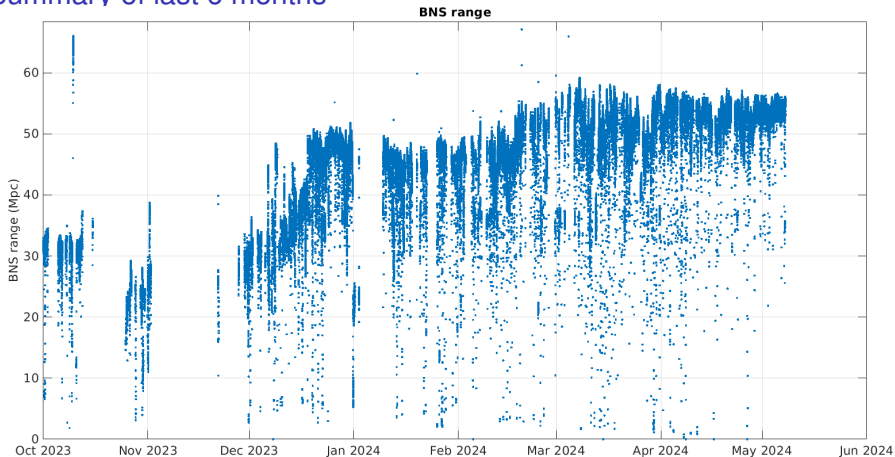


Commissioning

Michal Was

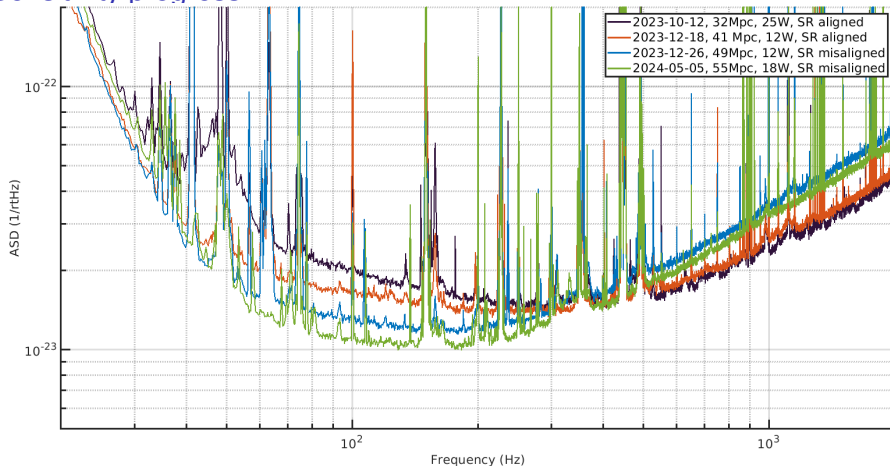
LAPP/IN2P3 - Annecy

Summary of last 6 months



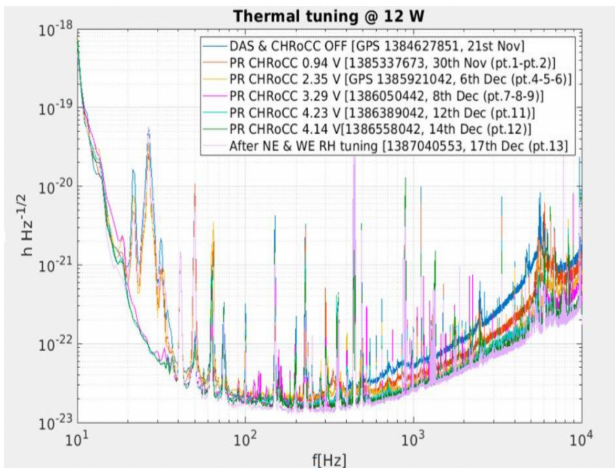
- November - Recover from power outage
- December - Redo thermal compensation tuning from scratch, misalign SR
- January - Replace OMC that has 10% losses
- February - Increase power, tune TCS, and tune SR misalignment
- March - Restart of all real time control software and reduced data flow by 25%
- April 10 - O4b starts

Sensitivity progress



- Reduced input laser power from 25 W to 12 W
 - ▶ Have wider region of stability with regard to thermal corrections
 - ▶ Almost no impact on shot noise as loss of power compensated by better thermal tuning
- Shape the $1/f^{2/3}$ mystery noise by misaligning SR
- Increase the input laser power from 12 W to 18 W

