The ESO Paranal Instrumentation Programme

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ABSTRACT

The Paranal Instrumentation Programme is responsible for planning and delivering the instruments and the associated infrastructure needed to keep the VLT and La Silla Observatories at the forefront of ground-based astronomy. The VLT second generation instruments KMOS, MUSE and SPHERE have been delivered and are in operations, GRAVITY is under commissioning at the renewed VLTI facility. The Adapative Optics Facility is moving towards completion, as well as the high resolution spectrograph ESPRESSO and the VLTI second generation instrument MATISSE. The mid-IR imager and spectrograph VISIR has been upgraded, and a major upgrade of the CRIRES spectrograph is under way. Finally, two new Multi Object Spectrographs projects have started, one for the VLT (MOONS), one for the 4M VISTA telescope (4MOST), and two new instruments for La Silla, (SOXS and NIRPS) fully funded by the community, are being agreed. The Programme follows a roadmap that foresees one new instrument/project or one upgrade starting every year. Active management, cost to completion and risk policy are in place.

Keywords: IR and optical ground based instrumentation, Paranal Observatory

1. INTRODUCTION

With the construction of the E-ELT, ESO has organized its instrumentation effort in different programmes. The Paranal Istrumentation Programme has been presented, with its strategic view and roadmap, at SPIE in 2012 and 2014 [1,2]. We are now in the full development of the first phase, in which the second generation VLT/I instruments need to be completed, and new projects are started, still keeping as much as possible the balance between specialised instruments and workhorse instruments, with the latter covering a wide range of scientific interests. In the past year ESO organized a discussion within the community on the mid and long term scientific strategy for Paranal. The outcome includes the following, preliminary recommendations:

Epoch 1: 2016 - 2020

a) Deliver GRAVITY by 2017 to observe the periapsis of S2, providing reliable, high- performance VLTI infrastructure and robust fringe tracking

b) Deliver AOF, ESPRESSO and CRIRES+ by 2018

d) Establish development plan for the VLTI (VLTI White Book, mid-2016)

e) Deliver MATISSE, ERIS and MOONS

f) Deliver new instrument for the NTT

j) Develop upgrade and replacement plan (VLT and VLTI), and

k) Select and design AO instrument.

Epoch 2: 2021 - 2025

a) Fully exploit the by-now existing VLTI infrastructure by expanding its instrumentation

b) Upgrade and replace VLT science capabilities, as defined in the upgrade plan

c) Deliver 4MOST to VISTA

d) Design and deliver AO instrument to VLT, and

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e) Encourage visiting instruments for VLT and VLTI.

With respect to the past, more emphasis is now given to maintain and upgrade the existing instrumentation, so the current plan foresees that approximately one new instrument and one instrument upgrade can be initiated every two years. Interspersing upgrades and new facilities shall in addition balance the ESO resources, reaching after ~2019 a quasi steady state with 6-8 projects running at any time. However, since the programme uses all the available resources, any increase of scope, delay or overspend must be accommodated within the resources available by either re-phasing or de-scoping the existing projects, or by shifting the start of new ones. The start of a new project is possible only after current projects are completed. As examples, in the pat year scientific and programmatic priority has been given to the Galactic Centre S2 event, and therefore to the completion of GRAVITY. This brought the decision of shifting some AOF activities by a few months. In the following, the status of the projects is given.

2. STATUS OF THE PROGRAMME

The last two years witnessed the full operations and optimisation work of three major 2nd Generation instruments: KMOS, MUSE and SPHERE, and the final commissioning and Science Verification of the upgraded VISIR. GRAVITY has been installed and commissioned in spectroscopic mode, after most of the VLTI infrastructure work has been completed and the VLTI laboratory has been closed for six months. The first two units of the AO system for GRAVITY have been installed. All the main components of the Adaptive Optics Facility have passed Preliminary Acceptance Europe and they have been or are going to be integrated and tested in Paranal. All other projects made significant advances. Within the ERIS project, the upgrade of SINFONI[3] has been completed.

2.1 Instruments in Operations or in Commissioning

MUSE[4]

MUSE (Multi Unit Spectrograph Explorer) is an Integral Field facility for the VLT. With a FOV of 1x1 arcmin, fine sampling, intermediate spectral resolution and large spectral coverage in the visible, it uses an advanced image slicer, twenty-four parallel spectrographs and a large detector area. In addition, MUSE will work assisted by the AOF, which will further enhance its performance.

