EUROPEAN ORGANISATION FOR ASTRONOMICAL RESEARCH IN THE SOUTHERN HEMISPHERE

For Information

COUNCIL

137th Meeting
Garching, 8th and 9th December 2015

Paranal Instrumentation Programme Plan 2016-2021
and 6 Monthly Report, September 2015

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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 the science prioritization document (STC-551, 2015), an instrumentation programme for Paranal is presented for the period 2016-2021 with the aim of keeping Paranal at the forefront of ground based astronomy. This plan is an update of Cou-1567 (2015) and includes:

- The completion of the current VLT/I 2nd generation instruments (GRAVITY, ESPRESSO and MATISSE)
- The delivery of the Adaptive Optics Facility (AOF) with the imager and spectrometer ERIS
- The upgrade of the VLTI infrastructure to accommodate the 2nd generation VLTI instruments
- Two multi object spectrographs (MOONS for VLT and 4MOST for VISTA)
- The upgrade of CRIRES
- A new UV spectrograph (CUBES) in collaboration with and funded by Brazilian institutes\(^1\)
- Two new instruments for La Silla, fully funded by the community, and
- Development of an upgrade and replacement plan for the VLT workhorse instruments.

The plan is divided into two phases:

- Until 2018, instruments are selected and developed with the criteria of fully exploiting the VLT capabilities and maintaining the balance between dedicated and general purpose facilities, and
- Beyond 2018, the instruments will be deployed in the era of full E-ELT operations. The strategy for the second phase is being shaped and will be consolidated in the coming years.

After 2017, approximately one new instrument and one instrument upgrade can be initiated every two year. Interspersing upgrades and new facilities shall balance the resources and the future allocation of GTO at the VLT, 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 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 will be possible only if current projects are completed, and no major emergencies arise. As examples, in the last year scientific and programmatic priority has been given to the Galactic Centre event, and therefore to the completion of GRAVITY. This, when added to the overall pressure on the organization’s resources, brought the decision of shifting some AOF activities by a few months. The extra staff effort needed to complete

\(^1\) Subject to Brazilian ratification of ESO membership.
the 2nd generation instruments and infrastructure has been financed by reducing the ESO participation to some projects and the available capital in the years 2019-2025.

A roadmap for the 2016-2019 period is presented. A Risk Policy has been implemented for the whole programme and planning control improved.

2 Introduction

With the construction of the E-ELT, ESO will offer two main observatories to its community after 2024: Paranal/Armazones (integrating the VLT and E-ELT) and ALMA.

The fundamental goals for the Paranal instrumentation strategy can be summarized 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-1377, 2011):

- 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 Priority for ESO” document (STC-551, 2014), that states for the Paranal Instrumentation:

**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
- 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 E-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 organization, supported by the governing bodies, has declared point a) above as a primary goal of the Programme in the short term. This prioritization has driven a number of actions and generated some important consequences.

The instrumentation development plan provides a framework within which to implement new instrumentation in the years 2016-2021, bearing in mind that, for the next 11 years, the Paranal Observatory will be the main source of ground-based optical and IR data for the ESO community. The plan proposes an implementation that will allow a continuous 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.

When considering the VLT instrumentation projects currently under construction, in 2018 the 2nd Generation VLT and VLTI instruments will be complete, and all but five VLT/I instruments will be either new or have been recently upgraded. X-Shooter and CRIRES will be less than 10 years old. FORS2 and UVES have been upgraded in the past. This complement of instruments (see Figures 1 & 2 and the Tables in the appendix), will cover most options in imaging (including Adaptive Optics (AO) and VLTI diffraction limit) and spectroscopy in the 300-24,000 nm range. Following the decommissioning of ISAAC, no low-resolution spectroscopy capability in the 2.4-5 micron range is available. Should the need for low-resolution spectroscopy in the 3-5 μm regime be identified as mandatory for the VLT, this capability could be inserted in the specifications of one of the new instruments to be built.

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. No deployable multi-object AO assisted spectrograph will be present. The Paranal observatory will provide polarimetry, high contrast imaging and coronography, fast photometry and superb astrometry, as well as the finest instruments for precise radial velocity determination. In order to keep the Paranal observatory competitive however, a continuous initiative regarding new instrumentation development is planned. The flow should be continuous because a peaked effort (similar to the one needed for the 2nd Generation instruments) is not affordable when simultaneously implementing the E-ELT programme.

