How to create space inside the VLTI: PIONIER 3D project

P. Bourget*[a], G. Zins[a,b], S. Guieu[a,b], N, Schuhler[a], P. Haguenauer[a], S. Poupar[a], J.P. Berger[b], F. Gonté[b], J.B. Lebouquin[c], T. Rivinius[a], A. Mérand[a], L. Jocou[c]
[a]European Southern Observatory (Paranal-Chile), [b]European Southern Observatory (Germany), [c]Institut de Planétologie et d'Astrophysique de Grenoble (France)

ABSTRACT

PIONIER is a four beams combiner instrument developed by the Astrophysics Laboratory of Grenoble (LAOG, now IPAG). This instrument arrived at the ESO Paranal Interferometer in 2010 as a visitor instrument and was supposed to be decommissioned with the arrival of the second generation instruments GRAVITY and MATISSE. However, the success of PIONIER induced the needs to keep it available for the scientific community inside the packed environment of the VLTI. This paper presents the technical solutions that were applied to place the instrument in mezzanine without impacting its performance and with the constraint of reducing its operational workload.

Keywords: Interferometry, PIONIER, VLTI

1. INTRODUCTION

The ESO Very Large Telescope Interferometer (VLTI) laboratory passed through different evolution phases since its beginning in operation in 2002. After the demonstration period with the instrument VINCI [1], the first generation of instruments MIDI [2], FINITO [3], AMBER [4] and PRIMA [5] already explored the VLTI Laboratory facility. The decommissioning of VINCI in 2005 way earlier before the arrival of the second generation instruments, GRAVITY [6] in 2015 and MATISSE [7] in 2017, offered a time and physical space for a possible visitor instrument. This opportunity was taken in 2010 by the Astrophysics Laboratory of Grenoble (LAOG) with the instrument PIONIER [8, 10].

After two years of operation supported by the consortium, PIONIER started to be maintained in operation on a best effort basis by the Paranal engineering department. The success of the instrument reported by the astronomical community pushed to investigate a solution to keep it after the arrival of GRAVITY. Moving PIONIER was possible because of its high reliability and optical stability. Also, solutions to reduce the workload in operation was conceivable. The relocation study (PIONIER 3D project) was done by an ESO-Paranal/LAOG team. Finally, PIONIER has been offered in operation in its mezzanine location for the P96 period. This paper presents the context and the technical solutions applied to fulfil the requirements in terms of space, performance and operation at the VLTI.

2. VLTI LABORATORY INFRASTRUCTURE

2.1 Context

In March 2011, the VLTI achieved its first ten years of operations. The VINCI commissioning instrument, and the two instruments offered to the interferometric community, AMBER and MIDI, have marked this first decade with numerous scientific successes. During this period the VLTI also went through a number of changes and upgrades which have led the facility to a fully functional and operable telescope. This has been made by a strong dedicated effort from ESO to deliver the best possible interferometer for science. After the removal of VINCI, the VLTI hosted the visitor instrument PIONIER. The ten years anniversary of the VLTI has been then celebrated with the first interferometric combination of four 8 meter telescopes [9]. This provide for the first time real imaging capability to the VLTI. The VLTI Laboratory configuration in 2010 is presented Figure 1.