The instrument has been offered since October 2014 and has excellent performance with throughput, peaking above 35% end-to-end, high image quality. The final configuration will include the GLAO correction on the large field and the instrument's Narrow Field Mode with the AOF. The long-term intervention plan to solve the detector noise is almost completed. Following a re-alignment of some spectrographs, remaining channels will be adjusted to improve the system sensitivity to thermal changes.

SPHERE[5]

SPHERE (Spectro-Polarimetric High-contrast Exoplanet Research) is able to detect faint objects very close to a bright star, reaching giant planets. In addition to high Strehl ratio, the SPHERE AO system is designed to attenuate the light of the central bright star and subtract the residual speckle halo. SPHERE incorporates three science instruments that efficiently reduce speckle noise and cover the visible and Near Infrared (NIR) spectral range: a dual imaging camera (IRDIS), the NIR integral field spectrograph (IFS) and the visible polarization instrument (ZIMPOL).

After a successful commissioning, SPHERE was offered for Observing in April 2015. The excellent performance and contrast (10^{6}) have been confirmed. Several actions have been adopted to optimise the system, that provides quite spectacular results.

The lifetime of the High Order Deformable Mirror (HODM) which currently has 18 (out of 1377) dead actuators is a concern. Since February 2015 there has been no further loss of actuators, nevertheless, a plan for the development of a new HODM has been prepared. A study is also being carried out to investigate the causes of bad images that sometimes form in low wind conditions, and the first results indicate the origin to be in the radiative emission from the UT spider.

VISIR Upgrade[6]

This upgrade optimises the performance of VISIR to enhance its scientific output. The approved project combines hardware upgrades and improved software support as well as enhancements of the science operations of VISIR, including the procurement and installation of a Water Vapour Monitor.

All but one of the upgrade steps (conducted in 2012) had been fully successful. The key element, however, the replacement of the detectors by larger 1k x 1k Si:As Aquarius arrays (a new development at Raytheon funded by ESO), did not result in the expected improvement of performance. The shortcomings of the Aquarius arrays and its root cause, which was diagnosed by ESO have been described separately[7]. Since the observed excess low frequency noise (ELFN) is inherent to the design of the device, the problem was addressed by introducing fast chopping (M2 with field stabilisation) on UT3 to limit the impact of the ELFN on the on-sky sensitivity. In April 2015, VISIR entered science operations with imaging and spectroscopy modes. Coronography, burst mode and Sparse Aperture Sampling modes were commissioned at the beginning of 2016 and science verification followed.

GRAVITY[8]

GRAVITY is a four beam combination second generation instrument for the VLTI. Its main operation mode makes use of all four 8m Unit Telescopes to measure astrometric distances between objects located within the 2" field-of-view of the VLTI. With the sensitivity of the UTs and 10μas astrometric precision, it will allow measurement of orbital motions near the Galactic Centre with unprecedented precision. Other modes of the instrument include imaging and the use of the 1.8m Auxiliary Telescopes. GRAVITY required a number of modifications to the Paranal infrastructure to be hosted in the VLTI laboratory together with MATISSE and to obtain its best performance.

The GRAVITY Beam Combiner Instrument (BCI) was installed on schedule in October 2015 in the VLTI laboratory (which was duly prepared in the 6 months shut-down period) and successfully commissioned with the ATs, showing superb performance for the fringe tracker. It has been offered for observations with the ATs for the next period. The coudé AO system (CIAO) layout has been re-designed. The first two CIAO systems were shipped to Paranal, re-assembled, mounted and commissioned; the 3rd unit has been packed and the last one is being integrated in Europe.

2.2 Projects currently under development .

MATISSE[9]

MATISSE (Multi-Aperture mid-Infrared SpectroScopic Experiment) is a four beam-combiner 2nd Generation instrument for the ESO VLTI, designed to be sensitive from the L to the N band. MATISSE's multi-way combination will provide a capability to create simple images at interferometric resolution of a wide range of targets.
The instrument is advanced in the integration and test phase.
In the past two years a substantial shift in schedule were produced by delays in the delivery of optical components and by high humidity in the laboratory, which damaged the detector electronics. The laboratory has now been upgraded and re-commissioned, and the test and AIV plans updated accordingly.