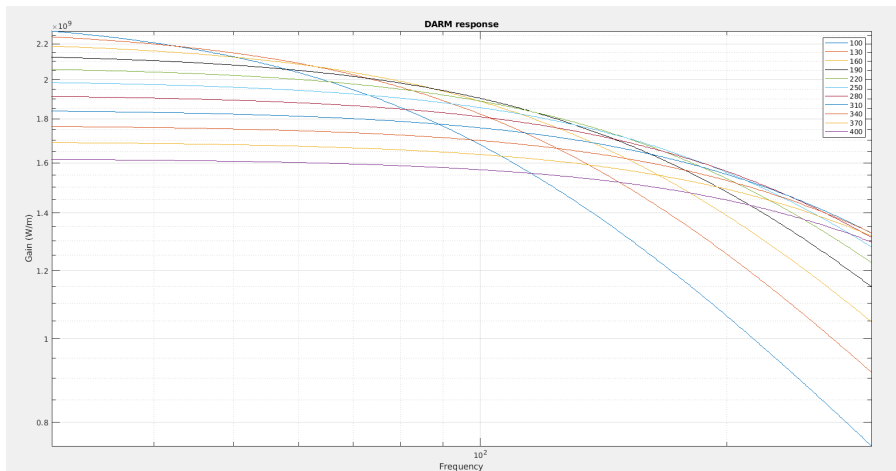
Thermal compensation tuning



- Thermal compensation redone from scratch after 25 W → 12 W power reduction
- Improvement in sensitivity from ~ 30 Mpc to ~ 40 Mpc
- Reduction in frequency noise
- Increase in optical gain by $\sim 10\%$ (critical for $1/f^{2/3}$ mystery noise)

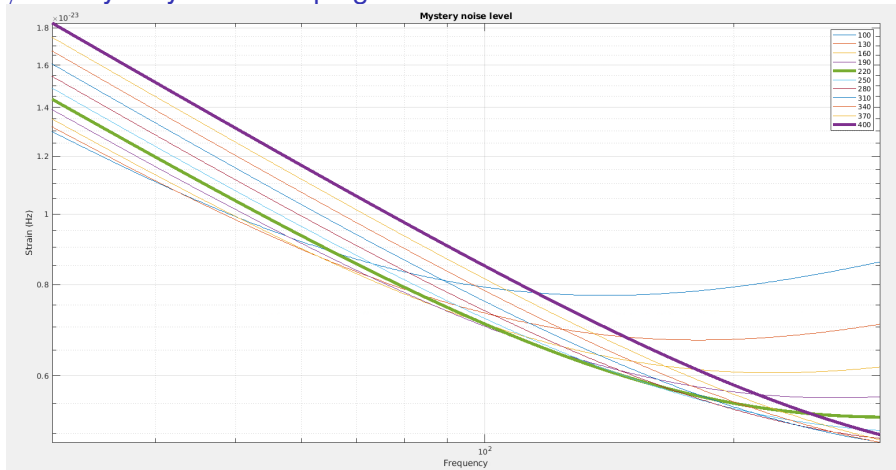
[VIR-0104A-24](#)

Effect of Signal Recycling misalignment



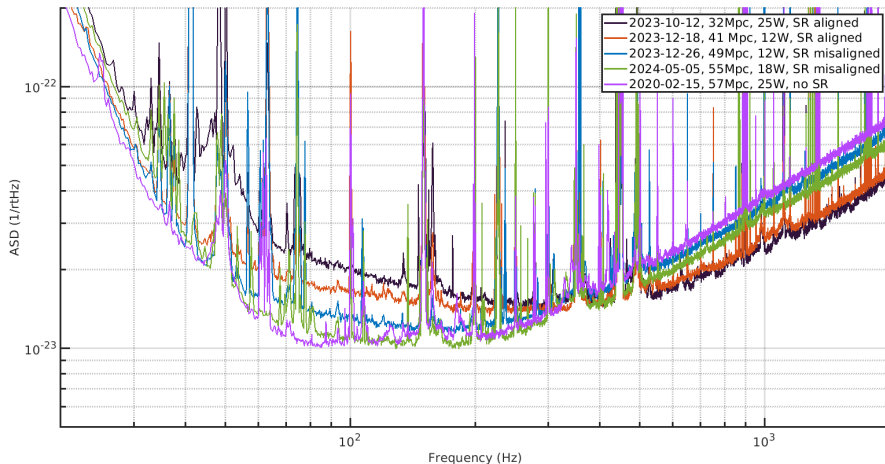
- Differential arm length optical response → conversion of meters to Watts on photodiodes
- When SR is misaligned optical gain increase and becomes more narrow band
 - ⇒ Response similar to more transparent SR but with high losses