*pbourget@eso.org; phone (56) 552243 5378

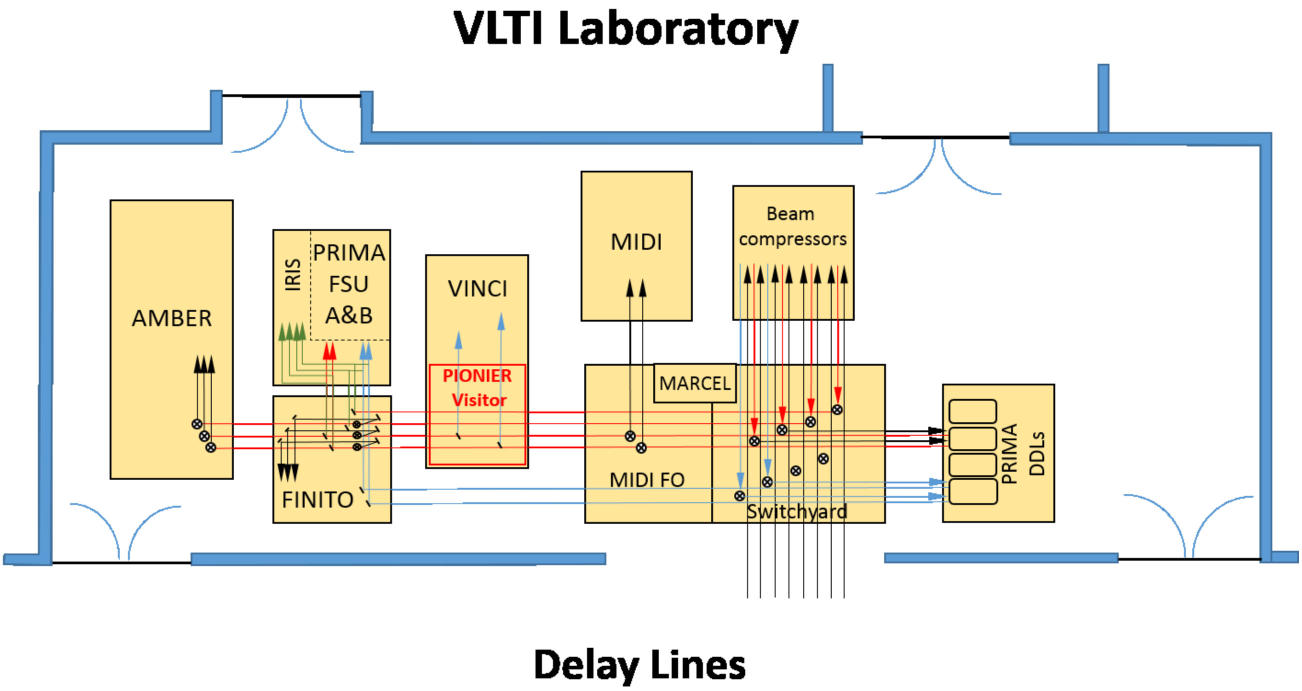

Figure 1. General layout of the VLTI Laboratory architecture in 2010. Optical path combinations are shown for the different instruments. The Differential Delay Lines (DDLs) used by PRIMA for off axis capability are also included. IRIS allows the image fast guiding and pupil alignment, MARCEL is the VLTI reference source used for calibrations and alignment monitoring. Switchyard and feeding optics (FO) are roughly presented to follow the different light path combinations. PIONIER appear in red before the arrival of GRAVITY.

In a laboratory already full, especially with the perspective of the second generation of instrument, the only solution was to use a vertical extension (3D). The best location without impacting the others instruments and future evolutions of the laboratory has been identified above FINITO (Figure 2).

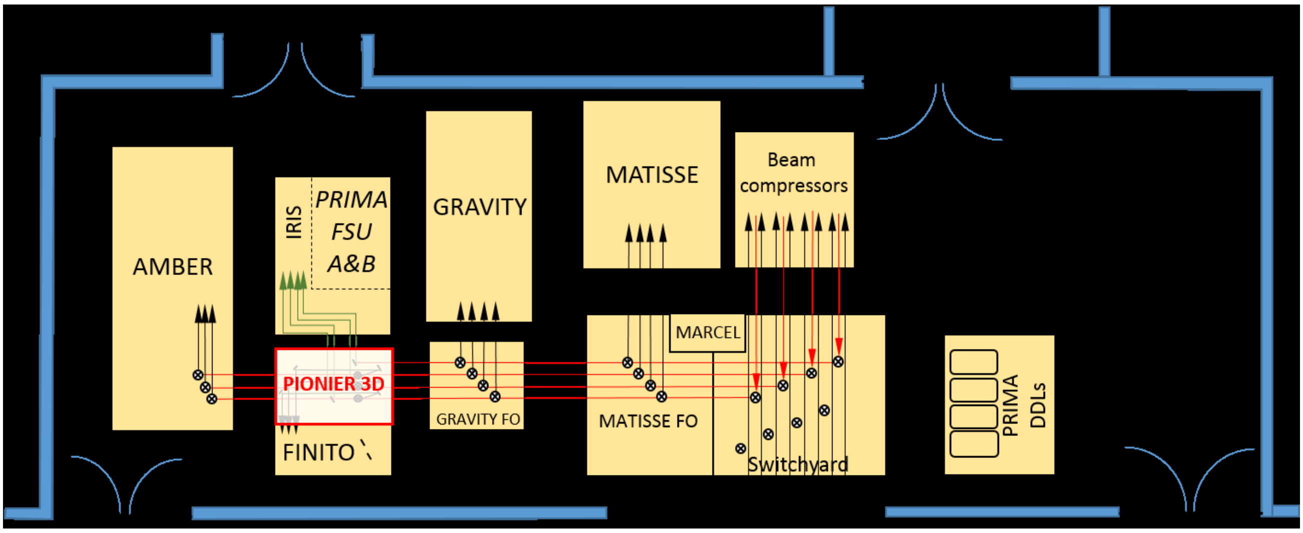

Figure 2. This implementation, at the cost of one more reflection, is done using a vertical periscope. The level of the PIONIER bench should also be sufficient to keep the full access to the feeding optics of the FINITO table for normal maintenance.

