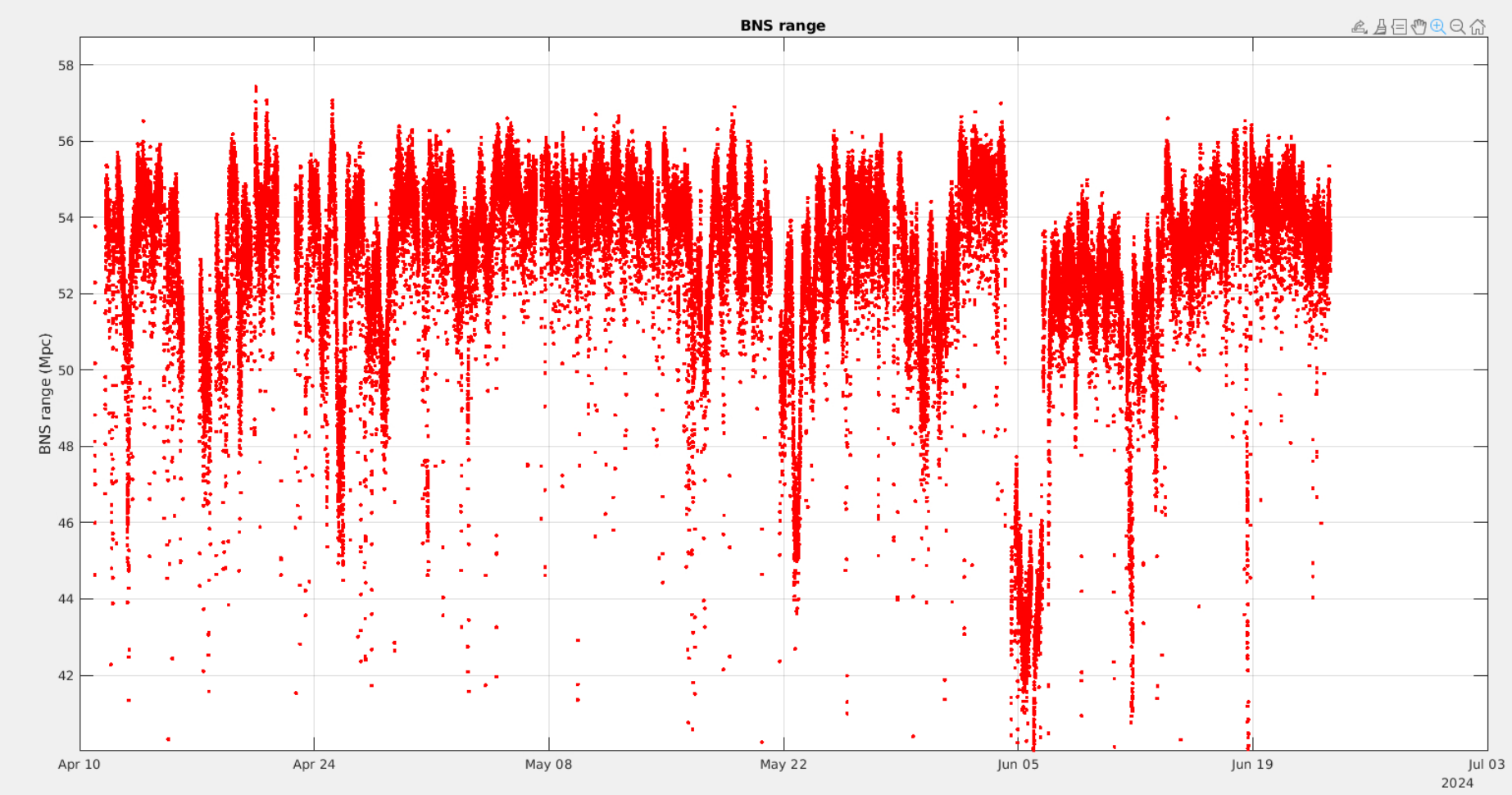
Commissioning report to EGO Council

Michal Was

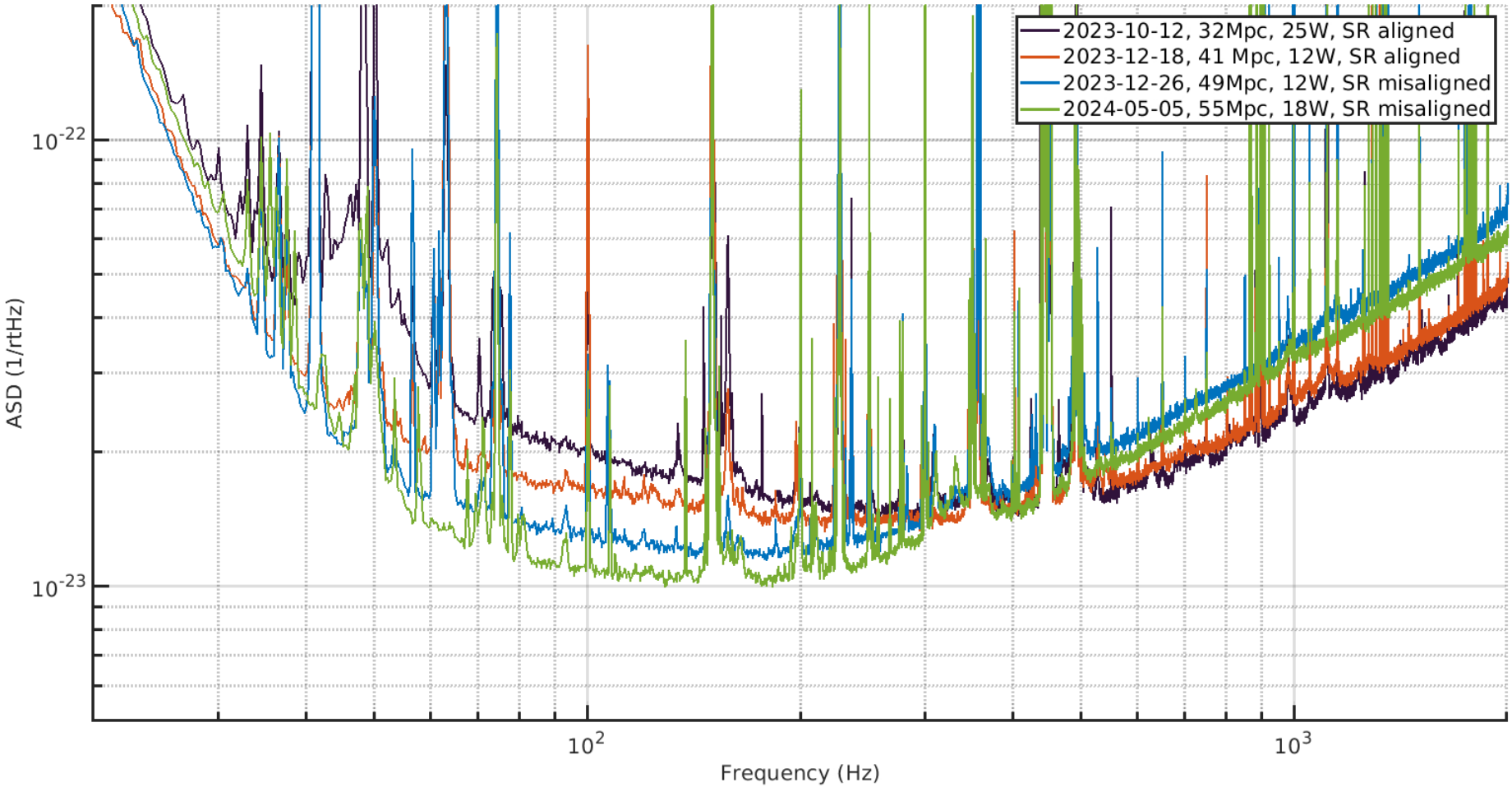
LAPP/IN2P3 - Annecy

Status since start of O4b - April 10



