Advanced Virgo 帰朝報告
(Report on Advanced Virgo stay)

宇宙線研究所 重力波観測研施設
東京大学 大学院理学系研究科 物理学専攻
KAGRA Observatory, ICRR, the University of Tokyo
長野 晃士 (NAGANO Koji)

ICRR
Institute for Cosmic Ray Research
University of Tokyo

Core-to-Core Program

Abstract

- From Jun. 8th to Jul. 1st, Enomoto-kun and I stayed in Pisa, Italy to join commissioning work of Advanced Virgo.
- In this talk, I will report our stay.
- At first, outline of Advanced Virgo will be introduced.
- Then, I will talk about what we did in our stay.
- Finally, I will show the recent progress of Advanced Virgo after we left.

Outline

1. What is Advanced Virgo?
2. What we did in Advanced Virgo
3. Recent progress of Advanced Virgo

What is Advanced Virgo?

- Advanced Virgo (NOT VIRGO) is an interferometer name like KAGRA (LCGT?) and is abbreviated as AdV (NOT aVirgo).
  - Virgo is not VIRGO since it is not acronym unlike LIGO.
- AdV is hosted by Italy and France and located in Pisa, Italy.
- Host institute is European Gravitational Observatory (EGO).
- AdV is a 2G GW detector which has 3-km arms.

Where is Advanced Virgo?

Where is Advanced Virgo?

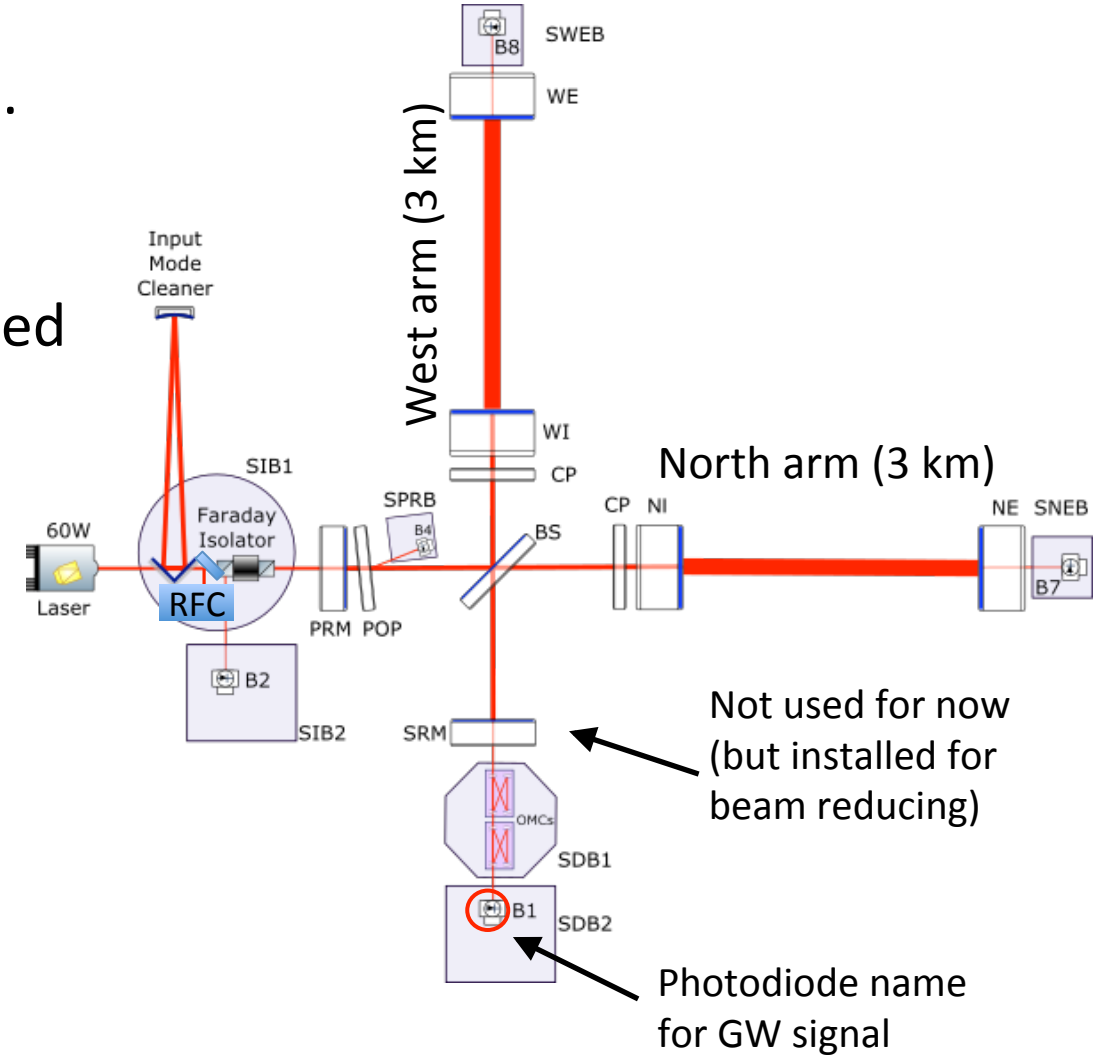
Our accommodation

Our accommodation

Advanced Virgo features

AdV features

- PRC and SRC are not folded.
  = No PR2(3) nor SR2(3).
- Tandem OMCs.
- OMCs are fixed on suspended bench (SDB1) with OMMTs, OFI, and so on.
- RFC is after IMC.



Lock acquisition of AdV

- How to lock AdV (PRFPMI with DC readout)?
  1. Lock IMC and RFC. (Initially, PRM is misaligned.)
  2. Lock both arms using the transmitted light with PDH method. (AdV does not have green lock system.)
  3. Lock MICH at mid fringe with DC signal.
  4. Align PRM and lock PRC with low finesse since MICH has just 50% reflectivity (mid fringe).
  5. Reduce MICH offset and lock MICH at dark fringe using PDH method.
  6. Switch on the frequency stabilization system with CARM. This system is called as SSFS (Second Stage Frequency Stabilization).
  7. Lock OMCs.
  8. Light reaches B1 PD and it outputs differential mode signal. Finally the signal is fed back to DARM and IFO reached low noise mode.

Optical layout

Interferometer Layout: Beams and Benches

D. Hoak, VIR-0442A-17

Several beams are extracted from the detector to measure the position and orientation of the mirrors, the lengths and alignments of the optical cavities, etc.

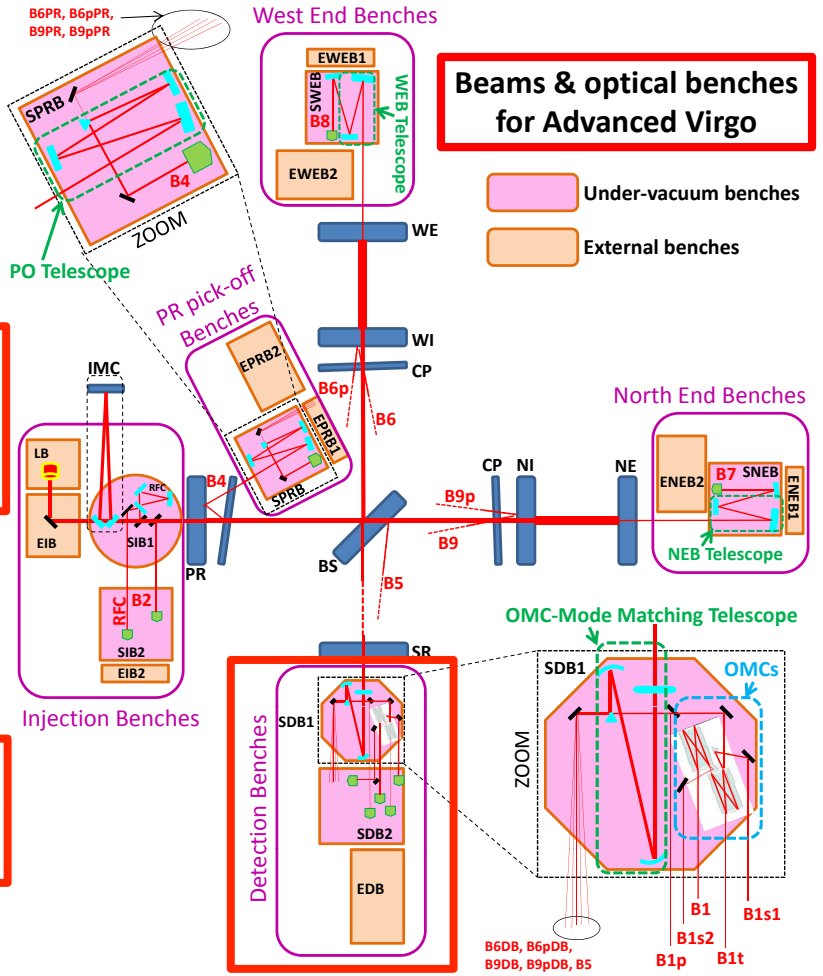
The photodiodes that measure the laser power in these beams are kept on various in-vacuum optical benches.

B1: from the antisymmetric port of the detector, measured on Suspended Detection Bench 2 (SDB2). This is where the GW signal is measured.

B2: from the symmetric port of the detector (also called the reflected port), the beam reflected by the PR. from Suspended Injection Bench 2 (SIB2).

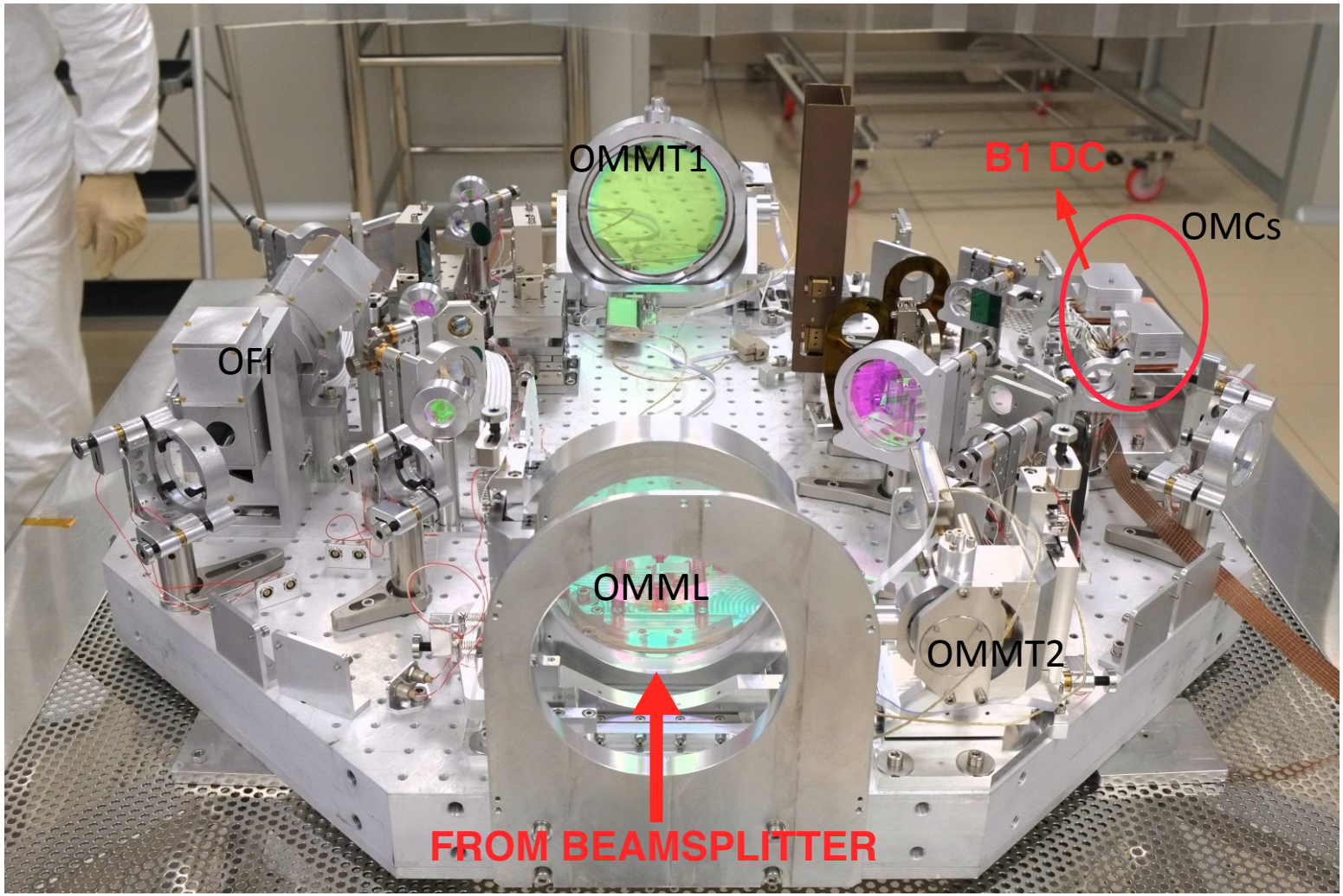
B4: a small pickoff (180ppm) of the light circulating inside the Power Recycling cavity (PRC). From SPRB.