2.2 PIONIER overview

Figure 3 shows an overview of the global design of PIONIER with the original PICNIC detector installed on the VINCI table.

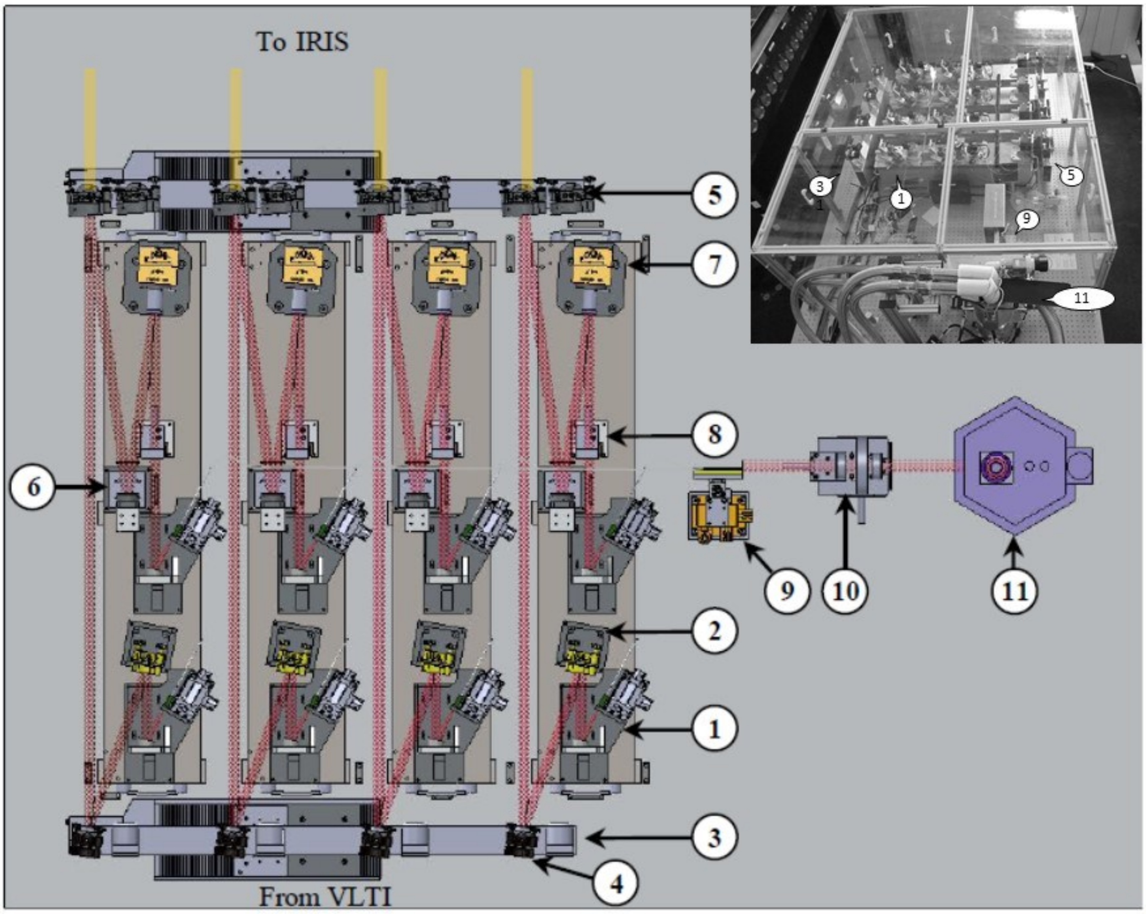

Figure 3. PIONIER can be decomposed in the following subsystems:

Unit description	Acronym	Ref	
Calibration and alignment Unit	CAU	1	Parabola
		2	Flat mirrors (relay optics)
		3	Calibration unit translation stage
		4	Folding mirrors
Injection and OPD control unit	IOPDU	5	Dichroics
		6	OPD piezo scanner
		7	Tip Tilt mirror
		8	Shutters
Integrated Optics Beam Combiner	IOBC	9	IO component and alignment mount (XYZ + Tilt)
Imaging Optics and Dispersion Unit	IODU	10	Lens and disperser optics
Detector	DET	11	PICNIC detector with tow filter wheels

Before the relocation of PIONIER the new generation detector RAPID [11] was installed instead of the PICNIC. The detector is a 220x255 APD array, a new technology and the first of its kind to be installed in an astronomical observatory. It is integrated inside a compact pulse-tube cryo-cooler of 1.4W of cooling power. It allows to cool down the focal plane down to ~70K without nitrogen. The calories are evacuated by the pulse-tube thought the water cooling circuit. The detector named RAPID can work at 1700Hz with still an equivalent readout noise of 1 electron. It allows fast and sensitive detection necessary for PIONIER to track and observe fringes. Contrary to Hawaii and the former PICNIC camera, RAPID has only one fast readout mode, equivalent to the DOUBLE mode (reset-read-read-reset).