Considering an overall instrument development time of ~7 years, the plan is separated in two phases, with a transition in ~2018.
The first phase is devoted to providing the VLT with instrumentation that maintains a balance between general purpose and dedicated instruments. The second phase is dictated by the strategy of how the VLT will be used in the E-ELT era. This strategy will be fully developed in the coming years and its development will profit from a thorough discussion with the community at large. The VLT Science Priority Document (STC XXX) addresses this topic.

Figure 1: Wavelength-Spectral Resolving power diagram for the VLT instruments of first and second generation.

Figure 2: Wavelength-angular resolution diagram for the VLT/I instruments of first and second generation.
3 Current Programme

3.1 Recent Instruments

The last 12 months witnessed the final acceptance of KMOS, the end of commissioning and the start of operations of two major 2nd generation instruments (MUSE and SPHERE) and of the upgraded VISIR. MIDI has been de-commissioned. The VLTI laboratory was closed for 7 months to implement the changes needed to host GRAVITY and MATISSE, and has now been re-opened and PIONIER and AMBER are back to operations, with the four AT STSs installed. The AOF team mounted and tested the first Laser Unit on UT4. After passing PAE, the GRAAL AO module, has been re-integrated in Paranal, and finally on UT4. The GRAVITY BCI passed PAE and is being re-integrated in the VLTI lab. All other projects made significant advances.

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 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. It has already produced a number of scientific results. The final PAC will include the commissioning of the instrument's Narrow Field Mode with the AOF. Last year the main remaining problem was the stability of the detector readout electronics, which is being solved thanks to a long-term intervention plan. Other activities (e.g. monitoring of the instrument performance, exchange of one spectrograph's detector that shines occasionally, SW improvements, etc.) took place.

3.1.2 SPHERE

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 Period 95 (April 2015), after Science Verification (SV) in December 2014. The excellent performance and contrast ($10^6$) have been confirmed. A few actions remain to be closed to reach PAC.
The main concern remains the lifetime and performance of the High Order Deformable Mirror (HODM) which currently has 18 (out of 1377) dead actuators. One new actuator died in the last year. A plan for the development of a new HODM has been prepared. The development will require at least two years and will cost between about 1 and 1.5 MEUR. The SPHERE PI has been contacted to inquire about providing expertise and financial support from the consortium. ESO is also following /fostering with interest some technological developments in the framework of the Technology Development programme, that could directly impact the delivery time and costs of the spare.

3.1.3 VISIR Upgrade

The VISIR upgrade optimizes 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 experts using Garching laboratory facilities, have been described previously. Since the observed excess low frequency noise (ELFN) is inherent to the design of the device, which had been optimized for operations in a low background environment, it cannot be remedied at detector level. Instead the problem was addressed by introducing fast chopping (M2 with field stabilization) on UT3 to limit the impact of the ELFN on the on-sky sensitivity.

Following a successful COMM 4 in April VISIR entered science operations. An initial drift of targets in the FoV observed during long exposures has been identified to be caused by mechanical flexure inside VISIR. This problem was resolved by an intervention during which the mounting of the instrument inside its vessel was corrected. VISIR is in operations with imaging and spectroscopy modes; burst mode needs additional commissioning before being offered to the community.

3.2 Projects Currently Under Development

A number of projects are being developed by consortia in ESO Member States. The GRAVITY BCI has passed PAE and has been re-integrated in Paranal, while MATISSE and ESPRESSO are well advanced in their integration phases. ERIS leadership has been transferred to a consortium and the project is proceeding towards PDR. MOONS is underway and PDR is imminent. The Paranal Instrumentation Programme is also responsible for the development of the infrastructure upgrades, enabling the instruments to exploit their best performance, and three of the main projects of the programme, the Adaptive Optics Facility (AOF), ESPRESSO and VLTI Facility are of this nature.
3.2.1 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 to measure 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 requires 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) has finished its assembly phase, solving the metrology problems it had encountered in the past and consequently passed PAE. After shipping to Paranal, the BCI has been re-integrated in the New Integration Hall, and its installation in the upgraded VLTI laboratory is planned for October. More serious problems have been experienced by the Coude Infrared Adaptive Optics system (CIAO). The CIAO system needed a substantial change in its layout and a strengthened team to cope with a schedule that demands delivery, mounting and commissioning of the four CIAO systems on Paranal in time for the Galactic Center S2 event in the first half of 2017. ESO has become heavily involved in this development and has dedicated a focused task force to support the Consortium.

