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Paranal Instrumentation Programme Plan and 6 Monthly Report

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1. Executive Summary

Following the ESO Council's 2004 resolution (ESO/Cou-991 rev.), the ESO strategic view as articulated in the ESO Long Term Perspectives (LTP, ESO/Cou-1377, 2011, and ESO/Cou-1689, 2016) and the Science Prioritisation Report (STC-551, 2015), the Paranal Instrumentation Programme (PIP) aims to keep Paranal at the forefront of ground based astronomy. This plan and report is updated biannually and it incorporates the recommendations contained in the Science Prioritisation Report (STC-551), and in the guidelines for decommissioning the VLT instruments and upgrades (STC-569 and STC-570, 2016, STC-587, 2017). The current plan includes (in *italics* the projects now in operations or integration/commissioning at Paranal):

- *The completion of the VLT/I second generation instruments (GRAVITY, ESPRESSO and MATISSE); with the commissioning of ESPRESSO and MATISSE, all second generation instruments are either offered or in Commissioning*;
- The *delivery of the Adaptive Optics Facility (AOF)* with the imager and spectrometer ERIS;
- *The upgrade of the VLTI infrastructure to accommodate the second generation VLTI instruments;*
- Two multi-object spectrographs (MOONS for VLT and 4MOST for VISTA);
- The upgrade of CRIRES;
- A new UV spectrograph (called CUBES in this document) with Phase A in 2019;
- Two new instruments (NIRPS and SOXS) for La Silla, fully funded by the community; and
- Development of an upgrade and replacement plan for the VLT workhorse instruments. *Two Phase A studies start in 2018: one for a visible MCAO instrument for UT4/AOF, and one for the FORS upgrade*.

Such a development ensures the successful implementation of the three phases recommended in STC-551 (see next section). Approximately one new instrument and one instrument upgrade are initiated every two years. Interspersing upgrades and new facilities balances the resources and the future allocation of GTO at the VLT, reaching after ~2019 a quasi-steady state with 6-7 projects running at any time. Increase of scope, delay or overspend must be accommodated within the total resources available by either re-phasing or de-scoping the existing projects, or by shifting the start of new ones. *The start of new projects is possible only if current projects are completed, and no major emergencies arise.* The exact timing and speed for the new projects depends on the schedule of the projects that are been completed in Europe and at Paranal, especially ESPRESSO and CRIRES, that have required more effort than planned in the last 6 months. The extra staff effort needed to complete the second generation instruments and infrastructure has been financed by reducing ESO participation in some projects and the available capital in the years 2019 - 2025.

A risk policy and a cost-to-completion policy have been implemented, similar to the ELT. Since October 2018 the indexation of the non contracted funds is in place. A report about the second generation instruments lessons learned is available in the Messenger (Vol. 166, p. 29, 2016). A community workshop to shape the VLT in the 30s is being organized for June 2019. A roadmap for the 2019 - 2022 period is presented and will be consolidated after the workshop.

2. Introduction

The fundamental goals for the Paranal instrumentation strategy can be summarised by quoting the strategic goals for ESO, formulated by Council in 2004 (ESO/Cou-994), and reported in the most recent ESO Long Term Perspectives document (ESO/Cou-1689 rev., 2016):

- ESO must retain European leadership in astronomical research in the era of Extremely Large Telescopes (ELTs) by carefully balancing its investment in its most important programmes.

- The VLT must continue to receive effective operational support, regular upgrades – especially to stay at the forefront of image quality through novel adaptive optics concepts – and efficient new instrumentation in order to maintain its world-leading position for at least another decade; the unique capabilities of the VLTI must be exploited.

The overall Paranal mid-term and long-term scientific strategy is discussed in the “Science Prioritisation Report” document (STC-551, 2015), that states for the Paranal Instrumentation:

Epoch 1: 2017 - 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;
c) Establish development plan for the VLTI (VLTI White Book, mid-2016);
d) Deliver MATISSE, ERIS and MOONS;
e) Deliver new instrument for the NTT;
f) Develop upgrade and replacement plan (VLT and VLTI); and
g) 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
e) Encourage visiting instruments for VLT and VLTI.

Epoch 3: Beyond 2025

Operate the ESO optical/NIR telescope system making best use of the synergies. With the ELT starting operations, the support role of the VLT, VLTI and the 4-m telescopes needs to be defined. Support capabilities for other ESO observatories, e.g. ALMA.

The instrumentation development plan provides a framework within which to implement new instrumentation and upgrades, bearing in mind that, until ~2025, the Paranal Observatory is the main source of ground-based optical and IR data for the ESO community. The plan proposes an implementation that allows a renewal of the Paranal instrumentation, consistent with the available resources, and maintaining the commitments taken for the running VLT and VLTI projects, provided there are no major delays to instruments under construction or increases of scope to the programme. In particular, the overall funding scheme must make sure that the resources are available within ESO to solve obsolescence problems and to maintain aging instruments, though these are beyond the scope of this plan and are covered in the LTP.

In 2018 the second generation VLT and VLTI instruments have been completed. This complement of instruments (see Figures 1 & 2 and the Tables in the appendix) covers most options in imaging (including Adaptive Optics (AO) and VLTI diffraction limit) and spectroscopy in the 300-24,000 nm range.

The wavelength/resolution plane is not the only relevant parameter space; four Integral Field Unit instruments (two AO-assisted) and at least four multi-object spectrographs will be in operation. The Paranal observatory provides polarimetry, high contrast imaging and coronography, fast photometry and superb astrometry, as well as the finest instruments for precise radial velocity determination.

This plan foresees new instruments and upgrades for the next years, to maintain a balance between general purpose and dedicated instruments. The flow of new initiatives is continuous and constantly monitored because a peaked effort (similar to the one needed for the second generation instruments) is not affordable when simultaneously implementing the ELT programme.

The strategy for the VLT into the era of the full ELT operations is developed through the discussion with the community at large and a workshop is being organized for June 2019. The VLT Science Prioritisation Report addresses this topic.

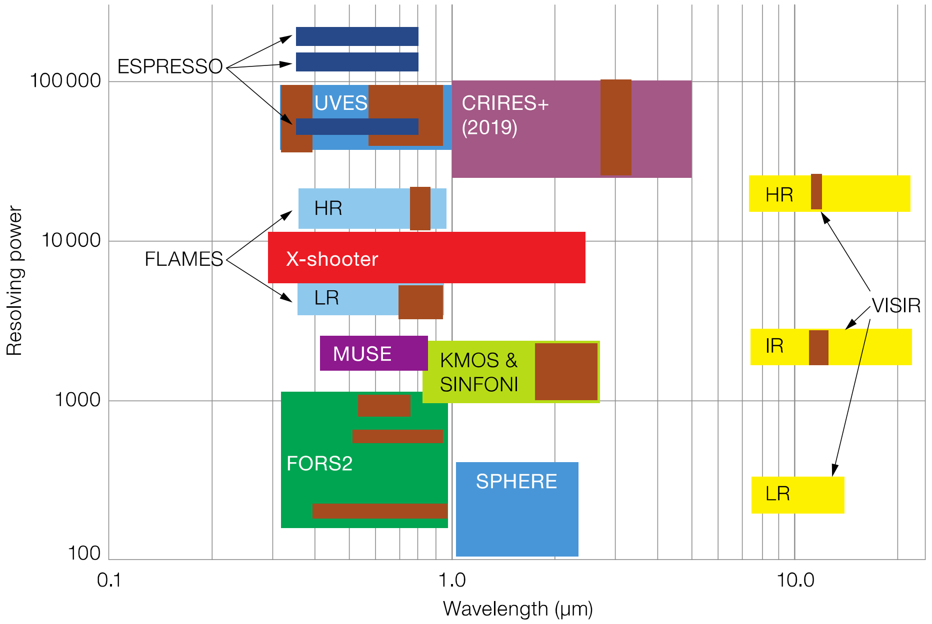

Figure 1: Wavelength - Resolving Power diagram for the VLT instruments, including second generation ones.

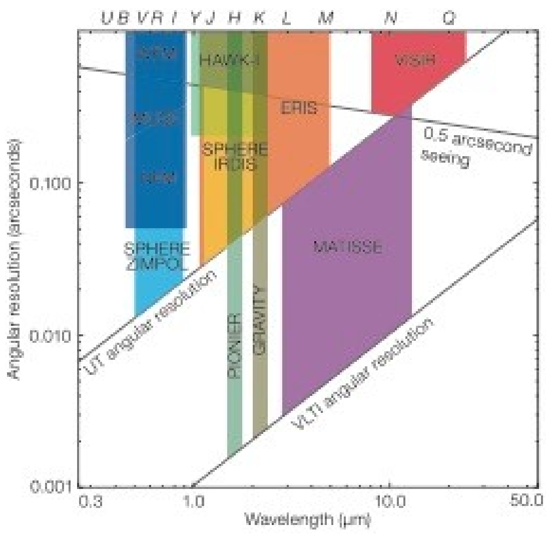

Figure 2: Wavelenth-Angular Resolution diagram for the VLT and VLTI instruments, including the second generation ones.

3. Current Programme

3.1 Recent Instruments at Paranal

The peak of activity at Paranal has decreased, and only minor interventions on AOF and NAOMI have been carried out, in addition to ongoing commissioning. All the second generation VLT instruments have been delivered to the observatory, and acceptance in Chile are to be finalized. The causes of the low efficiency of ESPRESSO have been identified, and new fibre systems are being manufactured. In Europe, CRIRES+ suffered several technical problems, that delayed the PAE.