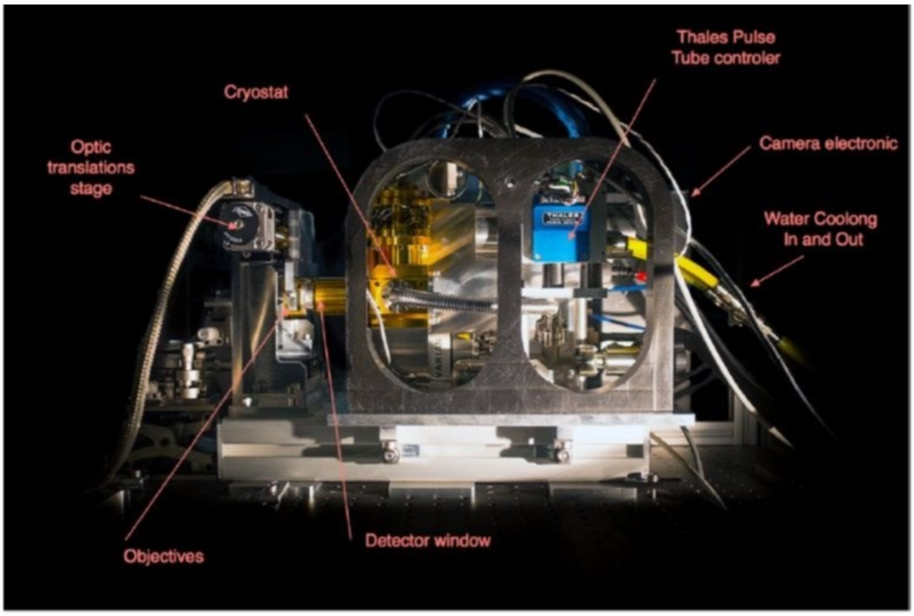

Figure 4 - Picture of the RAPID camera taken in laboratory with main part descriptions

3. PIONIER 3D PROJECT

3.1 Description

The PIONIER 3D project is a mezzanine above the FINITO table (Figure 5). The lower part of a four beams vertical periscope is mounted on a translation stage and serves as Feeding Optics (PIONIER FO). Dichroics in H band allow simultaneous feeding of PIONIER and IRIS for the guiding. The periscope configuration allows easier alignment of PIONIER to center pupil and image (the dichroics are very close to the VLTI pupil image plane). For calibrations with the CAU, folding mirrors are mounted on a translation stage. PIONIER was also co-aligned and co-phased with MARCEL for monitoring related to the VLTI.

3.2 Impact on performances

The main consequence of the elevation of the PIONIER optical bench is the sensitivity to vibrations. Even with a stiff structure, a geometrical amplification of the vibrations coming from the floor is induced. This could affect directly the performance of the instrument in terms of fringe visibilities but also the more dramatic sensitivity to earthquake. For seismic reasons a light optical bench was preferred and the original four steel beams of PIONIER (see Figure 3) were removed (Figure 5). Only the optics and mountings were installed on the new bench to reduce the weight.

The RAPID detector cooling system generates slight vibrations due to the pulse tube, if their effect is irrelevant when mounted on the big VINCI optical bench it is not the case anymore when mounted on the lighter optical bench. For that reason IOBC, IODU and Detector (Ref 9, 10&11) are mounted in the same plate; this plate is attached to the optical bench by a damping system to suppress the transmission of vibrations coming from the pulse tube.

