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SHARK-NIR: from design to installation, ready to dive into first light

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ABSTRACT

SHARK-NIR is a near-infrared (0.96-1.7μm) coronagraphic camera with low-resolution spectroscopic capability designed to exploit the excellent performances, in terms of resolution and contrast, of the LBT Adaptive Optics system SOUL (recently commissioned). Second generation instrument of the LBT, SHARK-NIR left 5 years ago its paper and models realm to become a real working instrument, through realization and testing of single components at first and then the full AIV of the system. Its compact size is a consequence of the available volume and required stiffness, but shall not convince you of a simple opto-mechanical design, translating in requirements for all the interconnected fields of software, electronics, archiving, etc. The instrument is equipped with a cryostat containing the H2RG detector, several custom made optics and motors to operate the instrument, like de-rotator, wheels (to introduce filters, coronographic masks, prisms for spectroscopy), ADC stages, linear stages and actuators for calibration and alignment to star purposes. Its main science target is the detection and characterization of exoplanets, to be achieved through a set of different coronagraphic techniques. However, the analysis and study of protoplanetary disks, stellar jets, AGN, QSOs and solar system bodies are also foreseen scientific cases of the instrument. Coupled with its visible counterpart SHARK-VIS, it will offer the possibility to perform binocular observations in a wide wavelength domain (0.5μm to 1.7μm).
In this paper we will report the main steps that let SHARK-NIR become a real instrument with laboratory validated performances, including procurement and shipment, the lessons learned and the upcoming path towards commissioning, focusing on the coordination, interfaces and interactions of all the different involved fields, expertise and institutes of the consortium as well as of the hosting telescope.

Keywords: exoplanets, coronagraphy, ground-based, project management, procurement, shipment, instrumentation, commissioning

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1. INTRODUCTION

Although not exhaustive on all the managerial aspects of this project, this paper aims to address the 6 Ws of SHARK-NIR, leading the instrument from the original concept into a real instrument satisfying the foreseen scientific requirements and the useful lessons learned in the process: What is the instrument and what it is needed for (Why question), Who is the team behind it, Where did things take place, hoW we have arrived at being ready for its installation on the LBT and, finally, When things did and will take place. Although trying to divide those aspects in sections, they will be addressed in different sections, as they are physiologically interlaced.

2. WHY & WHAT - SHARK-NIR DESCRIPTION

SHARK-NIR is a near-infrared (0.96-1.7µm) coronagraphic camera, equipped also with a low-resolution spectroscopic channel, mainly dedicated to detection and characterization of exoplanets. It has been designed to exploit the extreme AO correction of SOUL, AO system of LBT, in order to achieve high resolution and high contrast, which are two key characteristics for exo-planets direct imaging. Furthermore, in order to increase the contrast, a few technical improvements have been included in the design: a set of different coronagraphic techniques[2][3] (Shaped Pupils, Four Quadrant Pupil mask and Gaussian Lyot), an internal tip-tilt loop for fast (1 kHz) residual jitter compensation and an internal Deformable Mirror (DM) for a local NCPA correction, through the phase diversity technique[4]. The local DM allows to avoid the use of the LBTO Adaptive Secondary Mirror (AMS) to compensate for NCPA related to SHARK-NIR, which would translate into SOUL pyramid WFS performance degradation. Furthermore, a dedicated post-processing pipeline has been implemented.

A peculiarity of the instrument in this science realm, when compared to other existing facilities, is its synergy with other instruments at LBT, in particular, LMIRCAM from LBTI, and the visible counterpart SHARK-VIS[5]. SHARK-NIR will be installed in the SX central gregorial focal station, as visible in the CAD view on the left of Figure 1, LBTI is located in the central area, while SHARK-VIS will be installed on the DX side. In this trinocular observation mode, all wavelengths from B to M band can be covered simultaneously, with advantages also for other science cases, such as the analysis and study of protoplanetary disks, stellar jets, AGN, QSOs and solar system bodies.