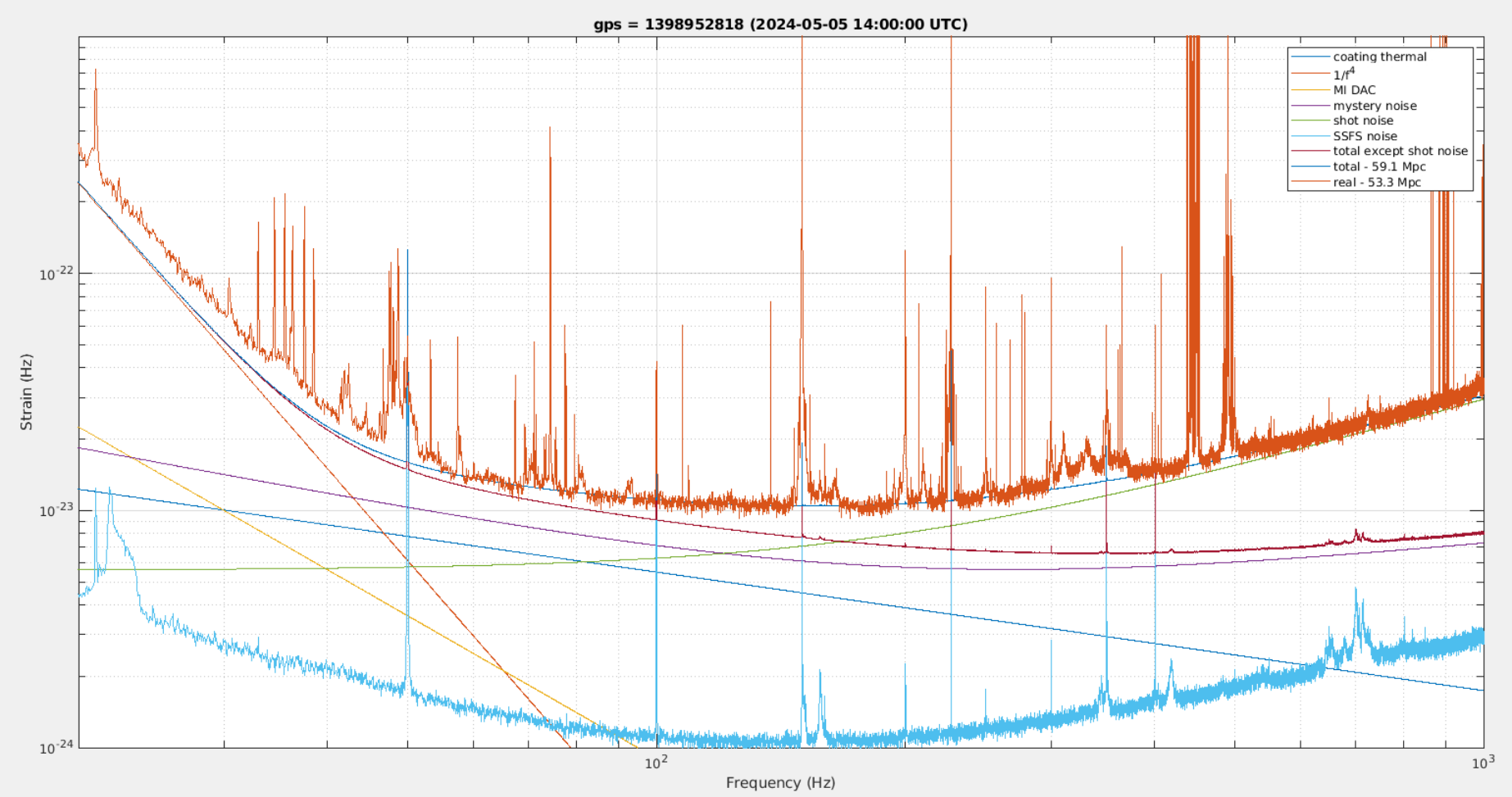
- Recovered from 5 different hardware and configuration issues that appeared in the first few weeks
- On-going work to keep a stable Binary Neutron Stare range of 55 Mpc