$1/f^{2/3}$ mystery noise shaping



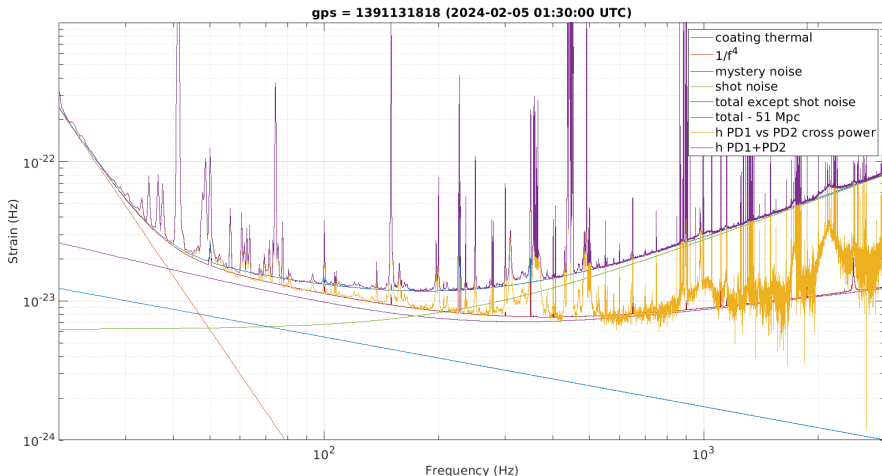
- Noise is constant in terms of $W/\sqrt{\text{Hz}}$ on photodiodes
 - ⇒ Higher optical gain means higher strain signal for same noise on photodiode
 - ⇒ Changing shape of optical response changes noise level in strain units
 - ▶ Design with 450 Hz bandwidth, optimum at 200 Hz, without SR 50 Hz bandwidth
- Improve sensitivity at low frequency but lose sensitivity at high frequency

Sensitivity progress



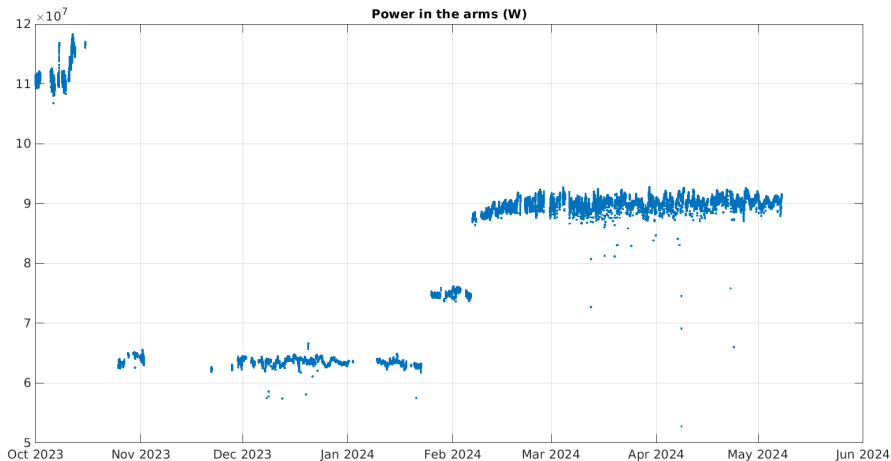
- SR misalignment is the main reason for sensitivity improvement
- This effect was initially hidden by an issue with $h(t)$ reconstruction
- Sensitivity curves ends up very similar to O3