B7, B8: light transmitted by the north & west arms, on SNEB/SWEB.



Optical layout

Optical Bench Example: ~~SDB2~~ SDB1 D. Hoak, VIR-0442A-17



Suspension systems in AdV

The Virgo Suspensions

D. Hoak, VIR-0442A-17

Superattenuators are used to suppress ground motion and control the position for the large optics: PR, BS, WI, NI, WE, and NE, plus the MC end mirror.

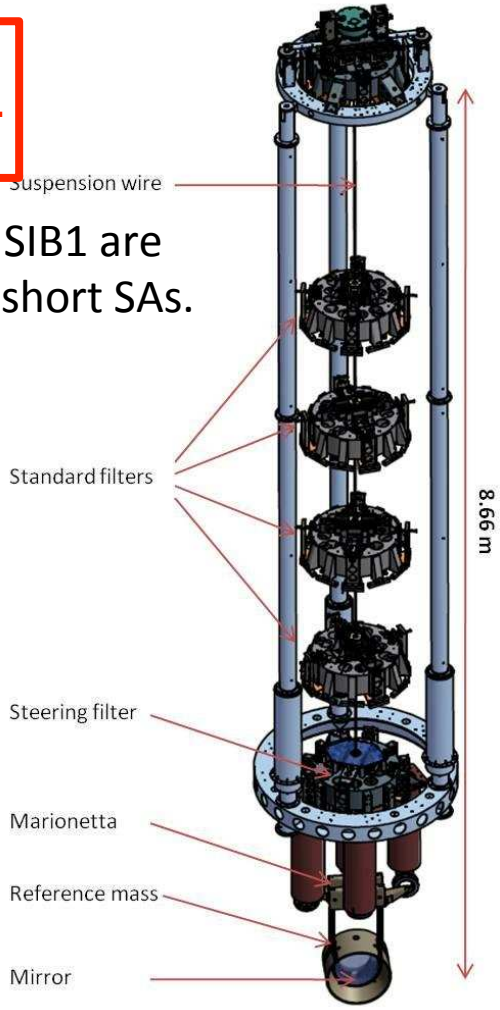
The PR suspension also includes the pick-off plate (POP), attached to the "filter 7" (F7) module. The NI and WI suspensions support compensation plates (CP), also attached to F7.

MCe, SDB1, and SIB1 are suspended with short SAs.

The position of the upper stages is measured using LVDTs.

The two lowest stages of the suspension are the marionette (MAR) and the mirror (MIR).

The position and orientation of these stages is measured using optical levers.



Superattenuators

Digital system and tools

- AdV digital system is different from LIGO one, which KAGRA import.
- Tools
  - DataDisplay: monitor data (fast and slow, real time and past) in several styles, such as time series, FFT, coherence, spectrogram, and so on.
  - VIM (Virgo Interferometer Monitor): Web based tool summarizing the IFO performance and environmental monitor data day by day. (See the actual page.)
  - BruCo: show the top 20 channels which have coherence with DARM (or any channel you choose) automatically for every frequency band.
  - (DB of known lines: listed the known line, e.g. calib. line. This might be very useful but was under preparation yet.)
  - And many others; Data Quality Segment Database (DQSEGDB), NoEMi, BRMSMon, Omicron, and so on.

Sudden storm

VIM | ANA | CAL | DAQ | DET | ENV | INF | INJ | ISC | SUM | SUS | TCS | VAC

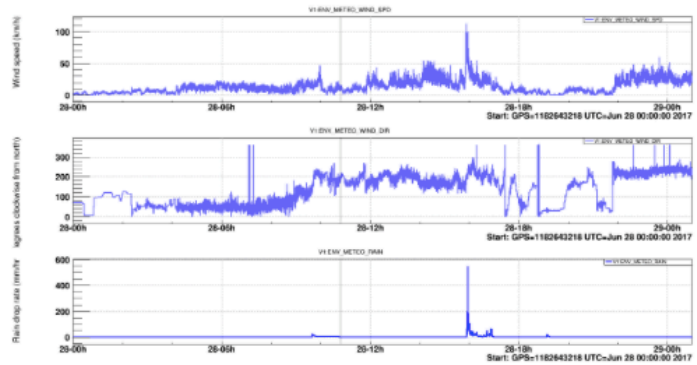
Weather

Wed, 28 Jun 2017 07:55:44

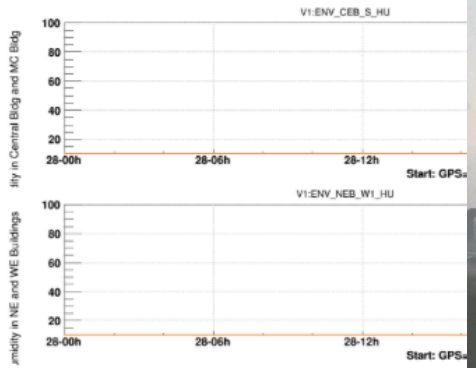
Useful links

METEO: Tuscan weather stations; forecasts (ilmeteo.it) | LIGHTNING: Real-time maps (Blitzortung), (Data archive) (Aereonautica militare)

Meteorological conditions (wind, rain)



Humidity in CB, MC, NE and W



Sea activity NE and WE Building (0.1-1.0 Hz)

Sea activity CE and MC Building

Environmental monitors

- Many environmental monitors had been installed.

V1:ENV* fast (1kHz÷20kHz) channels

Buildings monitoring (CEB, NEB,WEB,MCB)

- 1 3D-Seismometer (Guralp) up to 100Hz
- 3 Magnetometers (W,N,Vertical)
- 1 infrasound Microphone
- 1 RF antenna receiver (demod. at Virgo RF frequencies)
- Mains Voltage monitors (IPS and UPS)
- Mains Current monitor (IPS and UPS)

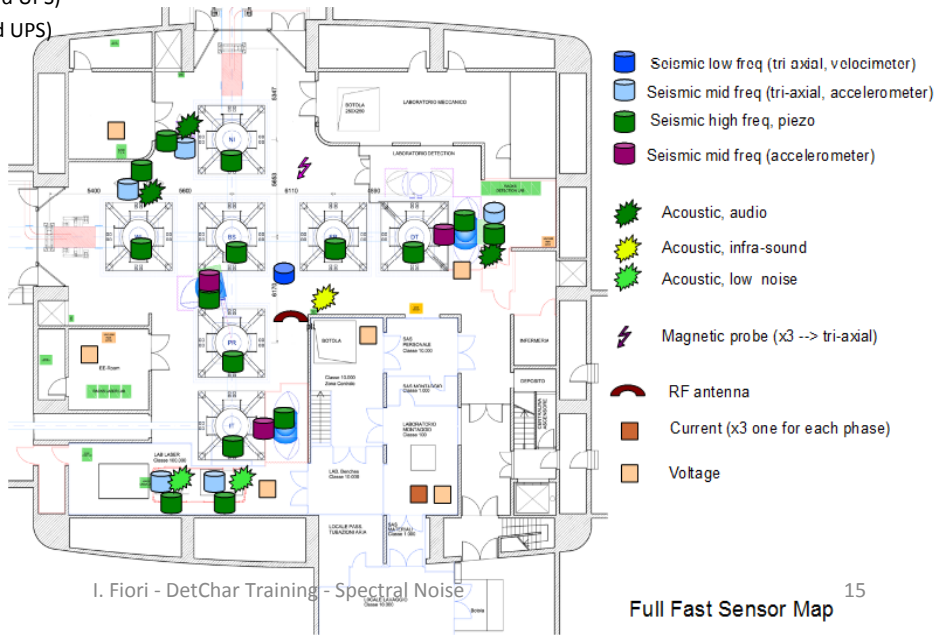
In-air Benches monitoring

(EIB, LB, 2 TCS, EDB, EMCB, next SQZ)

- Accelerometer (kHz range)
- 3D-seismometer (up to 100Hz)
- Microphone (standard)

Vacuum tanks monitoring
(each **Tower (10)**,
each **Cryo genic Trap (6)**,
some **intra-towers links**)

- Accelerometer (kHz range)
- 1D seismometer (< 100Hz range)



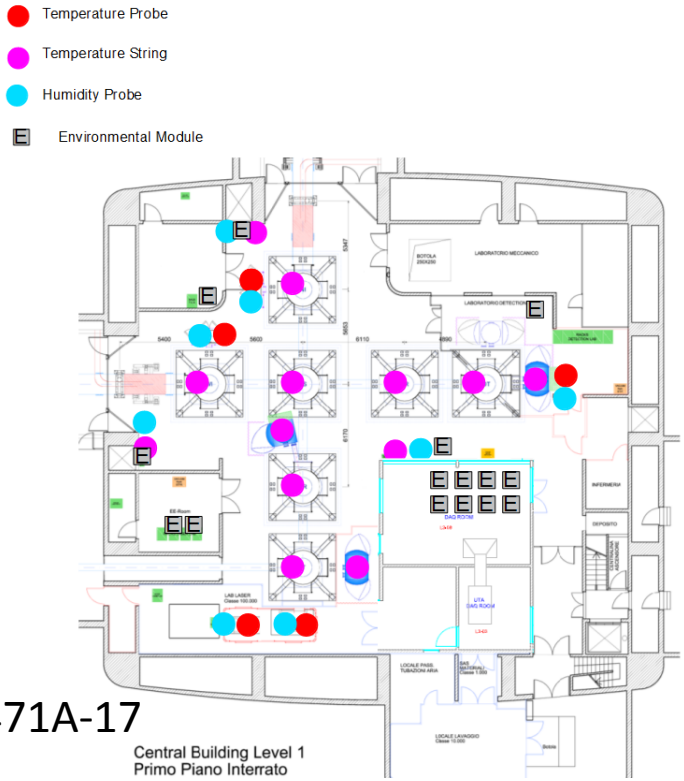
Full Fast Sensor Map

I. Fiori, VIR-0471A-17

Environmental monitors

- Many environmental monitors had been installed.

V1:ENV* slow (1Hz) channels



- **Each Building**
  - Temperature (probes at 2,4,8,10m height)
  - Pressure
  - Humidity
- **IJN and DET labs**
  - Temperature
- **Each Tower and Minitower**
  - Temperature probes, in-vac, at each SA filter
- **External Benches**
  - Temperature and Humidity
- **Weather Station (on Control Building)**
- **Lightning detector** (still missing) plan joining www.blitzortung.org

I. Fiori, VIR-0471A-17

What were did before out stay?