The main specifications of the instrument are hereafter summarized:

- **Wavelenghts**: 960-1700 nm; Y, J, H bands
- **FoV**: 18” x 18”
- **Detector:** Teledyne H2RG (although only a 1220 x 1220 pixel area is used)
- **Airy Radius @ λ = 0.96 µm:** 29 mas / 2 px (36 µm)
- **Plate-scale**: 14.5 mas/pixel
- Nominal **Strehl Ratio** (in all bands) > 98%
- **Star magnitude**: up to R=12
- **Observing modes** (4):
  - Imaging
  - Coronagraphic imaging
  - Long-slit coronagraphic spectroscopy
  - Dual-band simultaneous imaging

The compactness of the instrument main body (1.5*0.8*0.8 m), shown in Figure 1, originates from the available volume at the telescope and the stiffness requirements, but SHARK-NIR presents a complex opto-mechanical design. The optical path, depicted in yellow in Figure 1, consists of several mirrors (4 OAPs + 3 flat mirrors), an ADC, multiple optical components, the internal WFS loop to sense and correct jitter residuals, a DM to apply NCPA corrections and several motorized stages for operations and calibrations. The latter include seven motorized wheels, four allowing to switch between different observing mode and different coronagraph and three to change scientific filter.

Waveband does not include K-band, allowing the instrument to be kept at ambient temperature, obviously with the exception of the H2RG detector, whose dewar is visible in Figure 1. The complexity of the system, translates also in requirements for SHARK-NIR software (SHINS[6]), electronics, archiving, mechanical interfaces, … Further details of the system and of its science cases can be found in [1].

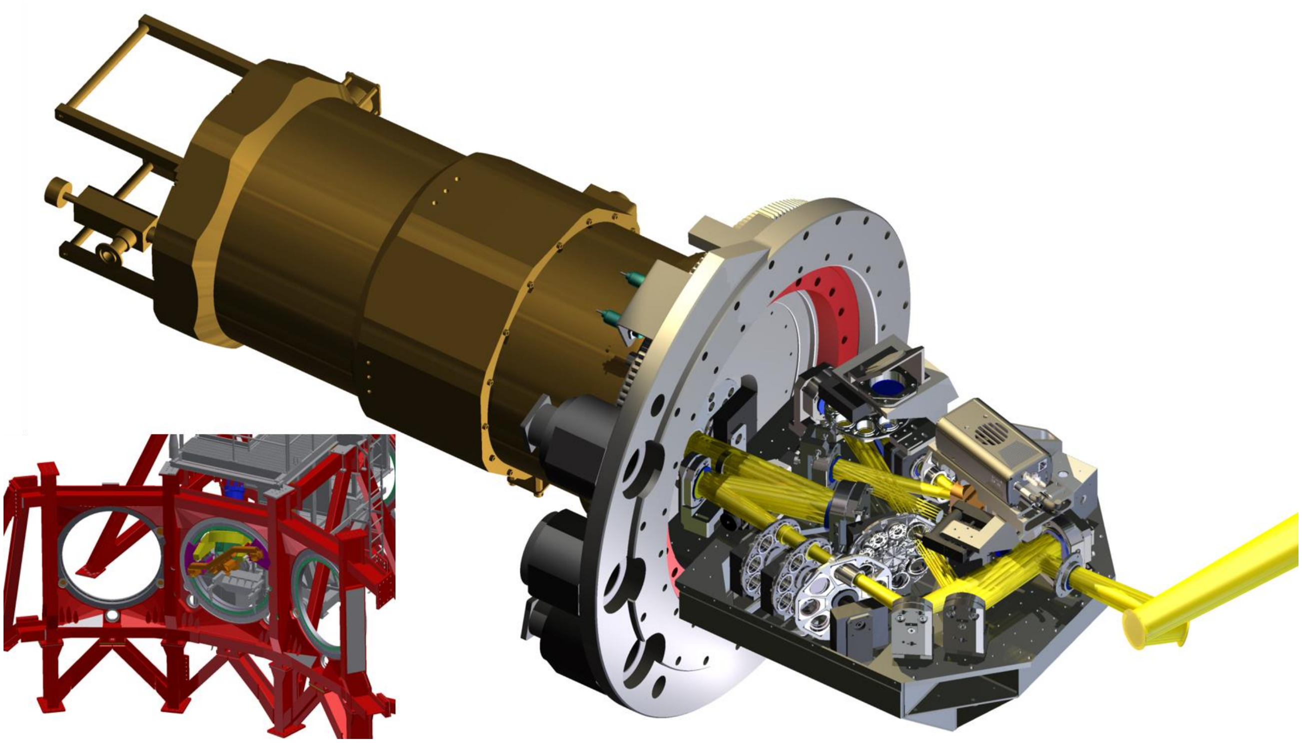

Figure 1: *Bottom-left*: CAD view of the location of SHARK-NIR instrument at the central Gregorian focal station on the SX side of the LBT. *Right*: SHARK-NIR main instrument CAD view: cryostat (bronze), derotator and populated optical bench.