3.2.2 MATISSE

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. The warm optics is fully integrated as well as the Cryostats. First fringes with four beams from the internal artificial source onto the L-band detector were achieved at the end of July.

As anticipated last year, the schedule has shifted because of the re-manufacturing of some warm optics components and some delays were also caused by unforeseen activities during the integration. PAE is now planned by November 2016.

3.2.3 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 4 UTs simultaneously.

Following the successful Δ-FDR, all the components are being manufactured and all subsystems started integration. The first subsystem (calibration unit) has been internally accepted. The interfaces of the coudé train components are installed for all
UTs. The combined coudé laboratory has been prepared, including the spectrograph’s thermal enclosure.

The spectrograph cameras have experienced a long delay by the manufacturer, and are now on the critical path. PAE has slipped by a few months to August 2016. The echelle grating has an efficiency within spec, but at the low side, and a replacement is searched. The optical bench and the vacuum vessel are at the integration side and all optics (with the exception of the cameras) are due to arrive within the next three months.

3.2.4 AOF

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 optimized 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, has been contracted to the University of Leiden and funded by NOVA.

Three important reviews took place in the first half of 2015:

1. In February 2015, a review was held to ensure that the first laser unit is ready for shipment to Paranal and installation on UT4. LGSU#1 has been installed and commissioned
2. The GRAAL PAE was granted in April 2015. GRAAL was shipped to Paranal and installed on UT4 in last August, and
3. The Astronomical Site Monitoring Upgrade has completed its design and manufacturing phase. A review was held in April 2015 to coordinate with Paranal staff the implementation and switch over from the old ASM to the new upgraded infrastructure.

The UT4 infrastructure upgrade has been completed and the final acceptance report has been released.

The focus of activity is shifting toward Paranal where more critical activities have been conducted recently. The installation of LGSU#1 involved a heavy workload for the 4LGSF team and allowed to prepare the way for the other three units. The preliminary results show that the system behaves as expected. Nominal power of 22W has been delivered and return flux is higher(!) than the expected range while the laser spot size fulfils expectations (1” FWHM for a 0.6” seeing). During the LGSU#1 commissioning the newly installed Laser Traffic Control Software was used successfully to avoid and predict collisions between telescope beams. The Directorate General of Civil Aviation Chile (DGAC) conducted positively an inspection of the facility.

All lasers for the 4LGSF have been integrated with the launch telescopes and successfully tested in Garching.
GALACSI WFM tests on ASSIST have been completed and performance goals have been reached; a PAE Test Report has been issued. The GALACSI Narrow Field Mode system tests are starting and completion is planned for the end of 2015.

The difficult schedule in Paranal, coupled with the higher priority of GRAVITY and CIAO, drove the Programme to instruct the AOF project to limit resources expenditures for 2016 and 2017. This has resulted in shifting by a few months the installation and commissioning of the DSM and GALACSI to the end of 2016. This will bring a global slip of 6 months in the PAC of AOF, but a scheme is developed to perform the early commissioning of GALACSI and WFM of MUSE to allow the prompt scientific use of this facility. The plan of the AOF has a sequence of milestones and foresees PAE 4LGSF and GALACSI in fourth quarter 2015 (unchanged), DSM Installation in Q4 quarter 2016 (shifted), PAC of AOF mid 2018 (shifted).

3.2.5 VLTI Facility Project

The mid-term VLTI implementation plan foresaw the construction and operations of a number of facilities aimed at enabling PRIMA and optimizing 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 plan was implemented through 6 separate projects created in 2012 (VLTI PR1-PR6). It has been recognized, 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. The project is led by a project team that includes a full time Project Manager (F. Gonté), a Project Scientist and a Project Engineer. The PM also oversees the implementation on site. 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.

3.2.5.1 AT Maintenance Station (PR1)

This work package includes mainly the construction of a new maintenance station for the Auxiliary Telescopes (AT). The old maintenance station had very limited access, which makes the integration and alignment of the Star Separator and NAOMI very difficult, and it necessitates the risky transport of the ATs down to the integration hall. The new maintenance station has been built on the VLT platform and connected to the AT rail system making its access as easy as any other station.

The work is completed and the new AT station has been already successfully used to mount the STS on the ATs for several months.

3.2.5.2 PRIMA Astrometry (PR2)

The project is discontinued.
3.2.5.3 **Adaptive Optics System for the Auxiliary Telescopes (PR3 = NAOMI)**

The New Adaptive Optic Module for Interferometry (NAOMI) will be developed for and installed at the 1.8-metre ATs. The objective of the work package 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 performances in median and poor seeing and to enable robust fringe tracking.