Sensitivity progress in the 6 months before O4b



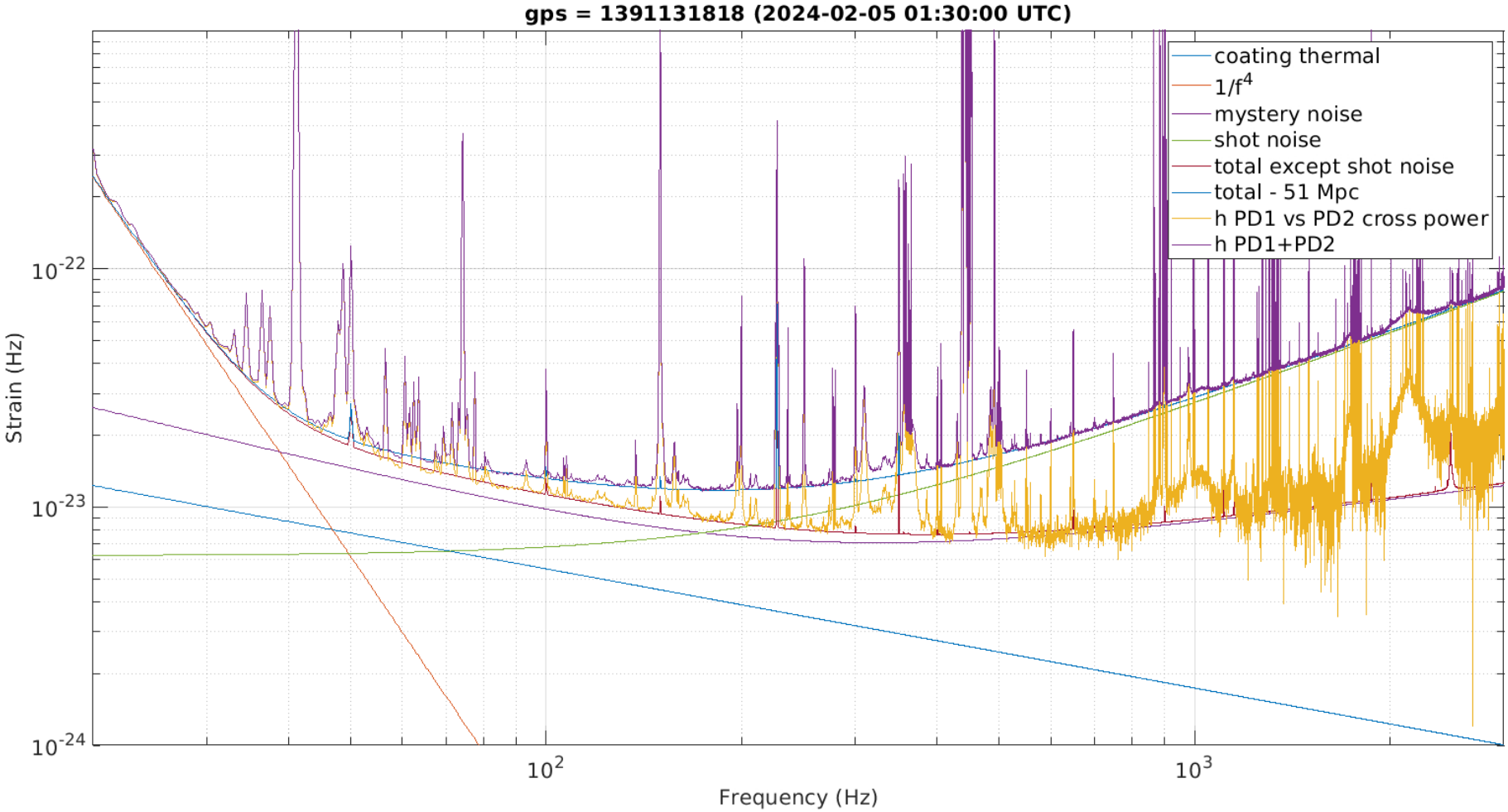
- Reduced input laser power from 25 W to 12 W
  - Have wider region of stability with regard to thermal corrections
  - Almost no impact on shot noise as loss of power compensated by better thermal tuning
- Shape the $1/f^{2/3}$ mystery noise by misaligning SR
- Increase the input laser power from 12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

Dominant noises



- Sensitivity well explained by: shot noise, $1/f^{2/3}$ 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 slope measurement

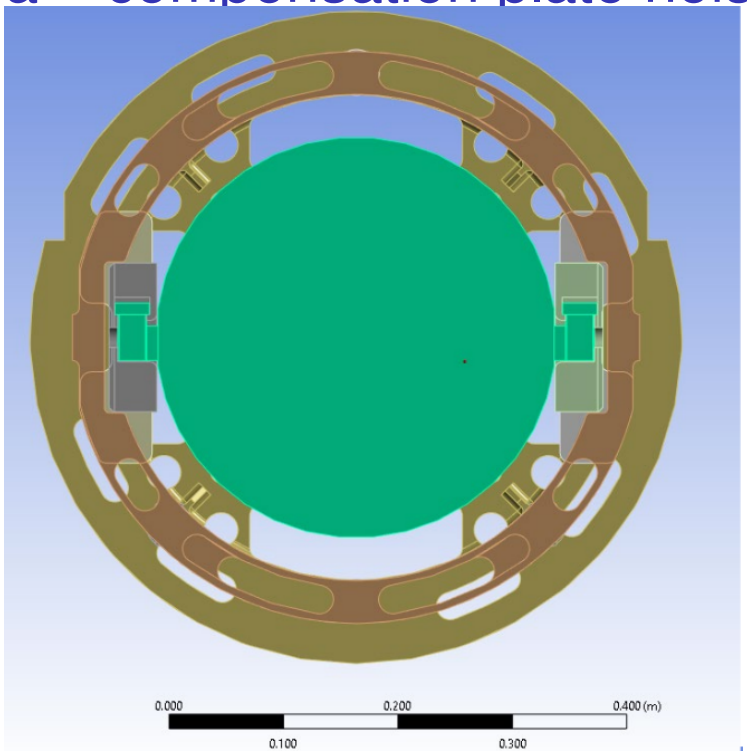


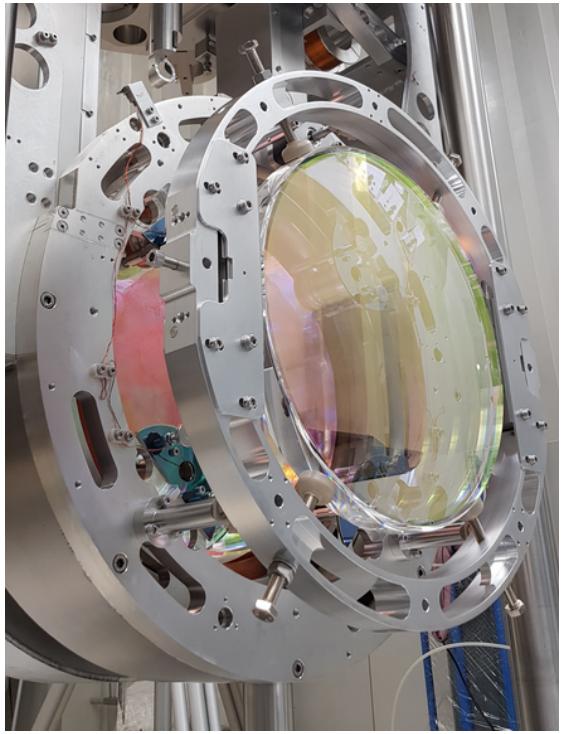
- Cross-correlate DC read-out photodiodes to obtain h(t) spectrum without shot noise
  - Same principle as stochastic gravitational wave searches
- Cross-correlated spectrum explained well by mystery noise + coating thermal noise
- Fit mystery noise amplitude and slope
- Slope of mystery noise is between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