3. WHO & WHERE -THE SHARK-NIR CONSORTIUM

The consortium is composed of four institutes, selected on the basis of their expertise in the related field:

- Steward Observatory (University of Arizona), for the scientific camera and for the interfaces to LBTI instrument;
- MPIA, for motor control electronics and software support;
- IPAG, for coronagraphy techniques;
- INAF, with the PI institute being Padova, involving the following observatories:
    - Padova (Project Office (PM, SE, Procurement), Optical design, Mechanical design supervision, Coronagraphic and instrument performance and simulations, AIV, ICS & SW, Data reduction)
    - Arcetri (AO/SOUL Interface)
    - Brera (Dispersive elements design)
    - Roma (Synergy with VIS Channel)
    - Trieste (Data archiving)

The science team is composed by about 100 astronomers from 25 institutes and is coordinated by INAF-Padova.

Furthermore, there is the telescope team (LBTO), crucial for the proper integration of the instrument in the very crowded designated area.

Part of the “hidden” factors to reach to the successful realization of the project were the coordination and smooth communication of the team people between two different time zones (CET and MST).

4. HOW – (SOME) PHASES OF THE PROJECT

As design phases have been discussed in previous papers [7], this section focuses the description of the following phases of the instrument, in particular, the procurement, the AIV, the shipment and the commissioning.

4.1 The procurement

After successful conclusion of the Final Design Review (FDR) and receiving the green light for construction of the instrument by LBT board, the procurement phase started. The work included preparation of all statements of work and technical specifications for the companies, followed by the acceptance performed in house after the delivery of the items and their documentation.

At FDR the procurement of all components had been included in the schedule shown in Figure 2 left, with timing obtained through iterations with a few companies on critical items and based on previous experience for the others. In the procurement planning we considered the use of multiple companies as risk reducer. This translated into contacting several companies and diversifying the orders between different companies, of course always considering the best balance of expertise, cost, quality, realistic delivery time. For direct comparison, in Figure 2 right are presented the actual dates and duration of the procurement performed by INAF, from which we can infer that while the estimated delivery time estimate was in general realistic, the placement of order date shifted more than expected. We can ascribe the latter mainly to the incoming funds availability, which did not follow the original estimated dates. A couple of optical items, the scientific filters and the ADC were more complicated to manufacture than expected, but companies and the SHARK-NIR team collaborated toward a result which was still allowing to reach the expected science performances. For scientific filters it required the involved companies to fine-tune their techniques and produce new items, thus delaying the work, while in the case of the ADC the originally selected substrate materials (N-FK58 + S-FPL51Y + F2HT) were identified during the manufacturing as the problem and the optical design was modified to switch toward materials easier to be worked in the required tight tolerances (S-FPL55 + N-PK51 + PBL1Y).

At FDR - estimate

Optical Bench parts procurement (incl. 20% contingency and shipping)	**332 days**	**Thu 08/06/17**	**Sun 16/09/18**
OAPs procurement	30 wks	Thu 08/06/17	Wed 17/01/18
Flat mirrors (FMs) and Narcissus procurement	3,5 emons	Thu 08/06/17	Thu 21/09/17
Window procurement	3,5 emons	Thu 08/06/17	Thu 21/09/17
Scientific Filters procurement	12 emons	Thu 08/06/17	Sun 03/06/18
BS procurement	6 emons	Thu 08/06/17	Tue 05/12/17
DM procurement	5 emons	Thu 08/06/17	Sun 05/11/17
Camera procurement	6 emons	Thu 08/06/17	Tue 05/12/17
WFS computer	5 emons	Thu 08/06/17	Sun 05/11/17
Low resolution prism procurement	4 emons	Thu 08/06/17	Fri 06/10/17
ADC optics procurement	4 emons	Thu 08/06/17	Fri 06/10/17
Wollaston Prism procurement	10 wks	Thu 08/06/17	Wed 16/08/17
Procurement of Calibration Unit pa	3,5 emons	Thu 08/06/17	Thu 21/09/17
Motorized stages procurement	3 emons	Thu 08/06/17	Wed 06/09/17
Mirrors mounts procurement	4,5 emons	Thu 08/06/17	Sat 21/10/17
Mechanics - Optical bench procurement	7 emons	Thu 08/06/17	Thu 04/01/18
Mechanics and stages integration	1 emon	Thu 04/01/18	Sat 03/02/18
Mechanics - Deployable arm procurement	4 emons	Tue 20/03/18	Wed 18/07/18
Mechanics - mount for telescope + handling for flexure + handling for installation	5 emons	Tue 20/03/18	Fri 17/08/18
ND Filters procurement	4 emons	Tue 20/03/18	Wed 18/07/18
Dichroic procurement	6 emons	Tue 20/03/18	Sun 16/09/18
Spectroscopic slits procurement	4 emons	Tue 20/03/18	Wed 18/07/18

