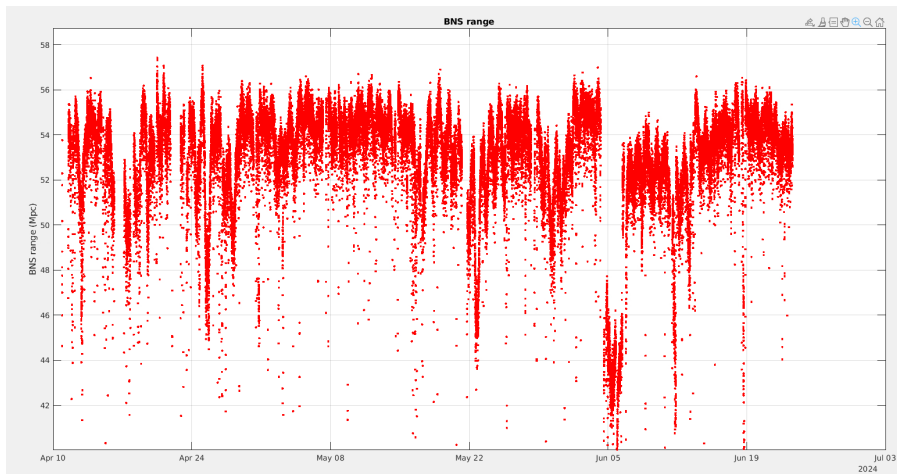


# Commissioning report to EGO Council

Michal Was

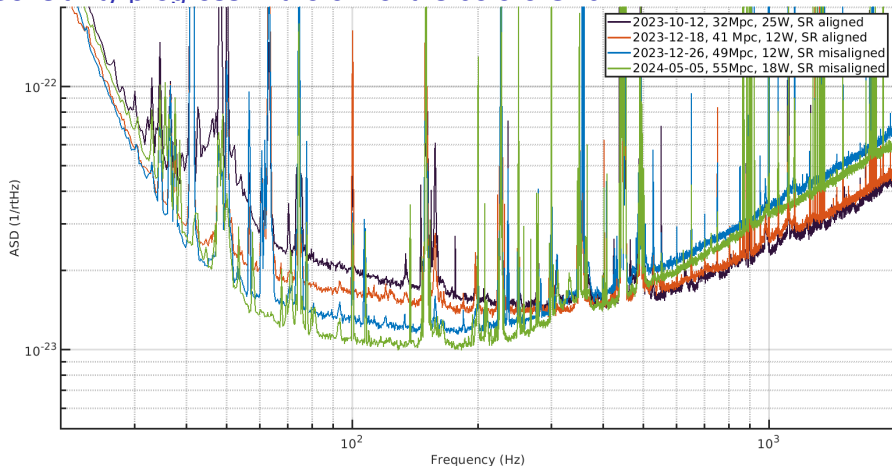
LAPP/IN2P3 - Annecy

## Status since start of O4b - April 10



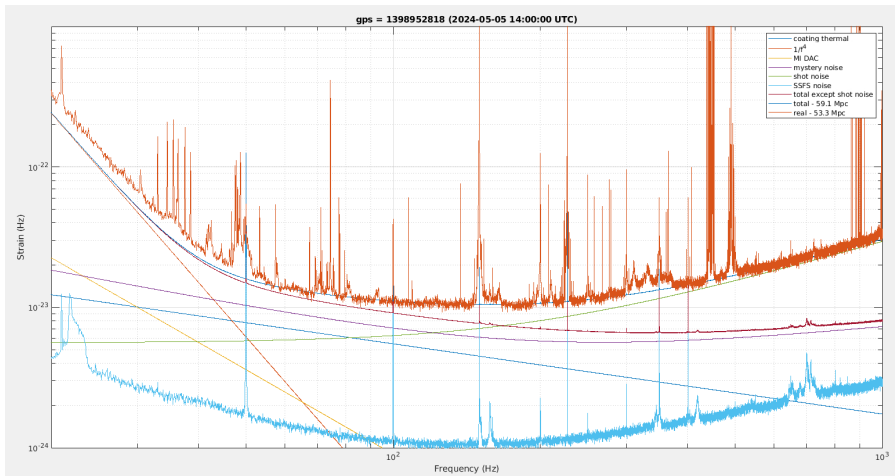
- Recovered from 5 different hardware and configuration issues that appeared in the first few weeks
- On-going work to keep a stable Binary Neutron Star range of 55 Mpc