- First stable lock with “full” interferometer, i.e. without SR, had been achieved in Mar. 2017. In other words, installation and integration phase has been finished.
- Thus, they started commissioning to improve the interferometer stability and sensitivity.
  - Both of them are important for GW network.
- Many works can be performed from a control room.

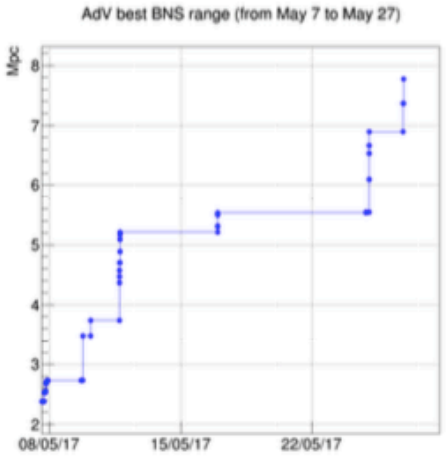
Control room

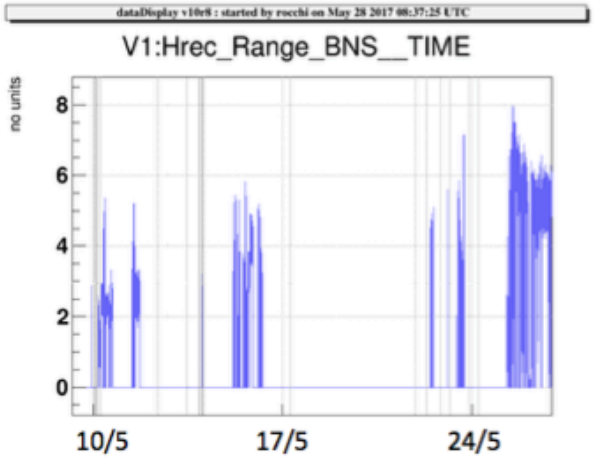
What were did before out stay?

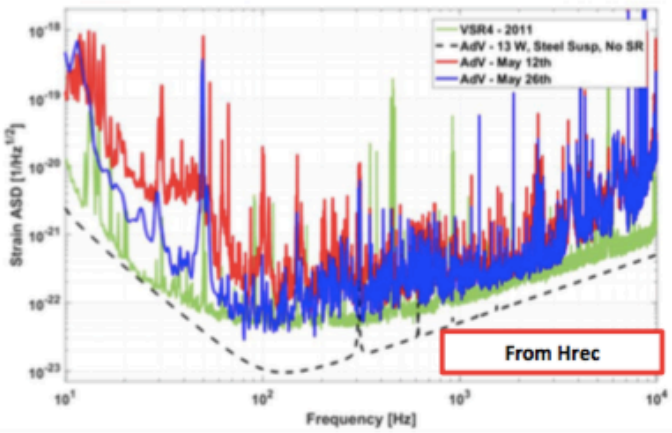
- Their mid-term goal was 20 Mpc in BNS inspiral range to join O2.
- To achieve this goal, many works were done after the first lock.
- Then…

What were did before out stay?

Sensitivity progress





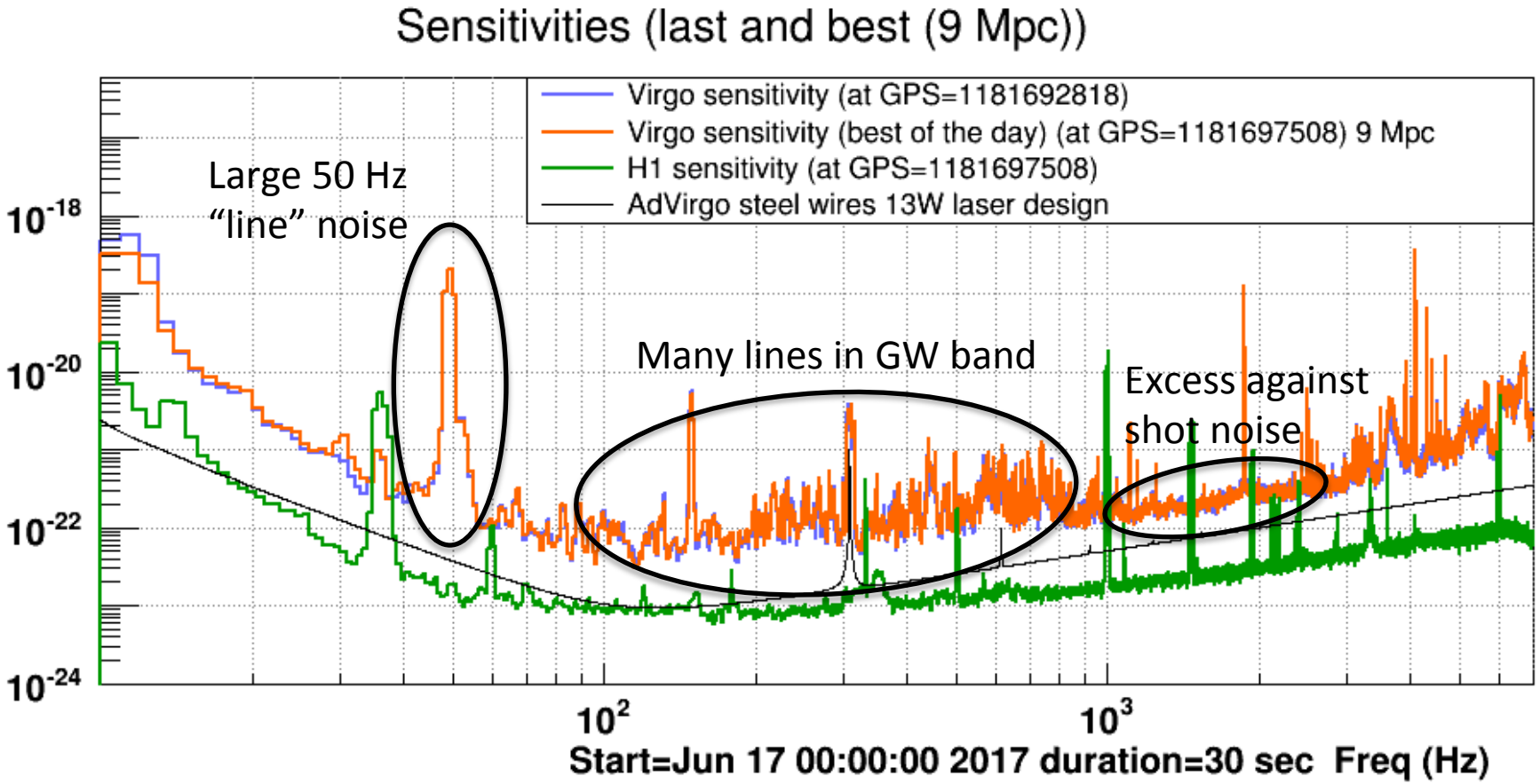


- These plots are full of information:
  - There has been a large improvement in sensitivity since C8;
  - Despite this, we're not there yet: a factor of two (at least) still missing → 20 Mpc (BNS) Range is our target to join O2 (as from the observing scenario document);
  - Distance from design sensitivity is higher at low frequency and in the bucket (100-200 Hz);
  - ITF performances under observation only for limited time.

A. Rocchi, VIR-0418A-17

What were did before out stay?

- Sensitivity of AdV on Jun. 17th.



From VIM page

Outline

1. What is Advanced Virgo?
2. What we did in Advanced Virgo
3. Recent progress of Advanced Virgo

出張の概要

- 期間: 6月8日から7月1日
- 財源: (旅費) 拠点形成、(レンタカー代) EGO
- 目的: Advanced Virgoのコミッショニング作業に参加・貢献して名前を売ること。そして、KAGRAの今後のコミッショニングに活かせるような技術を習得すること。
- その他: 昼食は、毎日サイト内の食堂で食べる。(我々の場合は)昼食代はEGOが出してくれた。すごく美味しいかった。あとは、昼休みには卓球をしていた。

Ping pong

Outline of our stay

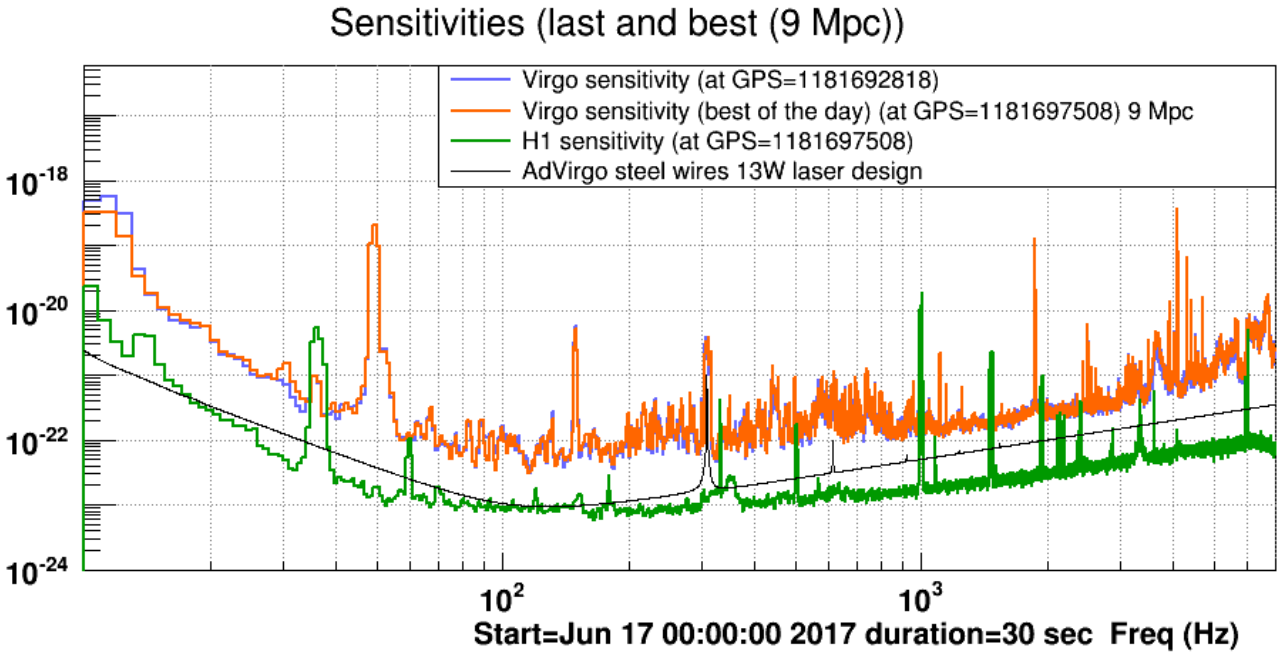
2017年6月

今日

日	月	火	水	木	金	土
4日	5日	6日	7日	8日	9日	10日
					Arrival	
11日	12日	13日	14日	15日	16日	17日
	Study about AdV and how to use its tools.		Investigation of SDB1 scattering		ER11a	
18日	19日	20日	21日	22日	23日	24日
ER11a	Investigation of SDB1 scattering		Investigation of the correlation between SSFS and DARM.		ER11b	
25日	26日	27日	28日	29日	30日	7月1日
ER11b	Investigation of shot-noise-like noise between 1k and 3 kHz band					Departure