ESPRESSO[10]

The Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations (ESPRESSO) is a super-stable Optical High Resolution Spectrograph for the combined coudé focus of the VLT. It can be operated using either one of the UTs or by collecting the light from the 4 UTs simultaneously.
All the subsystems of ESPRESSO are in full integration. All the coudé train interfaces have been installed. The vacuum vessel and bench are under vacuum tests. The blue detectors have been fully tested. All the spectrograph optics (except the cameras) have been received, as have most other subsystems. The project is proceeding at full speed, but two optical components suffered delay from the manufacturer: the coudé prisms, which are now on the critical path for the planned installation, and the blue camera optics. PAE is now expected in December 2016.

AOF [11]

The Adaptive Optics Facility (AOF) consists in a new M2-Unit hosting a Deformable Secondary Mirror (DSM) with 1170 actuators, four Laser Guide Stars (4 x 20 W Sodium beacons) launched from the telescope centerpiece and two wavefront sensor systems (GALACSI and GRAAL) to provide users with optimised adaptive modes with the MUSE and Hawk-I instruments. This effort is also a pathfinder towards the E-ELT design. A major upgrade of UT4 took place in order to accommodate the AOF. A 'telescope simulator' called ASSIST, for the end-to-end testing in Europe, was part of the project.

Activities in Europe are nearly complete, and the emphasis has shifted to Paranal, where several members of the AOF team have been temporarily relocated. All the main milestones for all sub-components took place in Europe and the modification works of the Unit Telescope 4, that will host the facility, have been completed.
The four Laser Guide Stars Units (LGSU) have been mounted on the telescope and successfully commissioned. In addition, a combined test of GRAAL with LGSU#1 took place and was very successful. The Laser beacon was acquired by the WFS of GRAAL and allowed testing part of the acquisition sequence and fine-tuning/debugging of a number of issues. The GALACSI system has been also fully tested in Europe, with excellent laboratory performances. The GALACSI performances are consistent with, or slightly exceeding the expected performance. The last task in Europe before shipping the DSM to Paranal, is the on-going test of the DSM spare thin shell.

The crowded schedule in Paranal, coupled with the higher priority of GRAVITY and CIAO, drove the Programme to shift by a few months the installation and commissioning of the DSM and GALACSI. This will bring a global slip of 6 months of the final acceptance of the AOF, but a scheme has been developed to perform the early commissioning of GALACSI and WFM of MUSE to allow the prompt scientific use of this facility. The plan foresees a three months telescope down time for the DSM installation in Q4 2016 and the final acceptance of AOF mid 2018.

VLTI Facility Project [12]

The VLTI facility project aims preparing all infrastructure to host and optimize the performances of the 2nd generation instruments GRAVITY and MATISSE, including adaptive optics for the Auxiliary Telescopes (NAOMI) and a second generation fringe tracker. The work was originally implemented through 6 separate projects (VLTI PR1-PR6). It has been recognised, however, that given the strong interconnections between the many VLTI components, a higher level of system view, planning and coordination was needed. Consequently, a "VLTI Facility project" has been defined, following the AOF scheme and encompassing the old projects as work packages.

One premise of the project was the construction of a new maintenance station for the Auxiliary Telescopes (AT). The work is completed and the new AT station has been already successfully used. A remarkable effort was needed to prepare all the infrastructure for the 2nd generation of VLTI instruments. It included the upgrade of the VLTI laboratory to host the GRAVITY and MATISSE instruments, the installation of star separators in the UT Coudé rooms and in the ATs. All these activities have been completed and the commissioning of GRAVITY with the UTs, Star Separators (STS) and CIAOs will start. As part of this project, AMBER and PIONIER are now served by the STSs, PIONIER was relocated and both instruments re-commissioned. The GRAVITY metrology equipment has been installed and aligned on the spiders of both the ATs and the UTs. Finally, new transmission measurements revealed that the transmission of the coude' optics of the ATs were degraded, so it has been decided to replace the mirrors of the AT coude' trains.
The New Adaptive Optics Module for Interferometry (NAOMI)[13] will equip all four ATs with a low-order Shack-Hartmann adaptive optics system operating in the visible in order to improve the VLTI performances in median and poor seeing and to enable robust fringe tracking. The project passed PDR; ESO will be supported by IPAG (Grenoble), for the development of the corrective optics and the support in the AIV phase in Paranal.