Mystery noise working group

- $1/f^{2/3}$ noise work package defined VIR-0425A-24
- A working group with 11 members started in June
- Review and document current understanding
  - 4 observational properties
  - 17 physical models considered
- Goal is to write a detailed report for November 1 (next STAC)

New idea – compensation plate noise

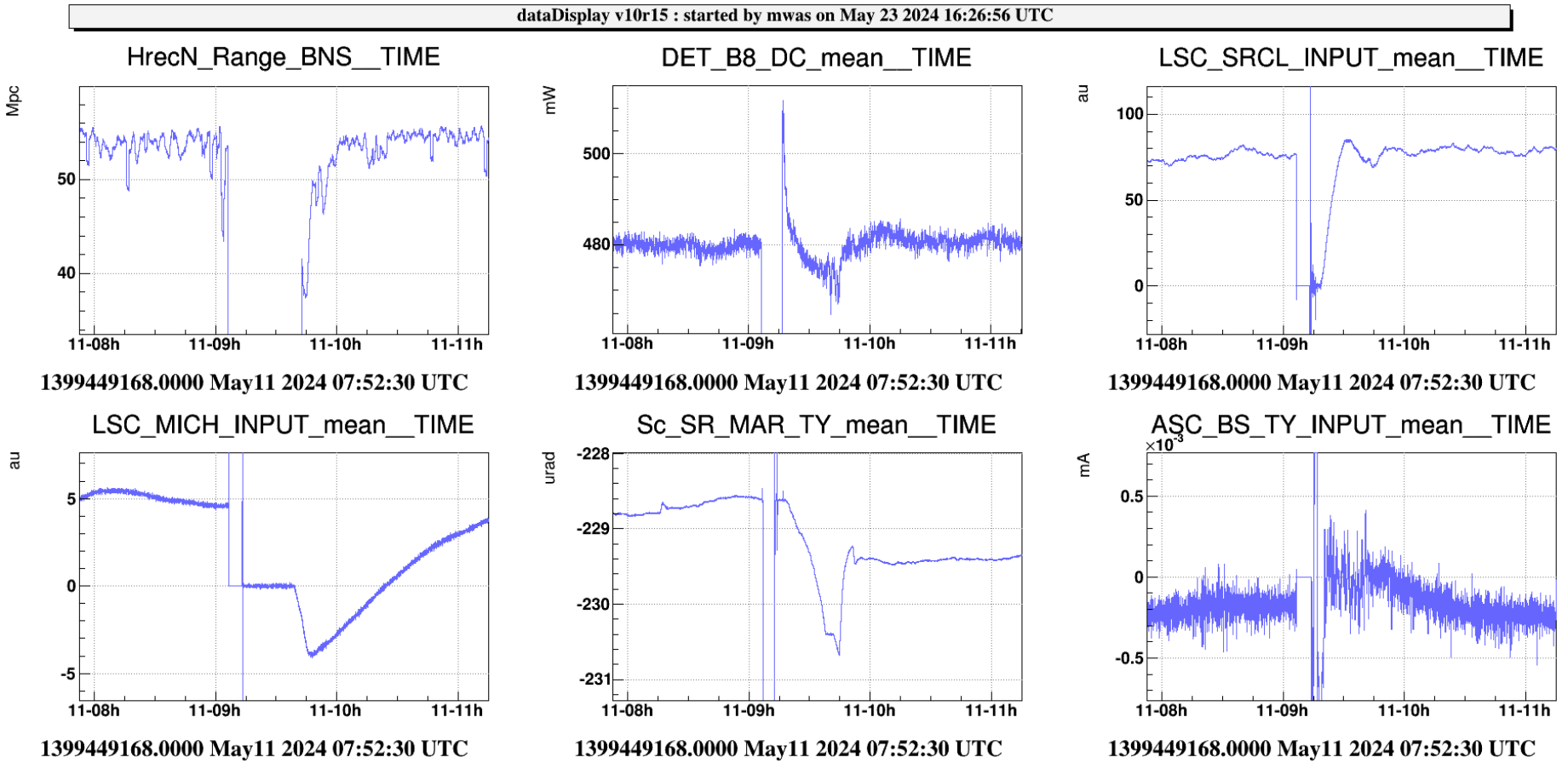




- CP are mounted rigidly - different from LIGO
- Due to assembly issues lateral screws are pressing on the side
- Variable stress on CP creates fluctuating birefrigence
- Creates a noisy P-polarized field
- Detection Faraday isolator might be misaligned by 1-2 degree and transmit some of that P-polarized field
- Could be sufficient to explain mystery noise and be compatible with current upper limits on polarization noise
- It is too early to tell whether this is actually the problem

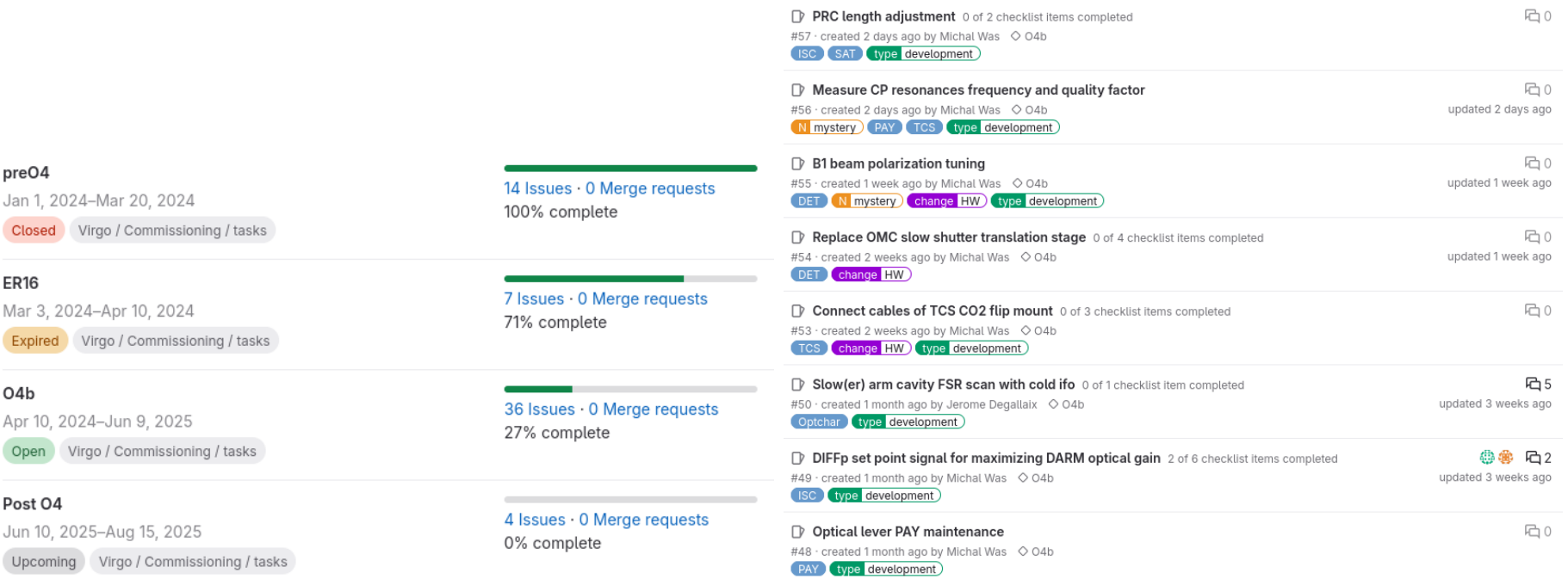
$\Rightarrow$ Testing experimentally in September - 1 week downtime