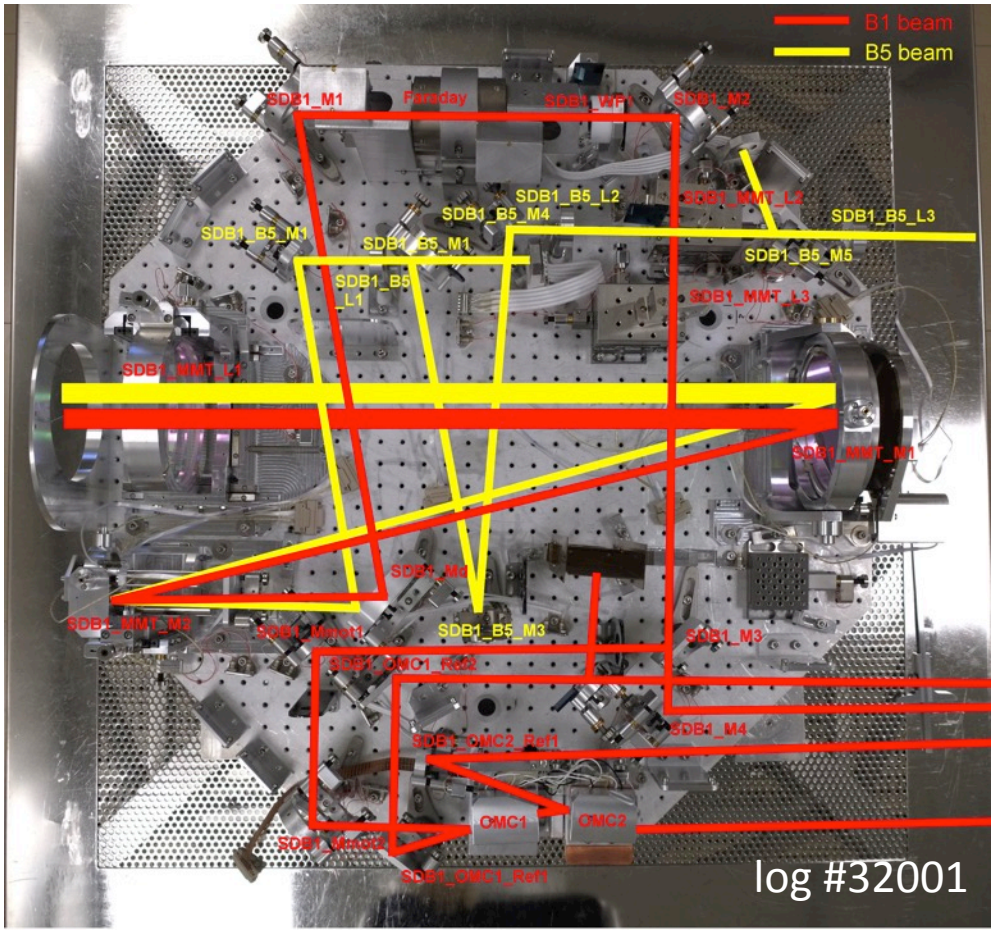
Scattering light problem

- As you can see, there were many lines and structures in DARM between 100 and 1k Hz.
- These noise were considered to come from SDB1 (or SDB2, where PDs are placed).
- This was because SDB1 was very crowded and we could see many bright spots with IR camera.



Scattering light problem

- Pictures of SDB1

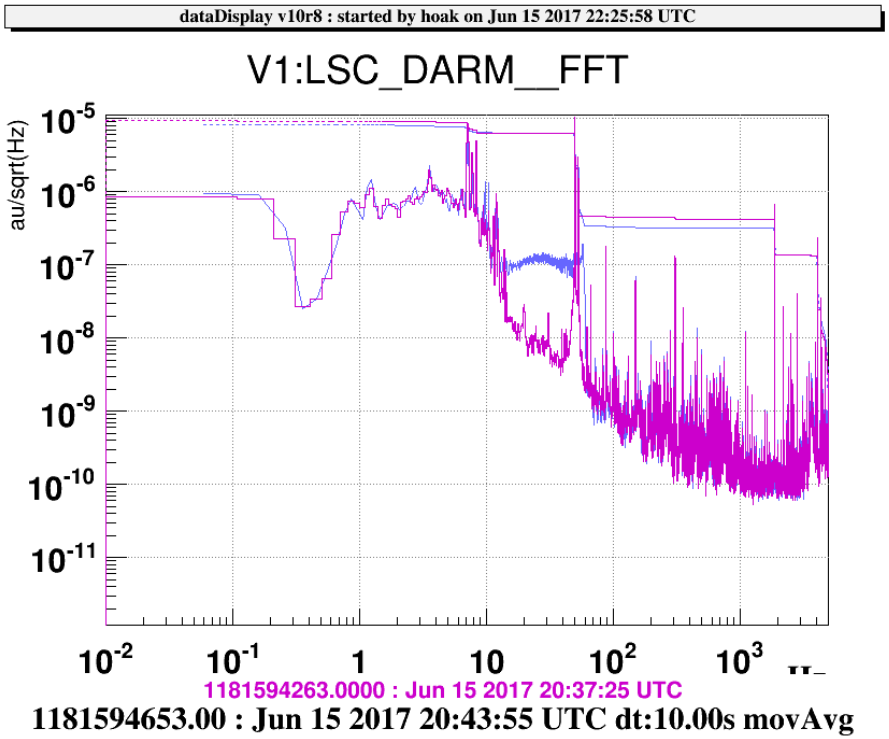


Scattering light problem

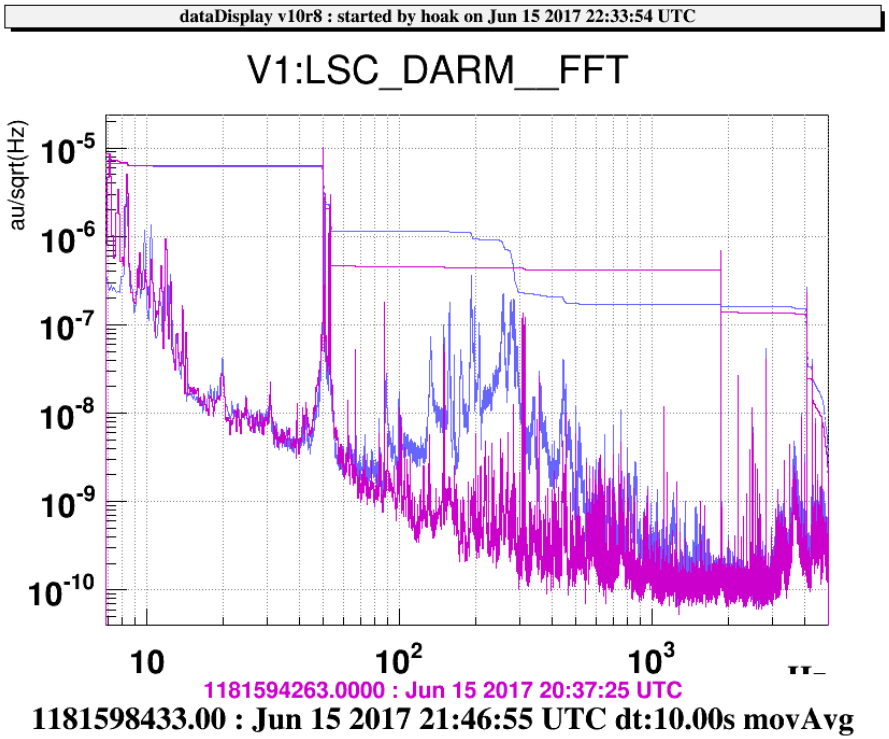
- Before we arrived, injection test into SDB2 was done. So the next step was SDB1 investigation.
- What were done:
  - Shake SDBx with white signal or slow certain frequency signal to see if any excess noise appear in DARM.
  - Monitor the bright spots during shaking.
  - And many others

