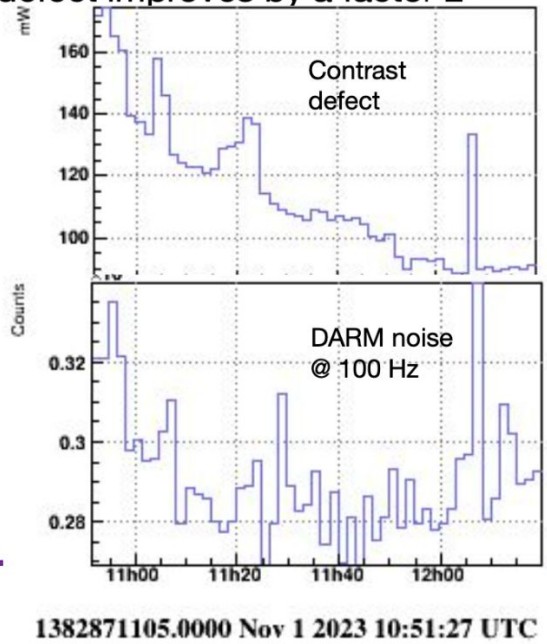
- Sensitivity improves when SR mirror is misaligned
  - noise @ 100 Hz reduced by more than 50% at the cost of 50% lower ITF bandwidth
  - **excludes displacement noise from TMs**



Hunting unmodeled $1/\sqrt{f}$ noise

- Sensitivity improves when SR mirror is misaligned
  - noise @ 100 Hz reduced by more than 50% at the cost of 50% lower ITF bandwidth
  - **excludes displacement noise from TMs**
- Effect basically due to increased optical gain
  - noise in DARM does not change substantially, though contrast defect improves by a factor 2
  - **excludes noise coupling from dominant HOMs**





Next Steps for AdV+ phase 2

- Focus on optimization of the optical configuration
- Start design for the suspensions of the RC optics
- Initiate production of all the project documentation
- External review committee set up by EGO Council
- Short configuration still has some critical aspects that need further study and prototyping + critical timeline
  - Interesting new “long” design (VIR-0219A-24) will be further explored in parallel
  - A “Plan B” without stable cavities will be studied and defined in detail

Post O5

- The Virgo_nEXT concept study was presented to the STAC in May 2022 and to the Council in June 2022