At end of procurement -real

Optical Bench parts procurement	**853 days**	**Wed 02/08/17**	**Mon 09/11/20**
OAPs procurement	37 wks	Wed 02/08/17	Tue 01/05/18
Flat mirrors (FMs) and Narcissus procurement	5 emons	Mon 11/12/17	Thu 10/05/18
Windows procurement	3,64 emons	Mon 08/01/18	Fri 27/04/18
Scientific Filters procurement	21 emons	Wed 03/01/18	Wed 25/09/19
BS procurement	3 emons	Mon 18/12/17	Sun 18/03/18
DM procurement	3,38 emons	Fri 11/08/17	Mon 20/11/17
WFS Camera procurement	5,4 emons	Wed 18/10/17	Thu 29/03/18
WFS Real time computer and test bench	12 emons	Mon 11/12/17	Thu 06/12/18
Low resolution prism procurement	4 emons	Mon 08/01/18	Tue 08/05/18
ADC optics procurement	15 mons	Mon 11/12/17	Mon 18/03/19
Wollaston Prism procurement	3 emons	Thu 15/11/18	Wed 13/02/19
Procurement of Calibration Unit parts	3,5 emons	Mon 08/01/18	Mon 23/04/18
Defocusing lens procurement	2,11 emons	Tue 20/02/18	Tue 24/04/18
Motorized stages procurement (1x type)	1,08 emons	Fri 04/08/17	Tue 05/09/17
Motorized stages procurement (remaining)	2 mons	Mon 20/11/17	Fri 26/01/18
Motorized stage for dichroic (depl. arm)	6 mons	Fri 08/06/18	Thu 06/12/18
Spare stages procurement	3 mons	Wed 15/05/19	Tue 27/08/19
Mirrors mounts procurement	6,46 emons	Wed 13/09/17	Mon 26/03/18
Mechanics - Optical bench procurement	6,35 emons	Tue 03/10/17	Wed 11/04/18
Mechanics and stages integration (at company premises)	1 emon	Wed 11/04/18	Fri 11/05/18
Mechanics - Optical bench modification	3 emons	Sat 01/09/18	Fri 30/11/18
Mechanics - Deployable arm procurement and mount for tel	10 emons	Mon 09/04/18	Sun 03/02/19
Mechanics - handling for flexure + handling for installation	8 emons	Thu 01/11/18	Sat 29/06/19
ND Filters procurement	3 emons	Tue 11/08/20	Mon 09/11/20
Dichroic procurement	6,08 emons	Mon 21/05/18	Mon 19/11/18
Spectroscopic slits procurement	4 emons	Fri 01/06/18	Sat 29/09/18

Figure 2: SHARK-NIR INAF procurement dates and delivery times estimated at FDR time *(left)* and the actual ones *(right)*

As lessons learned from this activity, are certainly to be included to start as early as possible any iteration with the companies, to understand actual feasibility and to evaluate the impact in terms of cost and deliver time. At the same time, it is crucial to clearly specify and discuss with the companies all the documentation/tests deliverable, to avoid the need to perform extra tests in house or to lose a significant amount of time in trying to retrieve the needed information from what can be obtained *a-posteriori* from the company. On the positive side, our strategy to have procurement involving multiple companies, together with AIV flexibility, supported us when facing a few issues, in particular the late arrival of funds and the public administration bureaucracy obstacles, which we had to deal with in some occasions.

4.2 The AIV

A useful working schedule was defined with the activities to be performed in order to have a working instrument satisfying the scientific requirements, with particular attention dedicated to the AIV activities, from component level test, alignment of single components, integration, using also engineering GUIs, to the overall evaluation of performances, and tests of the final software and templates. Wherever possible, the schedule was defined in a flexible way to be able to overcome any limitation due to late arrival of some components or any upgrade needed on instrument in case of discrepancies. The fully populated aligned optical bench obtained after AIV completion is shown in Figure 3. This AIV phase was followed by flexure tests, to simulate gravity variation of LBT telescope, realized thanks to specific dedicated handlings and tools, visible in Figure 4, where the full instrument is assembled. Characterizing the optical quality on and off-axis we obtained excellent results, with WFE residuals lower than 30 nm, namely a Strehl ratio above 98% in J Band for all configurations (but one specific derotator orientation). Details on AIV procedures and results of the obtained performances can be found in [8].