The last subsystem is a new fringe tracker for MATISSE. After studying several options, ESO has decided to pursue the use of GRAVITY as a fringe tracker for MATISSE. The project has been officially launched with allocated budget and effort. A contract has been made to obtain the necessary software support, which could not be provided by ESO staff. The Top Level Requirements are finalised in cooperation with the MATISSE consortium. The decision on the need for a stand-alone 2nd Generation Fringe Tracker is linked to the successful implementation of GRAVITY as a fringe tracker.

The VLTI facity must, in addition, guarantee that the performance of the VLTI infrastructure reach a level adequate to the challenging science cases of the 2nd generation VLTI instruments. Driven by the needs of GRAVITY, a performance

roadmap for the VLTI infrastructure has been developed and is followed. It contains goals on telescope Strehl improvements, baseline piston reduction, and astrometric baseline characterisation. With the arrival of GRAVITY on the ATs, the focus of the 2nd generation performance improvement work has shifted to the auxiliary telescopes. GRAVITY has become an excellent tool to investigate and track the evolution of the ATs performance. Vibrations are identified and, when possible, eliminated.

MOONS [14]

MOONS is a 0.8 to 1.8 micron multi-object spectrometer for the Nasmyth focus of the VLT. The instrument will be fibre-fed, and have at least 800 (goal 1000) fibres over a total field of 25 arc minutes in diameter. There will be two spectral resolutions: ~4000 spanning the full wavelength range and a higher resolution mode which gives ~9000 in the I window, and ~20000 in a region in the H window.

The MOONS PDR took place on October 2015. Three main areas were identified as high risk and needed further studies: find an affordable solution for the IR detectors costs (4Kx4K), review the cameras with a less challenging design, and decrease the weight on the platform. A novel camera design, which makes the instrument also lighter, has been adopted. A new agreement for the detectors could be found between ESO, the manufacturer and the consortium. The final design phase could start.

ERIS [15]

ERIS is a new instrument for the Cassegrain focus of UT4, consisting of a diffraction limited infrared (IR) imager which will replace a set of the most important NACO capabilities, an AO Wavefront sensor (WFS) module which will use the AOF deformable secondary mirror and any one of the 4 AOF lasers (one at a time - SCAO), and an upgraded version of SPIFFI to adapt it to the new AO module.

The SPIFFI upgrade took place in January 2016. The replacement of some mechanical parts was crucial due to unexpected mechanical wear. SINFONI is now back in operation; the performances of the instrument (spectral resolution, throughput) slightly improved, but the gain in spectral resolution is still below theoretical expectations. The causes are under study. In February 2016, the ERIS PDR took place, the team is now working on the detailed design.

2.3 Upgrades and Refurbishments

The programme is also involved in several upgrade and refurbishment projects. Given the operational nature of the instruments, these projects are led by ESO. Having 17 running instruments at Paranal and 3 at La Silla, the average mean-life of the instruments is on average expected to be longer than 15 years. This means that special attention on upgrades must be kept. Following the mid and long term strategy, the instruments for the VLT/I that will stay many more years at the telescope will be subject to upgrades and refurbishments.

CRIRES+ [16]

The CRIRES Upgrade project will transform CRIRES into a cross-dispersed spectrograph. By using 6 gratings as cross-dispersing elements, it will be possible to cover the whole 1-5 μm wavelength range and increase the simultaneous wavelength coverage by a factor of at least 10 relative to the present configuration. New gas cells will be used to calibrate the instrument over the whole spectral range and obtain precise (a few ms^{-1}) radial velocities. A polarimetric unit will be added. The project is developed in collaboration with an external consortium. It successfully passed PDR and FDR and all components are now being procured. When removing the instrument from the Observatory, the warm optics (AO) module suffered of an accident and some of the components need to be replaced. This is now part of the CRIRES+ scope. CRIRES+ will occupy Nasmith B of UT3 and PAE is planned for the end of 2017.