3.1.1 MUSE

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 Wide Field Mode works assisted by the AOF (in operation), which enhances its performance, while the narrow Field Mode will be commissioned in 2018.

MUSE has been offered since October 2014 and has excellent performance, with throughput peaking above 35% end-to-end, and high image quality. The re-alignment of the IRLOS tip-tilt system for the Narrow Field Mode was performed in November 2018 and it recovered almost all the sensitivity.

3.1.2 GRAVITY

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.

GRAVITY has been successfully offered for observations with the ATs for period 98 and offered in spectroscopic mode with the UTs and the MACAO optical AO module for P99. After a mission to re-allign the UT3 unit, the on-axis mode of CIAO has been fully integrated into the VLTI operations and is now offered. All modes have been commissioned, only the astrometric mode remains to reach specification. GRAVITY together with the recently upgraded VLTI infrastructure have demonstrated its full and unique capability.

3.1.3 MATISSE

MATISSE (Multi-Aperture mid-Infrared SpectroScopic Experiment) is a four-beam combiner second 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 commissioning of MATISSE is continuing very smoothly. The instrument is showing a sensitivity in line with expectations. Only one intervention is planned before the end of the year to install the newly manufactured high resolution grating.

3.1.4 ESPRESSO

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 four UTs simultaneously.

Several commissioning runs have shown that while most requirements (including the short term radial velocity) are achieved, the overall throughput is lower than expected, especially at the blue edge of the spectrum. The intervention that took place in September and October 2018 was successful in identifying the cause of the efficiency losses, that originated in the fibre system. A new fibre train is being manufactured and will be exchanged in April. The folding mirror of the red camera was exchanged, and the red detector cleaned, but the latter without producing a major improvement. The temperature stability of the blue detector seems excellent, and the blue system still shows large instability than the red one. ESPRESSO has been offered since Period 102 in 1UT mode and since period 103 also in 4UT mode.

The Laser Frequency Comb has been split in two separate (Red and Blue) units. The LFC Red unit has also been shipped to Paranal and has been tested with the ESPRESSO, and will also be repaired in April-May.

3.2 Projects Currently Under Development

A number of projects are being developed in collaboration with consortia in the ESO Member States. After passing the final design, ERIS and MOONS and 4MOST are in AIT Phase, (the second part of the 4MOST FDR was held in March 2019, a few days before the corresponding VISTA design upgrade has been reviewed). The Paranal Instrumentation Programme is also responsible for the development of the infrastructure upgrades, enabling the instruments to exploit their best performance, and four of the main projects of the programme, the Adaptive Optics Facility (AOF), ESPRESSO, the VLTI Facility and 4MOST are of this nature.

3.2.1 AOF

The Adaptive Optics Facility (AOF) consists of 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 centrepiece and two wavefront sensor systems (GALACSI and GRAAL) to provide users with optimised adaptive optics correction for the MUSE and HAWK-I instruments. This effort is also a pathfinder towards the ELT. 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 contracted to the University of Leiden and funded by NOVA.

With the commissioning of the NFM of MUSE, the AOF commissioning is finished. All modes are offered. A corrective intervention to re-align the IRLOS tip tilt sensor took place in November, and was successful, bringing the limiting magnitude close to the specifications (H=15). A last intervention in February was needed to bring the SW to VLT2018 and to close open actions for the final acceptance (PAC).

The PAC process for the AOF is finished. ESO is waiting for the final acceptance by Paranal. This topic will not be reported in the future and ESO would like to take the opportunity to thank again the AOF team for their hard work for more than a decade.

3.2.2 VLTI Facility Project

The mid-term VLTI implementation plan foresaw the construction and operations of a number of facilities aimed at enabling PRIMA and optimising the performances of the second generation instruments GRAVITY and MATISSE, including adaptive optics for the Auxiliary Telescopes (NAOMI) and a second generation fringe tracker. The plan was implemented through six separate projects created in 2012 (VLTI PR1-PR6), to which the "VLTI facility project" has been added, with the functions of coordinating, planning the activities and maintaining the system view. One of the original work packages, PRIMA, has been discontinued after a critical review. While GRAVITY and MATISSE remain separate projects, they report to the VLTI facility as far as interfaces and intervention on the infrastructure (including schedule) are concerned.

3.2.2.1 AT Maintenance Station (PR1)

This work package includes mainly the construction of a new maintenance station for the Auxiliary Telescopes (AT). The work is completed and the new AT station in use successfully. PAC has been awarded and the project is closed.

3.2.2.2 Adaptive Optics System for the Auxiliary Telescopes (PR3 = NAOMI)

The New Adaptive Optics Module for Interferometry (NAOMI) has been developed for and to be installed at the 1.8-metre ATs. The objective is to equip all four ATs with a low-order Shack-Hartmann adaptive optics system operating in the visible in order to improve the VLTI performance in median and poor seeing and to enable robust fringe tracking.

The long period of installation, testing and re-commissioning of the AT+NAOMI+ VLTI instruments (GRAVITY, MATISSE, PIONIER) was concluded with success in November 2018, after which all the instruments were offered and operated with the ATs + NAOMI. This has brought relevant sensitivity improvements. A final commissioning period to assess the performance improvements at the level of the VLTI instruments in operation (Gravity and Pionier) was carried out in late February 2019. NAOMI PAC meeting is scheduled for 30 April 2019 / Science Verification for early May 2019.

3.2.2.3 Infrastructure for VLTI second Generation Instruments (PR4)

This work package covers the infrastructure to be implemented for the second generation of VLTI instruments. It includes the upgrade of the VLTI laboratory in preparation for the arrival of the GRAVITY and MATISSE instruments, the installation of star separators in the UT coudé rooms and in the ATs.

Preliminary Acceptance Chile (PAC) has been granted basically all the HW components. Only the dichroic for MATISSE has a transmission lower than expected at the edges of the wavelength range covered and a new procurement is being considered.

The Interferometer Supervisory Software (ISS), continues to be under development: release 2, that will include NAOMI and GRA4MAT, will be finalized and accepted in 2019.

3.2.2.4 Fringe Tracker for MATISSE Gra4MAT (PR5)

Gravity for MATISSE (Gra4MAT) will make use of GRAVITY as a fringe tracker for MATISSE. The project has been officially launched with allocated budget and manpower. Limited on-sky technical activities will be carried out over the May-June 2019 period in order to prototype the Gra4Mat design and prepare a review before the summer.

3.2.2.5 VLTI second Generation Performance (PR6)

The objective of this work package is to proactively improve the performance of the VLTI infrastructure and reach a level compatible with the challenging science cases of the second generation VLTI instruments. Driven by the needs of GRAVITY, the performance roadmap for the VLTI infrastructure delivered in May 2014 is still being followed. It contains goals on telescope Strehl improvements, baseline piston reduction, and astrometric baseline characterisation.

The only open point is the daily operations of the vibration metrology (VibMET). The system has a low flux return and the retroreflector needs to be re-designed.

3.2.3 MOONS

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: ~4,000 spanning the full wavelength range and a higher resolution mode which gives ~9,000 in the I window, and ~20,000 in a region in the H window.

The huge cryostat, consisting of a centre piece and two covers, has been significantly delayed partly due to one of the covers warping during manufacturing. This warp has now been corrected and is undergoing final machining. This delay in the cryostat has led to the Integration Readiness Meeting to be postponed until Q3 of 2019 and will ultimately delay PAE until Q3 of 2021. The optical bench has been scanned and shown to comply with the specifications. The first two science grade Hawaii 4RG detectors have been delivered.

The collimator and first of the six cameras have been delivered to the consortium. The camera has been integrated and alignment is due to begin in April. The second camera is due for delivery soon. The dichroics and first of the gratings have also been delivered.

The focal plane positioners have successfully completed their life time testing and are ready to begin manufacturing. A prototype of fibre slit has been demonstrated and shown not to cause focal ratio degradation when cooled. There have been problems accurately aligning the micro lenses with the fibres as the original approach failed. A new method is being developed.

3.2.4 ERIS

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 four AOF lasers (one at a time - SCAO), and an upgraded version of SPIFFI to adapt it to the new AO module.

The project is advancing with manufacturing and integration of the subsystems, but some delays are emerging i.e. with the calibration unit, the AO and the NIX camera, so the delivery date of the latter has now been moved from April to July. Current activities involve assembly and integration. Next the alignment and verification activities will start.

As for the ESO contributions, the contract for the handling tool had its kick-off in November and a PDR in February. It is on track for delivery in July. The science detector for NIX was sent to Edinburgh and installed in the cryostat. After successful tests, it was removed to avoid damage while the other mechanisms are installed in the cryostat.

SINFONI will be decommissioned in June and SPIFFI sent to Garching for upgrade to ERIS-SPIFFI.

3.2.5 4MOST

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 2,400 fibres and will work in the optical (0.3-0.9 μm). It will have 1,600 fibres to feed two lower resolution spectrographs (R~5,000), and 800 fibres to one higher resolution spectrograph (R~18,000). The project also foresees the full operations of the facility by the 4MOST Consortium for the first five years and makes provisions for an extension of the operations beyond this limit.

The 4MOST project is presently progressing with the MAIT phase and finishing the design phase through dedicated reviews.

The 4MOST FDR2 took place at Garching on 6 & 7 March 2019. The review included the Metrology Camera, the Fibre Feed and the Focal Surface Test Tool. On this occasion the main board recommendations made at FDR1 (the WSF and AG design, the Cooling design, some of the Facility performance, the AIT and AIV plans) were also reviewed.