$1/f^{2/3}$ noise slope measurement



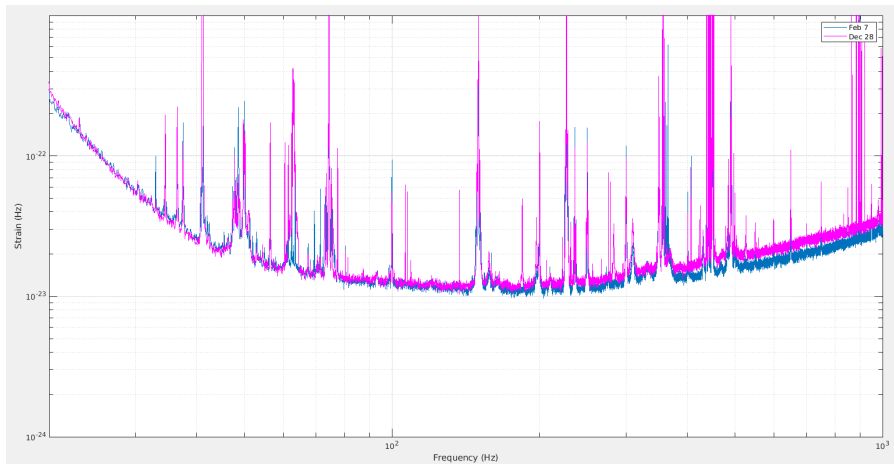
- Cross-correlate DC read-out photodiodes to obtain $h(t)$ spectrum without shot noise
 - ▶ Same principle as stochastic gravitational wave searches
- Cross-correlated spectrum explained well by mystery noise + coating thermal noise
- Fit mystery noise amplitude and slope
- Slope of mystery noise is between -0.65 and -0.7 times the optical response

Change of power in the arms



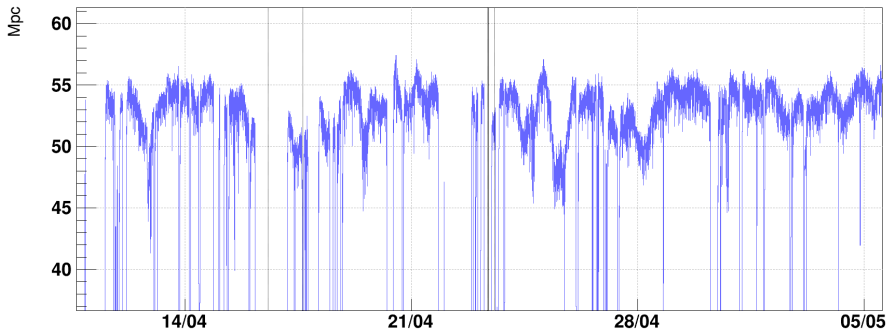
- Redo interferometer thermal tuning that was critical
- Study $1/f^{2/3}$ noise as function of laser power
- Change the input laser power from 25 W to 12 W and then to 18 W
- 110 kW $\rightarrow$ 65 kW $\rightarrow$ 90 kW

$1/f^{2/3}$ noise input power dependence



- Input power change 65 kW $\rightarrow$ 90 kW has no direct impact on $1/f^{2/3}$ mystery noise
- Power stored in the interferometer increased by factor 1.4
- Shot noise decreased by $\sim 20\%$

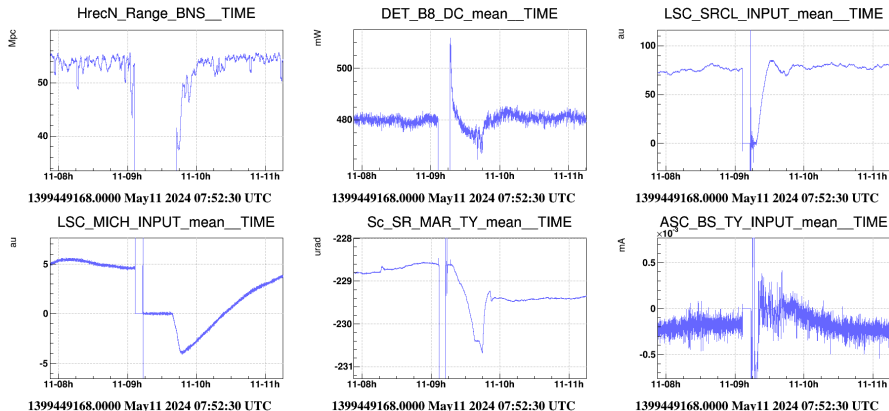
Start of O4b - recovered from a series of duty cycle limiting failures



- Changed accelerometer demodulation frequency to resolved PR F0 glitch
 - ▶ Glitch still present but not affecting suspension control anymore
- MIR/MAR allocation causing instability at 1.8 Hz
 - ▶ Turned out to be actually a too large gain in the CARM loop
- OMC slow shutter translation stage stop not working in one direction
 - ▶ Rely on counting motor steps instead, can stay like this for remainder of O4b
- ALS WE green failure, amplifier replaced by spare, new spare ordered
 - ▶ Highlights critically low person power, 0.3 FTE
- TCS flip mirror in wrong state by mistake
 - ▶ At the same time as bad weather
 - ▶ This flip mirror was added during commissioning and its state currently cannot be monitored