## Sensitivity progress in the 6 months before O4b



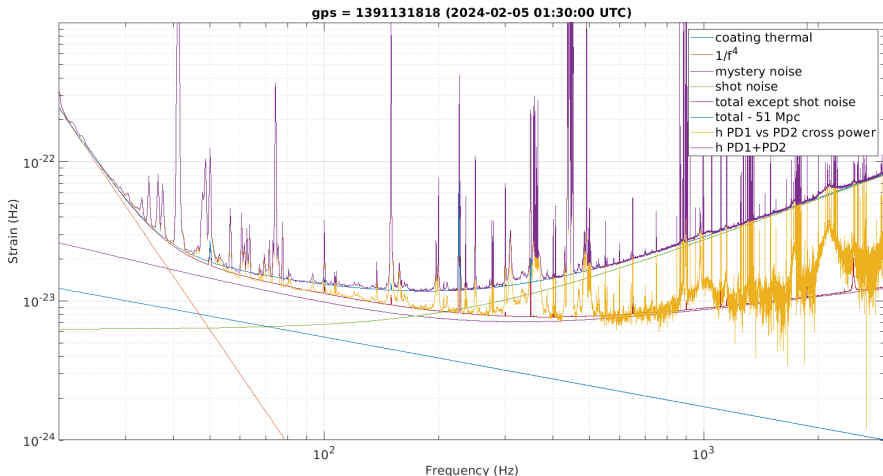
- Reduced input laser power from 25 W to 12 W
  - ▶ Have wider region of stability with regard to thermal corrections
  - ▶ Almost no impact on shot noise as loss of power compensated by better thermal tuning
- Shape the  $1/f^{2/3}$  mystery noise by misaligning SR
- Increase the input laser power from 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  $\sim 20$  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



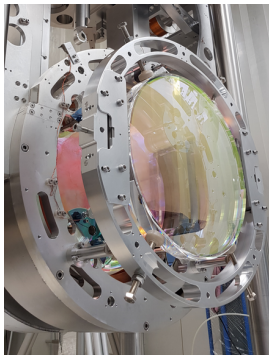
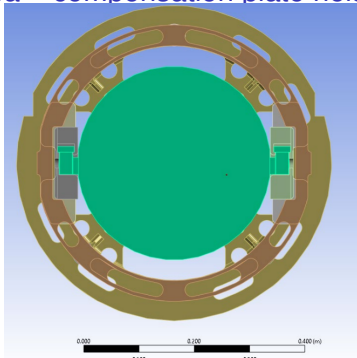
- Cross-correlate DC read-out photodiodes to obtain  $h(t)$  spectrum without shot noise
  - ▶ Same principle as stochastic gravitational wave searches
- Cross-correlated spectrum explained well by mystery noise + coating thermal noise
- Fit mystery noise amplitude and slope
- Slope of mystery noise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