The project went through PDR on May 21 & 22 2015. Several critical action items were identified. In particular, the project needs to improve its coordination with the rest of the VLTI facility and to face some obsolescence present in the ATs.

To mitigate the overall over-pressure on ESO effort, the corrective optics for NAOMI will be built under contract by the Institut de Planetologie et d'Astrophysique de Grenoble. The agreement and SOW are in an advanced preparation stage.

Given the pressure in several AO-related areas, the NAOMI project has been given a lower priority with respect to the other VLTI Facility packages. FDR has slipped to 2016 and shipment of the first system to Paranal in the third quarter 2017. The installation of the remaining three systems is planned by the end of 2017.

3.2.5.4 **Infrastructure for VLTI Second-Generation Instruments (PR4)**

This work package covers the infrastructure to be implemented for the 2nd 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.

The VLTI was closed for operations for seven months starting in March 2015 to allow major modifications to the laboratory and to the ATs to host the new instruments. The number of changes and new installations needed was rather impressive and work has been largely completed, with a minimum shift on a very successful oriented schedule (a slip of 1 month). At the time of writing, all AT STSs have been implemented and tested, and two UT STSs are mounted. The infrastructure was reviewed at the end of August and found no show-stoppers for the delivery of the VLTI to operations ad for the installation of GRAVITY.

PIONIER has been relocated and re-commissioned together with AMBER with the ATs + STS in the new lab. The results of the first run are being investigated.

3.2.5.5 **Fringe Tracker for MATISSE (PR5)**

The work package main requirements include the delivery of the differential delay lines (DDL) #3 and #4, currently being manufactured, and of the fringe tracker for MATISSE.

In collaboration with the MATISSE consortium, a Phase A study has been carried out to investigate the feasibility to use of GRAVITY as a fringe tracker for MATISSE. The
report has been reviewed and has shown that this is possible; the next step will be to quantify the MATISSE performance with this (limited) fringe tracker. In case of a positive outcome, the plan is to make GRAVITY the Fringe Tracker of MATISSE, but only after the commissioning of both instruments. The final decision on the need for a stand-alone 2nd Generation Fringe Tracker is linked to the successful implementation of GRAVITY as a fringe tracker.

3.2.5.6 VLTI 2nd 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 2nd 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.

With the focus of the VLTI Facility Project on the VLTI shutdown, the limited progress on performance assessment resulted from the post-shutdown re-commissioning period. On the Auxiliary Telescopes, ultra-fast flux dropouts seen in PIONIER datasets have been traced to the drive electronics of the fast tip/tilt actuator; a fix is expected. On the Unit Telescopes, the effectiveness of the vibration tracking algorithms, developed as part of the MACAO obsolescence activity, were confirmed. In addition, issues in the behaviour of the MACAO control loop were identified; a fix may allow revisiting the Call for Proposal statement that PIONIER on the UTs is not significantly better than on the ATs.

The performance investigations are expected to ramp back up over the following period, with the arrival of the GRAVITY fringe tracker on the mountain, and the scheduled UT astrometric baseline investigations.

3.2.6 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 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.

MOONS has delivered the documentation for PDR (October 22 and 23, 2015), which is being reviewed. One major risk is the sudden cost increase of the baseline IR detectors (4Kx4K) that makes the full project unaffordable. One potential solution which is being explored is based on 2Kx2K mosaics and the possibility to cannibalize the VISTA detectors when VIRCAM is retired. This will impose some change in the schedule, with a full implementation made in two steps. The detector strategy will be discussed at PDR.
3.2.7 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 4 AOF lasers (one at a time - SCAO), and an upgraded version of SPIFFI to adapt it to the new AO module.

During the 2014 six months hiatus the detailed effort planning for all ESO projects was completed, which led to the clear conclusion that ESO cannot continue to lead ERIS. At the same time the Science Prioritisation exercise led by the Director for Science confirmed that ERIS is needed and should be delivered as soon as possible. Therefore, ESO has asked the ERIS Consortium partners to take the leadership of the instrument together with several of the ESO work packages, leaving at ESO only two subsystems (detectors and wave front sensors).