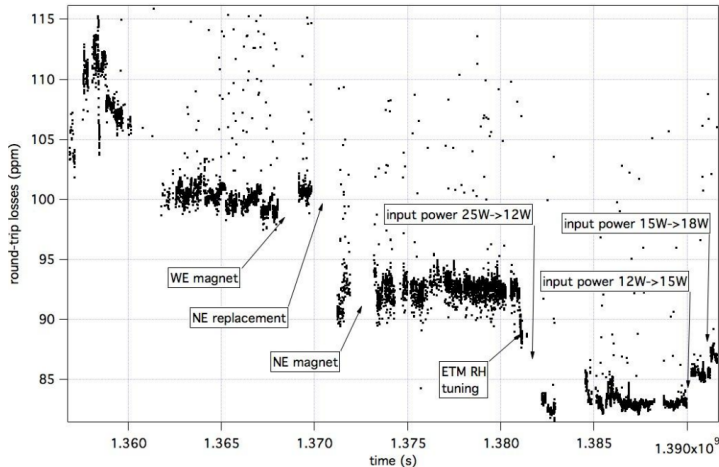
Main lesson from O4 commissioning

dataDisplay v10r15 : started by mwas on May 23 2024 16:26:56 UTC



- Commissioning a marginally stable dual recycled interferometer is extremely time consuming
- Many radio-frequency signals do not work, replaced them with mechanical dithers
 - ▶ Control response time hour instead of seconds
- The time needed to do any adjustments increases with higher power
- In addition marginally stable signal recycling amplifies noise in addition to signal

Losses in arms

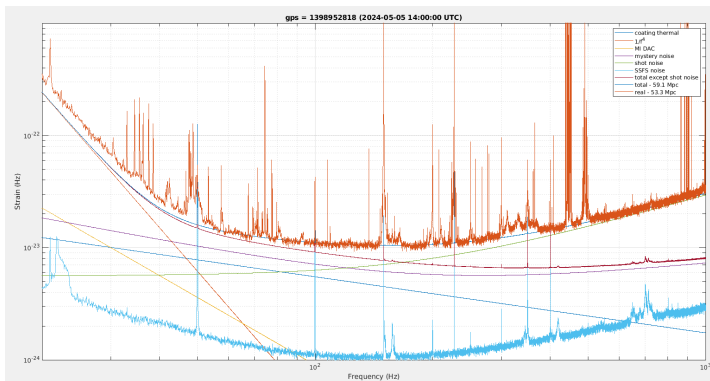


- Losses in arms increase with power
- When NE was replaced by spare mirror losses reduced significantly
- On-going to discussion if, when and which test masses to replace
- Also seen point absorbers disappear after cleaning of WI
- In the mean time increasing input power brings limited improvements

Lessons from O4 commissioning - continued

- Exercise in listing all the hardware limitation encountered during O4 commissioning [VIR-0120A-24](#)
 - ▶ 18 slides in that presentation, list is still growing
- Laser noise at 2 MHz not optically filtered
 - ⇒ causes cross contamination between 6 MHz and 8 MHz sidebands
 - ▶ High finesse Pre-Mode Cleaner with cut-off at 200 kHz instead of 2 MHz
 - ▶ Change sideband frequencies to be more widely separated
- Fiber laser - high power but failure rate of 1/year and high noise in interferometer
 - ▶ New solution to be found for O5
- Replace CP that have high lens (reduce TCS actuation correction)