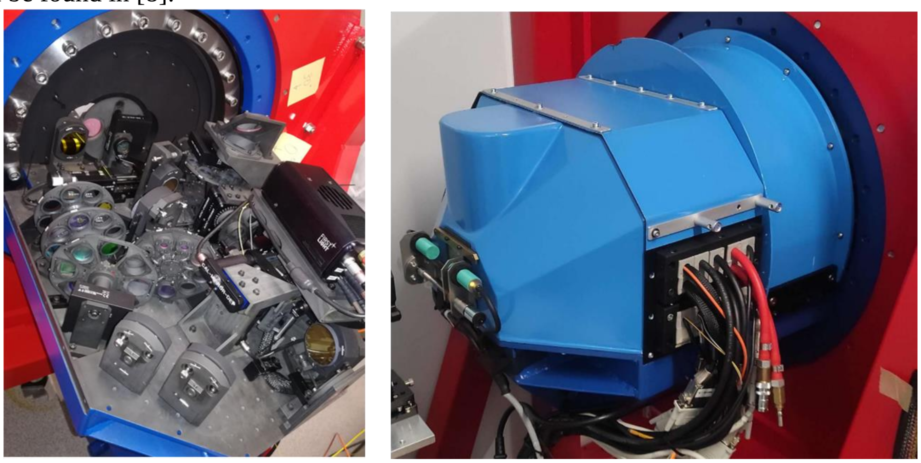

Figure 3: *Left*: Fully populated and aligned SHARK-NIR optical bench after AIV completion. *Right:* the carter covering the bench.

Figure 4: fully assembled SHARK-NIR instrument (scientific camera, optical bench, bearing, deployable arm, mounting structures) in its flexure tests configuration in the laboratories of INAF-Padova. The red structures are mock-up representing the LBT bearing, to which the instrument will be connected.

4.3 The shipment

The instrument was not shipped as a full unit, with the main driver of the choice being to limit as much as possible any internal misalignment or risk during the shipment. This decision was also eased by the fact that some parts of SHARK-NIR have to be directly connected to the telescope (e.g. the deployable arm containing dichroic and flat mirror to deviate the beam toward our instrument), so, essentially just the scientific camera was disconnected to the rest of the instrument.
This latter was done also in consideration of the fact that the scientific camera had been temporarily imported from the University of Arizona to INAF-Padova and this temporary admission policy requires the received content to be shipped back in the exact same conditions.
We selected air shipping between Europe and USA, despite its higher costs, to reduce time of shipment and to increase safety (shorter exposure to atmospheric agents).
The shipment was divided into two tranches, since the camera, together with its electronics and workstation had to be shipped in advance with respect to the rest of the instrument parts, handlings, tools, electronics, workstations and all spare components. This occurred because the camera required some internal modification and verification at Steward Observatory premises before being transported to the LBT summit.
One of the main activities involving the shipment was the selection and procurement of the proper boxes required. Some of the boxes being custom made, such as the one containing the aligned optical bench (Box #1), which is a double-box with special dumping system, visible in Figure 5 left. Mechanical parts were packed into US-certified wooden box and sensitive components packed either in aluminum boxes protected by foam or inside custom made boxes with pre-cut foam, such as Box #3 containing the deployable arm components, visible in red rectangle of Figure 5 right. All boxes need to be movable by forklift and for this reason some of them had to be tied onto US-certified pallets. Before shipment all boxes or pallets were equipped with tilt and shock sensors to be able to inspect any possible damage as soon as they were delivered. Box summary containing details on content, dimension, material and fragility level are presented in Table 1. A detail list of all boxes content was prepared both to estimate final value of shipment and to be able to ease logistics once at the telescope.

Table 1: SHARK-NIR shipment boxes content description and main physical characteristics (dimensions, weight, material, content fragility level). Numbering is not consequential, as four boxes were removed with respect to the original plan to reduce costs.