In order to maintain a schedule in the 2019 timeframe it was also clear that a simplification of the technical concept was necessary. Such a concept includes:

- Replacing the Pyramid WFS by a copy of the GALACSI/GRAAL WFS – avoiding testing and a new development, and
- Eliminating the IR tip-tilt sensor.

The PI is R. Davis (MPE) and the Consortium is including UK-ATC for the construction of the science camera. The basic documents have been finalized and a new agreement, which will amend the existing agreements with the partners, is in preparation. Progress on ERIS and a discussion of the science cases within the new timeframe are separately presented at the STC. PDR is planned for Q1 2016.

3.3 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. They do not include standard obsolescence fight and maintenance, which is taken care by the Directorate of Operations. Given that, with the possibility of starting at most one project/yr and having 17 running instruments at Paranal and 3 at La Silla, the average mean-life of the instruments is to be expected to be longer than 15 years. This means that special attention on this subject has been requested by the STC. In collaboration with the STC and the Directorate of Science, PIP is developing 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. These instruments will then be subject to upgrades and refurbishments.
3.3.1 CRIRES+

The CRIRES Upgrade project (CRIRES+) 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 led by ESO but developed in collaboration with an external consortium.

In July 2014, CRIRES, including the MACAO fore optics module, was removed from the Nasmyth platform of UT1 for NACO to be reinstalled in lieu of CRIRES and the MACAO-CRIRES warm bench suffered severe damage in an accident during its transport from UT1 to the storage area.

The full CRIRES has been shipped to Garching and has been re-mounted in the new Integration Hall, to perform standard measurements before the changes are implemented. CRIRES+ had PDR and Optics FDR in June 2015, which was passed after critical actions had been completed.

The ESO effort on the project was stopped in 2014 for 6 months, the Consortium partners were keen to continue their work during the hiatus and a critical minimum support by ESO was provided during this period, but some delay in the project was introduced. The repair of the MACAO has been added to the scope of the CRIRES+ upgrade. The capital impact of the warm optics is not major, but it has added scope to the project. Furthermore the scope of the project now also includes dealing with obsolescence. A post PDR critical review of the schedule shows now PAE at the end of 2017.

3.3.2 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 recognized. A special STC meeting was held in December 2013 to evaluate different solutions; the recommended one was to re-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 materialized and the initial science detector of CONICA actually died after the restart of the instrument. The old ISAAC detector was used for CONICA but there are still some detector socket issues which are planned to be addressed during a Paranal planned intervention (for the repair of the objective wheel of CONICA) in October/November 2015.
A refurbishment plan was originally developed, showing that the full intervention would require a major upgrade, with the cost of 1 MEUR, the need for at least 10 FTEs over a total duration of three years, including a substantial downtime from the telescope. After the 6 months hiatus in 2014 and considering all the risks, plus the fact that the resources needed for this refurbishment were considerable and that they partially overlapped with the needs of other high priority projects, and the fact that NACO will be decommissioned after ERIS is in operation; it has been decided to implement a minimal survival project, aiming at producing a full set of spares for the critical components of NACO. Spare parts for the science & wavefront sensor detector controllers have been identified and successfully tested. RTC spare parts have also been identified and three out of 5 boards have been successfully tested. Given the modularity of the RTC boards it may be possible - by swapping modules between the spare boards - to obtain a set of working spares for each type of board: this is being investigated further. Finally, the proposal from Raytheon for the repackaging of the old ALADDIN array from CRIRES as a spare detector for CONICA will be accepted.

As far as mitigating risk for the observations of the Galactic Centre, the backup solution of using MAD, already recommended by the STC, (ESO/STC-497) has been considered as a fallback for unrecoverable failure of NACO; the MAD parts have been identified but not re-assembled.

### 3.4 Recommended Instruments pending contract agreement

#### 3.4.1 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 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, and is very well suited for a Brazilian partnership. The project has passed Phase-A review and has been recommended by the STC. 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 Kick Off (KO) meeting to PAE.

#### 3.4.2 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 2400 fibres and will work in the optical (0.3-0.9 μm). The goal is to have sixteen hundred 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. It has been proposed to work in survey mode for a minimum of five years.
After a Call for Ideas in 2010 and competitive Phase A studies, 4MOST was recommended for design and construction by the STC (ESO/STC-522). The consortium PI is R de Jong and installation and commissioning on the telescope is foreseen in 2021.