Main lesson from O4 commissioning



- 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
  - 2 hours to reach a steady state
- The time needed to do any adjustments increases with higher power
- In addition marginally stable signal recycling amplifies noise in addition to signal

Commissioning activity organization



- Introduced use of gitlab to organize tasks
- Keep track of 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

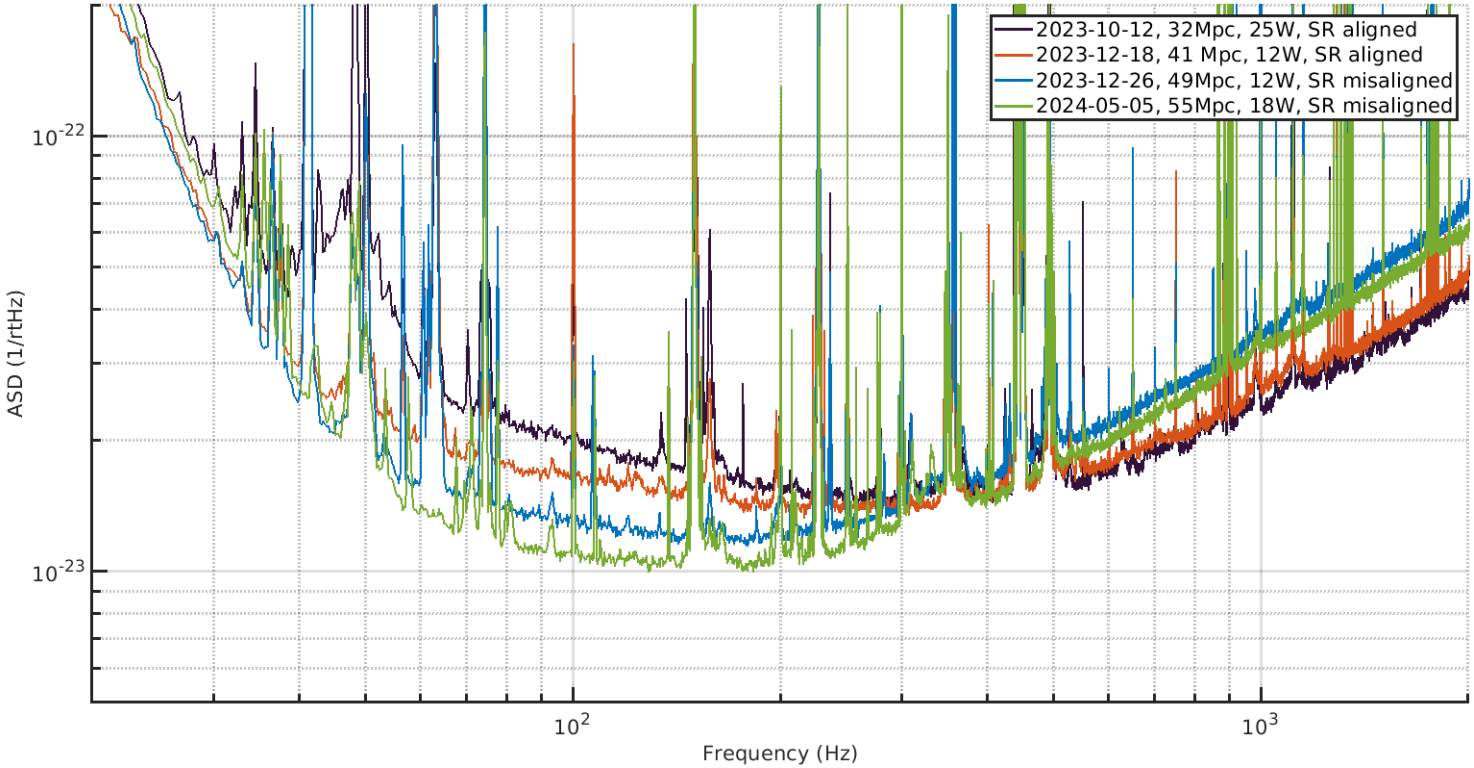
Priorities

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

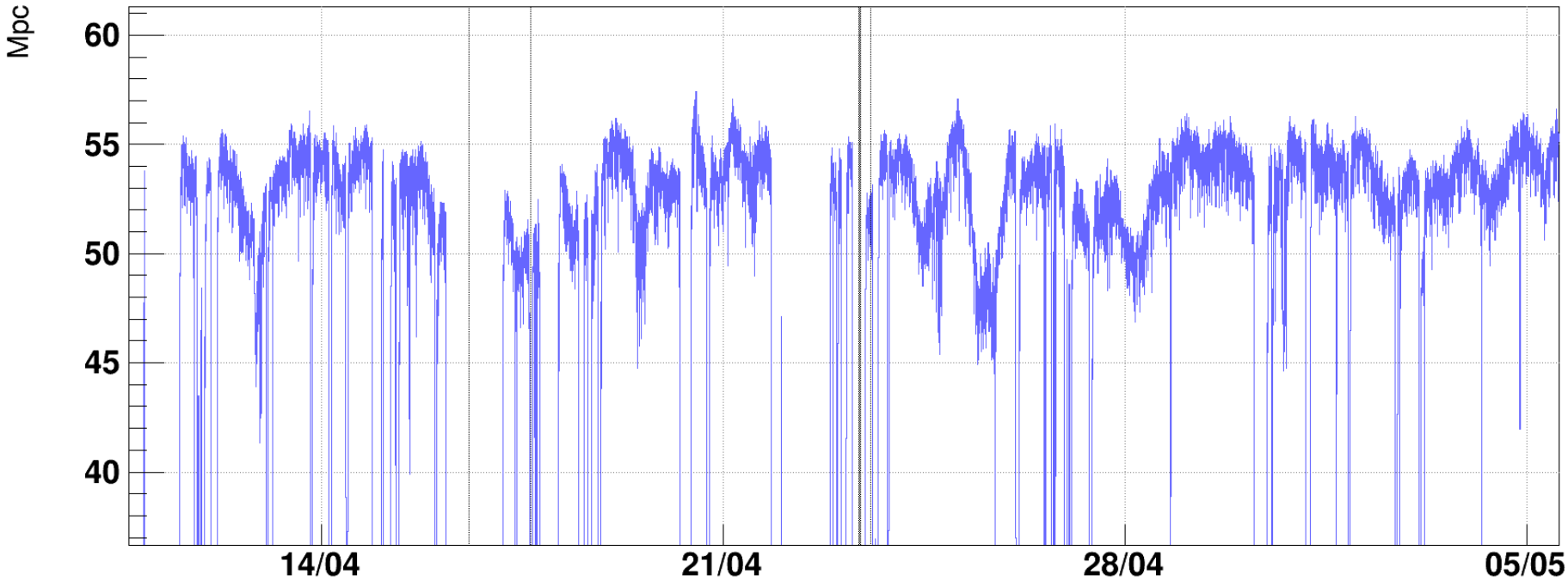
Month	Activity	Downtime	Commissioning task issue
Apr 2024	Etalon 2D set point search		
May 2024	EM RH tuning		https://git.ligo.org/virgo/commissioning/commissioning-tasks/-/issues/44
Jun 2024	Squeezing paper measurents		https://git.ligo.org/virgo/commissioning/commissioning-tasks/-/issues/47
Jul 2024	PRC length adjustment		https://git.ligo.org/virgo/commissioning/commissioning-tasks/-/issues/57