Box #	Main content description	Size (l*w*h) cm	Weight kg (content+box)	Material	Type	Fragile level
1	Bench	124*104*122	239+256.5	Wood	Custom - Tomelleri	High
2	Cryostat/SCICAM	67*66*126	65+50	Wood	Custom Steward Observatory	High
3	Deployable arm	166*75*32	99+65	Multi-layer panel and HPL	Custom BottegaQuadra	High
5	Supporting shelves	128*108*61	320+77	Wood	Custom	Low
6	Installation handlings	223*111*83	230+120	Multi-layer panel and HPL	Custom BottegaQuadra	Low
7	Laboratory & parking handling	128*108*146	222+132	Wood	Custom	Low
9	Equipment for Cryostat/SCICAM	90*76*60	40+25	Plastic	Pelican	High
10	Mocon and DM electronics & cables	80*59*60	54	Aluminum	Zarges Eurobox 239l	High
11	Electronics assembled shelves and cables	80*59*60	48	Aluminum	Zarges Eurobox 239l	High
12	Spare parts (optics, fibers); Alignment tools and supplies	80*59*60	71	Aluminum	Zarges Eurobox 239l	High
13	Spare parts (Motorized stages, Mocon and all cables)	80*59*60	48	Aluminum	Zarges K470 239l	High
16	Workstations	80*59*60	68	Aluminum	Zarges Eurobox 239l	High

Figure 5: *Left:* Custom double-box with dumping system to ship the aligned optical bench (Box #1). *Right:* boxes after arrival at LBT premises. Tilt and shock sensors are visible. *Red square*. Custom box with pre-cut foam to transport the deployable arm (Box #3).

Both shipments transited from Milan, Paris and Los Angeles airports and reached their destination in less than a week. The first shipment, including the camera and its tools, left the Padova observatory premises on July 13th and reached Steward Observatory premises on July 17th. The second shipment, the rest of the instrument, spare parts and tools, left on June 17th and reached LBT Base-camp, in Safford, on June 23rd. Customs clearance was likely accelerated by the fact that the shipping company had been in contact with brokers in advance to make sure the pro-forma invoices were containing all needed information (proper description of sender and addressee, boxes description, HS codes, reference to any peculiar situation, e.g. indication of special law allowing admission free of duty, ITAR protected equipment,…). A couple shock sensor for the vertical direction were retrieved triggered, but thanks to the inner foam and proper packaging, this did not translate into an unfortunate event.

4.4 The commissioning

Another planning activity has been the detailed definition of the commissioning plan. SHARK-NIR commissioning has been divided in four phases, including multiple runs, two of them of pre-commissioning activities, meaning day-time activities at the telescope and two of actual night-time commissioning. They are briefly summarized hereafter:

Phase 1: day-time activities in the lab
  Pre-Com-Run-1 (June 26th-July 12th 2022): instrument unpacking, re-integration, functional checks and performance verification in the lab

Phase 2: day-time activities on the telescope
  Pre-Com-Run-2 (14 days): instrument installation and alignment to LBT
  Pre-Com-Run-3 (11 days): day-time test and characterization

Phase 3: night-time activities
  Com-Run-1 (7 nights): Direct Imaging on sky verification
  Com-Run-2 (3 nights): Coronagraphic Imaging on sky verification
  Com-Run-3 (4 Nights): Dual Band Imaging on sky verification
  Com-Run-4 (3 nights): Coronographic Spectroscopy on sky verification

Phase 4: science verification
  SN-Run-1 (21 Nights): main SHARK-NIR science objectives have been included and are visible in in Table 2 right.

For each run we devised list of tasks, with estimate duration and detailed content, identifying prerequisites, procedures, success criteria and when/if telescope support was needed. The Phase 1, Pre-com-Run-1 activities are shown in Table 2 left. They took place in the laboratories of LBT between June 26th and July 12th. A few pictures showing boxes opening and installation onto handling, cabling inside the clean tent for functional verification and camera focus adjustment, are shown in Figure 6.

Table 2: *Left* Phase 1, Pre-Com-Run-1 detailed list of activities R*ight*. Phase 4 (science verification) list of foreseen activities

#	Activity Name	Duration (days)
P1.1	Inspection of the closed boxes	0.5
P1.2	Opening of boxes in LBT Hall, inspection of the contents and installation of units on their handlings	1
P1.3	Installation of SHARK-NIR HW and electronics in clean room	1.5
P1.4	Cable in the instrument, power on, install workstations, connect to LBT network, and cryostat cooldown preparation	1
P1.5	SW & HW functional checks and cryostat cooldown	1
P1.6	SCICAM refocussing	1.5
P1.7	Science detector calibrations	0.5
P1.8	Complete system functional verification, filter artifacts/defects verification, NCPA measurement, and internal tip-tilt loop verification	1.5
P1.9	Testing of SCICAM image grabbing by SOUL-AO	0.5
P1.10	Internal alignment verification	1
P1.11	Instrument re-alignment (minor modifications)	2
P1.12	Verification of the contrast for coronagraphic masks	1
	Total without contingency	13 days
	Total with 10% contingency	**14 days**