Council approved the GTO for 4MOST at its June meeting in 2015. Signature of the 4MOST agreement is currently foreseen for the end of 2015. All main documents are in advanced form and will be reviewed internally at ESO in October 2015. The design work is proceeding. The present baseline and agreement is for two spectrographs (One low resolution and one high resolution), but provision for implementing the third spectrograph is present in the agreement, should the full funding become available. 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.

4MOST is a major project and will impact significantly the existing VISTA infrastructure. It will therefore be treated as an “infrastructure project” (see section 3.2 above) from the outset.

3.5 La Silla Instrumentation

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

3.5.1 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 cm/s 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 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. A second commissioning run is planned for Q1 2016.

3.5.2 New Instrument 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 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. Additional observing time with the new instruments will be available for interested groups through the co-funding of the NTT operations.

The NTT Call for Ideas was open for specialized instruments taking advantage of large amount of dedicated observing time, as well as for state-of-the-art workhorse instruments addressing broad needs of the ESO community. Such an instrument is required to be at negligible cost to ESO. After selection, seven groups were invited to answer a Call for Proposal and 5 answered. As far as new instruments are concerned, SOXS for the NTT and NIRPS for the 3.6m telescope have been selected to continue to design and construction phase.

SOXS (Son of X-Shooter) 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. It will occupy one of the Nasmyth foci of the NTT.

NIRPS is a 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.

The strategic view is specializing the NTT for the follow-up of transient events, and the 3.6m telescope for exo-planets studies, to support future exo-planets space missions. The timeline of these projects for construction and operations extends the La Silla lifetime beyond 2023+.

4 The Future Programme

4.1 Programmatic drivers

This instrumentation development plan follows from consideration of a number of basic drivers. These are discussed below to give a flavour of the factors what will be taken into account when selecting new projects and upgrades.

4.1.1 Phase 1

In the next decade the VLT will remain the leading ground-based telescope until the start of operations of the E-ELT. There is no indication that the size of the Paranal user community will decrease. On the contrary, new Member States may join ESO, increasing the pressure on the Paranal facilities. Consequently, in Phase One the scientific use and output of Paranal instruments should be optimized, not only maximizing their throughput, but also their operational efficiency. It is important to balance as much as possible the pressure between the different telescopes and to preserve a balance between specialized and workhorse instruments, with the latter covering a wide range of scientific interests.
4.1.2 Phase 2 – Paranal & E-ELT

From 2019 onwards, new instruments and upgrades will be considered part of Phase 2. This phase is still relatively open and different scenarios can be envisaged. The E-ELT will be fully operational and astronomical research with 8-metre class telescopes may evolve towards a model where a large fraction of the time is devoted to dedicated experiments and large collaborative projects. In this context the four VLT Unit Telescopes together could provide a unique opportunity to dedicate up to ~1200 nights/year to a single problem. This approach could open up new opportunities in astronomical research. ESPRESSO and VLTI are already able to exploit the 4UTs simultaneously but new options are possible, such as equipping the 4UTs with 4 clones of the same instrument, to perform really vast, dedicated surveys.

The last two projects of the decade (starting phase A in 2019/2020) will likely start operations after the first generation E-ELT instruments. Their selection will occur after a careful reflection on the scientific use and role of the VLT in the E-ELT era.

The E-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 E-ELT capabilities are therefore important criteria for the VLT. Several aspects are unique to the VLT with respect to the E-ELT: the larger FOV, the VLTI angular resolution, and the access to the UV domain. The E-ELT will be one telescope, while the VLT includes 4 UTs. More observing time will be available at the VLT for a single programme or user. Some E-ELT instrumentation capabilities should be duplicated at the VLT, to ensure that the E-ELT is used only when its special characteristics are really needed.

4.1.3 Paranal, HST & JWST

By 2018 the HST will most likely no longer be in operation, and JWST will be about to enter operations. HST capabilities that will be unavailable include UV spectroscopy and high-resolution imaging in the B- to R- bands. The former is impossible from the ground beyond the atmospheric limit. Providing diffraction-limited observations in the B- to R- bands over a sufficiently large field could recover an important part of the missing parameter space.

Complementarity with JWST includes:
- High resolution spectroscopy
- Observations of Bright sources
- Diffraction limited observations at short wavelengths
- Flexible operations
- Wide wavelength coverage, and
- Wide field.

It might also be advantageous to provide some overlapping capabilities with JWST.
4.1.4 Paranal & Ground Based Observatories

The relationship of Paranal with other ground-based observatories (including ALMA) has still to be discussed in depth. In general, the Paranal choices will be driven by the scientific requests of the ESO community rather than by the developments of its competitors.