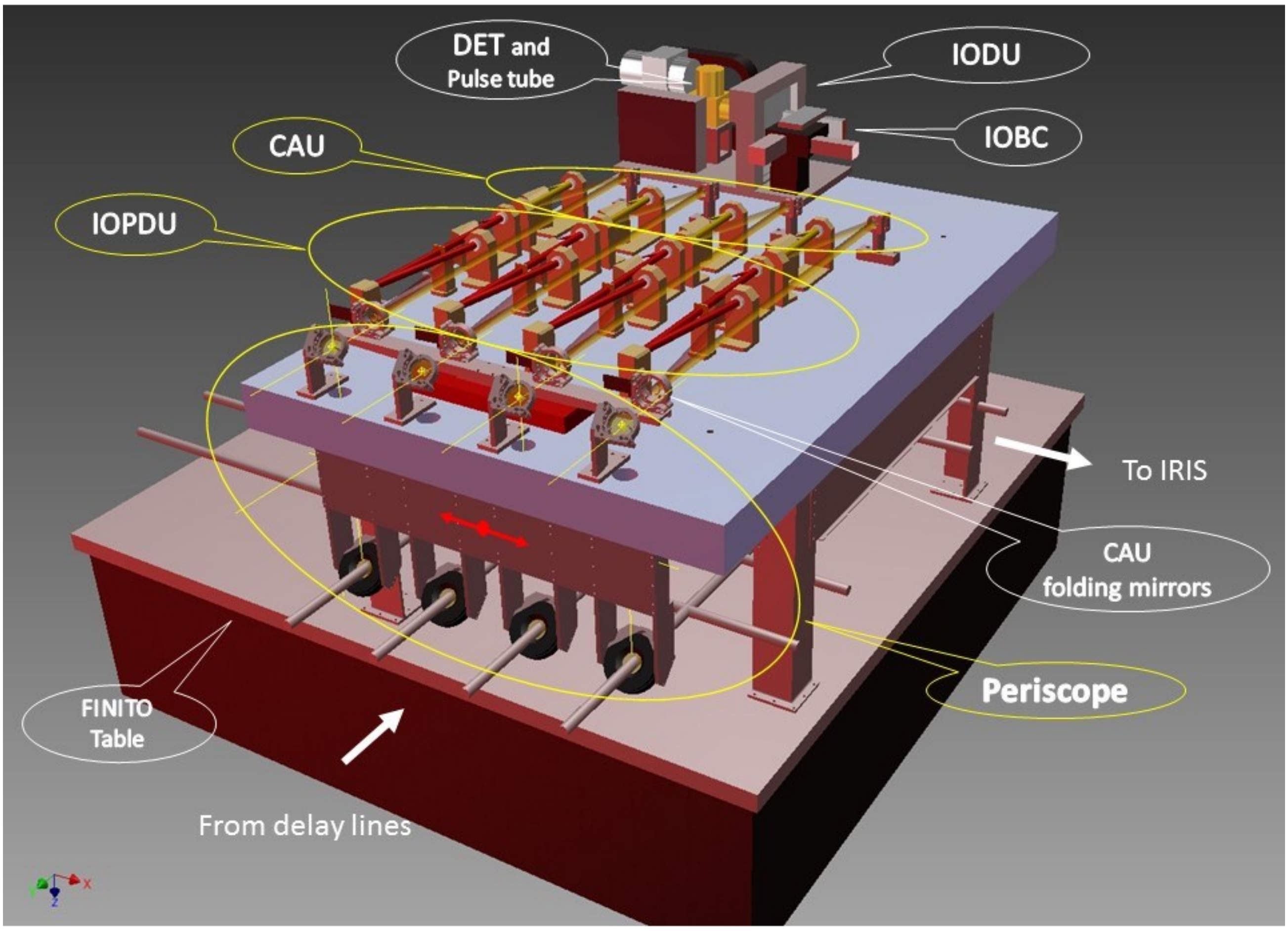

Figure 5. PIONIER 3D overview. The configuration shows PIONIER in calibration mode on the CAU with the folding mirrors IN. The lower part of the periscope (PIONIER FO) is also IN but the reflected beams on the dichroics are not present.

Vibrations measurements were done using accelerometers from B&K type 4370 associated with a Nexus amplifier 2692 and the Tiepie Handyscope HS4. An accelerometer was placed on the PIONIER feeding optics (acc1) (Figure 6), another on the PIONIER table on the front right corner* (acc2), another on the back right corner (acc3) and the last one on the back left corner close to the PIONIER detector (acc4).

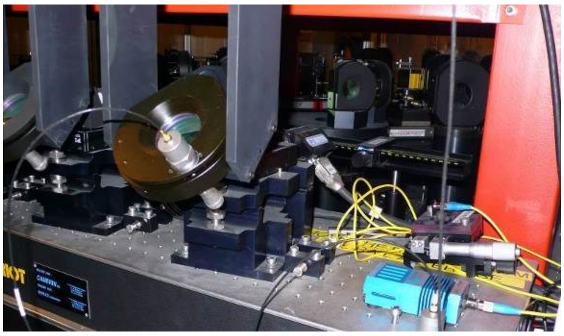

Figure 6. Accelerometer (acc1) mounted on the lower part of the periscope amplifying vibrations.

After analysis it was found that the feeding optics mount (lower periscope) was a vibrations amplifier. This helped us to quickly identify potential sources not seen by the others accelerometers:

- FINITO Front End Cabinet
- IRIS Irace Cabinet
- PIONIER pulse tube

FINITO Front End Cabinet and IRIS IRACE cabinet were damped using small cylindrical mounts (ref V12Z02MFF252508 from advanced antvibration Components). PIONIER detector plus IOBC and IODU support plate were damped using a softest model (The efficiency is shown on the Figure 7).