The VISTA Modification Review followed on 8 March. The project will modify the VISTA infrastructure to make it compatible with the arrival of 4MOST.

Finally, the Call for Proposal Readiness Review took place 21 March. This is a key milestone for operations, prior to the issue of the first call for letters of intent from the community. The Consortium deliverables concern the performance of the simulator, the set-up of a helpdesk infrastructure, the exposure time calculator, documents describing the performances of the instrument and the surveys planned by the GTO team.

In parallel to these review activities, the procurement and manufacturing of the 4MOST facility is progressing, and all major subsystems have delivered components. In particular the detector work package (ESO contribution) is close to the end, and nine detector vessels with science detectors have been delivered to AIP.

The consortium prepared a series of white papers for a special issue of The Messenger (March 2019) to present the overall instrument performance, the operational concept and the GTO surveys. The aim is to prepare to community to answer to the first call for letters of intent. In addition, a workshop jointly organized by ESO and the Consortium will be held on 6-8 May at ESO Headquarters, to further prepare the community to use this new facility.

3.3 Upgrade and Refurbishments

The programme is involved in several upgrade and refurbishment projects. Given the operational nature of the instruments, these projects are led by ESO. They do not include standard obsolescence fight and maintenance, which is taken care of by the Directorate of Operations. Given that, with the possibility of starting at most one project/year and having 17 instruments running at Paranal and three at La Silla, the average mean-life of the instruments is expected to be longer than 15 years. This means that special attention to this subject has been requested by the STC. In collaboration with the STC, the VLT/I programme scientists have developed a strategic view that identifies the ‘workhorse’ instruments for the VLT, i.e. instruments that will have a substantially longer lifetime and will stay many more years at the telescope (STC-570 and STC-587). These instruments will then be subject to upgrades and refurbishments.

3.3.1 CRIRES+

The CRIRES Upgrade project (CRIRES+) transforms CRIRES into a cross-dispersed spectrograph. By using six gratings as cross-dispersing elements, it is 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 previous configuration. New gas cells are 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 led by ESO, but developed in collaboration with an external consortium. From 1 March 2019 Joël Vernet has been appointed as new $CRIRES^{+}$ project scientist after the departure of Anna Brucalassi.

On the 12 December 2018 a CRIRES$^+$ PAE progress meeting was held. Various PAE tasks and inspections could be concluded including the safety, EMC, AO system, instrument control software and control electronics aspects. Overall the subsystems were considered PAE ready.

In addition to the repair of the cross-dispersion grating wheel function with a new spider arm, various improvements include a better axial guiding, the replacement of over-stretched springs, a more solid sensor and end switch attachment and better routing of the connection cables with a guiding arm. The ball bearings and an old cryogenic motor were replaced to allow long term reliability of the function.

After further testing, it became clear that the cross-disperser grating wheel function does not meet the requirements for reproducibility even after its repair and improvements. The behaviour of the wheel and its locking function have been investigated in great detail and the re-positioning requirement cannot be met inside the instrument. Currently the repeatability of the echellogramms are ~1 pixel in dispersion direction (requirements: 0.5 pixel) and ~6-10 pixel in cross-dispersion direction (requirements: 1 pixel) with the locking in place. As recommended at the PAE progress meeting, a request for waiver has been drafted to address this non-compliance including a mitigation proposal with attached calibrations and metrology techniques.

With cooldown No. 9 the focus of the metrology fibres, the slit viewing detector as well as the orientation of the slit-viewing detector have been verified and are all satisfactory. All echellogrammes are close to final positions and only marginal fine tuning will be required by shimming. Strong astigmatism (causing an elongated defocused image) was identified. Standalone measurements of the camera and the grating wheel optics confirmed that the camera was producing coma and a lower astigmatism component, the grating wheel mirror and gratings were producing large astigmatism which mostly explained the aberrations seen. Warm measurements show now acceptable aberration. In addition, a finite element analysis was done and confirms the approach adopted.

Currently the instrument is cooling down to verify image quality and full functionality of the instrument. Next step is merging of cold and warm parts plus possible shimming of gratings and final focus adjustment if needed. The current schedule needs to be revisited by the end of March 2019 after the results of cooldown No.10.

3.3.2 IRLOS Detector Upgrade

After the re-alignment of the system in November 2018, the present magnitude limit for the Tip Tilt star of the IRLOS system is close to the specification, that is H=15. The brightness of the tip-tilt object is the main limitation for the observation of quasars and active galactic nuclei. About two magnitudes could be gained by using the SAPHIRA detectors instead of the present HAWAII 1RG. Such an upgrade has a limited cost and contained effort impact has been positively recommended by STC at its 92nd Meeting. A project has been approved once the availability of internal resources has been made.

The project will start with a short design phase to evaluate whether a modification of the warm optics is required (adaption of plate scale to a larger pixel size, improvement of few mechanical mounts) and to confirm the expected gain in limiting magnitude. Particular care will be given to simulate the impact of sky and thermal background, leading to the design and definition of proper baffling as well as IR filter cut-off. The necessary Saphira read-out modes will be defined during the course of the design study.

The technical activities will start after kick-off. However, some preliminary actions have already been launched, such as the gathering of drawings and documents describing the current IRLOS cryostat design and launching end to end simulations to explore the performance vs. noise parameter space. A preliminary conclusion is that the plate scale does not need to be changed. This is in line with the strategy to proceed with a swap of cryostats, without modification of the warm optics.

3.3.3 FORS upgrade

A request to upgrade the FORS2 detector has been filed for a long time by the instrument operations team. The use of a 4Kx4K pixel CCD detector would bring substantial observational and operational efficiency benefits. In view of extending FORS2's lifetime for 15 years (STC-587), further items need to be replaced. In particular, its electronics and instrument software need to be brought to the VLT present standards.

The Phase A study of the FORS upgrade started in Q1 2018, the documents were produced and the Phase A review took place on 15 March 2019. The study presented a project, limited in scope and size, that will last 3 years. The Phase A review has been successful but the project will be submitted for approval only after the internal resources have been identified and allocated.

The goals of the upgrade include the upgrade of instrument control electronics and software as well as whole operations and data flow software with the latest standards and technology. FORS upgrade project has defined the design optimisation, development verification, re-commissioning, RAMS and management of the upgrade of FORS2. A constraint is the minimum downtime of FORS2. For this reason FORS1 will be moved to Garching and all changes tested on it first. During the Phase A, the option of upgrading both FORSs was considered; the project finally opted for the upgrade of FORS2, discarding the double upgrade option, which would have increased the effort and the costs dramatically.

3.4 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.

3.4.1 SOXS and NIRPS: new Instruments for NTT and 3.6m

Following the STC recommendations, 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 will be available to the ESO community 50% of the time. Additional observing time with the new instruments will be available for interested groups through the co-funding of the NTT operations. Such an instrument is required to be at negligible cost to ESO.

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 is a scaled down version of VLT X-shooter. SOXS will be a high-efficiency spectrograph with a Resolution-Slit product of 4500" over the entire band capable of simultaneously observing the complete spectral range 350 ~2050 nm. SOXS will have a 12" slit length for the entire spectral range.

The FDR closure meeting was held in Brera/Milano in October 2018 . The design work is being completed, while the procurement of parts is ongoing. ESO has provided various items on loan to the consortium (NTT simulator, CFC cryostats, surplus CCD-associated hardware). The pipeline development is being prepared and the official start is planned with a kick-off meeting in May 2019.

NIRPS 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. NIRPS must cover the Y, J, H bands and could also encompass Z and/or the K band. NIRPS will have a high precision (R>100,000) and a high efficiency mode (R ~ 80,000). The agreement foresees that the consortium will also operate the instrument for the community, and that the NIRPS consortium will have 145 nights/year of GTO time.

The NIRPS Consortium is organized with a number of CO-Is, with two main institutes leading the project (Montreal and Geneva). The front end is well advanced and the PAE process has started and inspections were carried out. Software and system tests are pending. All optics and mechanics of the fibre system have been delivered. An acceptance meeting for the fibre feed is planned for early May.

Vacuum and cooldown tests at Herzberg institute in Victoria are supposed to start before the end of March. Optics and optomechanics procurement are done and the integration is planned to begin in June 2019 at Laval.

The only weak component is the echelle grating that has a lower efficiency than expected. In addition to work to solve the problems with the original manufacturer, an alternative one has been contracted.

4. <u>The Future</u>

4.1 Programmatic drivers

This instrumentation development plan follows from consideration of basic drivers.

Until ~2025, the VLT will remain the leading ground-based telescope and there is no indication that the size of the Paranal user community will decrease. On the contrary, new Member States or partners join ESO, increasing the pressure on the Paranal facilities. Consequently, the scientific use and output of Paranal instruments should be optimised, not only maximising their throughput, but also their operational efficiency. It is important to balance the pressure between the different telescopes as much as possible and to preserve a balance between specialised and workhorse instruments, with the latter covering a wide range of scientific interests.

The new instruments will start their operations close to the first light of the first ELT ones and, with a foreseen lifetime of at least 15 years, synergies with the ELT must be considered. The ELT will be an additional telescope in the Paranal observatory, and the strengths of each unit in the entire system should be maximised. Synergy and the ability to complement ELT capabilities are therefore important criteria for the VLT. Several aspects are unique to the VLT with respect to the ELT: the larger FOV, the VLTI angular resolution, and the access to the UV domain. The ELT will be one telescope, while the VLT includes four UTs. More observing time will be available at the VLT for a single programme or user. Some ELT instrumentation capabilities should be duplicated at the VLT to ensure that the ELT is used only when its special characteristics are really needed.