NACO Refurbishment

NACO was originally supposed to be decommissioned after its removal from UT4, but the importance of keeping an AO imager at the VLT before the arrival of ERIS, in particular to continue the monitoring of the Galactic Centre and support

observing the peri-event in 2017/18 has been recognised. ESO decided to install NACO at the focus of CRIRES on UT1, which would be vacated for the CRIRES upgrade. The re-installation of NACO carried some risks, because of the critical state of three major components: the detector systems, the field selector and the real time computer. One of these risks materialised and the initial science detector of CONICA died after the restart of the instrument.

The old ISAAC detector initially used to replace the dead IR array of CONICA had contacting issues between the socket & the detector. After several CONICA opening iterations, three of the four quadrants have been offered for science operation. Raytheon is now repackaging the old CRIRES Aladdin detector to be used for NACO. A full set of spares is being prepared for all the other critical components; this is quite challenging for some of the critical electronics, which are 16 years old.

X-Shooter ADC

The X-Shooter ADC is presently disabled because it has shown mechanical erratic positioning, which is especially vulnerable in the winter season.

A mock-up of the X-Shooter ADC has been built and tested, but soon revealed that these tests could not be conclusive and the mechanism needs to be re-designed. A new concept is being developed and an alignment procedure was found that allows to integrate the new ADC driver without the need to dismount the whole instrument, hence without requiring a long (6 months) downtime.

2.4 Recommended Instruments pending contract agreement

CUBES[17]

In UV spectroscopy from the ground (300-380 nm spectral range), a large increase of efficiency with respect to existing instruments (UVES and X-Shooter) is possible. In addition, this spectral range is complementary to the E-ELT and JWST. An efficient UV spectrograph can cover a broad science case and will be a world-leading instrument for many years to come. Located at the Cassegrain focus, it will be built to be easily exchangeable. The CUBES concept was developed by a consortium of Brazilian institutes and ESO. It is an instrument of intermediate size and cost, mostly funded by the external partners. The project has passed Phase-A review.

The detailed design and construction will commence following the ratification of Brazilian accession to ESO. The development plan foresees a duration of only three years from the Kick-Off (KO) meeting to PAE.

4MOST[18]

4MOST will be located on the 4-metre VISTA telescope, with a field of view of more than three square degrees. It will host up to 2400 fibres and will work in the optical (0.3-0.9 μm). The goal is to have 1600 fibres that feed two lower resolution spectrographs (R~5000), and 800 fibres to one higher resolution spectrograph (R~18000). Currently, the consortium has secured funding for two of the three spectrographs, but provision for implementing the third spectrograph is made, should the full funding become available. The project also foresees the full operations of the facility by the 4MOST Consortium.

After a Call for Ideas in 2010 and competitive Phase A studies, 4MOST was recommended for design and construction, delayed after MOONS. The installation and commissioning on the telescope is foreseen in 2021. The design work is proceeding and PDR is planned for June 2016. 4MOST is a major project and will impact significantly the existing VISTA infrastructure.

2.5 La Silla Instrumentation

The Paranal Instrumentation Programme also covers projects for La Silla. These projects by design are only contemplated if they are at a minimal cost to ESO.

Laser Frequency Comb (LFC) for HARPS

The project aims at developing and procuring a novel calibration unit for HARPS at the 3.6m telescope based on the Nobel Prize-winning technology of Laser Frequency Combs. This new calibration system shall ensure, among others, a long-term precision of ~30 cms^{-1} with HARPS, and it is the technology adopted as the baseline for the ESPRESSO calibration.

The LFC is required to be a turn-key system with minimal maintenance requirements and the current durability of the fibre is not compatible with this requirement. The project has suffered a substantial delay in achieving the necessary durability of the photonic crystal fibre used for the last stage of spectral broadening. The LFC was installed at La Silla and underwent a first commissioning period in April 2015. Many thousands spectra were acquired, with a large broadening and excellent results, but the reliability of the system still needs further improvement.

New Instrument for NTT and 3.6m

ESO launched a Call for Ideas for scientific projects at the NTT that includes a new instrument to be provided by the community. This new instrument can replace either SOFI (in operation since 1998) or EFOSC2 (in use since 1990) or both and will be available to the ESO community for 50% of the time.
The NTT Call for Ideas was open for specialised instruments taking advantage of a large amount of dedicated observing time, as well as for state-of-the-art workhorse instruments addressing the broad needs of the ESO community. After selection, seven groups were invited to answer a Call for Proposal and five answered. SOXS (Son of X-Shooter) for the NTT and NIRPS for the 3.6m telescope have been selected to continue to design and construction phase. The strategic view is specialising the NTT for the follow-up of transient events, and the 3.6m telescope for exo-planet studies to support future exo-planet space missions. The timeline of these projects for construction and operations extends the La Silla lifetime beyond 2023+.