Aug 2024	Arm loss mapping		https://git.ligo.org/virgo/commissioning/commissioning-tasks/-/issues/68
Sep 2024	Polarization in front of SDB1 Faraday isolator	1 week including venting/pumping SDB1	https://git.ligo.org/virgo/commissioning/commissioning-tasks/-/issues/55
Oct 2024			
Nov 2024	OMC on EDB looking at B1s beam	1 day	https://git.ligo.org/virgo/commissioning/commissioning-tasks/-/issues/15
Dec 2024			
Jan 2025			
Feb 2025			
Mar 2025			
Apr 2025			
May 2025	Final calibration measurements		

Conclusions



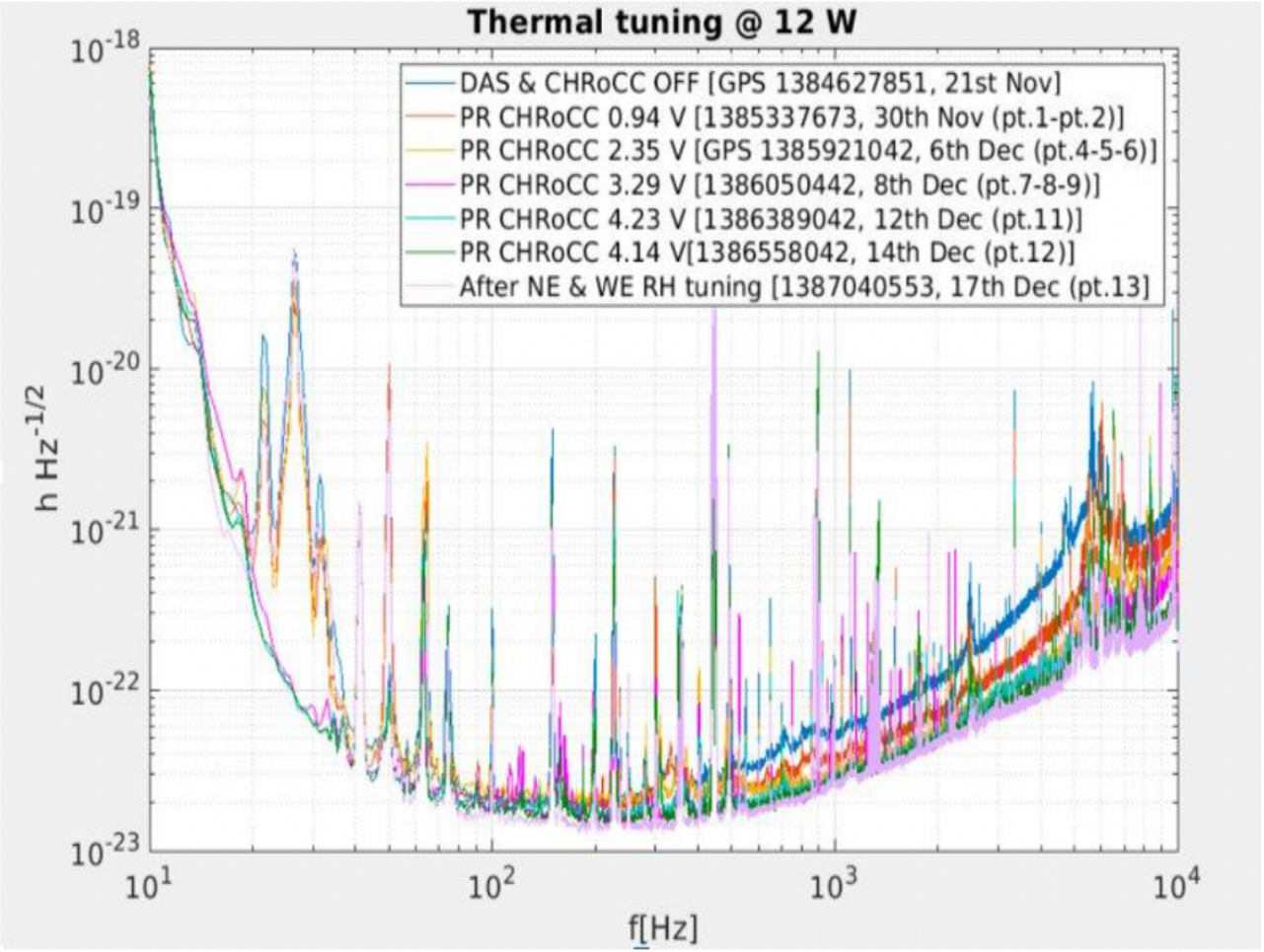
- Redoing thermal compensation tuning at low power improved sensitivity to ~ 40 Mpc
- Then misaligning SR reduces coupling of $1/f^{2/3}$ noise to reach ~ 55 Mpc
- O4b began with a BNS range around 53 Mpc
- Duty cycle at 85% once initial hardware problem solved
- Started working group to continue study of $1/f^{2/3}$ noise
  - Write report on current understanding
  - Continued experimental and theoretical investigations
- Plan under construction on how to expand commissioning team for O5