The scenario in the era of mature ELT operations is still relatively open and different options will be discussed with the community.

4.1.1 Paranal & Ground Based Observatories

In general, the Paranal choices will be driven by the scientific requests of the ESO community rather than by the developments of its competitors.

4.1.2 Visitor Focus

The availability of a free focal station to host visitor instruments was advocated in the past. However, with all foci occupied, a focus becomes a valuable resource. It does not seem worthwhile to leave a focus permanently unused. Should a compelling case be presented for a future visitor instrument, a facility instrument may be temporarily moved. Both the “Science Prioritisation Report” and the “VLT Science Priority” document emphasise that, for the period post-2021, Paranal should facilitate hosting visitor instruments. This concept has been also advocated by the second Generation VLT/I Instruments Lessons Learned forum. While an exchange on a regular basis may be feasible at Cassegrain focus where some instruments can be removed, if this is pursued at Nasmyth, it will imply to free a platform. The more pragmatic approach seems to be to provide regular access to a Cassegrain focus shared with an instrument built explicitly to be easily removed (e.g. CUBES). In principle, according to

STC-569, FLAMES should be decommissioned in the long term after VIMOS and NACO. Since only two instruments (CRIRES+ and MOONS) will be brought to the VLT, one Nasmyth focus could be made free until a new facility instrument is built. VLTI Visitor focus is officially open as of P104, and two instruments can be accommodated: one on the AMBER table and one on the FINITO table.

4.1.3 Maximise Efficiency/Optimise use of observing time

The fact that the pressure is particularly high on some instruments must be considered i.e. to provide maximum scientific return implies also to maintain a similar pressure on all telescopes.

4.1.3.1 Improve efficiency

The possibility of greatly improving efficiency (throughput) and operational efficiency (duty cycle) of the instruments is generally limited. Detectors are close to optimal performance in most cases. Improvements in throughput or operations may bring small gain. Some exceptions, such as VIMOS and VISIR, were identified and led to upgrades. Further exceptions are high resolution IR and UV spectroscopy, where a gain of factor of up to 5 can be obtained, and they are addressed by the CRIRES+ and CUBES projects. The upgrade of FORS will improve the operational efficiency of the instrument.

4.1.3.2 Enlarge spectral coverage

Enlarging the simultaneously covered wavelength range saves telescope time when multi-wavelength observations are needed. Considering the success of X-Shooter, this path is surely interesting. However, it should be noted that enlarging spectral range and maximising efficiency may be conflicting requirements.

4.1.3.3 Share Foci

Optimising operations and answering the requests of the observers in a flexible way is also an aspect of improving efficiency. The capability of sharing a focus among different instruments is an optimisation. There are several flavours of sharing that can be considered:

- **Simultaneous observations** – Observe objects in the same VLT field simultaneously with different instruments. This would bring an immediate gain in efficiency. In practice, this scheme is complex to implement and has been used only in FLAMES, where GIRAFFE and UVES can observe simultaneously within the same field (and within the same scientific project). The same approach is adopted by 4MOST. Simultaneous observations with MATISSE+GRAVITY could be a natural extension of GRAVITY for MATISSE fringe tracker.

- **Exchange instruments** – Adding the requirement to design instruments for easy removal and storage would add flexibility and may help to optimise the use of the telescope. The idea is to allow one exchange every few months. Such a requirement has been built into the CUBES specification and will also provide the possibility to easily free a focus for visiting instruments.

- **Multi-port adaptor –** Another interesting approach is to build adaptors that serve more (smaller) instruments at the same focus. This is the case of ERIS, and such a requirement is proposed for the MAVIS instrument at Nasmyth of UT4.

4.1.4 Instrument development duration

The typical development time for second generation VLT instruments has been almost ten years from the time of conception, and six to seven years after the start of the design phase. A long lead time should not be assumed to be inevitable and the programme can develop simpler instruments on shorter construction times if this becomes an agreed goal.

One interesting opportunity is to expand the current procurement scheme and create a new class of visitor instruments. These would be operated by the constructing team, but also executing proposals from the community at large (in the manner of the VLTI instrument PIONIER). A similar scheme is foreseen, with different flavours, for the 4m class telescopes with the new instruments (4MOST at VISTA, SOXS at NTT, NIRPS at the 3.6m). The successful experience of PIONIER has been praised by the second Generation VLT/I Instruments Lessons Learned Board.

4.1.5 Refurbishments/Upgrades

As expressed in section 3.3, special attention is given to maintain and enhance the performance of the existing workhorse instruments through a series of upgrades and refurbishments.

4.2 Instrument Definition and Procurement Procedure

Input for the selection of new instruments is provided via normal routes such as the STC and its sub-committees, scientific conferences, or directly from the community. The first workshop, “ESO in the 2020s”, took place in January 2015 and contributed to shape the science prioritisation report. A second, smaller workshop of AO experts took place in September 2015, followed by an AO Community Workshop on September 2016 that paved the road to the definition of the new instrument (MAVIS) for AOF.

The procedure leading to instrument construction follows the normal VLT model. Top-Level Requirements are prepared and issued with a Call for Proposals. One or more Phase A studies can be funded to develop concepts, draft technical specifications, cost-to-completion and schedule. Following Phase A reviews, a decision is made on construction of the instrument. All steps are done in consultation with the STC.

In case the procurement model is an ESO-led consortium, a competitive process is normally used to select external institutes as partners. For upgrades or smaller projects (or in case of urgency), this competitive process may be waived.

When possible, R&D or prototyping is carried out and funded within the instrument projects themselves. Areas of general development which are essential for instrumentation and cannot be allocated to a single instrument, or have development times that go beyond the construction period of one instrument, are carried out by the Technology Development Programme.

The programme must retain flexibility to react to the evolving scientific and technological landscape and to re-assign priorities. New proposals are evaluated in collaboration with the STC against the existing plan. Acceptance of a new project may result either in cancelling/de-scoping or re-phasing planned projects. A similar evaluation is made if one of the running projects requests a substantial increase in the allocated resources. In planning resources for new projects (which have not yet been fully defined), figures derived based on past experience are used. The governing bodies are kept fully appraised of the evolution of the planning as well as the status of the approved programme through this document and presentations to the STC and its Paranal subpanel.

4.3 Instrument decommissioning

With the arrival of ESPRESSO, all VLT/I foci are used, including the incoherent combined focus. ISAAC was decommissioned to make way for SPHERE, and MIDI has been decommissioned at the beginning of 2015 to be replaced by GRAVITY. AMBER has been decommissioned after P101 and VIMOS after P100. The scientific characteristics of the individual instruments are described in Appendix A.

The decommissioning of VLT/I instruments follows a discussion with the STC (see STC-569): CRIRES+ replaces VIMOS, the decommissioning of NACO will be in 2019 (later replaced by MOONS), possibly followed by FLAMES.

Each time a new instrument is accepted, the instrument to be de-commissioned will be identified (at the latest at the time of the new project Final Design Review), on the basis of a grid of criteria that includes scientific potential, complementary with new instruments (and therefore coverage of the parameter space), instrument status and future perspectives, as explained in STC-569.

Of the remaining instruments in the programme, CUBES needs to share a Cassegrain focus; ERIS uses the AOF and must be at Cass of UT4, and the new visible MCAO will replace HAWK-I and GRAAL.

This would leave one Nasmyth focus free for visitor instruments until a new facility instrument is built.

4.4 Potential new instruments and upgrades for the VLT/I

After examining the current complement of Paranal instruments at the telescope or in construction, a number of potential developments have been identified which are listed below. The list is not intended to be exhaustive.

4.4.1 Visible MCAO on AOF

In answer to the STC request for a plan for AO instruments at the VLT, ESO is developing ERIS first, and has defined a new ambitious instrument to exploit the full potential of the AOF in the focus occupied by HAWK-I (Adaptive Optics Planning ESO/STC-493 (2011), ESO/STC-482). The scientific requirements and the characteristics of such an instrument have been discussed in September 2015 and in 2016 in two AO dedicated workshops and have been reported to the STC by the VLT programme scientist (STC-568 and STC-581). Three potential paths were explored:

- Optical AO
- Improved XAO
- Multiplexed AO (MOAO)

The conclusions were that XAO improvements could well trace an upgrade path for SPHERE, MOAO needed some more work, and that optical AO was the most interesting avenue.

Following the STC88 recommendations, a pre-Phase A of the new MCAO-based visual imager took place in 2017, and science cases were presented at STC90 together with the Top Level Requirements. Following the STC90 recommendation, a competitive Phase A call for proposals was launched and two proposals received, out of which, one (MAVIS, led by Prof. Rigaut at ANU) was compliant. The Phase A has therefore started at the beginning of 2019 and will last 15 months.

4.4.2 UV Spectrograph (CUBES)

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 ELT and JWST. An efficient UV spectrograph can cover a broad science case and would be a world-leading instrument for many years to come. Located at the Cassegrain focus, it is intended to be easily exchangeable. The CUBES concept was developed by a consortium of Brazilian institutes and ESO.

The original proposal was for an instrument of intermediate size and cost, mostly funded by the external partners. In September 2012, the project passed Phase A review (STC-509) and it has been recommended by the STC to pass to the design and construction phase (STC-510, presented at the Council Meeting), after a broadening of the science cases discussed in a scientific workshop with the community took place in 2013.