<b>1 Observational knowledge</b>	<b>2</b>
1.1 Noise level constant in terms of mW/rHz, changing only in terms of h(t) when misaligning SR [Valeria]	2
1.2 The noise level in terms of h(t) does not depend on the DARM offset, i.e. does not depend on the power on B1 [Edwige],[Fiodor]	2
1.3 The slope of the noise in terms of mW/rHz is between -0.65 and -0.7 [Barbara]	3
1.4 The noise doesn't depend on the power of dominant carrier higher order modes [Fiodor],[Edwige]	3
<b>2 Considered noise source</b>	<b>3</b>
2.1 HOM amplitude noise [Edwige]	3
2.2 Polarisation fluctuations inside ITF beam [Sibilla]	4
2.3 Polarisation fluctuations from SDB1 Faraday isolator [Edwige],[Sibilla]	4
2.4 Clipping inside Faraday isolator [Barbara],[Sibilla]	5
2.5 Thermorefractive noise impact on IM reflectivity through Etalon effect [Valeria]	5
2.6 Thermorefractive or other length noise on OMC [Fiodor]	5
2.7 Electronic noise coupling via static charge on mirrors [Enzo]	5
2.8 Thermal noise from TMs [Fiodor],[Enzo],[Paola]	5
2.9 Thermal noise from SR [Enzo]	5
2.10 Thermal noise in CP [Enzo],[Pay team]	5
2.11 Birefringence noise in CP [Flavio],[Pay team]	5
2.12 Electronic sensor noise [Edwige]	5
2.13 Electronic actuator noise [Jean-Pierre],[Barbara]	5
2.14 Noise in digital computations [Enzo]	5
2.15 Relative amplitude modulation noise [Edwige]	5
2.15.1 Relative intensity noise on the input beam	6
2.15.2 Sidebands noise leaking through the OMC	6
2.15.3 Frequency noise	6
2.15.4 Implementation of the RAM servo: observations	7
2.15.5 Summary on relative amplitude modulation noise	8
2.16 Phase noise from INJ/PSL [Enzo],[Edwige ?]	8

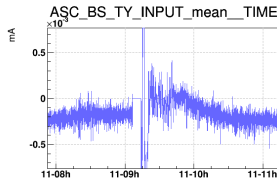
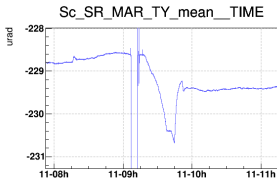
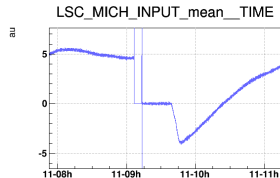
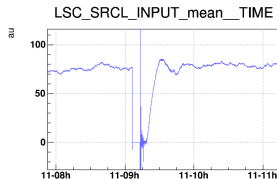
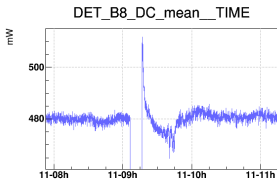
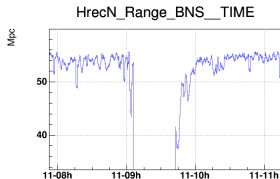
## New idea – compensation plate noise



- CP are mounted rigidly - different from LIGO
  - Due to assembly issues lateral screws are pressing on the side
  - Variable stress on CP creates fluctuating birefringence
  - 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**
- ⇒ Testing experimentally in September - 1 week downtime

# Main lesson from O4 commissioning

dataDisplay v10r1S : 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
  - ▶ **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

## preO4

Jan 1, 2024–Mar 20, 2024

Closed Virgo / Commissioning / tasks

14 Issues · 0 Merge requests  
100% complete

## ER16

Mar 3, 2024–Apr 10, 2024

Expired Virgo / Commissioning / tasks

7 Issues · 0 Merge requests  
71% complete

## O4b

Apr 10, 2024–Jun 9, 2025

Open Virgo / Commissioning / tasks

36 Issues · 0 Merge requests  
27% complete

## Post O4

Jun 10, 2025–Aug 15, 2025

Upcoming Virgo / Commissioning / tasks

4 Issues · 0 Merge requests  
0% complete

PRC length adjustment 0 of 2 checklist items completed

#57 · created 2 days ago by Michal Was · 04b

ISS SAB Type Development

Measure CP resonances frequency and quality factor

#56 · created 2 days ago by Michal Was · 04b

M mystery HW TCS Type Development

B1 beam polarization tuning

#55 · created 1 week ago by Michal Was · 04b

ISS M mystery Control HW Type Development

Replace OMC slow shutter translation stage 0 of 4 checklist items completed

#54 · created 2 weeks ago by Michal Was · 04b

DET channel HW

Connect cables of TCS CO2 flip mount 0 of 3 checklist items completed

#53 · created 2 weeks ago by Michal Was · 04b

TCS channel HW Type Development

Slow(er) arm cavity FSR scan with coldifo 0 of 1 checklist item completed

#50 · created 1 month ago by Jerome Degalax · 04b

Control Type Development

DIFFp set point signal for maximizing DARM optical gain 2 of 6 checklist items completed

