平成(　　)年度国立天文台滞在型共同研究報告書
Activity Report for NAOJ Visiting Joint Research in FY（2018）

年　　月　　日
2018／08／15

申請者 Applicant	氏　名 Name	Leonardi Matteo
	所属・職 Division・position	GWPO – Assistant professor
研究課題名 Research Title	Development of optical phase locked loop (OPLL) for the fre quency dependent squeezing experiment in TAMA	
研究場所 Place	NAOJ Mitaka Campus – TAMA300	
共同研究者 氏名・所属・職名 Joint researcher's Name・Institution・Position/ Graduate Student year	Marco Vardaro Universita' degli studi di Padova Postdoctoral Researcher	

1. 研究概要（Summary of research）

For this paragraph and the following one please refer to the attached document "Report-MarcoVardaro.pdf".

２．研究成果(Research achievements)

For this and the previous paragraph please refer to the attached document “Report-MarcoVardaro.pdf”.

３．本制度に対する意見、要望など【申請者記載欄】
(Any comments on this program【For applicant】)

This program allows the growth of our group giving us the possibility to invite at NAOJ Campus highly qualified researchers from around the world. With this specific visit the project did a huge step ahead and the students had the possibility to greatly improve their training.

４．本制度に対する意見、要望など【本事業で来訪した共同研究者記載欄】
(Any comments on this program【For joint researcher】)

I believe this program is among the best visiting programs I had the possibility to see: it gives great support and allows researchers to share experiences and common goals. This program introduced me also to the NAOJ, which is, unfortunately, not very well known in the gravitational wave community of my institute.

５．共同研究者の滞在日程(Joint research period)

氏名・所属 （Name・Institution）	Marco Vardaro – Universita’ degli studi di Padova
滞在日程（Period of stay）	日数(days)
年　月　日　～　年　月　日 2018/06/02　～　2018/07/01	30日間(days)
年　月　日　～　年　月　日 YYYY/MM/DD　～　YYYY/MM/DD	日間(days)
合　計（Total）	30日間(days)

NAOJ Visiting - Activities report

August 9, 2018

During the month of June I carried on a scientific visiting to the Matteo Leonardi group in the framework of the filter cavity R&D experiment. The experimental activities are performed in collaboration with Matteo Leonardi, Eleonora Capocasa and Yu-Whang Zhao. The main goal reached in the visiting period are related to the developement of the frequency independent squeezed vacuum source and are:

- improvement of the design of the optical bench;
- installation of the AUX1 and AUX2 laser and all the optics related to the two OPLL subsystem;
- developement and characterization of an electronic board to lock the two auxiliary lasers with the squeezer main laser;
- reorganization of the rack, re-cabling of the experiment and improvement on the RF generation setup.

1 Optical bench design

We redesign the optical bench scheme because in the original design the optical setup of the two OPLL servo loops did not consider all the steering mirrors to inject the light into the fiber collimators. Moreover we add into the optical setup the final position of all the photodiodes used for the OPO locking and for the coherent control loop. Fig. 1 shows the optical bench design: the region with the white background represents the optics that are already mounted on the bench before June, the region with the turquoise background represents the re-designed optical setup, whereas the region with the brown setup shows the optical components installed during the visiting period.

2 The OPLLs (Optical Phase Locked Loop)

The design, development and installation of the optical and electronic part of the two OPLL servo loops was the main task of the carried on activities. This squeezed light source needs two auxiliary lasers: the first is the coherent control laser (AUX1) and the second is the OPO locking laser (AUX2). These two lasers must be locked in phase with respect the Main laser (ML) with a frequency offset.