4.1.5 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 Priority at ESO” and the “VLT Science Priority” document emphasize that, for the period post-2021, Paranal should facilitate hosting visitor instruments. 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 would be to provide regular access to a Cassegrain focus shared with an instrument built explicitly to be easily removed (e.g. CUBES).

4.1.6 Maximize Efficiency/ Optimize use of observing time

The fact that the pressure is particularly high on some instruments must be considered: to provide maximum scientific return implies also to maintain a similar pressure on all telescopes. With the advent of SPHERE at UT3 and MUSE at UT4 a well balanced pressure on the 4UTs is being reached.

4.1.6.1 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 gains. Some exceptions, such as VIMOS and VISIR, were identified in the past and lead to important upgrade projects. The VIMOS upgrade is completed, while the VISIR one is very close to completion. 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.

4.1.6.2 Enlarge spectral coverage

Enlarging the wavelength range which is simultaneously covered 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 maximizing efficiency may be conflicting requirements.
4.1.6.3 **Share Foci**

Optimizing 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 optimization. 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 attractive 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).

- **Exchange instruments** – Adding the requirement to design instruments for easy removal and storage would add flexibility and may help to optimize 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 would be to build adaptors that serve more (smaller) instruments at the same focus.

4.1.7 **Instrument development duration**

The typical development time for 2nd generation VLT instruments has been almost 10 years from the time of conception, and 6-7 years after the start of the design phase. On the other hand, 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, with a broader interest to the community; 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).

4.1.8 **Refurbishments/Upgrades**

As expressed in section 3.3, special attention will be 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 will be provided via normal routes such as the STC and its sub-committees, scientific conferences, or directly from the community. In the case of conferences, the emphasis will be on 8-metre telescope science, rather than technological concepts. The first workshop, “ESO in the 2020s”, took place in January 2015 and contributed to shape the science priority report. A second, smaller workshop of AO experts took place in September 2015.

A key aspect of future instrument planning will be an attempt to develop and coordinate longer-term strategy more effectively. To help this it was previously proposed to create a small working group with representation from ESO, the STC and the broader community to advise the ESO Executive on the selection, deployment and decommissioning of instruments. This concept is no longer being pursued, because the interaction is proposed to occur directly with the STC and LSP. Support will be provided by conferences or dedicated workshops similar to that held recently for the next AO instrument.

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

In situations where the procurement model is an ESO-led consortium, a competitive process will normally be 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 will be 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 is not static, and must retain flexibility to react to the evolving scientific and technological landscape and to re-assign priorities. New proposals will be 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 will be 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 in 2016, all VLT/I foci will be 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 will remain in operation until GRAVITY is offered for science at which point it will also be decommissioned. The scientific characteristics of the individual instruments are described in Appendix A.

MUSE has taken the focus of NACO, which has replaced CRIRES during the upgrade. When CRIRES+ returns, one of the first generation instruments will have to be dismantled.

In the future, each time a new instrument is accepted, the instrument to be decommissioned 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.

The instruments in the current programme that will be delivered before 2020 and for which a focus will need to be identified are CRIRES+ and MOONS (which need Nasmyth foci) and CUBES (which needs to share a Cassegrain focus). ERIS is by definition at Cass of UT4.

Among the candidates for decommissioning before 2020 on the UTs are FLAMES, VIMOS, NACO and UVES, all of which would free up Nasmyth foci.

- FLAMES and VIMOS are both almost 15 years old, GIRAFFE will hardly be competitive beyond 2017 and VIMOS can only work with limited configurations. They could be de-commissioned after the spectroscopic surveys have been completed. The recently started spectroscopic surveys on VIMOS have set a time limit until which this instrument must be operated.
- After the S2 event in 2018 and with the advent of ERIS, NACO will be decommissioned.
- With the installation of ESPRESSO and CUBES, most UVES capabilities will be offered (and improved). It might be conceived therefore that, at this point, UVES could be de-commissioned after some 20 years. The UVES slit mode remains however unique.

After the start of operations of JWST, the scientific competitiveness of VISIR will substantially decrease which could free up a Cassegrain focus.

The important point is that there are sufficient decommissioning options to accommodate the new instruments.
Looking further forward, HAWK-I is the natural candidate to free a focus for a new instrument to fully exploit the AOF (see section 4.4.2 below). HAWK-I is not currently heavily in demand, but it is expected to have a second life with the Ground Layer AO correction offered by the AOF. Nevertheless, it could be de-commissioned after a several years of operation with AOF.