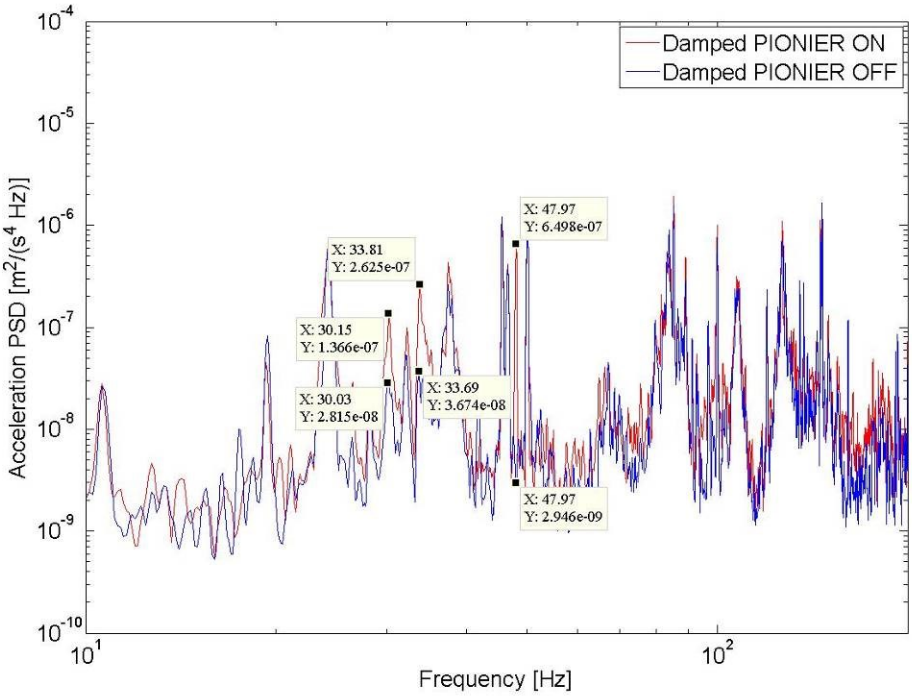

Figure 7. Accelerometer (acc1) measurement pulse tube ON/OFF. The Pic around 24 Hz is due to the vacuum pump of GRAVITY working during day time.

3.3 Impact on operations

A necessary condition to keep PIONIER in operation was the decrease of the workload on the engineering department to be able to deal with one instrument more after the arrival of GRAVITY and MATISSE. The daily alignment tasks on PIONIER were focused on the birefringence control and the alignment of the integrated optics component (IOBC).

- **Birefringence control:**

The birefringence of the optical fibers and the IOBC introduces a differential OPD between the two perpendicular linear polarizations, this dramatically decrease the fringe contrast. One need to separate both polarizations with a Wollaston prism to obtain a good visibility on each polarized fringe pattern, nevertheless the total flux is divided by two on each channel. A birefringence control system allows the co-phasing of the two perpendicular linear polarizations. This was introduced in PIONIER by Bernard Lazareff, it maximizes flux of the the fringe pattern. This system uses Lithium Niobate crystal windows (hereafter Niobate) on each beam, the rotation of those windows around the crystal axis induces a differential OPD between booth polarizations and can compensate the fibers and IOBC birefringence.

The time consuming and delicate adjustment of the orientation of the Niobate was in a first step motorized using Pico motors (see figure 8). This avoid the daily enclosure opening for the alignment that affects the thermal stability and decrease the risk of incidents. Finally, the second step of a full automatic adjustment by software was implemented by Gerard Zins and Jean-Baptiste Lebouquin after the PIONIER recommissioning.