Dominant noises



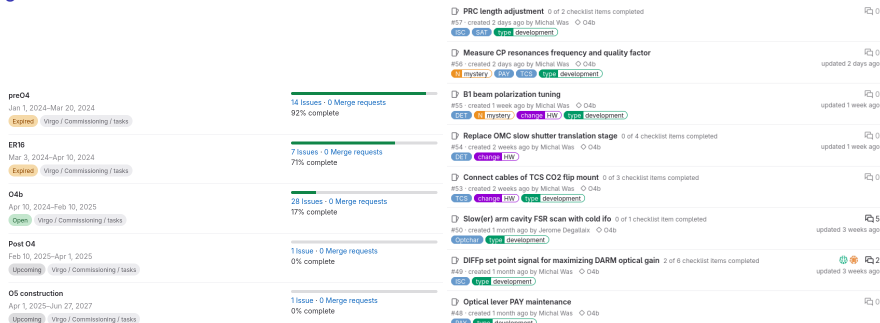
- Sensitivity well explained by: $1/f^{2/3}$ noise, shot noise, coating thermal noise
- $1/f^{2/3}$ noise still reduces BNS range by ~ 20 Mpc
 - ▶ 15 Mpc due to current noise level with misaligned SR
 - ▶ 5 Mpc due to higher quantum when SR misaligned (squeezing ineffective)
- $1/f^{2/3}$ noise work package defined - [VIR-0425A-24](#)
- Team of 6 people meeting first time last week
- Goal is to write a detailed report over next 6 months
 - ▶ Technical document describing noise sources that have already been considered
 - ▶ Or publication describing the physics of understood noise source

Commissioning activity organization

coordinators

- Official start of mandate on April 10 (start of O4b)
- Appointed Diego Bersanetti as deputy

gitlab



- Helps me remember everything that is on the to-do list
- Foster a documented discussion of each topic

<https://git.ligo.org/virgo/commissioning/commissioning-tasks/-/milestones>

Commissioning during O4b

Priorities

1. lock stability & reliability
2. BNS range stably at 55 Mpc
3. Measurements for papers on commissioning
4. $1/f^{2/3}$ noise investigations (mystery noise)

Current plan

Month	Activity	Downtime	Commissioning task issue
Apr 2024			
May 2024	EM RH tuning		https://git.ligo.org/virgo/commissioning/commissioning-tasks/-/issues/44
Jun 2024	Squeezing paper measurents		https://git.ligo.org/virgo/commissioning/commissioning-tasks/-/issues/47
Jul 2024	PRC length adjustment		https://git.ligo.org/virgo/commissioning/commissioning-tasks/-/issues/57
Aug 2024			
Sep 2024	OMC on EDB looking at B1s beam	1 day or fit during maintenance + scheduled shifts?	https://git.ligo.org/virgo/commissioning/commissioning-tasks/-/issues/15
Oct 2024			
Nov 2024	Polarization in front of SDB1 Faraday isolator	1 week including venting/pumping SDB1	https://git.ligo.org/virgo/commissioning/commissioning-tasks/-/issues/55
Dec 2024			
Jan 2025			
Feb 2025			

Commissioning person-power survey

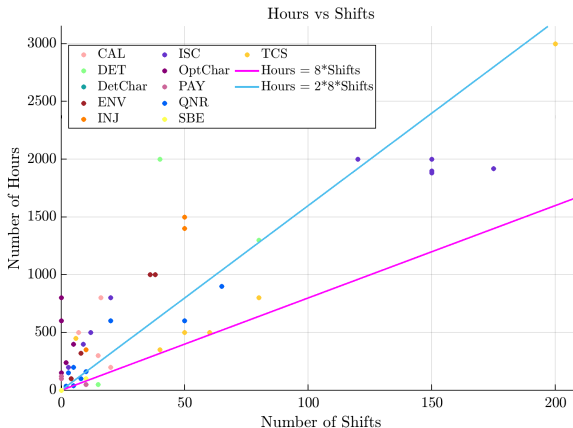
The goal of this form is to understand how much person power was used during O4 commissioning. The default is to report for the 2023 calendar year. You can choose to report any other 12 months period during O4 commissioning, but please write down what time period it is. It corresponds in principle to 1610 working hours by standard Virgo definition. The questions are:

- Number of commissioning shifts performed during that 12 months
- Number of hours worked on commissioning in total, including the hours spend during shifts. A shift requires time to prepare before and analysis time after. There is also time spent on meetings, presentations and studies, which is also part of commissioning. It is ok if total number of hours exceeds Virgo defined standard working hours. Some people have worked over time.
- A short list of main topics that you have contributed to

Accuracy is not very important, what matters is the order of magnitude, 1 shift, or 10 shifts, or 100 shifts.