Scattering light problem

- Slow injection result

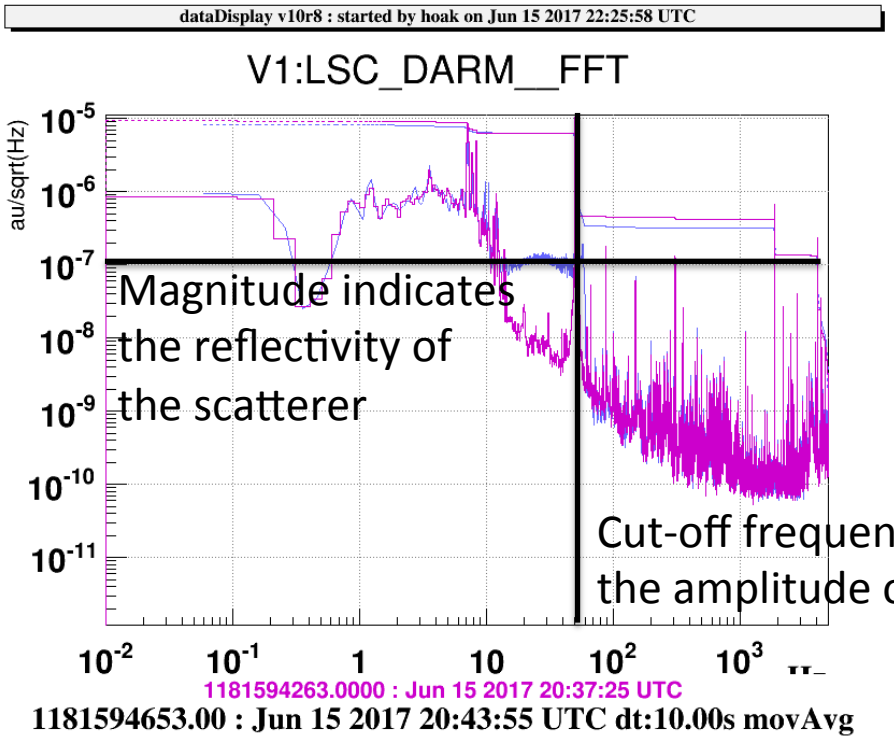


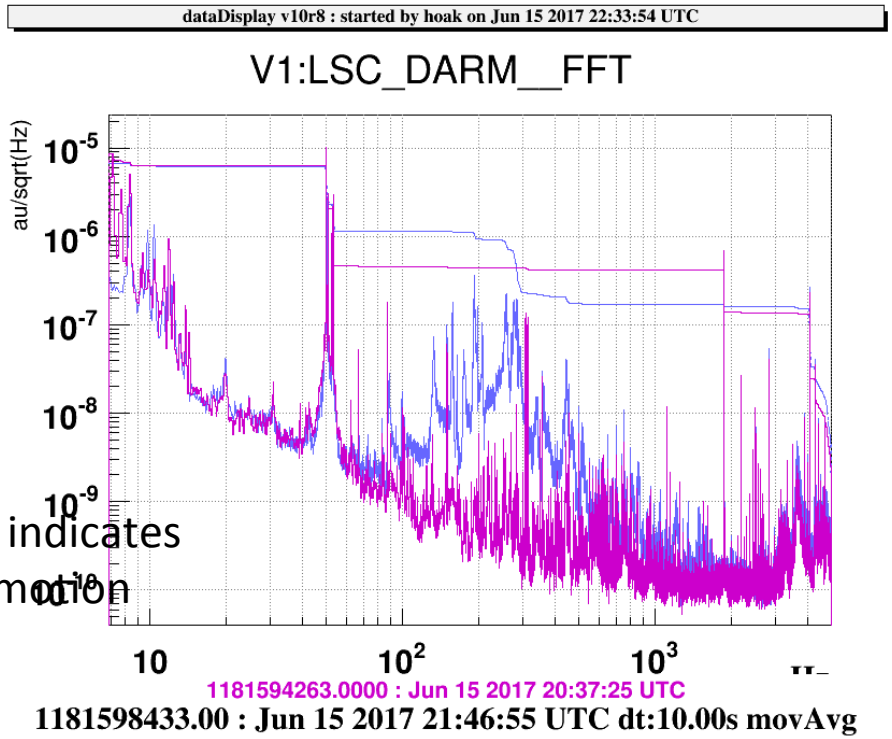
- Broad band injection result



Scattering light problem

- Slow injection result
- Broad band injection result

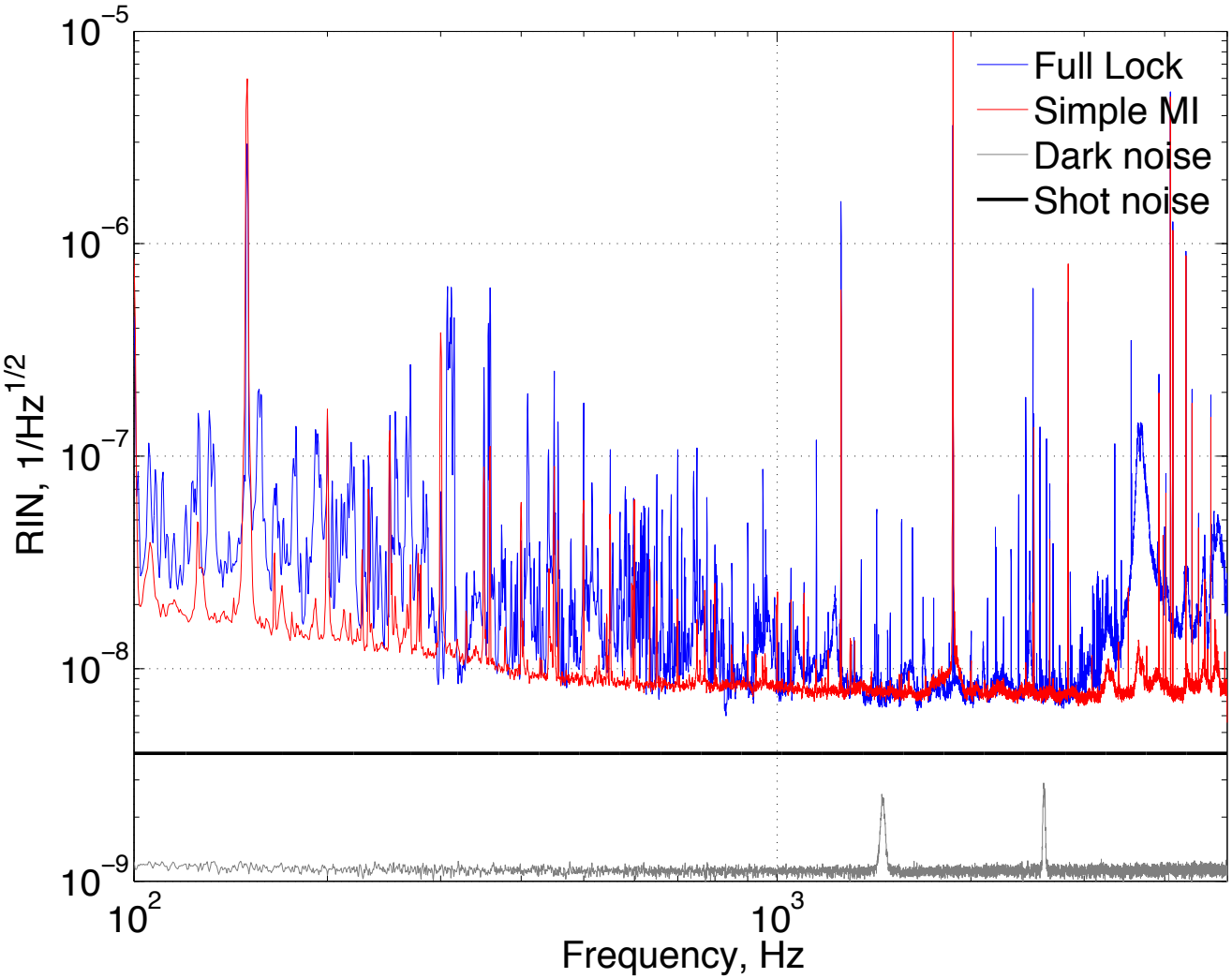




Scattering light problem

- This injection test implied that the noise coupling with some resonance on SDB1 might be problem while the noise coupling with the slow motion of the SDB1 was smaller than the current sensitivity by a factor of 10.
- Next question is, where does the light which make the noise coupling with SDB1 motion come from?
- To identify the origin of the light, sensitivities with full IFO and with simple Michelson were compared. (This study was done before our arrival.)

Scattering light problem



Scattering light problem

- As a result, we concluded that the scattered light came from somewhere in PRC and made the many lines and structures in DARM.
- From this study, we leaned that **dealing with scattering is very very important for the interferometer sensitivity.**

Scattering light problem

- As a result, we concluded that the scattered light came from somewhere in PRC and made the many lines and structures in DARM.
- From this study, we leaned that **dealing with scattering is very very important for the interferometer sensitivity.**
- By the way, more investigations after we left revealed that our conclusion was not perfect.
- This story will be told later.

Outline of our stay

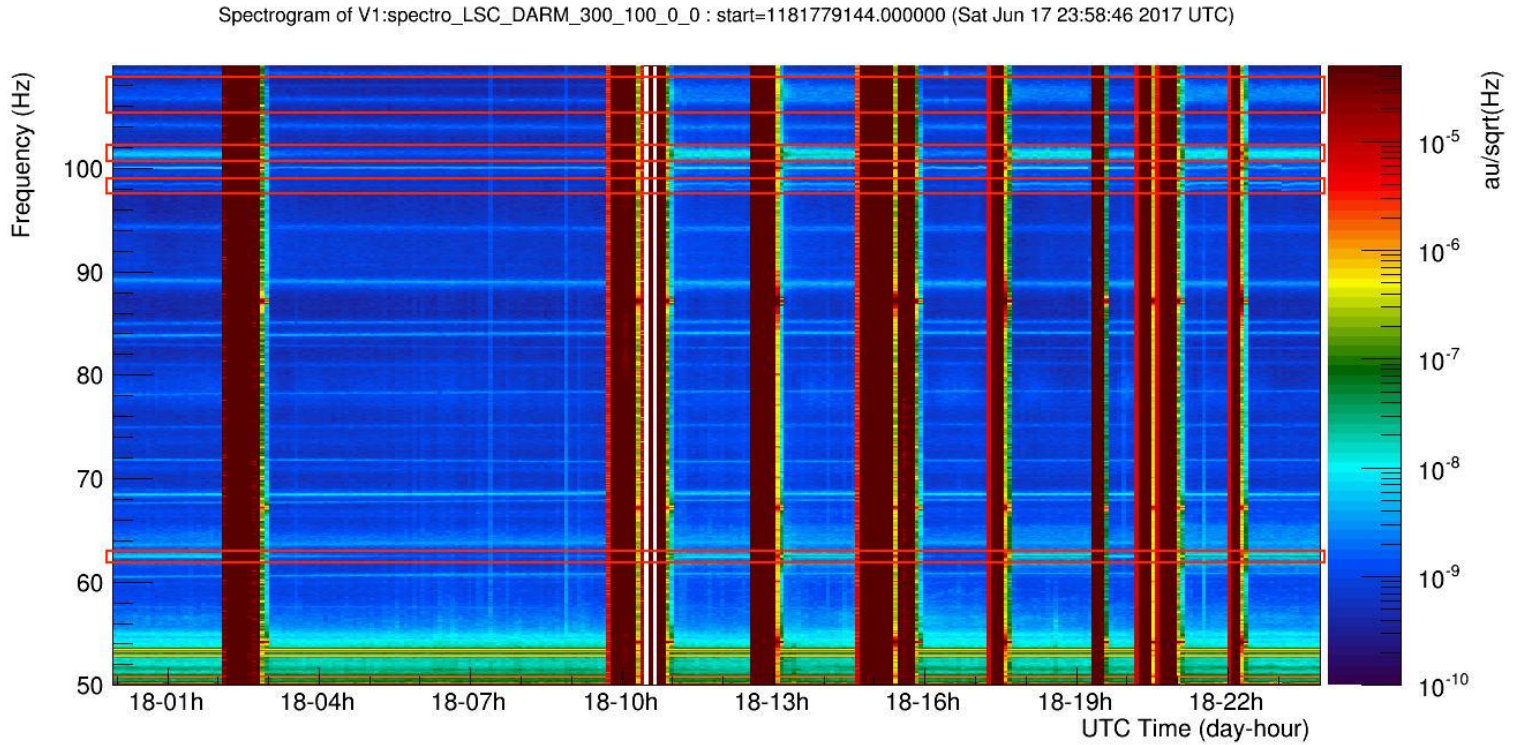
2017年6月

今日

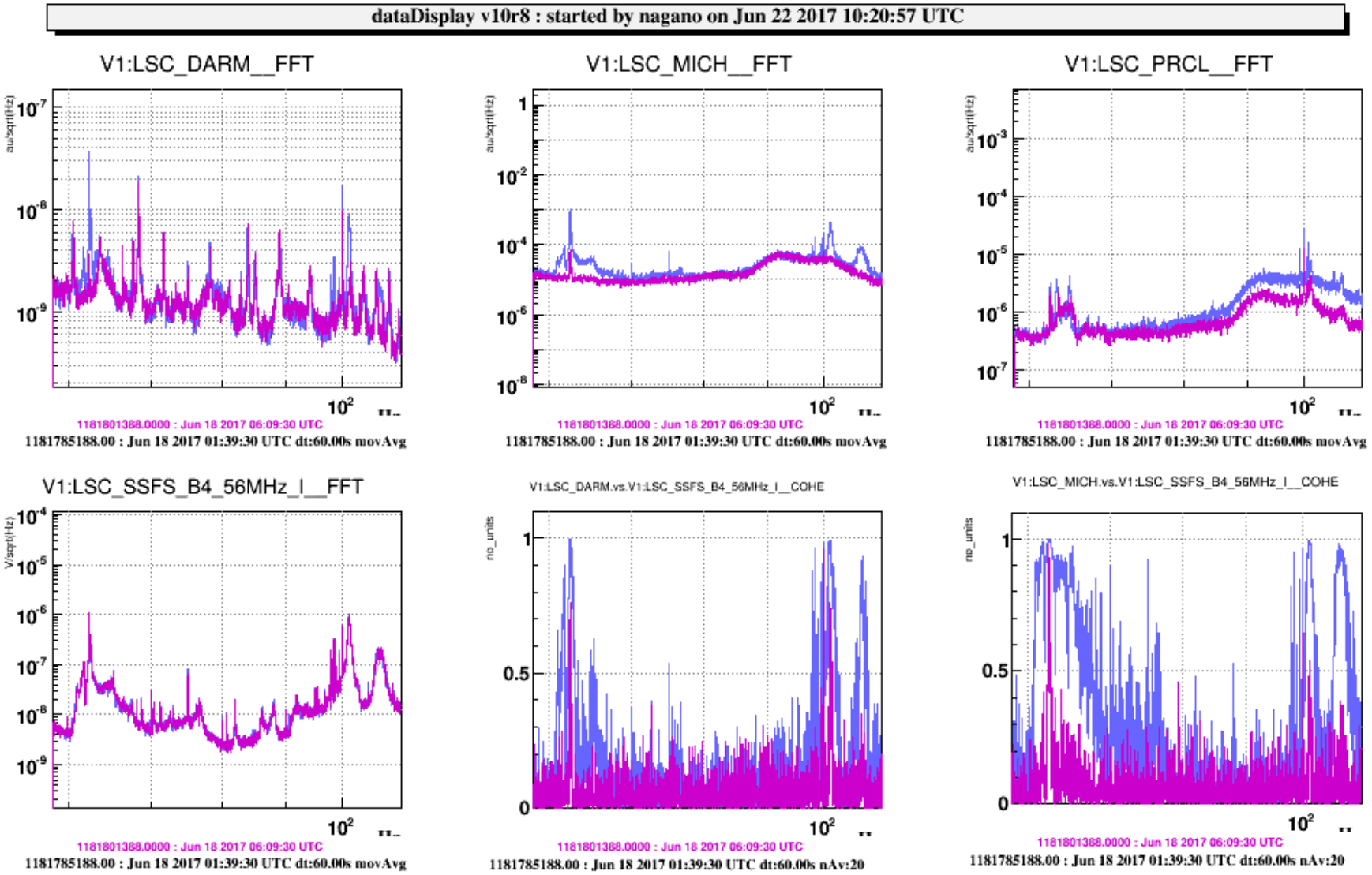
日	月	火	水	木	金	土
4日	5日	6日	7日	8日	9日	10日
					Arrival	
11日	12日	13日	14日	15日	16日	17日
	Study about AdV and how to use its tools.		Investigation of SDB1 scattering		ER11a	
18日	19日	20日	21日	22日	23日	24日
ER11a	Investigation of SDB1 scattering		Investigation of the correlation between SSFS and DARM.		ER11b	
25日	26日	27日	28日	29日	30日	7月1日
ER11b	Investigation of shot-noise-like noise between 1k and 3 kHz band					Departure

Correlation between MICH and DARM

- After ER11a, I found that some structures in DARM and MICH during ER11a appeared and disappeared simultaneously lock by lock.