SOXS[19] has a wide science case mainly focusing on transient objects. It will be a single object spectrograph covering a large spectral range at a resolving power of R~5000 and will occupy one of the Nasmyth foci of the NTT.

NIRPS[20] is an IR high resolution spectrograph, dedicated to high precision spectroscopy for the detection of exo-planets, especially around low mass stars, and to the study of exo-planets atmospheres. It will be hosted at the 3.6m telescope and be able to observe simultaneously with HARPS. Several optical design options have been explored and the preferred one chosen. The procurement of the detector has started.

3. ROADMAP

The roadmap laid out in the tables below shows the projects under construction and the planned future projects. It is based on the present planning and on the ESO resource allocations for the running projects. For future projects, the projections have been made using typical effort figures expended on previous VLT instruments. Table 1 summarises all the projects currently running under the Paranal Instrumentation Programme, providing a short description of their purposes. Table 2 provides an update of their development milestones. A similar table was presented in the 2014 SPIE paper[2]. With respect to it, we can notice that several projects have shifted their delivery dates by almost one year. Among the reasons of the shifts, a common one is that most teams underestimated the time needed for the final integration and test phase. In this phase all projects have been affected by delays or problems with at least one key component by the manufacturers. On the ESO side, the effort to complete the projects requiring heavy interventions on the infrastructures has been systematically underestimated, and the additional effort required had an impact on the instruments competing for the same expertize.

Table 1: Projects presently running in the Paranal Instrumentation Programme. VLTI infrastructure and AOF facilities have been split into their main projects and subsystems. Delivery dates are given in table 2.

	Project Name	Description	Status
1.	VISIR Upgrade	Upgrade	Operations

2. SPHERE	Extreme AO Planet finder	Operations
3. MUSE	Giant Optical IFU	Operations
4. GRAVITY	VLTI Astrometry	Commissioning
5. MATISSE	VLTI mid IR imager	Integration Europe
6. ESPRESSO	High Resolution 1UT & 4UT	Integration Europe
7. ERIS	AOF Imager and Spectrograph	Detailed Design
8. NACO Refurbishment	Spare parts for NACO Survival	Ongoing
9. CUBES	UV Spectrograph	Awaiting Brazilian ratification
10. CRIRES+	Upgrade, X-disperser, new detectors	Detailed Design
11. MOONS	IR Multi-Object Spectrograph for VLT	Detailed Design
12. 4MOST	Optical Multi-Object Spectrograph for VISTA	Design, Contract agreement pending
13. X-Shooter ADC	X-Shooter ADC repair	Detailed design
VLTI Facility		
14. PR1	AT Service Station	Completed
15. PR2 – PRIMA	PRIMA Astrometry	Discontinued
16. PR3	NAOMI (AO for ATs)	Detailed Design
17. PR4	Infrastructure for MATISSE & GRAVITY	Construction
18. PR5	GRA4MAT Fringe Tracker	Design
19. PR6	Coordination, System	Design
AOF	AO Secondary for UT4 plus its subsystems:	Part test in Europe, part installed
20. 4Lasers	AOF Lasers & Launch telescope	Commissioning
21. DSM	Deformable Secondary Mirror	PAE passed
22. GALACSI	AO module for MUSE	PAE passed
23. GRAAL	AO module for HAWK-I	Installed on UT4
24. UT4 Upgrade	UT4 Preparation & modification	Complete
LA SILLA		
25. LFC for HARPS	Laser Frequency Comb	Testing La Silla
26. SOXS @ NTT	X-Shooter – for NTT	Definition
27. NIRPS@3.6m	IR Planet RV and atmospheres	Definition