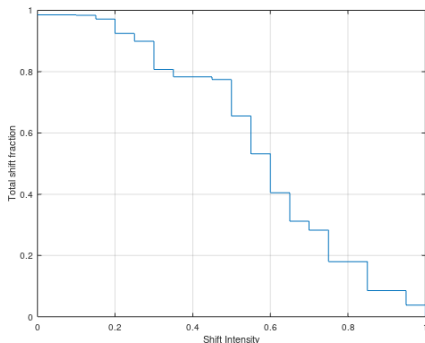
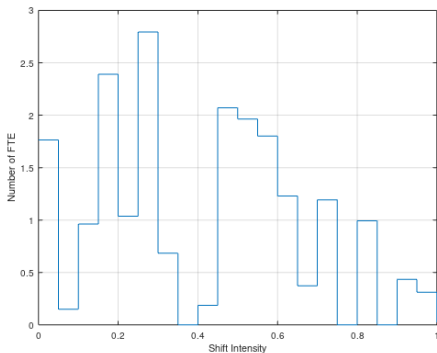
- Simple survey with number of hours and shifts spent on commissioning in 2023
 - ▶ For O4 commissioning organized in 8h long shifts, 13 per week
- Received 65 answers
- 20 FTE and on average 2.5 person per shift
- Average looks ok, issue is distribution
- 80% of shifts done by 15 people, 50% of shifts done by 6 people

Commissioning survey



- 8h long commissioning shift
- magenta line - spend time only doing shifts
- blue line - equal amount of time for doing shifts and thinking about them
- ideally everybody should be above but near blue line
 - ⇒ Two shifts per week

Shift intensity



- Shift intensity = $8h \times \# \text{ shifts} / \# \text{ hours}$
- Shift intensity = 0.5 - means half of time in shift and half of time analyzing/preparing/simulating shifts
- ideally everybody should be at 0.5 or below
- Distribution is uniform
 - ▶ Includes work on simulations for commissioning
 - ⇒ 66% of shifts done by people not having enough time to think about their work
 - ⇒ Reduces motivation and leads to burn-out
- Two solution to avoid overworking commissioners
 - ▶ Have 20 FTE clustered at 40% shift intensity
 - ▶ Have 30 FTE distributed uniformly between 0% and 50%

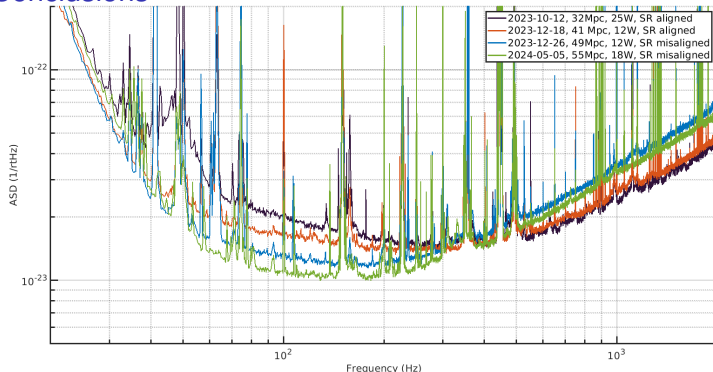
Commissioning training

- How long does it take to train a commissioner?
 - ▶ one year for someone to be autonomous
 - ▶ First sit next to someone doing commissioning and ask questions
 - ▶ Then press buttons doing commissioning with someone telling you what to do
 - ▶ Be left alone in the control room and try
- Metaphor - Similar to learning a foreign language
 - ▶ Can learn some of it from books
 - ▶ Can learn some of it from lessons
 - ▶ Then need to start using it and struggle without help

No plan yet but some emerging ideas

- Restart week long training session, once or twice per year
- Restart guest house at EGO
- Create list of achievable projects for students
- Don't send first year PhD student to EGO, basic training needs to be provided by group / supervisor
- Training capacity at EGO, one student per two scientists
- Training of Virgo permanent members
 - ▶ Can provide support over many years and do first step of training of students
- 6 new suspension to commission for stable cavities - will require much more FTE
 - ▶ Training opportunity, experts commission first suspension
 - ▶ More repetitive tasks can be taught to others for other suspensions
 - ▶ Could commission many suspensions in parallel if enough people are trained

Conclusions



- Redoing thermal compensation tuning at low power improved sensitivity to ~ 40 Mpc
- Then misaligning SR reduces coupling of $1/f^{2/3}$ noise to reach ~ 55 Mpc
- Benefits of higher power mostly offset by increase in issues with defects
- O4b began with a BNS range around 53 Mpc
- Duty cycle at 85% once initial hardware problem solved
- Commissioning continues during O4b
- Starting work package to continue study of $1/f^{2/3}$ noise
- Starting discussion on how to expand commissioning team for O5