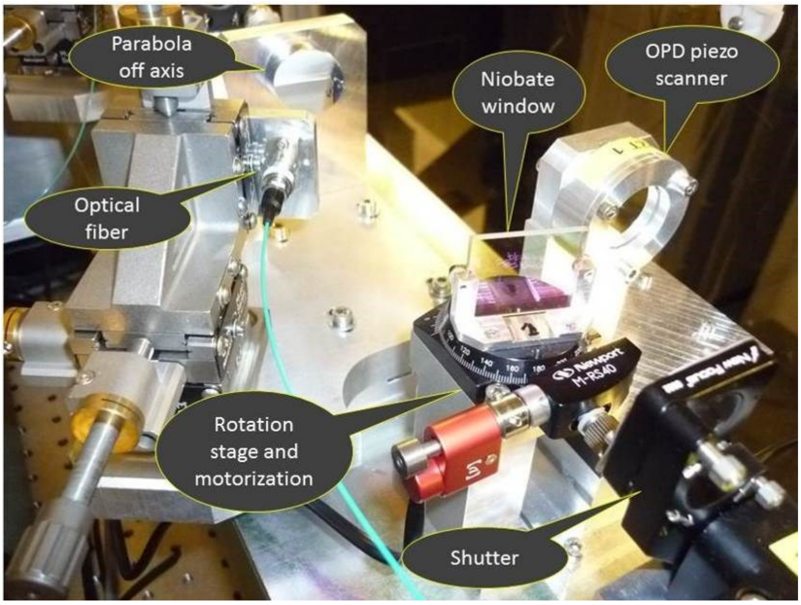

Figure 8. Niobate motorized rotation stage (Pico Motor 8353-RC New Focus) and fiber injection module.

- **IOBC alignment**

The purpose of this alignment is to ensure that the images of the outputs of the integrated optics beam combiner (IOBC), imaged by the relay optics, fall on the right pixels of the camera. This alignment is performed moving lateral and vertical position of the IOBC. Taking advantage of the PICNIC removal to install the RAPID detector, the two steeper motor channels of the filter wheels were allocated to the vertical and lateral translations of the IOBC.

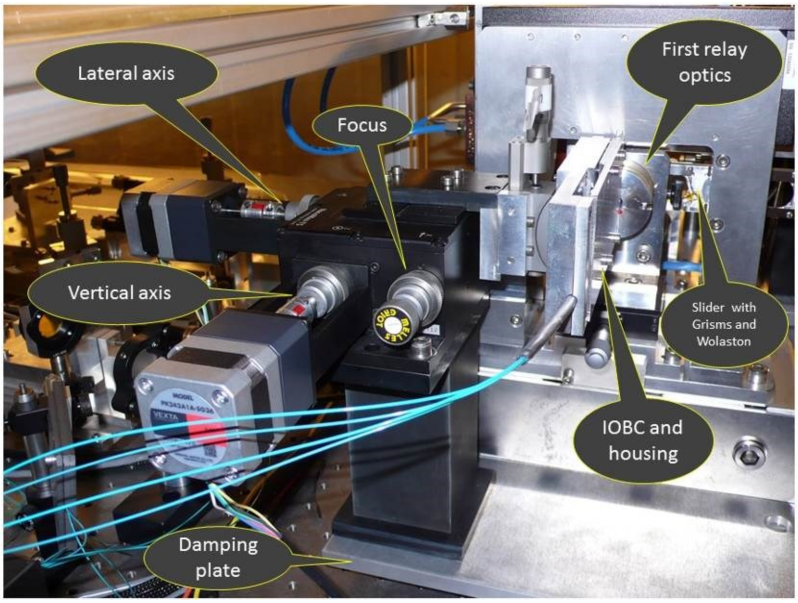

Figure 9. XYZ mount Nanomax-TS from Melles Griot motorized on two axis. Focus adjustment manual.

The automatic centering of the IOBC was implemented by software. Due to the small discrepancies of image positions between the two resolution modes (FREE, SMALL, LARGE), the IOBC was before always aligned for the dominant mode of the observing program planned for the night. The automatic centering now allows an optimization for the desired observing mode in real time.