#	Activity Name / Observing Case	Duration (nights)
P4.1	Exo-planet: Giant planets and brown dwarfs in SFR, stellar associations, & young open clusters	8
P4.2	Exo-planet: Astrometry	1
P4.3	Exo-planet: Spectroscopic Characterization of known sub-stellar companions	3
P4.4	Disk: High-contrast images of circumstellar disks	3
P4.5	Disk: Coronagraphic imaging of stellar jets	0.5
P4.6	Disk: Jets investigated with long-slit spectra	0.5
P4.7	Extragalactic: QSO & AGNs	3
P4.8	Solar system: Size and shape of main-belt astroids	0.5
P4.9	Solar system: Surface heterogeneity of trans-neptunian objects	0.5
	Total duration with 5% contingency	**21** nights

Figure 6: Pictures of Pre-Com-1 activities. *Left:* Optical bench removal from Box #1 and installation onto its handling. *Center:* SHARK-NIR instrument cabled inside LBT clean tent. A temporary lab camera was used in place of the scientific camera. *Right:* Scientific camera installation after its correct focus position has been determined.

While details on the activities and results can be found in [1], let me give here a few highlights:

- Workstations were installed in the server room and configured to the LBT network operations.
- Internal alignment verification allowed verifying that transportation precautions were sufficient to maintain the alignment. On-axis PSF WFE residuals retrieved were of the order of 30 nm, similarly to data taken in Padova.
- When correcting any residual aberration with the internal DM, through the hardware upgraded phase diversity technique[1], we achieved a residual WFE lower than 10 nm (see Figure 7).

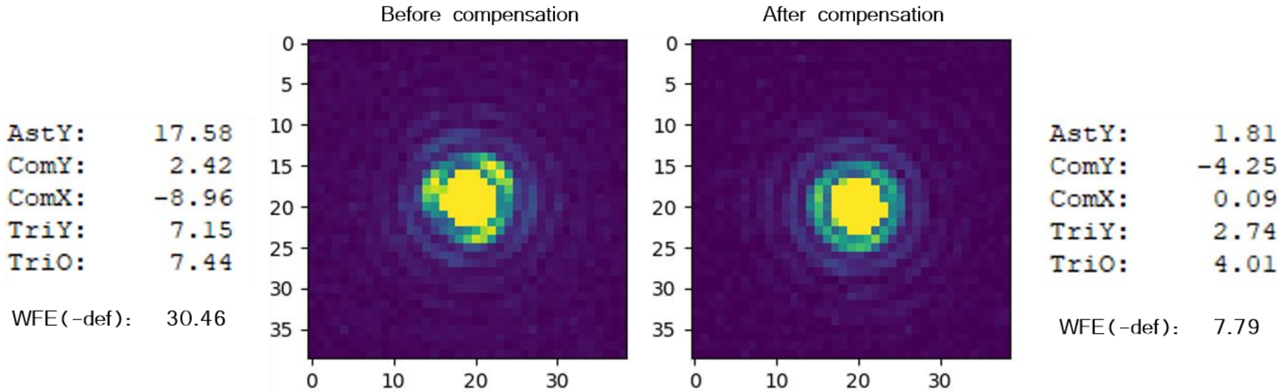

Figure 7: *Left.* On-axis PSF measured with a flat DM, with an overall WFE around 30 nm. Aberrations retrieved using the PD technique are shown. *Right.* On-axis PSF after applying by means of the DM the aberration compensation previously retrieved. Overall WFE drops down to around 8 nm. Defocus term was removed, as errors in the analysis is due on the used technique itself. Units are nm.