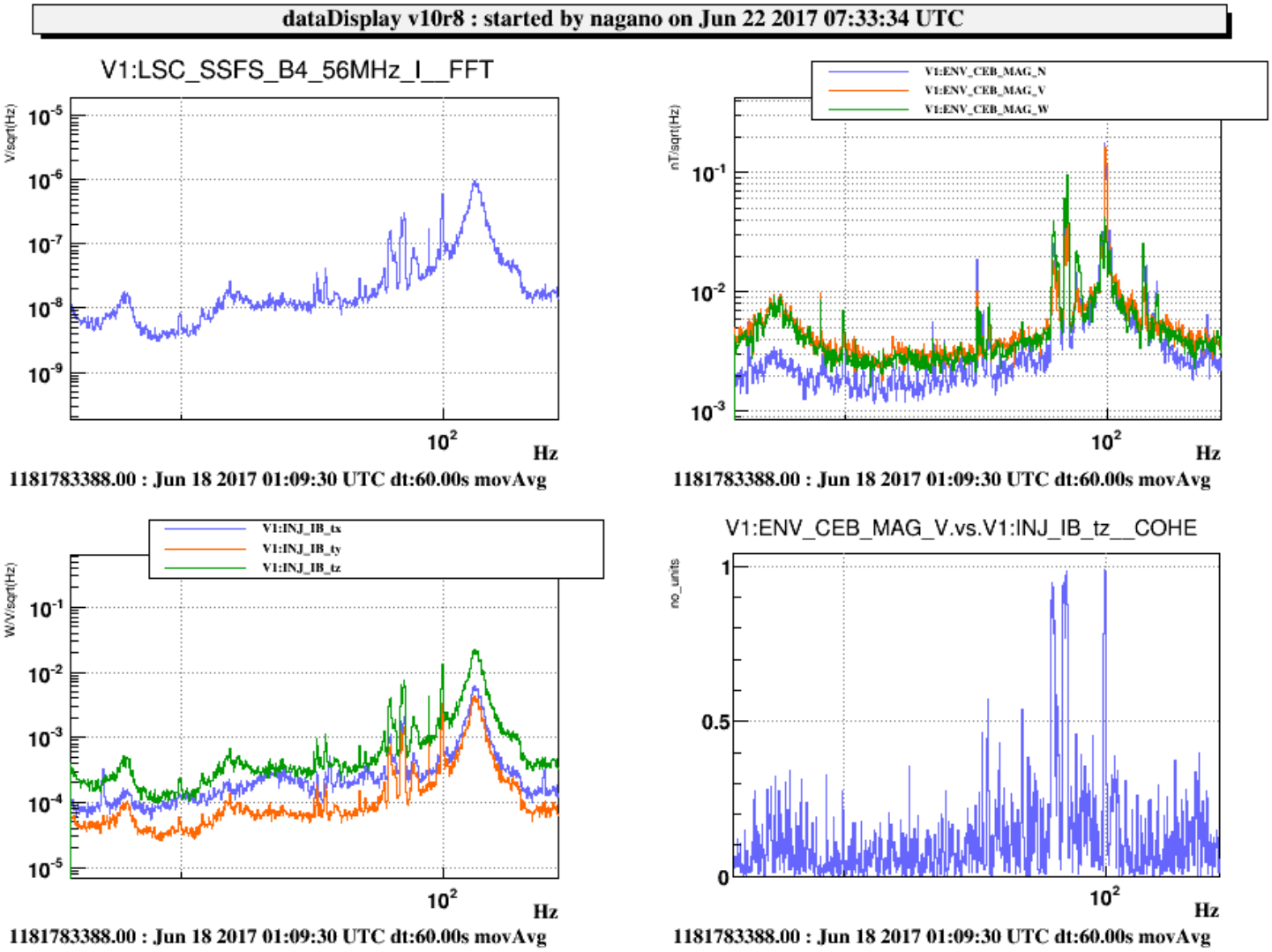
Correlation between MICH and DARM



Correlation between MICH and DARM

- Their shape in the FFT seemed to be similar to that of SSFS.
- Enomoto-kun found that these shape was also similar to the suspended injection bench 1 (SIB1) local control signal. Also, I found that it is also similar to some magnetometer signals.
- This indicated that the SIB1 motion is excited by magnetic field through electro-magnetic actuator on SIB1.

Correlation between MICH and DARM



Correlation between MICH and DARM

- Above things suggested that the structures were generated by frequency noise related with SSFS loop and/or beam jitter noise.
- These noise are related with MICH asymmetry which can be related with alignment performance.
  - We tried to identify specific IFO parameter related with this noise. However, we could not.
- Thus the appearing/disappearing behavior can make sense.
- From this study, we leaned that **environmental monitors were very helpful to identify the noise sources.**

Outline of our stay

2017年6月

今日

日	月	火	水	木	金	土
4日	5日	6日	7日	8日	9日	10日
					Arrival	
11日	12日	13日	14日	15日	16日	17日
	Study about AdV and how to use its tools.		Investigation of SDB1 scattering		ER11a	
18日	19日	20日	21日	22日	23日	24日
ER11a	Investigation of SDB1 scattering		Investigation of the correlation between SSFS and DARM.		ER11b	
25日	26日	27日	28日	29日	30日	7月1日
ER11b	Investigation of shot-noise-like noise between 1k and 3 kHz band					Departure

Shot-noise-like noise above 1 kHz

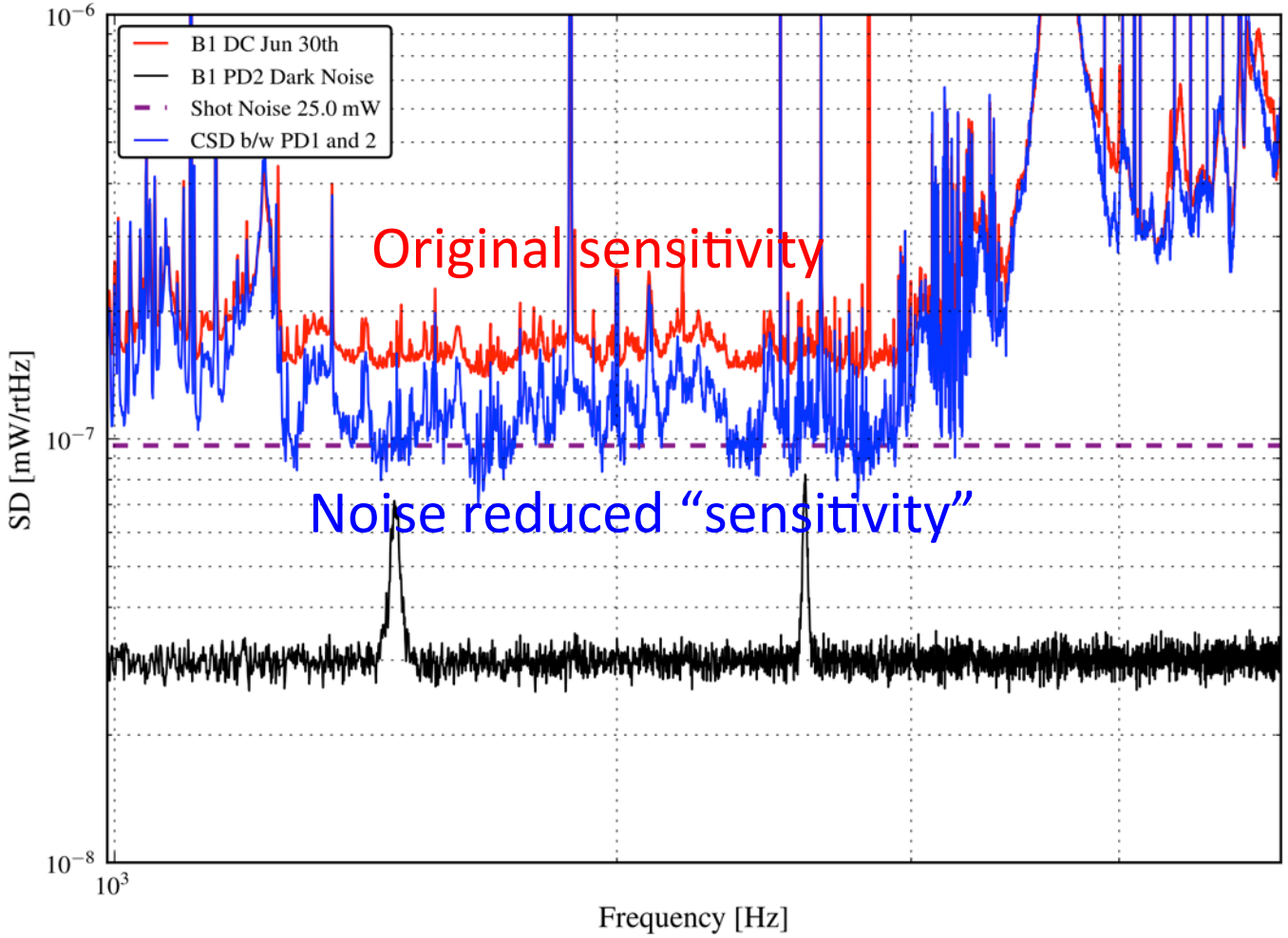
- At first glance, the sensitivity seemed to be limited by shot noise between 1k and 3 kHz.
- However, the noise exceeded shot noise level estimated with laser power by a factor of 1.4.
- To identify the source of the excess noise, we measured cross spectra of the two B1 PDs.
  - By the way, one of them did not work when we arrived since it had been burned by too much power.
  - The PD was replaced before ER11b by new one.
  - This story tells us that **beam shutters and spares of PD (and any other instruments) are important.**
  - In fact, the new PD was burned again because of the wrong beam shutter setting.

Shot-noise-like noise above 1 kHz

- What happen in the cross spectra of the output PDs?
  - If the sensitivity is limited by the noise from bright port (e.g. frequency noise) and shot noise, the noises will be reduced.
  - As a result, the spectra reveal the level of the hidden classical noises in the gravitational wave channel.
  - For detail, please see D. V. Martynov et. al., “Quantum correlation measurements in interferometric gravitational wave detectors”, PRL? (2017).