Following the clarification within the Brazilian and European astronomical scientific and technical communities by ESO Council in March 2018, a new scheme has been worked out, and, following the STC 90th meeting recommendations, ESO will issue a RFI in the community. This will happen before the end of 2019, if compatible with the ESO resources and priorities. The STC will be kept informed of developments and asked for recommendation before passing to the next phases. Depending on the response to the RFI, the current CUBES concept could undergo a short Phase A to bring it up to date (especially the science case). If a massively different instrument is desired it would have to compete as a future instrument.

4.4.3 Further Upgrades

The document STC-587 clearly identifies which instruments will be operated in the long term, and will therefore require an upgrade or a refurbishment to maintain them at the forefront for the next ~15 years. In addition, the results of the MUSE NFM commissioning and Science Verification show how critical the magnitude limits of the Tip Tilt star are, calling for a rather urgent upgrade of the IRLOS system:

- **UVES:** The case for keeping UVES has been emphasised in STC-570 and STC-587. In the long term, a general refurbishment of this instrument is necessary in order to guarantee its life and to improve its efficiency. This may include new cameras, detectors and cross-dispersers, in the blue or both arms, enlarging as well the wavelength range covered simultaneously. The complementarity with CUBES shall be also considered.

- **SPHERE:** In the longer term, the possibility of enhancing XAO capabilities of SPHERE was identified in the AO workshops (see 4.4.2). A link between SPHERE and ESPRESSO has been proposed (Lovis et al. 2017, A&A 599, L16) as a unique combination to characterise the atmosphere of Prox Cen b. Such a link would require a substantial upgrade of SPHERE. The coupling of high contrast imaging and high resolution spectroscopy is also advocated to link SPHERE to CRIRES+ with lower SPHERE upgrade in that case (IR). The SPHERE HODM has several faulty actuators. Even if no further losses occurred in the last years of operations in Paranal, this status is risky in the long term and a SPHERE upgrade should include the procurement of the HODM spare (or a new HODM).

Of the instruments foreseen to be operated in the long term, **KMOS**, **MUSE** and **GRAVITY** have been recently installed, **X-Shooter** ADC has been fixed, **VISIR** has been upgraded and **CRIRES+** is going through an upgrade. **ESPRESSO**, **MATISSE**, **ERIS**, **MOONS**, **4MOST** are to be finished or commissioned. No urgency for planning an upgrade is at present identified. The only exception is GRAVITY for MATISSE, which will be implemented as an upgrade.

All major upgrades are treated as new projects and compared to running or planned instruments in order to decide on priorities.

4.4.4 New Workhorse instrument to complement/support FORS2 and X-Shooter

UVES, FORS2, X-Shooter, MUSE are among the most popular, versatile and productive ESO instruments. They are typical workhorses and the user pressure on them is very high. It is important that ESO preserves this class of instrument. The question is whether the new workhorse is a multi-function multi-wavelength instrument or a copy (perhaps slightly modified) of one of the existing, most requested instruments. Such questions will be fully addressed with the STC and in the 2019 workshop.

4.4.5 New VLTI Instruments

No new VLTI instrument/upgrade is foreseen beyond what is currently under design or construction. New initiatives will be evaluated only after the completion of the second generation instruments and discussed at the upcoming VLT/I 2030 Workshop. The VLTI Roadmap foresees no new instrument or upgrade before 2020, in addition to the running initiatives.

4.5 Roadmap

The roadmap laid out in tables 1 to 3 below shows the projects under construction and the one planned. 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. In the past years the FTE requests for the PIP programme exceeded what was established in the ESO Long Range Plan for the years 2015 - 2021. The reasons are: enhanced scope of the programme, (such as the NACO refurbishment, the CRIRES warm optics accident, and the support of CIAO), delays in major projects, and underestimate of the effort needed. As a consequence, the PIP programme has utilised more ESO staff effort, which decreases to reach a total effort of 27.5 FTEs/year in 2019 and become steady at 25.2 FTEs/year after 2021. This additional staff effort cost is being compensated by a cut in the cash resources available to the programme. This means that the currently approved projects can be completed, and the available resources can support starting one new project and one upgrade every two years on average. Starting in 2017 staff effort contingency has been inserted at programme level to cover potential delays in the projects and unforeseen extra scope. Provision has been made to cover part of the additional staff effort needed in the years 2016 to 2019 by a cut of 2.5 MEUR to the capital investments budget. Since only minimal funds are available for the SPHERE HODM spare, with the strategy being to keep the present HODM and a new one (or a spare) is included into the future SPHERE-link project.

For the period after ~2020 the programme may require a reduction of ~0.3MEUR/year to the capital investments budget in order to compensate for additional staff effort.

Project Name	Description	Status
1. MUSE	Giant Optical IFU	Operations/ PAC pending
2. GRAVITY	VLTI Astrometry	Operations/Commissioning
3. MATISSE	VLTI mid IR imager	Operations/Commissioning
4. ESPRESSO	High Resolution 1UT & 4UT	Operations/Commissioning
5. ERIS	AOF Imager and Spectrograph	Integration Europe
6. CUBES	UV Spectrograph	Awaiting Phase A call
7. CRIRES+	Upgrade, X-disperser, new detectors	Integration Europe
8. MOONS	IR Multi-Object Spectrograph for VLT	Integration Europe
9. 4MOST	Optical Multi-Object Spectrograph for VISTA	Integration Europe
10. IRLOS Upgrade	Low noise Detector for IRLOS	Design
VLTI Facility		
11. PR1	AT Service Station	Completed
12. PR2 – PRIMA	PRIMA Astrometry	Discontinued
13. PR3	NAOMI (AO for ATs)	Completed
14. PR4	Infrastructure for MATISSE & GRAVITY	Construction
15. PR5	GRA4MAT Fringe Tracker	Design
16. PR6	Coordination, System	Implementation
AOF	AO Secondary for UT4 plus its sub-systems:	Operations/PAC pending
17. 4Lasers	AOF Lasers & Launch telescope	Completed
18. DSM	Deformable Secondary Mirror	Completed
19. GALACSI	AO module for MUSE	Completed
20. GRAAL	AO module for HAWK-I	Completed
21. UT4 Upgrade	UT4 Preparation & modification	Completed
LA SILLA		
22. SOXS @ NTT	X-Shooter – for NTT	Integration Europe
23. NIRPS@3.6m	IR Planet RV and atmospheres	Integration/PAE

Table 1: List and summary description of running Paranal Instrumentation projects. VLTI infrastructure and AOF facilities have been split into their main projects and sub-systems. Delivery dates are given in table 2.

Table 1 summarises all the projects currently running under the Paranal Instrumentation Programme and provides a short description of their scope.

Table 2 shows the development timetable. For the new projects, one year of Phase A is foreseen plus a development time of five years. This duration is on the short side when compared to second generation instruments such as MUSE, KMOS, SPHERE, but is not unrealistic.

Year	Phase A	Design & Construction	Delivered
2013		CRIRES+ MOONS	MUSE
2014	NTT Call for Ideas	4MOST	SPHERE PRIMA Astrometry (discontinued)
2015		NIRPS NACO Survival	LFC for HARPS VLTI PR1 GRAVITY BCI
2016		SOXS X-Shooter ADC	GRAVITY CIAO VISIR Upgrade VLTI PR4 NACO Survival
2017	MCAO for UT4 (Pre-Phase A)		ESPRESSO X-Shooter ADC MATISSE
2018	FORS Upgrade		AOF VLTI PR3 (NAOMI)
2019	MCAO for UT4 UV Spectrograph	FORS Upgrade (TBC) IRLOS Upgrade	CRIRES+ NIRPS VLTI PR5 (GRA4MA)
2020	New V	UV Spectrograph MCAO for UT4	ERIS SOXS
2021	New VI	New V	IRLOS Upgrade MOONS
2022		New VI	4MOST FORS Upgrade (TBC)

Table 2: Development plan for the Paranal Instrumentation Programme. One year of Phase A is expected to be carried out for new instruments, and the overall duration is typically estimated in six/seven years. Column "Delivered" refers to shipping to Paranal for instruments and to the end of the integration for infrastructure projects (AOF, VLTI). Dates with TBC are current estimates, to be confirmed.

The roadmap assumes that the projects currently close to completion do not suffer substantial delays with respect to the present schedule. Effort is allocated for 2019 to the new initiatives, and no major delays are expected for the projects under commissioning. In a similar way, projects presently at lower priority (MOONS, 4MOST, ERIS, La Silla) may be affected in case of conflicts of critical expertize with those close to completion.

ERIS, MOONS, 4MOST, IRLOS upgrade, SOXS and NIRPS are active, plus optimization activities for the VLTI (e.g. GRA4MAT). ESPRESSO and MATISSE will have in 2019 the final commissioning runs, and MCAO for UT4 is in phase A study. FORS Upgrade is awaiting the confirmation of the internal resources to start the implementation phase, and the UV spectrograph phase A study is expected to be launched in the second part of the year.

Figure 3 shows the status of the Paranal instrumentation in year 2022, according to the present programme plan.