#49 · created 1 month ago by Michal Was · 04b

ISS Type Development

Optical lever PAY maintenance

#48 · created 1 month ago by Michal Was · 04b

HW Type Development

- 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

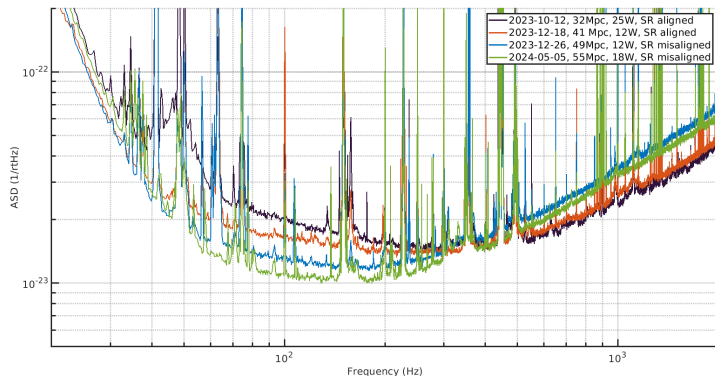
## Priorities

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

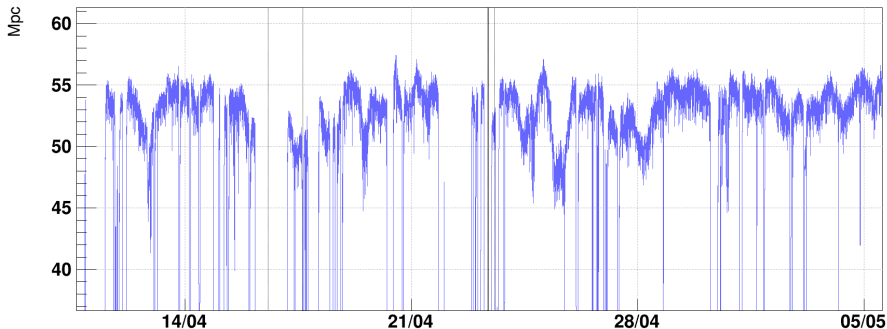
Month	Activity	Downtime	Commissioning task issue
Apr 2024	Etalon 2D set point search		
May 2024	EM RH tuning		<a href="https://git.ligo.org/virgo/commissioning/commissioning-tasks/-/issues/44">https://git.ligo.org/virgo/commissioning/commissioning-tasks/-/issues/44</a>
Jun 2024	Squeezing paper measurements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

# Conclusions



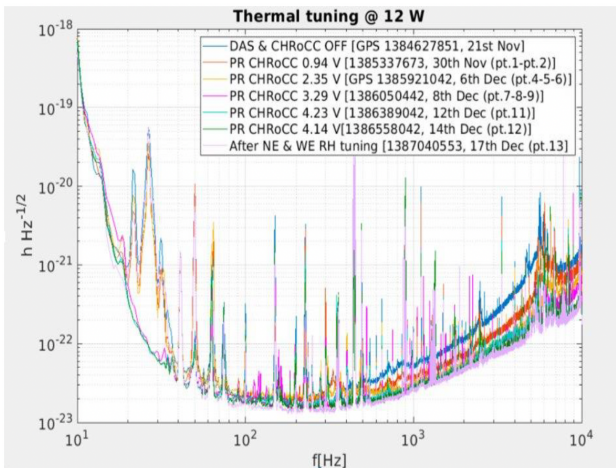
- Redoing thermal compensation tuning at low power improved sensitivity to  $\sim 40$  Mpc
- Then misaligning SR reduces coupling of  $1/f^{2/3}$  noise to reach  $\sim 55$  Mpc
- O4b began with a BNS range around 53 Mpc
- Duty cycle at 85% once initial hardware problem solved
- Started working group 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