Shot-noise-like noise above 1 kHz

- Spectral density of DARM (without calibration)



Shot-noise-like noise above 1 kHz

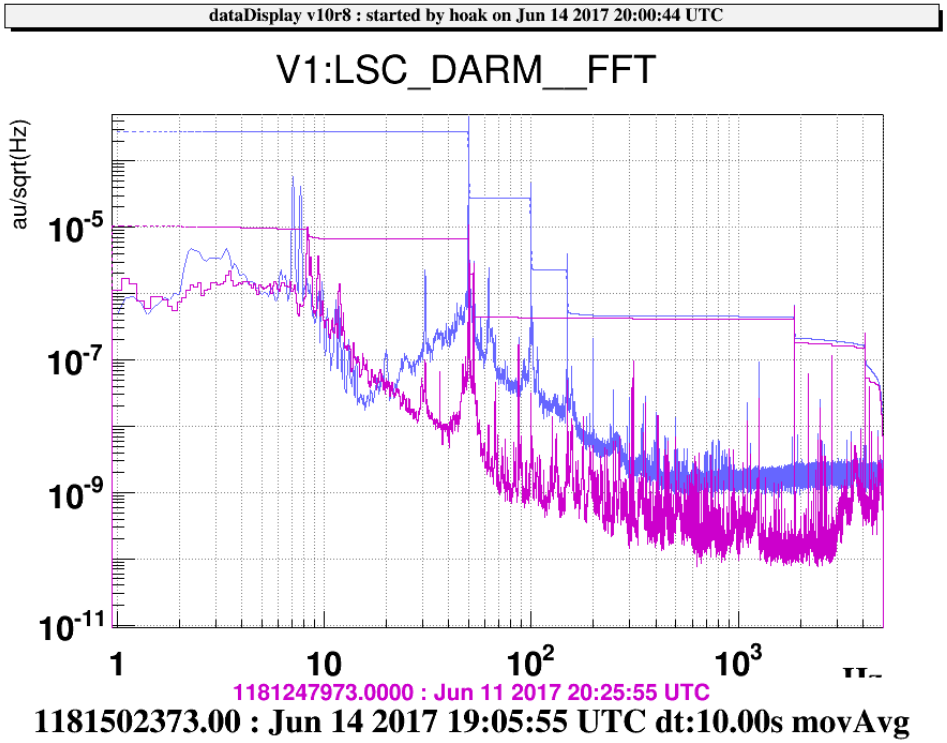
- This figure indicates that the sensitivity is limited by noise from BP, maybe laser frequency noise, and can be improved when the alignment is improved.
- However, even if the alignment would be perfect, the sensitivity could not reach shot noise level and be limited by some classical noise.
  - The specific noises source was not identified.
- From this study, we leaned that **two PDs after OMC must exist** for noise study, redundancy, and confirming if the PDs works well. (We need TWO PDs after OMC!!)

Other interesting things

- Other interesting things during our stay were listed below:
  - 50 Hz line increase and decrease
  - Moving line investigation
  - Engineering run 11
  - …

50 Hz noise increased

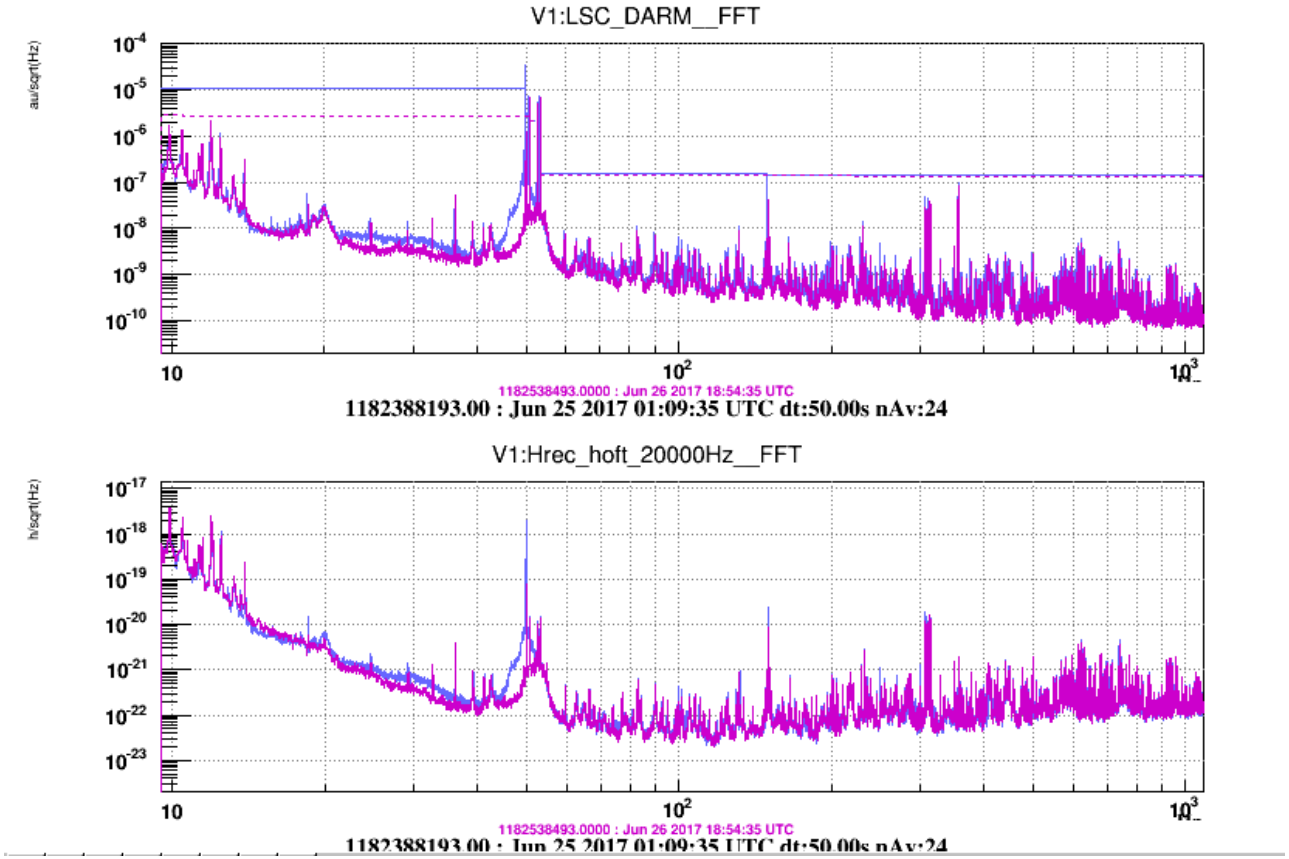
- When cabling around BS was modified, 50 Hz noise got worse by a factor of 40.
- This noise was reduced when the cable was just unplugged and plugged.



log #38010

Switch off test

- When some device was turned off, 50 Hz noise was reduced.

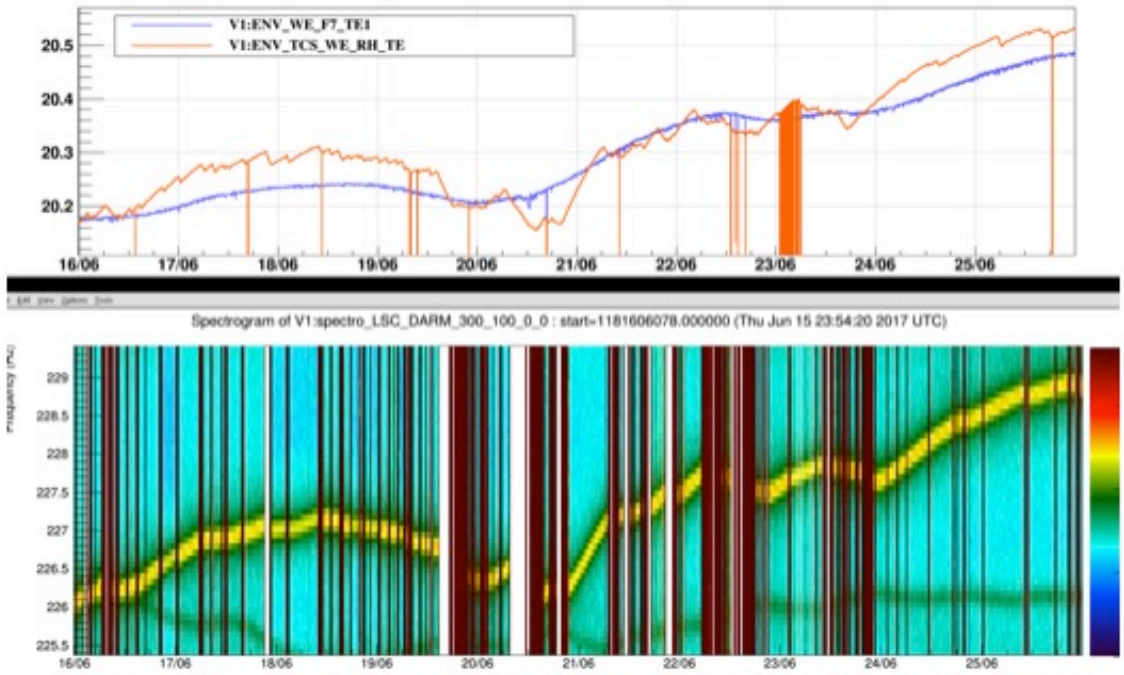


log #38261

Moving line investigation

Drifting lines

- Temperature sensors at RH are the best correlated ones.
- Frequency drift is linear with temperature, and slope is about **10Hz / 1°C**



17/07/30

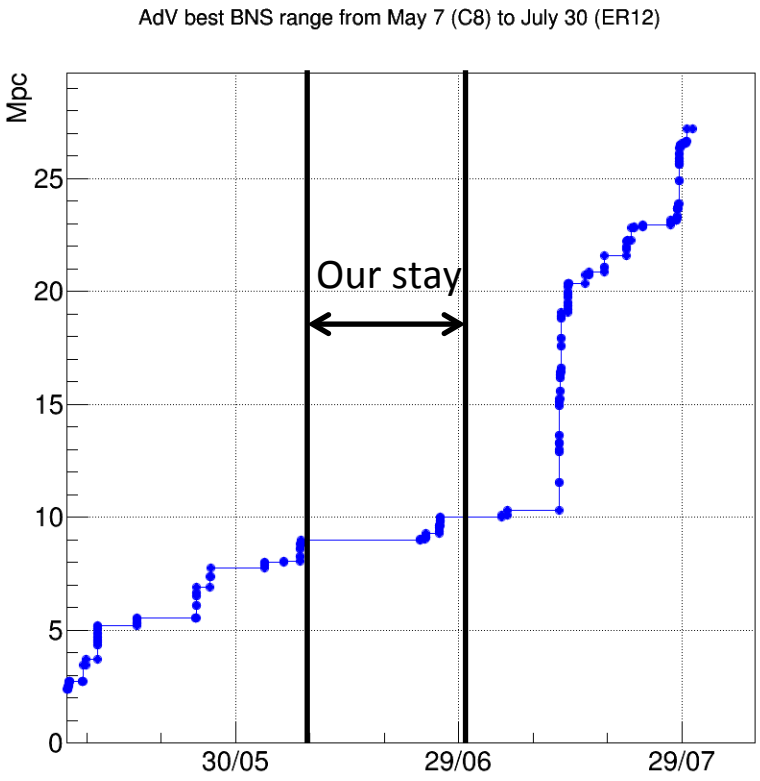
I. Fiori, VIR-0540A-17

Outline

1. What is Advanced Virgo?
2. What we did in Advanced Virgo
3. Recent progress of Advanced Virgo

Recent progress of AdV

- When we left AdV, BNR of AdV was about 10 Mpc.
- After we left, many works were done.
- As a result, BNR of AdV reached 20 Mpc, which was a mid-term goal to join O2, was achieved.
- Therefore, AdV joined O2 from 1st Aug..
- In the next a few slides, some works after our stay will shown.