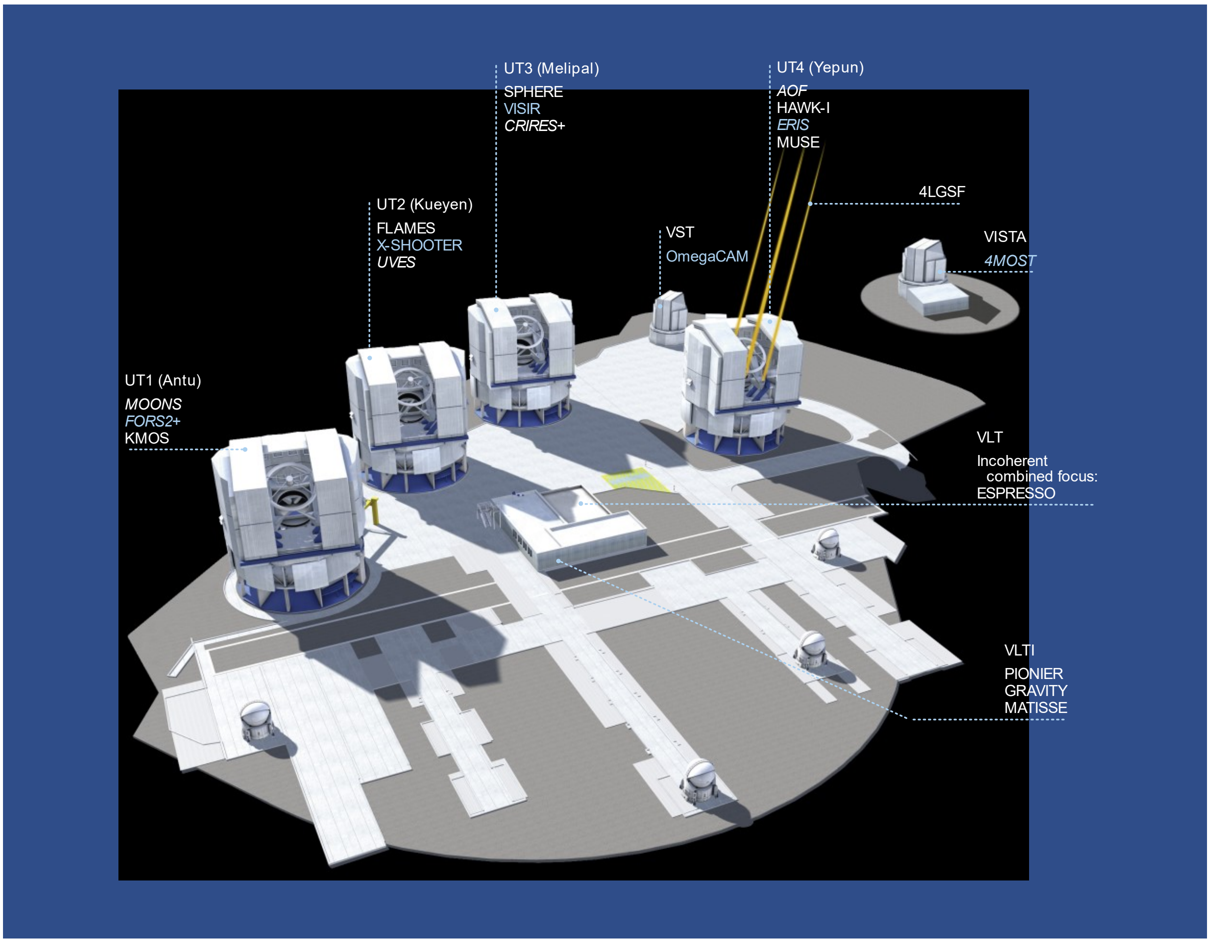

Figure 3: Paranal Instrumentation configuration in 2022, according to the present plan. Instruments in *italics* are presently in design or construction phase, new instruments/upgrades will be in different phases of completion.

4.6 Milestones for the coming projects

The following table summarises the approval and definition milestones for the next periods.

Date	CUBES	MCAO for UT4	FORS Upgrade
Q1 18		CfT Phase A	Phase A KO
Q2 18			
Q3 18		Deadline CfT	
Q4 18		Phase A KO	
Q1 19			Phase A Review
Q3 19	Phase A		Start Design
Q2 20		Agreement	

Table 3: Summary of the expected start milestones for the coming projects. CUBES (UV spectrograph) Phase A will not start earlier than Q3 19.

As seen from table 3, the Phase A of the visible MCAO instrument for UT4 (MAVIS) has started, and the Phase A of the FORS upgrade concluded.

The table below shows in more details the upcoming milestones for the major projects:

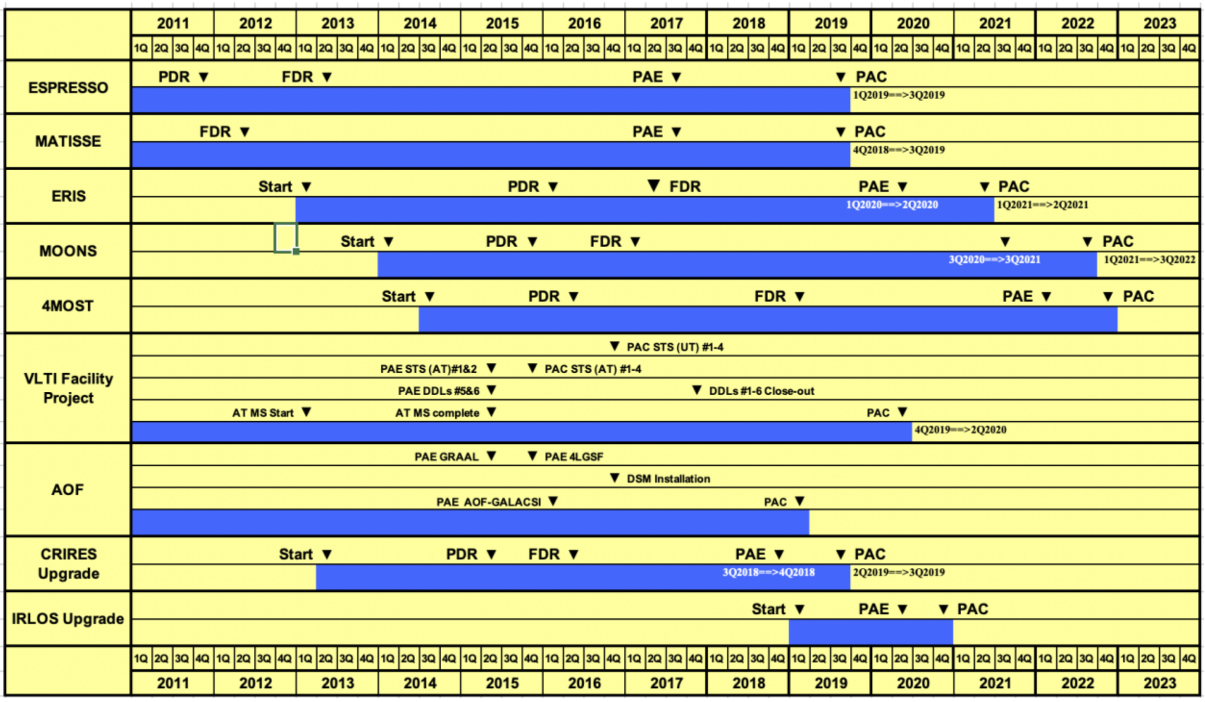

Table 4: Detailed Milestones for the major PIP projects.

5. Managing the Programme

The Paranal Instrumentation Programme is managed according to the approved ESO internal project management procedures. One programme manager and one programme engineer run the Paranal Instrumentation Programme, guided by two programme scientists, one dedicated to the VLT, Survey Telescopes and La Silla, and one to the VLTI.

5.1 Resources

Resources (cash and effort) are allocated to the programme according to the Budget and Forward Look document. Each project has an allocated budget and cash expenditure profile and a cost to completion (CtC), that includes cash and staff effort. Project managers request resources from the ESO matrix through the standard ESO process

A table summarising costs-to-completion for all PIP projects is given in **Table 5** (page 31). This is updated in each issue of this document.

A limited contingency is included, but not assigned to each project, rather held by the programme manager who has to contain all costs within the approved value of the total programme. Unexpected costs beyond this due to technical problems, delays, or enlarged scope, will need to be paid from the future programme resources, requiring delays or cancellation of future instruments.

Similarly, major requests for staff effort in areas of high priority will cause delay in other running projects or a strategic change in their organisation, for instance by increased outsourcing to institute partners. The risk of delays to one project impacting other projects is mitigated by allocating staff effort contingency beyond the currently planned completion dates of each major project.

The plan is based on the 2018 BFL. The overall effort and expenditure profile is shown in Figures 5 and 6. After the completion of VLTI and AOF, overall funding (including staff effort) decreases to reach a roughly constant value of approximately 3.8 (2018) MEUR/year cash plus 25.2 FTEs/year of staff effort. After 2019, the programme will reach a quasi-steady state of around six to eight projects running at any time. In the short term the Programme requires more staff effort than planned, and some capital is being used to hire temporary effort in order to finish the running projects.

The staff effort for future projects are requested by the Programme, and kept in one job, until, after a successful Phase A review and acceptance of the project proposal, the project is approved. At this point a separate job is created and the project becomes autonomous.

The evolution of the allocated staff effort with time for the whole Paranal Instrumentation Programme is shown in Figure 4. Different project types have different colours, and the brown edge on top shows the FTEs available for the future projects. The detail of these allocations (as at present) for the FORS upgrade and MAVIS are also given in Figure 4. An adequate staffing is allocated, when considering that the direct contribution of ESO (as a partner) to these projects will be very limited. Requests for FORS2 will be updated, following the management plan presented at the Phase A review.