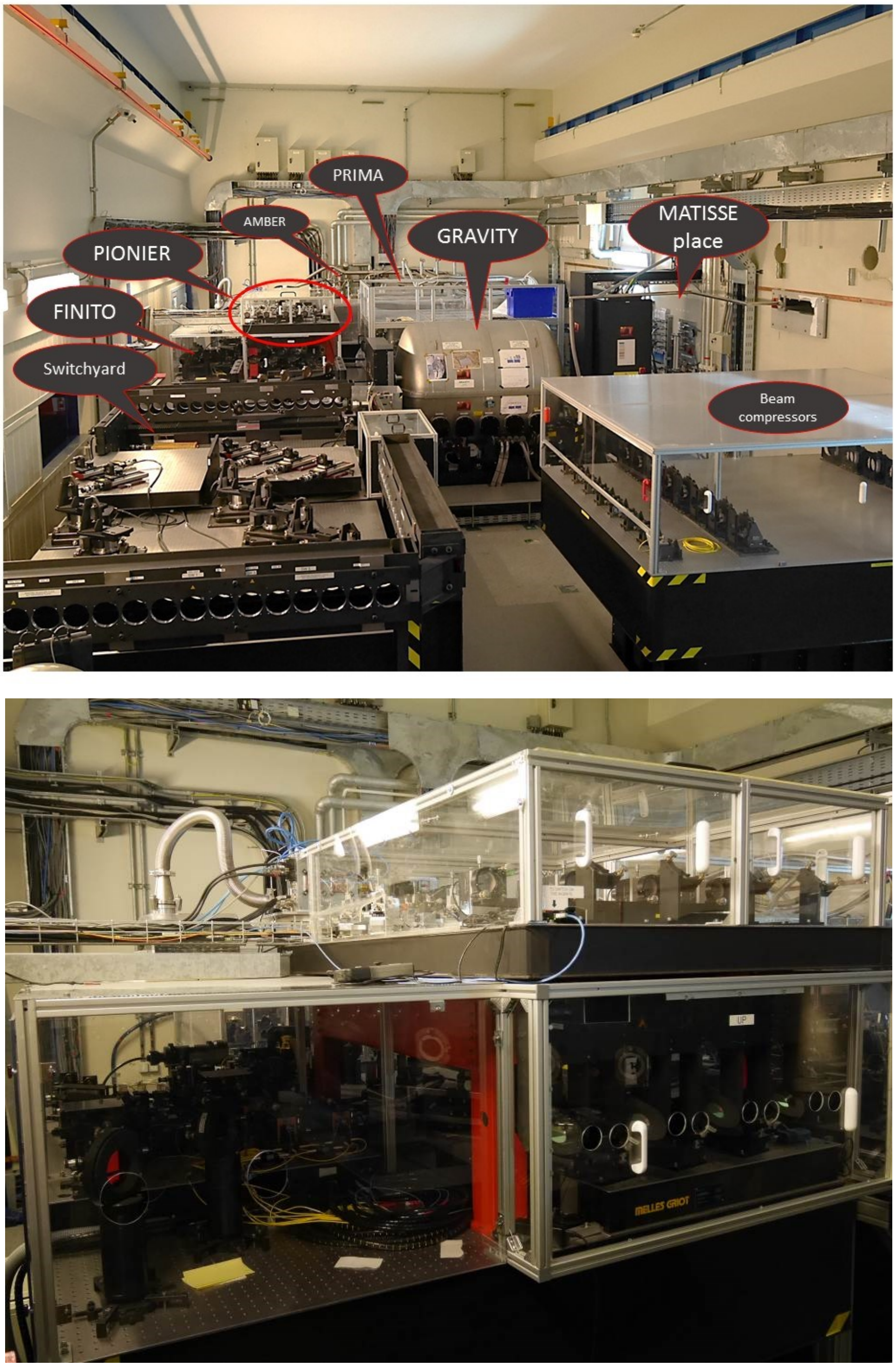

Figure 10. Views of the final implementation of PIONIER inside the VLTI laboratory above the FINITO table (2016).

4. RESULTS

PIONIER, was a VLTI visitor instrument from the Astrophysics Laboratory of Grenoble (LAOG). It was the most demanded VLTI instrument since 2014. The PIONIER 3D project is an answer to the interferometric community will to keep offering such a fruitful scientific instrument. It has been done by the Paranal Observatory in collaboration with the LAOG. This fast and low cost project to move the instrument, from a visitor to a permanent ESO instrument status, was done without impacting the VLTI infrastructure. PIONIER has been fully automated to decrease the operational workload, a mandatory constraint to be able to deal with one more instrument after the arrival of GRAVITY and MATISSE.

REFERENCES

[1] "First light of the VLT interferometer", ESO press release eso0111, 2001. http://www.eso.org/public/news/eso0111/

[2] C. Leinert, et al., "MIDI Combines Light from the VLTI: the Start of 10 µm Interferometry at ESO," ESO Messenger No 112, pp 13-18, 2003.

[3] M. Gai et al, "FINITO: the VLTI fringe tracker", Proc of SPIE, vol 5491, 2004.

[4] "Adding new colours to interferometry", ESO press release eso0410, 2004. http://www.eso.org/public/news/eso0410/

[5] "First light for the PRIMA instrument", ESO press release eso0829, 2008. http://www.eso.org/public/news/eso0829/

[6] F. Eisenhauer et al., "GRAVITY: observing the universe in motion", Proc. SPIE 8445-27 (2012).

[7] B. Lopez et al., "MATISSE: perspective of imaging in the mid-infrared at the VLTI", Proc. SPIE 8445-25 (2012).

[8] "Light from four telescopes combined at ESO's Paranal Observatory", ESO press release ann1081, 2010. http://www.eso.org/public/announcements/ann1081/#1

[9] "Light from all four VLT Unit Telescopes combined for the first time", ESO press release ann11021, 2011. http://www.eso.org/public/announcements/ann11021/

[10] J.-B. Le Bouquin et al., "PIONIER: a status report", Proc. SPIE 8445-17 (2012).

[11] S. Guieu et al., " RAPID: a revolutionary fast optical to NIR camera applied to interferometry", Proc. SPIE 9146-56 (2014).