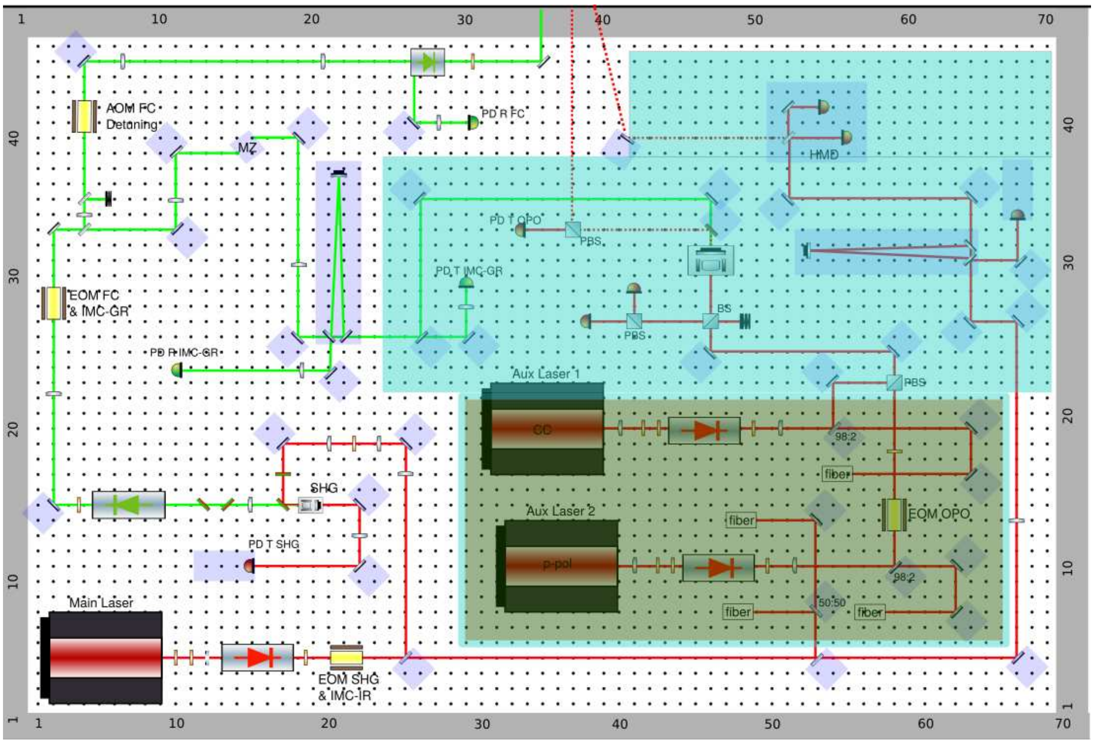

Figure 1: Squeezed light source optical scheme

Optical setup

In this setup the OPLL beam splitters and the photodiodes used to detect the beat note are fibered. The optical setup of the OPLL is shown in Fig. 2 and consists in the two auxiliary lasers, their respective quarter and half wave-plates, the Faraday optical isolators, the two lenses optical telescopes and the fiber collimators. The light coupled into the optical fibers is about the 70% of the collimator input power. In order to lock the two auxiliary lasers in frequency with the main laser we extract a pick-off of the ML in the path towards the filter cavity, we design another 2 lenses telescope and we inject this beam into the two fibered beam splitters (Fig. 1)

Laser PZT gain characterization

We measured the gain of the laser piezoelectric element as function of the frequency. The measurement is performed as follows:

- we superposed the beam of two different laser on the BS;
- we set the laser crystal temperature in order to have the beat note frequency in the photodiode bandwidth;
- we drove the laser PZT with a sinusoidal signal with fixed amplitude (0.5 V) and frequency between 1 kHz and 300 kHz;
- we measure the beat note width as function of the frequency.

We performed this measurement for the three lasers. Fig. 3 shows the PZT gain characterization of the AUX1 laser.