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
  - ⇒ Could almost lock the interferometer with half of TCS off

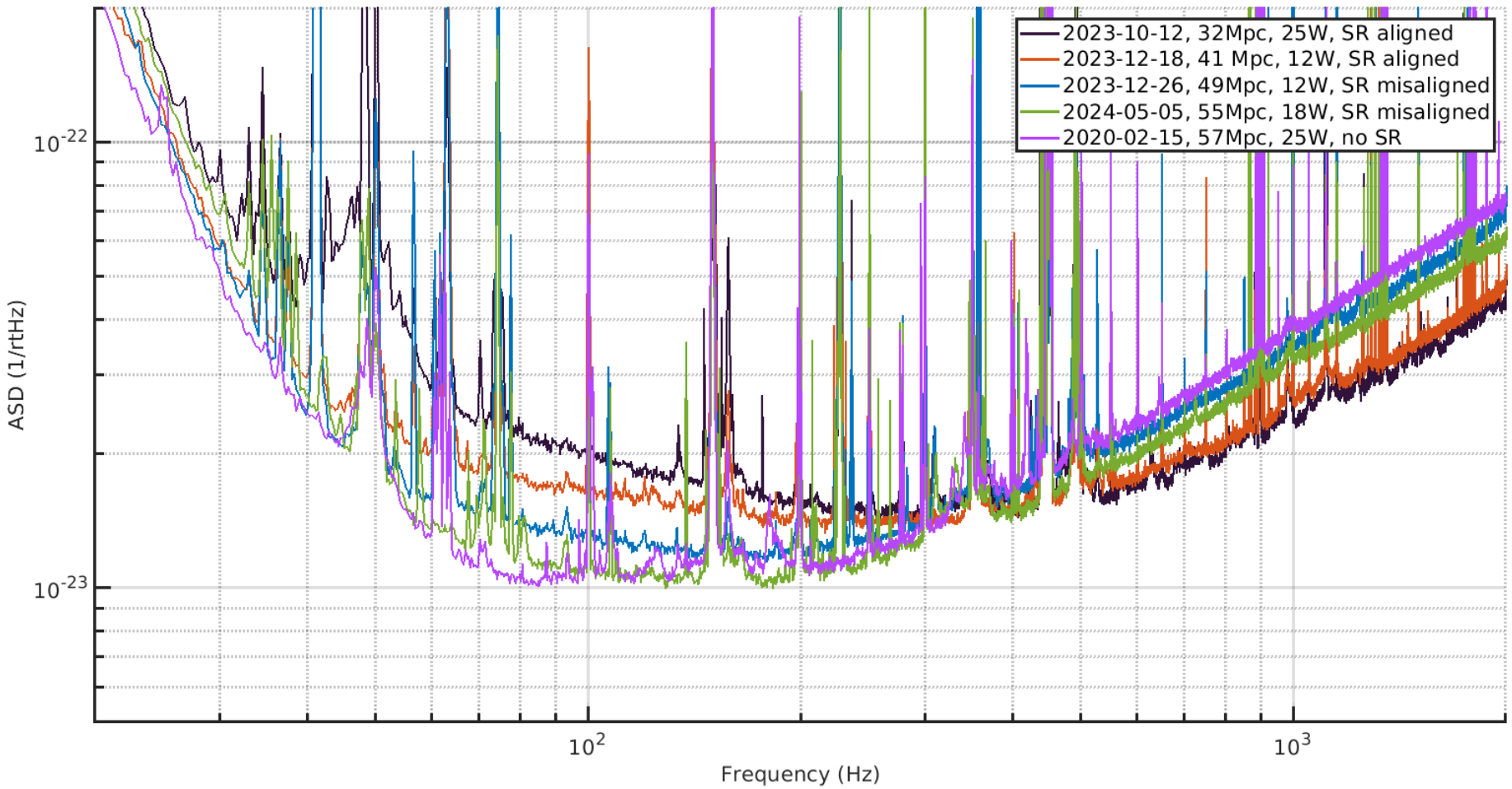
Thermal compensation tuning



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

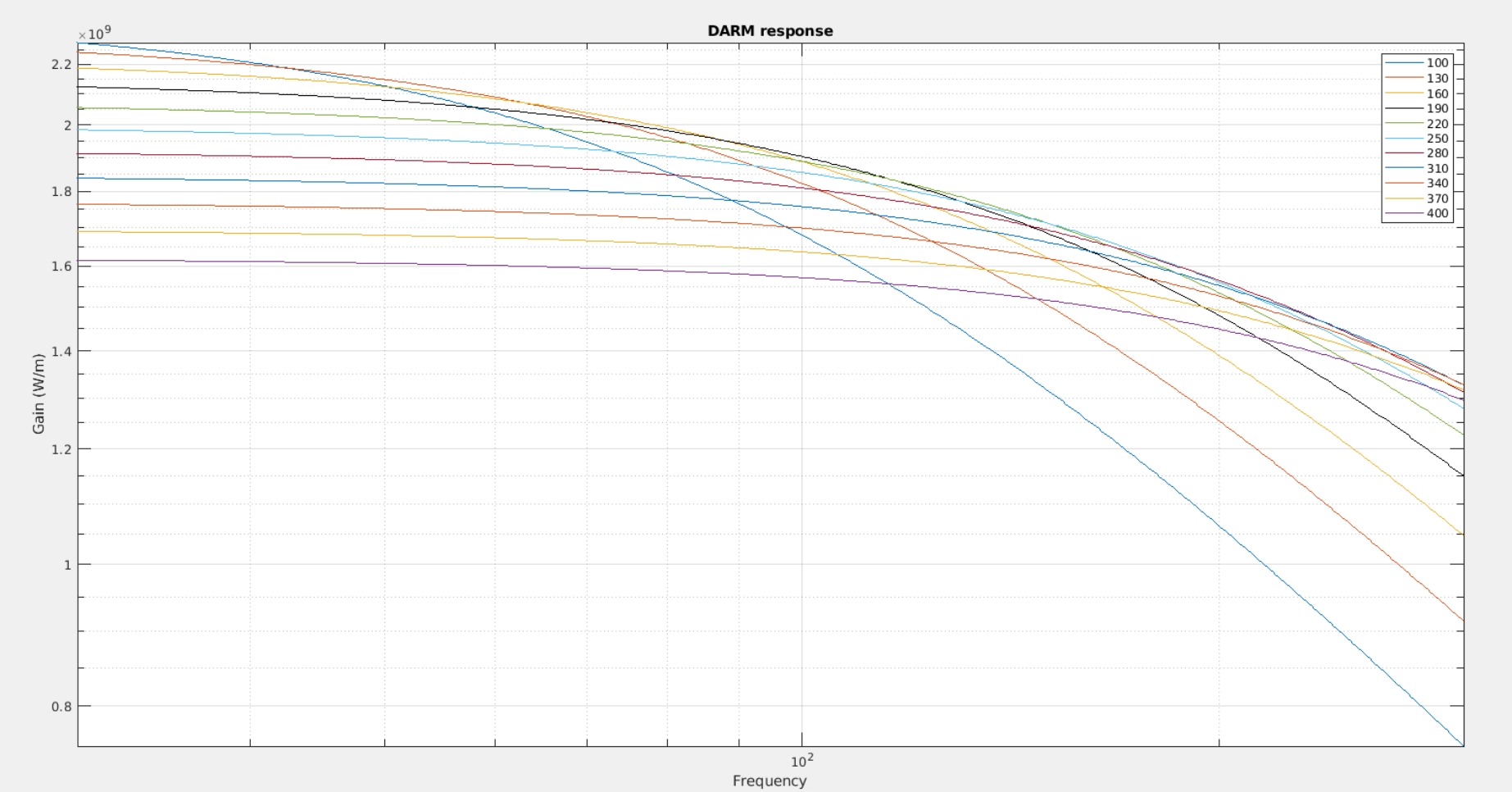
VIR-0104A-24

Sensitivity progress