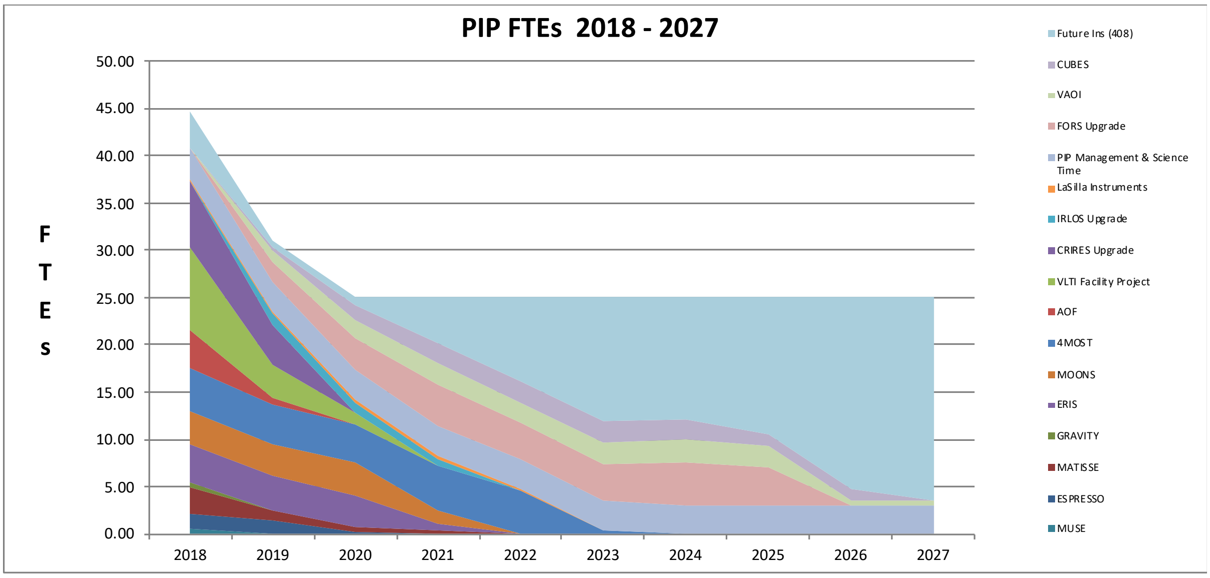

Figure 4: **Distribution of the ESO allocated human resources for the Paranal Instrumentation Programme, for the different projects. The slice on top (JOB408) is available for new projects. The presently allocated resources for FORS upgrade and MCAO Visible instrument (in phase A, not approved) are provided.**

5.1.1 Resource indexation:

From 2019, the Paranal Instrumentation Programme will benefit from indexation, adjusting the resources to the official ESO inflation index, as for the rest of the ESO budget. The indexation is implemented in two ways: as far as staff effort is concerned, this is kept at a constant level after 2021, irrespective of the increase in the staff cost, so it is allocated in FTEs and not in Euros. As far as capital is concerned, the non-committed capital is now indexed, and the cash evolution is shown in Figure 5, in which the committed and uncommitted expenditures are separately given. The reason of indexing the uncommitted fraction only is based on the fact that PIP agreements, MOU and contracts are all fixed price values, not indexed, and they will continue to be so. The committed component of the budget is therefore not influenced by the cost increase.

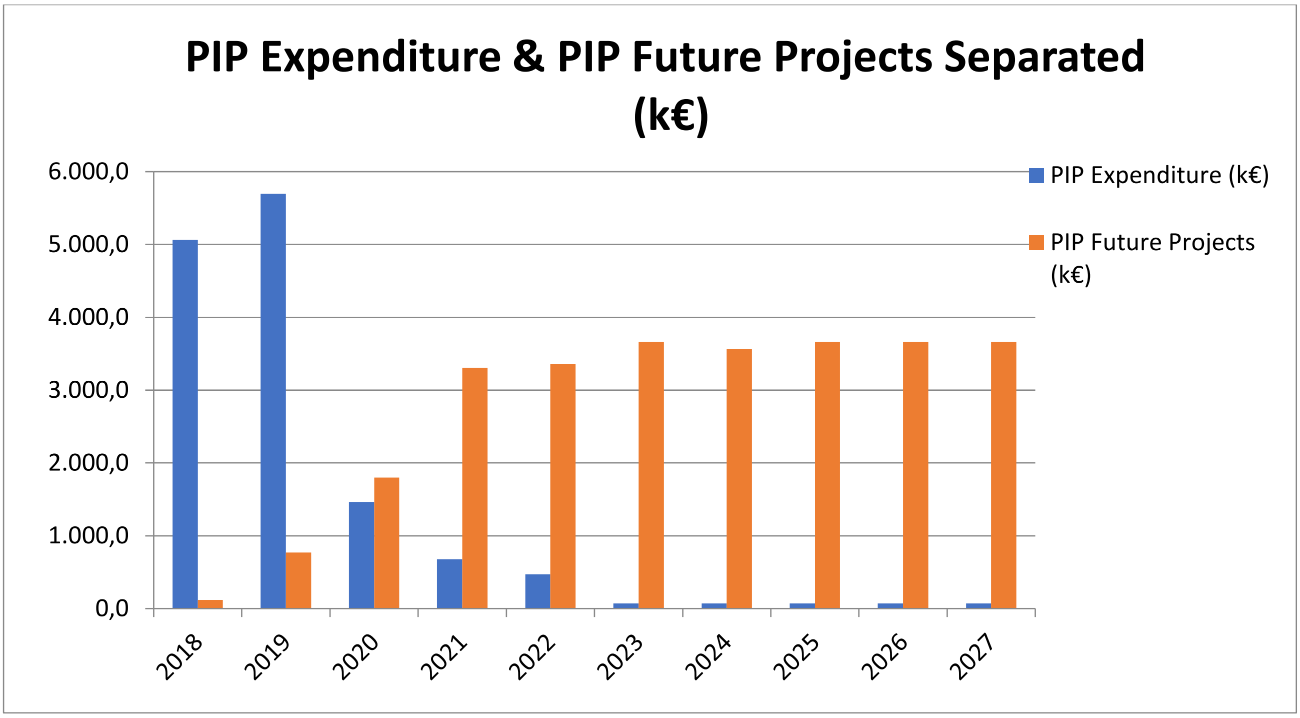

Figure 5: **Paranal Instrumentation Programme capital expenditure profile (staff effort not included), according to past real expenditures and actual projections. In red the funds not yet committed to approved projects, to which indexation has been applied.**

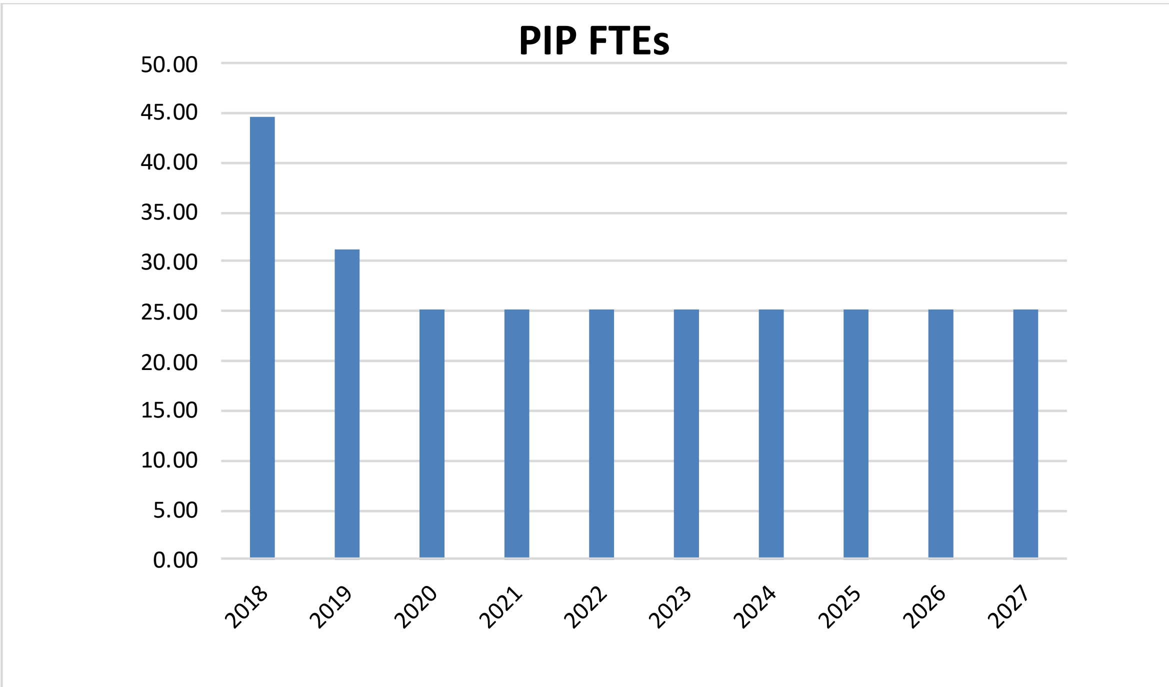

Figure 6: **Paranal Instrumentation Programme staff (ESO staff effort only) as March 2019**

5.1.2 Planning

The Paranal Instrumentation Programme covers 19 foci and 21 instruments (14 foci and 16 instruments for the VLT/I only). With one new instrument or upgrade starting every year, it is clear that the average life of an instrument in operations on VLT will, in the steady state, be some 16 years. By interspersing the programme with upgrades, the instrument suite can be maintained and will remain world leading. However, the overall resource situation (both cash and staff effort) is at a level where further reductions have a damaging impact. It should be noted that NIRPS and SOXS are possible only because these instruments are at a very low cost to ESO.