B4 ghost light scattering

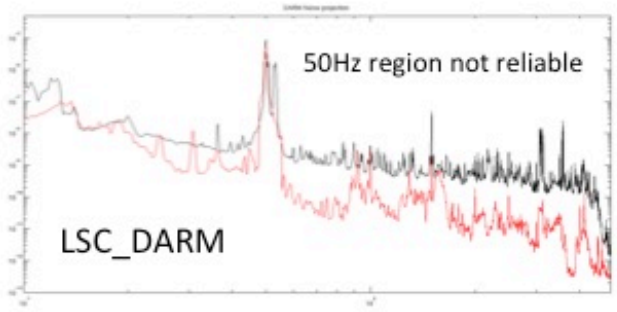
- As I said, scattering in PRC might be problem.
- Thus, some investigations were done and it was found that B4 ghost light might be a problem.
  - B4 is a PD in PRC observing MICH and CARM signal.

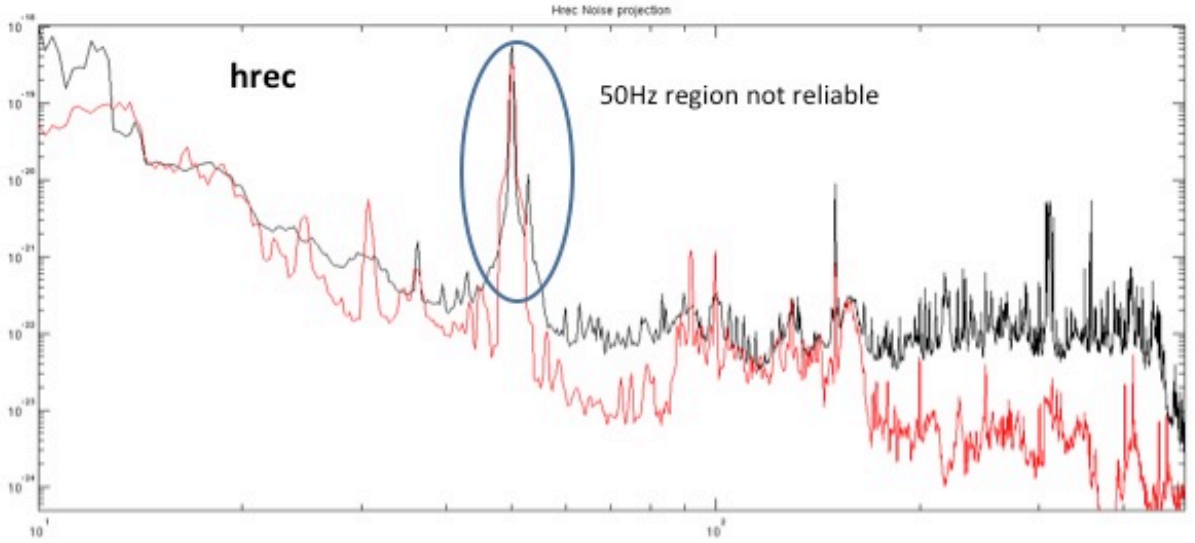
B4 ghost light scattering

I. Fiori, VIR-0540A-17

Scattered light, B4 ghost

- New from last week: projection on hrec
- B4-ghost scattered light seems to explain hrec noise below 20Hz and between 90Hz and 60Hz….
- Do we really need to cure this S.L. ?





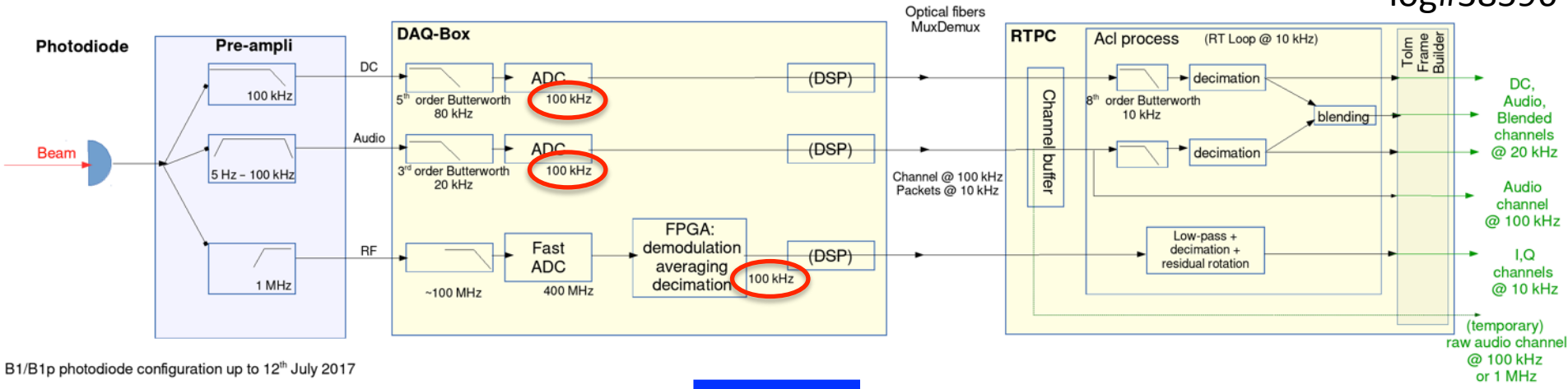
17

DAQ boxes and ADCs update

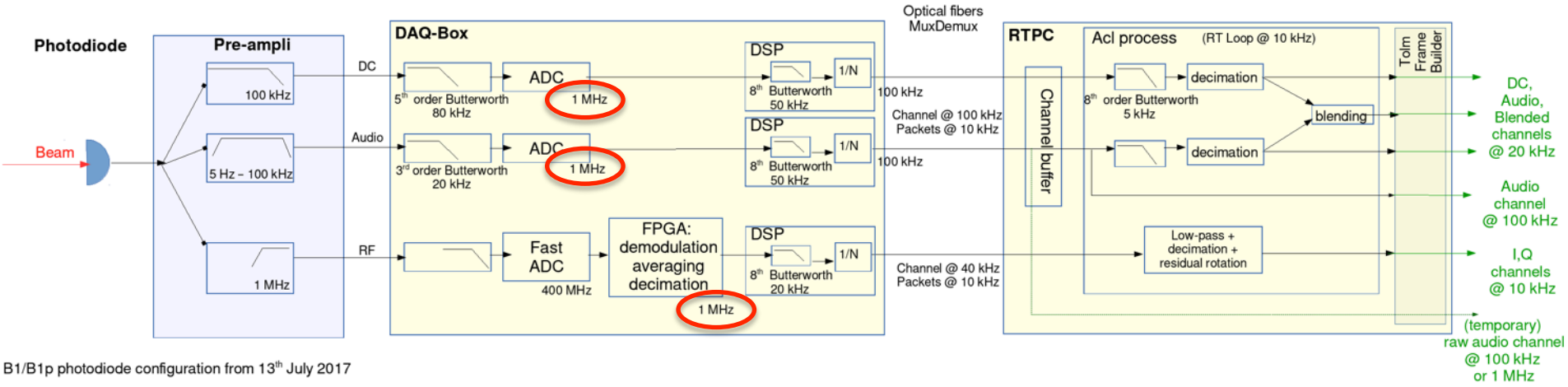
- The scattering light affected the sensitivity to some extent.
- However, what improved the sensitivity to 20 Mpc was not related with the scattering.
- The improvement is due to the upgrade of the DAQ boxes and ADCs firmware, allowing for running at 1 MHz and improving the anti-aliasing filters (logbook #38596).

DAQ boxes and ADCs update

log#38596

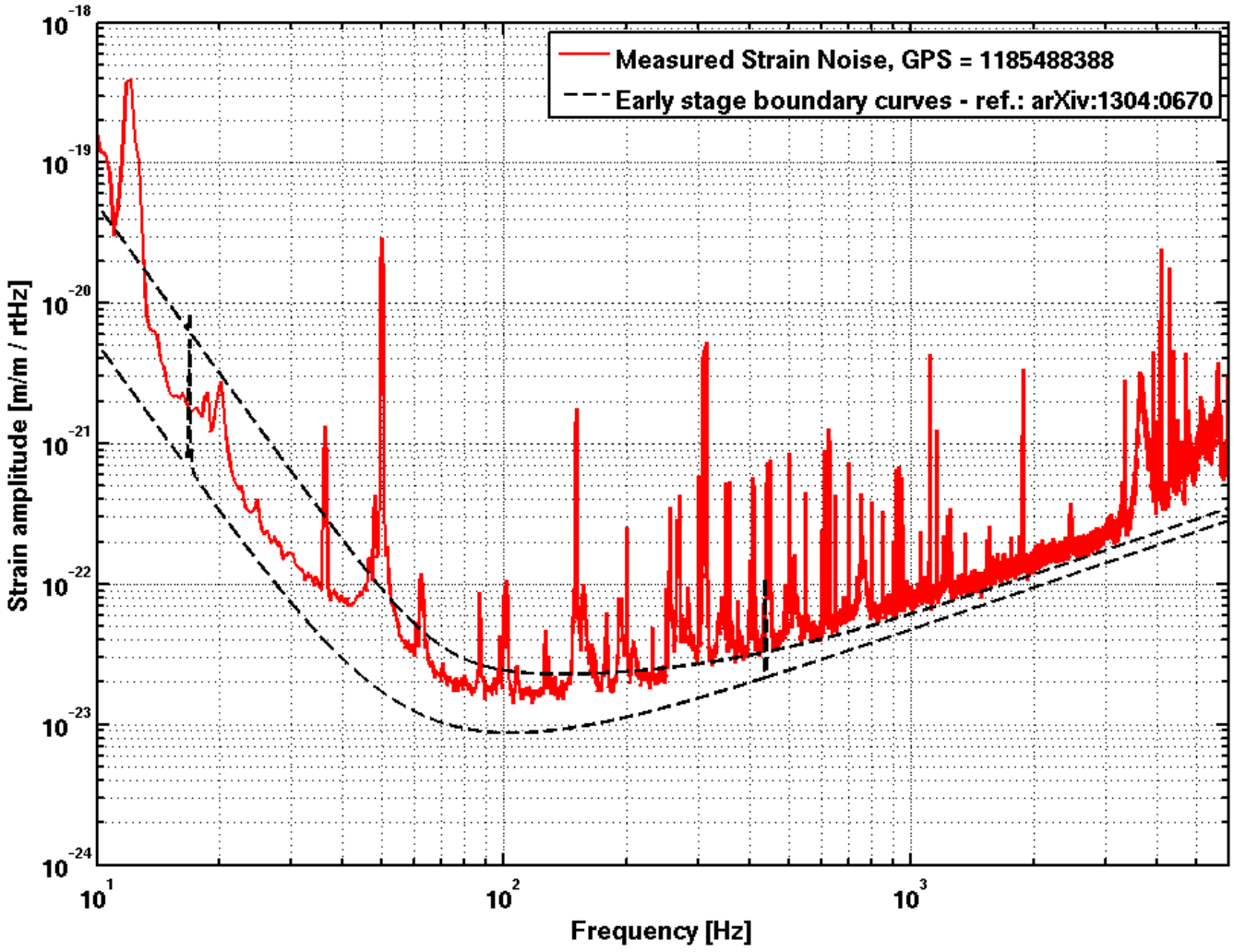


B1/B1p photodiode configuration up to 12th July 2017



B1/B1p photodiode configuration from 13th July 2017

Sensitivity reaching 28 Mpc!



Conclusions

- Commissioning was very interesting!

OMAKE