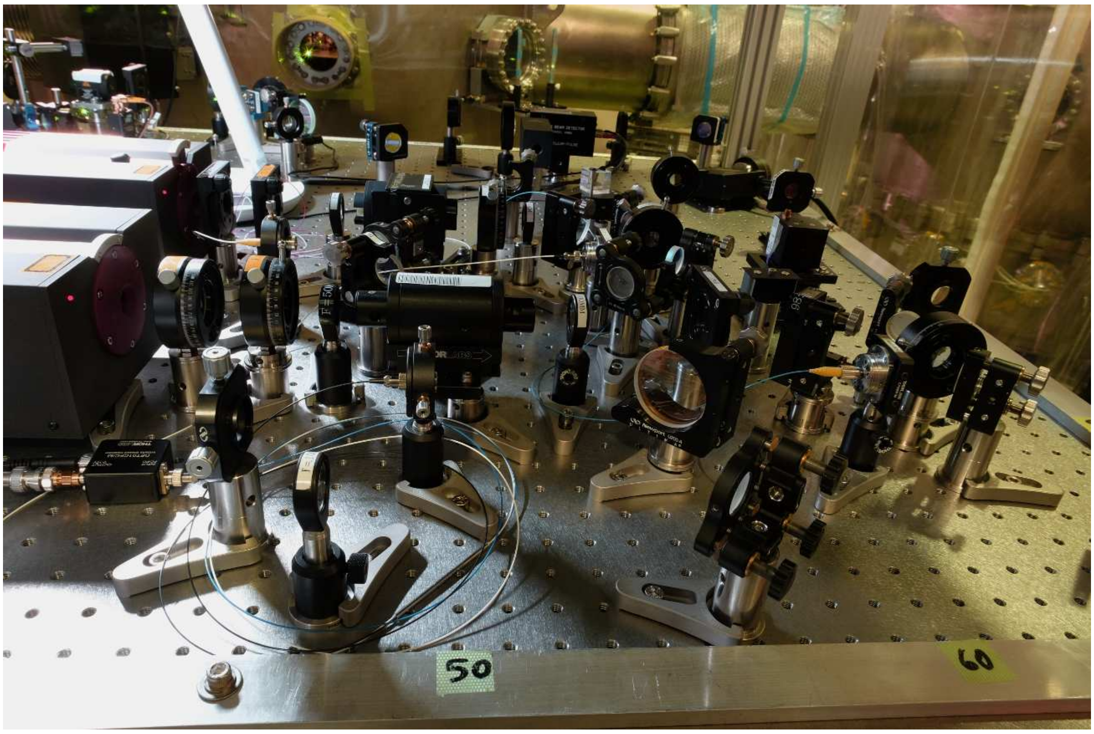

Figure 2: Optical setup of the OPLL

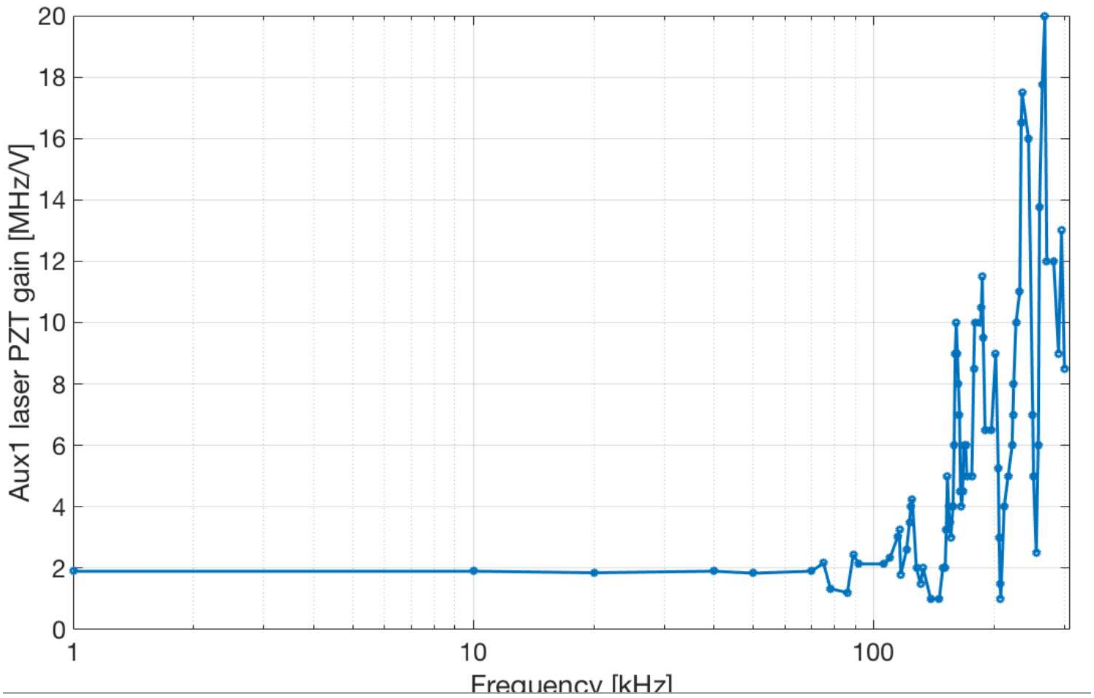

Figure 3: AUX1 piezoelectric gain as function of the frequency

OPLL electronic board and performances

The OPLL servo loop compares the beat note frequency with the frequency of a reference signal generated by the RF signal generator of the bench, i.e. the AD9959 DDS boards. The used phase detector is the ADF4002 phase frequency detector (PFD) of Analog Devices. The laser frequency is controlled acting both on the PZT and the PLT elements, thus we design an electronic board that acts on both the actuators, in particular the servo loop on the PZT have an high bandwidth (30-60 kHz), whereas the servo loop on the PLT has a small bandwidth (1-10Hz). The conceptual design of the board is shown in Fig. 4. The fast loop is composed by

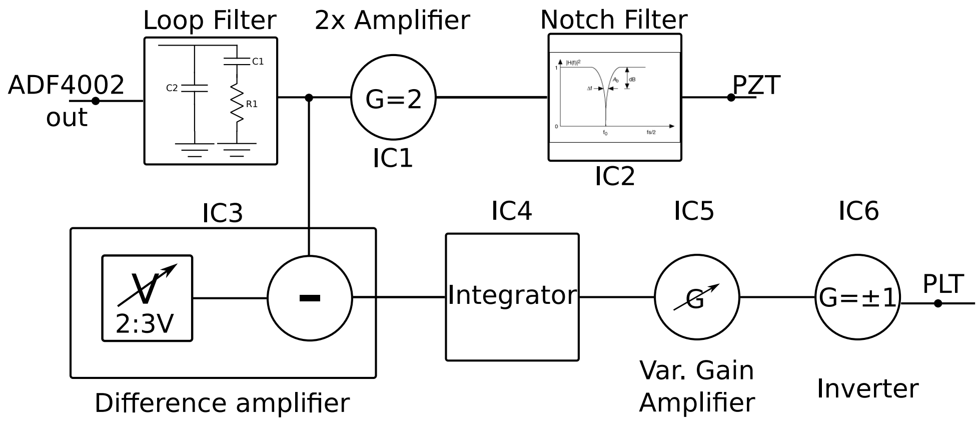

Figure 4: OPLL board block scheme

the PLL loop filter (two capacitors and one resistors C1=18nF, C2 = 450 nF, R1 = 33 Ω) and a notch filter centered at 170kHz to suppress the laser PZT resonances. Whereas the slow servo loop is composed by a differential amplifier with settable offset, an integrator, a variable gain inverting amplifier and an inverter to select the loop sign.

We developed only one board and we tested it for both the OPLL servo loops. Both the loops show a long term stability measured night time. Concerning the phase stability we measure it in the bandwidth between 100 Hz and 100 kHz using the demodulation technique. The RMS value of the phase noise in the measured in this bandwidth is about 5 mrad as required. Fig. 5 shows the spectrum of the phase noise of the two OPLL servo loop, the first closed on the AUX1 laser and the second closed on the AUX2 laser. We measured the phase noise in three configuration: with the master laser (Main Laser) free running, with the filter cavity servo controller electronic switched on but with the loop opened and with the filter cavity locked. We saw an excess of phase noise when this controller is switched on. This problem is not fixed during the period, but the group will investigate on it.

3 Rack re-organization, cabling and RF generation

We add a second rack in the clean room, moreover we reorganize all the electronics in order to act better on all the controllers. Fig. 6 shows the final configuration of the rack and is organized as follows:

A. Filter cavity servo loop;

B. NIM crate for PDH and PLL servo loops;

C. Cavity ramp generator;

D. RF generator for the green AOM;

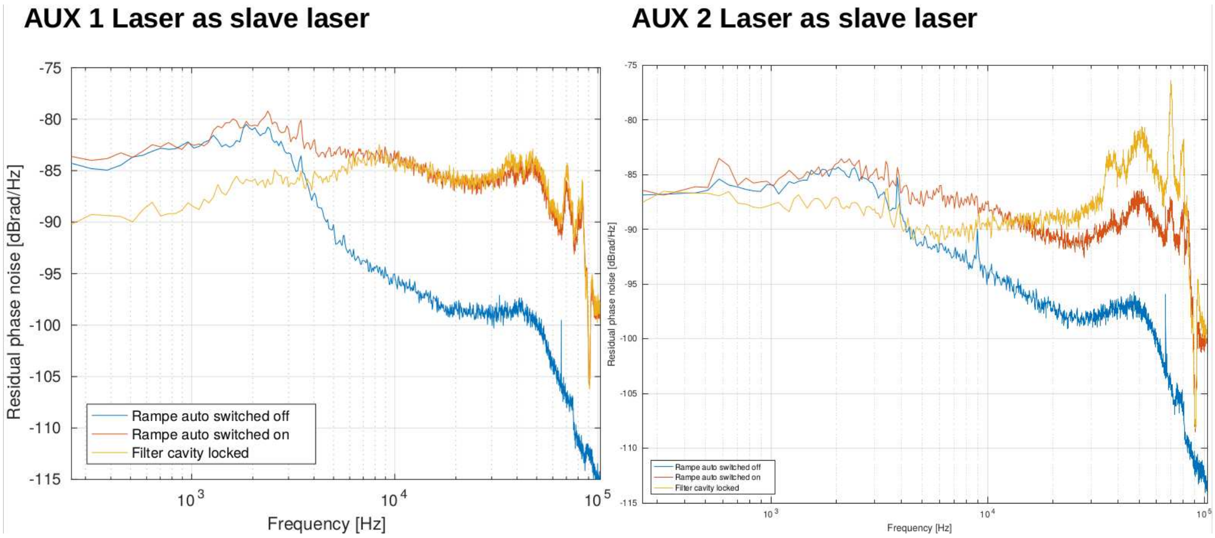

Figure 5: On the left residual phase noise of the PLL that acts on AUX1 laser, on the right the phase noise of the PLL on AUX2 laser.

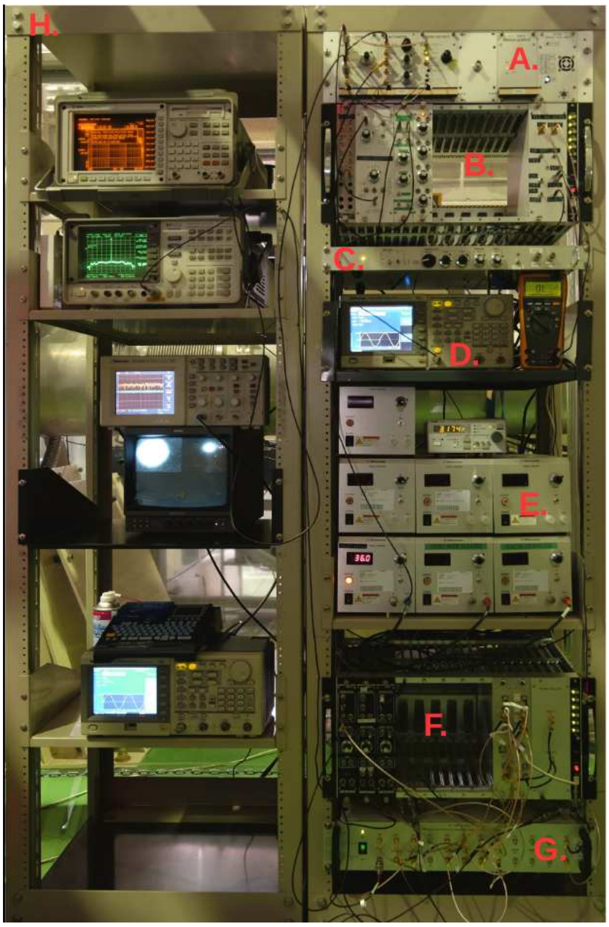

Figure 6: Rack configuration

E. High voltage amplifier for cavity PZT elements and SHG temperature controller;

F. RF generators and PDH error signal demodulation

G. RF amplifier box

H. Measurement and diagnostic rack

Concerning the RF system we installed the second AD9959 4 channel DDS RF generator in order to replace all the bench-top signal generators, we check all the gain of the RF amplifier box and we tune them in order to have the right amplification of the two PLL beat notes.