The table below summarises cost-to-completion for running PIP projects. It also provides figures for GTO nights and Consortia furnished equipment. The material costs in the first column indicate costs to ESO. The invoiced amounts refer to March 2019. ESO FTE (planned) refer to what was foreseen for each project at the end of Phase A. When comparing the numbers with FTE (cost-to-completion), it is clear that most projects have substantially underestimated the need of ESO effort in the past, as well as the total time, by a factor ~1.5. With the more rigorous project control approach, ESO should have improved these figures for the projects that started recently.

Instrument	Cost to Completion (k€)	Invoiced (k€)	ESO FTEs (Planned)	Cost of ESO FTEs (Planned) (k€)	ESO FTEs (cost to completion)	ESO FTEs (Actual)	Cost of ESO FTEs (Actual) (k€)	Guaranteed Time Observing (Observing Nights) UT/VISA/4m/3.6m	Consortium Furnished Equipment (k€)
ESPRESSO	4 029	3 867	21,15	2 672	30,76	42,07	5 368	273/0/0	4 776
MATISSE	1 349	1 813	20,77	2 338	22,95	25,60	3 360	150/173/0	3 125
ERIS	3 341	3 319	25,60	3 416	25,60	23,56	3 127	210/0/0	2 700
MOONS *	6 912	4 516	9,30	1 265	11,48	11,59	1 569	298/0/0	3 700
4MOST	5 200	2 567	23,45	3 228	27,38	19,15	2 607	0/0/1278	14 766
VLTI Facility Project	18 713	21 433	260,80	25 766	319,65	320,16	33 025	120/0/0	1 620
**AOF ** **	21 774	21 814	116,60	12 187	191,94	198,64	23 856	30/0/0	597
CRIRES Upgrade ***	1 069	1 238	15,30	2 061	18,23	29,55	3 600	62/0/0	1 700
LaSilla (NIRPS & SOXS)	100	33	5,60	775	5,60	0,95	125	0/0/0/725	4 485
IRLOS Upgrade	300	0	3,00	417	3,00	0	0	n/a	n/a
GRAND TOTAL	**62 787**	**60 600**	**501,57**	**54 125**	**656,59**	**671,27**	**76 637**	**1901/330/1318/725**	**37 469**

(*) MOONS has received a financial contribution from the Consortium in the amount of 600 kUS-$, assumed 1 € = 1.10 US-$

(**) AOF is funded by the EC in the amount 680 € (Ref.: OPTICON Contract No. RII3-CT-2004-001566 dated 26 April 2004)

(***) CRIRES Upgrade: The Thüringer Landessternwarte Tautenburg (TLS) transferred the amount of 380 k€ to ESO

Table 5: Cost-to-completion table for all running Paranal Instrumentation Projects. These are costs to ESO, i.e. do not include external funding when present.

5.2 Risk Register

A document describing the risk policy for the whole programme and applicable to all projects has been released, in line with the one adopted ESO–wide and similar to the ELT. A programme risk register has been prepared and is regularly reviewed and updated. It contains presently 5 active risks. A description of the top programme active risks is given below.

Risk	Description	Impact	Mitigation
Availability of engineering capabilities for future instruments	FTE availability for new projects is still uncertain. Mostly concentrated in the areas of software and electronics.	Non implementing or delaying new projects, loss of reputation	Delay start of new projects, allocate higher staff complement, finance the resources needed through collaborations with community/ outsource.
SPHERE HODM	The HODM had an increase number of dead actuators during AIV. No spare available	If deterioration continues, it will impact SPHERE performance/contrast	Actively control the environment (No further deterioration in Paranal)/ Include acquisition of new HODM in future upgrade
Delays in CRIRES+, MOONS, 4MOST	Delays of more than 6 months announced.	Increased need of ESO staff, which is not available for new projects.	FTE contingency, close monitoring. Delay new projects

Table 6: Main active Programme Risks.

The highest risk at present is the combination of possible resource (both human and cash) overrun by on-going projects close to completion, especially in critical area, that may delay the start of the new projects or the completion of lower priority ones. In a couple of areas the non availability of staff for new projects may be critical for their start.

5.3 Schedule and Coordination

The need for a higher level of schedule coordination for the Programme has been recognised, especially to better manage the many interventions at Paranal and the use of common resources and facilities (telescope, integration hall, etc.). A link to each schedule is available through the PIP project summary in the PIP intranet and a programme-wide planning is maintained and updated.

In addition to the main milestones, it is essential to prepare and follow-up the schedule of the activities in Paranal. This includes not only the telescopes and instruments, but also the use of the integration facilities and other resources. The coordination of these activities is one of the main tasks of the programme engineer. A schematic example of the coming activities in Paranal is provided in the table below for Q2 and Q3 2019:

	UT1	UT2	UT3	UT4	VLTI-AT	NIH	CCL/VISTA
April	Gravity CIAO on ESPRESSO 1UT comm	ESPRESSO 1UT comm	ESPRESSO 1UT comm	NEAR Comm ESPRESSO 1UT comm	MATISSE COMM		ESPRESSO fiber recovery
May	ESPRESSO 4UT comm	ESPRESSO 4UT comm	ESPRESSO 4UT comm	NEAR Comm ESPRESSO 4UT comm	NAOMI SV MATISSE SV		
June				***NEAR campaign***			
July	ESPRESSO SV	ESPRESSO SV	SINFONI back to Europe for ERIS ESPRESSO SV	***NEAR campaign*** ESPRESSO SV		CRIRES-AIV?	VISTA prep 1 for 4MOST
August			CRIRES warm?			CRIRES-AIV	
Sept.	GRA4MAT	GRA4MAT	GRA4MAT CRIRES warm	GRA4MAT	GRA4MAT	CRIRES-AIV	NIRPS-FE @ 3.6m

Table 7: Planned Paranal activities in Q2 and Q3 2019 (In lilac: for background information – outside PIP scope of work)

APPENDIX A: Characteristics tables of Paranal instruments in 2021

VST + ΏCAM	(0.3-1 µm 1x1 Degree)
VISTA	(0.8-2.5 µm eq. 46x46 arcmin)
FORS2	(0.3-1 µm, 6.8x6.8 arcmin)
WIFI, SOFI, EFOSC (?)	
AO assisted	
HAWK-I + AOF (GLAO)	(0.8-2.4 µm 7x7 arcmin)
Diffraction limit (1 UT)	
VISIR	(0.8-24 µm 32x32 arcsec)
ERIS	(1-5 µm 2x2 arcmin)
SPHERE	(0.6-2.3 µm 11x11 arcsec)
Diffraction limit (VLTI)	
MATISSE	(3.5-12 µm, ~1 arcsec)
GRAVITY	(2-2.4 µm, 2 arcsec)
PIONIER	(1.5-2.4 µm)

Table 8: Imagers at Paranal in 2021.

IFUs	
MUSE	(1x1 arcmin) (7.5x7.5 arcsec **AO assisted**)
FLAMES	(7x7 arcsec, 15*2.4x3 arcsec)
ERIS (SPIFFI)	(0.8x0.8, 3.3x3.3 arcsec) **AO assisted**
KMOS	(24* 2.8x2.8 arcsec on 7 arcmin Ø field)
X-Shooter	(1.8x4 arcsec)
SPHERE	(1.73x1.73 R=50)
MOS	
FORS2	19
KMOS	24 mini-ifus
FLAMES	< 130 or 15 mini-ifus + 7 to UVES-RED
MOONS	1000
4MOST (VISTA)	>1500
No MOS AO assisted	

Table 9: IFUs and MOS at Paranal in 2021.

GRAVITY	2-2.4 µm R=22 & 500 & 4,000
VISIR	8-13 µm R~500
FORS2	0.3-1 µm R=300-3,000
MUSE	0.46-0.93 µm R~3,000
ERIS	1.1-2.45 µm R=2-4,000
KMOS	0.8-2.5 µm R~3,600
SPHERE	1-2.3 µm R-100-700
4MOST/MOONS	0.4-0.92/0.8-1.6 µm R~6,000 and ~20,000 (both)
X-Shooter	0.3-2.4 µm R=6-10,000
FLAMES	0.37-0.9 µm R=6-20,000
VISIR	10 µm R=3,200 & 25,000
CRIRES	0.95-5 µm R=40-100,000
UVES	0.3-1 µm R=40-120,000
ESPRESSO	0.38-0.8 µm R=130-210,000 ***4UT R=70,000**
HARPS (3.6m La Silla)	038-0.68 µm R=115,000
NIRPS (3.6m La Silla)	0.98-1.8 µm R=100,000

Table 10: Spectrographs at Paranal in 2021.

Polarimetry: FORS2 (Circ.and Lin.), HARPS, SPHERE, CRIRES
High Contrast/Coronography: SPHERE, VISIR
RV Precision: ESPRESSO (<0.1 m/s), HARPS (<0.3 m/s), CRIRES (<3 m/s), NIRPS
FAST Photometry: VISIR (5ms?), HAWK-I Bust mode (2ms), FORS2 (2ms)
Astrometry: Gravity (30 µarcsec, goal 10), ERIS(300 µarcsec)

Table 11: Summary of some of the special modes present in the Paranal instruments in 2020.