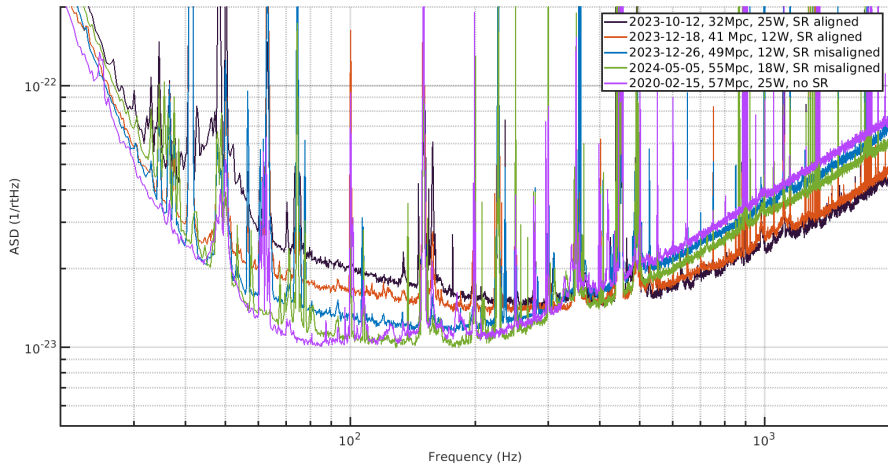
# Thermal compensation tuning



- Thermal compensation redone from scratch after 25 W  $\rightarrow$  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)

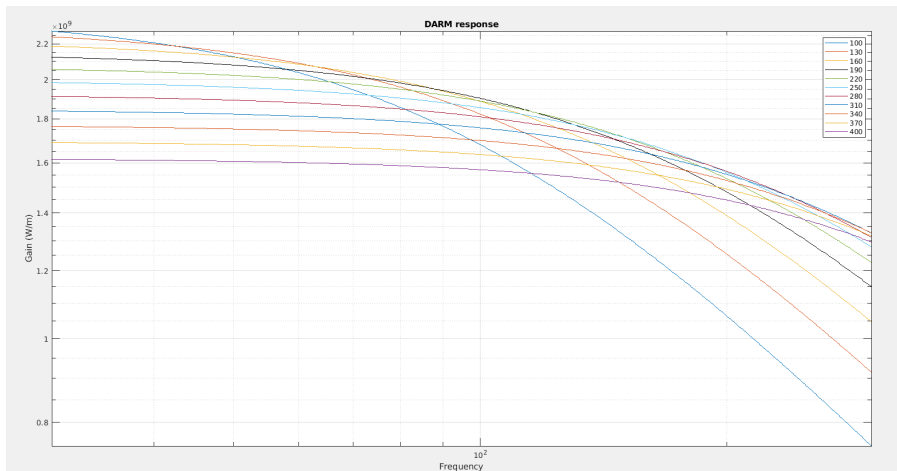
[VIR-0104A-24](#)

# Sensitivity progress



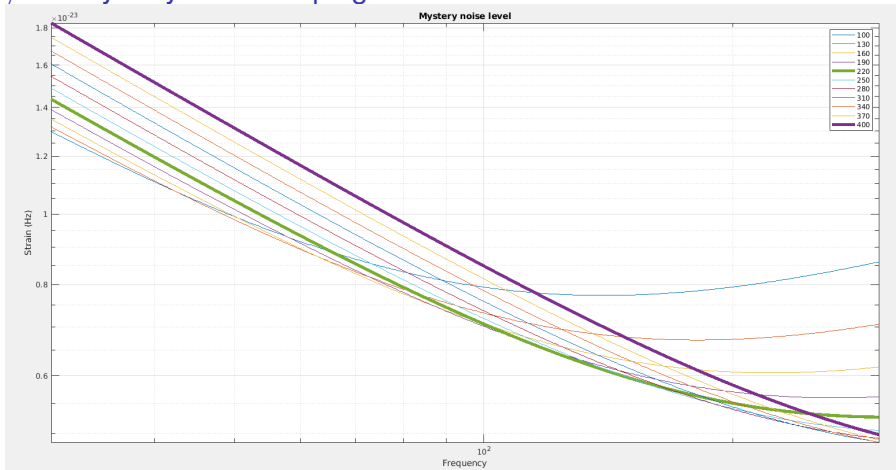
- SR misalignment is the main reason for sensitivity improvement
- This effect was initially hidden by an issue with  $h(t)$  reconstruction
- Sensitivity curves ends up very similar to O3

# 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  $W/\sqrt{\text{Hz}}$  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