5. WHEN -THE MILESTONES AND THE SCHEDULE

SHARK-NIR project was proposed in 2014 in the framework of the *"Call for Proposals for Instrument Upgrades and New Instruments"* by LBTO. A few months later it was selected and at the beginning of 2016 it passed the Preliminary Design Review. After successful conclusion of the Final Design Review, including an addendum delta-review of three months, requested by the panel board to address a few critical aspects and include some design upgrades into the system (such as the DM for NCPA local correction), the instrument received green light for construction in July 2017. Procurement phase, described in Section 4.1, started immediately and AIV at component level a few months later, as soon as the first items were received. In January 2018 most activities were sensibly slowed-down or delayed because we noticed discrepancies between the telescope CAD model and reality, which would have prevented SHARK-NIR to fit in the free envelope. As a consequence, a full re-design of mounting structure was needed, delay in mechanics procurement occurred and totally new installation procedures and tools had to be devised. In February 2019 system AIV started. The scientific camera was received and integrated onto the instrument in February 2020, a few weeks before the beginning of INAF-Padova institute lockdown, due to COVID19 pandemic. AIV ended in January 2022, after flexure tests were completed, although further tests and software improvements continued in the following months. The review of documentation by a LBTO panel started in December 2021 and PAE review was concluded by a demonstration of software ability and performances achievable by the instrument, which took place live (but remotely), on March 16th, 2022. After receiving an excellent review outcome by the panel and the formal LBT board approval at the end of April 2022, shipping was confirmed. Despite some last minute unfortunate events, such as the damaging of the DM coating at the end of May 2022 and the subsequent very fast procurement, characterization, integration and alignment of a new DM, on the middle of June 2022 the instrument left Padova directed toward the LBT telescope. It was safely delivered about a week later and the first pre-commissioning run immediately started (more details in sections 4.3 and 4.4). Installation to the telescope is pending LBT schedule definition but is foreseen for the next semester, probably in October 2022.

With respect to the very-tight original schedule foreseen at FDR, beginning of commissioning occurred roughly three years later than planned. In sight of future projects, it is crucial to make an analysis to better understand the reasons leading to such a delay.
One major delay (of the order of 9 months) is ascribable to the mechanical interference issues discussed at the beginning of this section and the main lesson learned is to include a personal site inspection in the case of very reduced clearances. The second major delay is, instead, the impact of COVID19, which affected SHARK-NIR just after integration of the scientific camera, in a moment where we still needed to be physically present for alignment of components, other than refilling the camera with liquid nitrogen. Even after the first 3 months of total closure, in the following two years, the institute implemented strict rules, following the Italian legislation, reducing the number of people allowed to enter in the observatory premises or totally limiting them for a non-negligible number of weeks. Also, it needs to be underlined how COVID19 affected also telescope activities, delaying the foreseen commissioning of other instruments and regular

operations, maintenance, approved programs. Considering the points just mentioned, although it is hard to exactly quantifying the impact in terms of schedule delay, a reasonable estimate is 15 months.

We are left with about a year of delay, which is not ascribable to unpredictable circumstances and need further analysis. One candidate could be the procurement activities, however its impact is limited. In fact, although the procurement effort itself was larger than expected and funds arrival was delayed, the procurement strategies were continuously optimized and successfully worked minimizing delays, as described in Section 4.1. We have identified three main aspects being major responsibles in this delay: the over-allocation of FTEs, a key Work-Package (WP) manager leaving the project in a critical moment and the coronagraphic techniques. The first one is mainly related to the involvement of team people (with relevant roles in SHARK-NIR) on large and extremely large telescope projects (again, with relevant roles), which occurred after FDR. Extremely large projects design and construction phases are somehow draining the existent basin of experts in the astronomical instrumentation community and new resources with proper background to be formed are hard to find and of course needing time. This delay was mitigated with project priorities inside the institutes, but still had a relevant impact. The second one is the fact that the SW/ICS WP manager left the team in the beginning of 2021, before being able to properly handover to its substitute. The third is an underestimation of complexities in the non-standard coronagraphic techniques we are using and the highest goal we have set in terms of contrasts, therefore being able to reproduce in reality what happens in simulations required more time, more analysis and more tests than expected.

6. CONCLUSIONS

Second generation instrument of the LBT, SHARK-NIR left 5 years ago its paper and models realm to become a real working instrument, through procurement and testing of single components at first and then the full AIV of the system, concluded verifying that the expected requirements were met and the expected performances could be achieved. Shipment to the telescope and performance verification in clean room have occurred exactly in a month timeframe between mid June and mid July 2022 and the first light is foreseen in 2023, after installation at the telescope and day-time characterization, following a detailed commissioning strategy, with actual dates pending telescope confirmation. Although being a compact instrument, it presents a complex opto-mechanical design and an international team spread over two countries, thus, we believe that the description of phases and the lessons learned in this paper can be useful insights for other large telescope and extremely large telescope instrumentation developments.

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