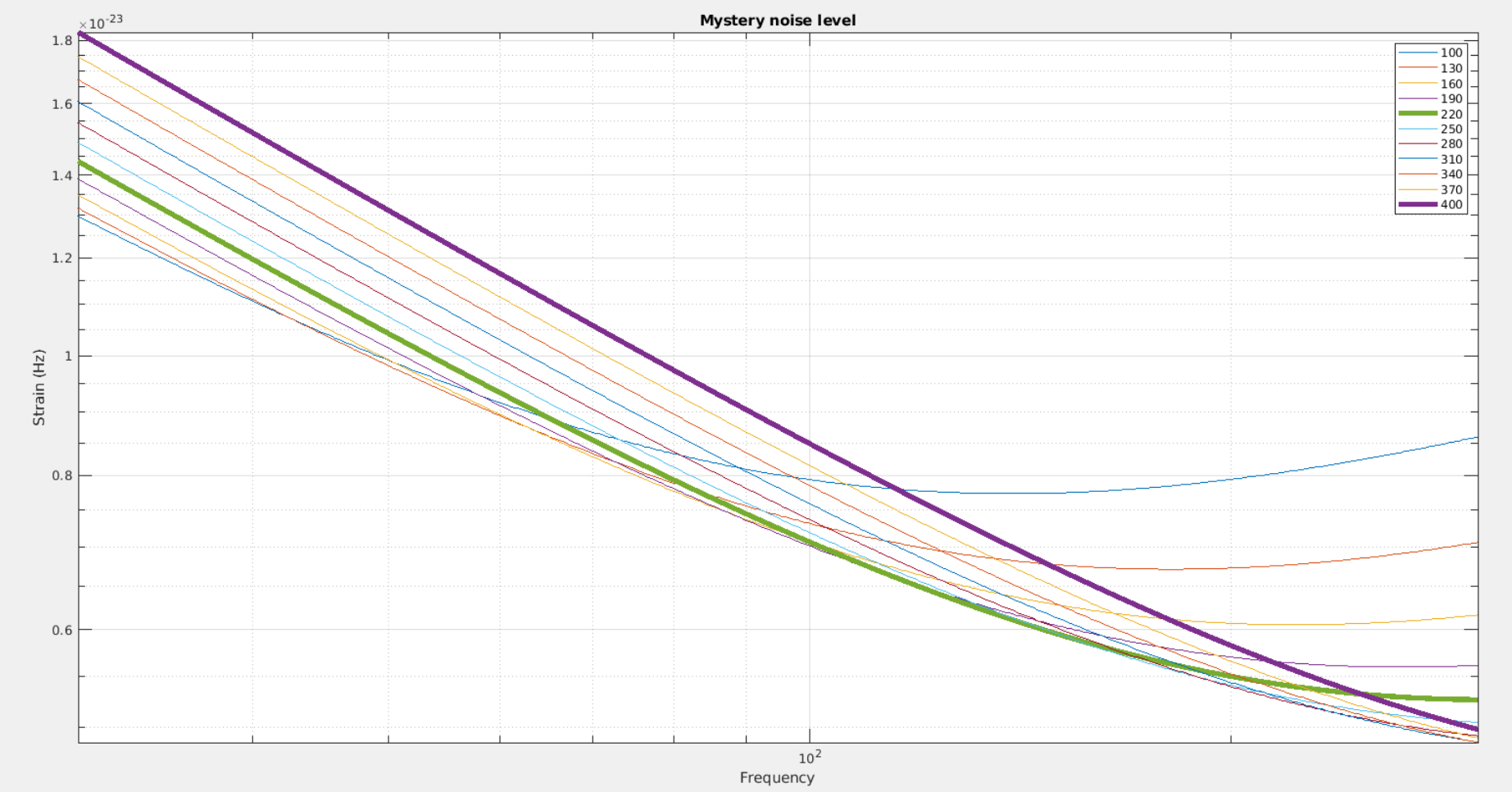
- SR misalignment is the main reason for sensitivity improvement
- This effect was initially hidden by an issue with h(t) reconstruction
- Sensitivity curves ends up very similar to O3

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 $W/\sqrt{Hz}$ 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