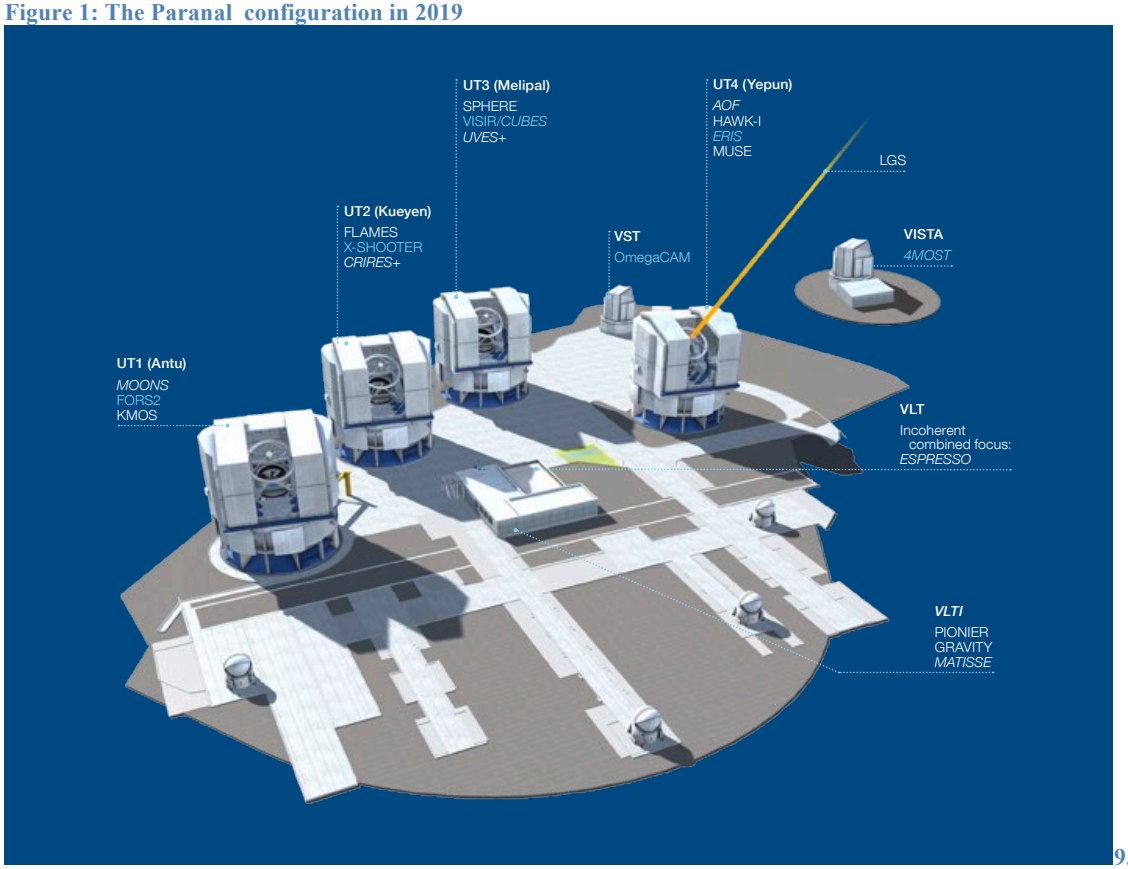
As far new projects, New II (Phase A will start in 2017) will be a new instrument to replace HAWK-I at UT4-AOF. Figure 1 shows the expected configuration of the Paranal Observatory in year 2019.

Table 2: Milestones for the running and future Paranal Instrumentation Programme projects. A similar table was provided in the 2014 SPIE paper. The instruments with ? delivery dates the agreements have not been signed yet.

Yr	Phase A	Design & Constr.	Delivered
2013		CRIRES+ MOONS	MUSE
2014	NTT Call for Ideas	4MOST	SPHERE PRIMA Astrometry (discontinued)

2015		NIRPS (New I)	LFC for HARPS VLTI PR1 GRAVITY BCI
2016		SOXS (New I)	GRAVITY CIAO VISIR Upgrade VLTI PR4 NACO ESPRESSO
2017	New II (for UT4)	CUBES(?)	MATISSE CRIRES+
2018	New III	New II (for UT4)	AOF VLTI PR3 & PR5 SOXS&NIRPS(?)
2019	New IV	New III	MOONS
2020	New V	New IV	ERIS CUBES(?) 4MOST
2021	New VI	New V	

Figure 1: The Paranal configuration in 2019



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