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 can be identified which are listed below. The list is not intended to be exhaustive.

4.4.1 Workhorse instrument to complement/support FORS2 and X-Shooter

UVES, FORS2, X-Shooter, (and also EFOSC at NTT) are among the most popular 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. With the decommissioning of ISAAC, IR spectroscopy in the 2.4-5 \( \mu \text{m} \) range is no longer available. Should the new workhorse be a multi-function multi-wavelength instrument? Or a copy (perhaps slightly modified) of one of the existing, most requested instruments? Such questions are posed in the VLT Scientific Priority document and need to be fully addressed with the STC and ad-hoc dedicated workshops.

4.4.2 New Instrument for AOF

In answer to the STC request for a plan for AO instruments at the VLT, ESO has proposed a development in two phases: first ERIS, that will follow-up NACO; then a new ambitious instrument, which is still to be specified, and would exploit the full potential of the AOF in the focus occupied by HAWK-I (Adaptive Optics Planning ESO/STC-493 (2011), ESO/STC-482). For this instrument it is critical to evaluate its complementarity and competitiveness with the existing facilities, E-ELT and JWST. Considering that high resolution imaging in the B- to R- bands with HST will most likely no longer be available, a high-Strehl B- to -R band imager might be an attractive possibility. The scientific requirements for a new AO instrument at AOF Nasmyth and the characteristics of such an instrument have been discussed in a recent (September 2015) AO expert workshop at ESO and will be reported to the STC separately by the VLT scientist.

4.4.3 Upgrades

Upgrades which have been requested and are partially on hold are:

**X-Shooter:** Two proposals to upgrade X-Shooter\(^2\) have been submitted to the Programme Manager. They are presently on hold, because the first priority will

\(^2\) One from the Netherlands and one from Denmark.
be given to solving the poor behaviour of the ADCs. This repair will be considered after the causes of the failure clearly identified. A mockup of the X-Shooter ADC has been built in Garching and will be tested in several ambient conditions to reproduce the failures and understand their causes.

**FORS2:** A proposal to upgrade the FORS2 detector is being prepared by the instrument operations team. The use of a 4kx4k pixel CCD detector would bring substantial operational benefits. In view of having an extended lifetime for FORS2, further items may need a critical evaluation.

All major upgrades are treated as new projects, and compared to running or planned instruments in order to decide priorities. Starting one project implies that either a new instrument or a major upgrade can be initiated, but not both.

### 4.4.4 New VLTI Instruments

No new VLTI instrument/upgrade is foreseen beyond what currently under design or construction. New initiatives will be evaluated after the completion of the second generation instruments and after the delivery and approval of the VLTI white book.

### 4.5 Roadmap

The roadmap laid out in Tables 1 to 3 below shows the current 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. In the most recent planning exercise over the summer of 2015, 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, delays in major projects, and underestimate of the effort needed, in particular for the big infrastructure upgrades. As a consequence, the PIP programme is utilising considerably more ESO staff effort starting with an additional 10 FTE in 2016 and decreasing to reach a steady state total effort of 27.5 FTEs/yr in 2019. 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, but with no new projects starting for the VLT before 2017.

A staff effort contingency line 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 (the BFL period) by a cut of 2.5 MEUR to the capital investments budget. This will imply that only minimal funds will be available for the SPHERE HODM spare and, that cash contingency will be essentially zero in this period. The remainder of the increase staff effort costs after 2019 are compensated by a reduction of ~0.3 MEUR/year to the capital investments budget.
The table below summarizes all the projects currently running under the Paranal Instrumentation Programme, providing a short description of their purposes.

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Description</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. VISIR Upgrade</td>
<td>Upgrade detector, disperser, water vapour monitor</td>
<td>Operations, PAC pending</td>
</tr>
<tr>
<td>2. SPHERE</td>
<td>Extreme AO Planet finder</td>
<td>Operations, PAC pending</td>
</tr>
<tr>
<td>3. MUSE</td>
<td>Giant Optical IFU</td>
<td>Operations, PAC pending</td>
</tr>
<tr>
<td>4. GRAVITY</td>
<td>VLTI Astrometry</td>
<td>Integration Paranal (BCI) &amp; Europe (CIAO)</td>
</tr>
<tr>
<td>5. MATISSE</td>
<td>VLTI mid IR imager</td>
<td>Integration Europe</td>
</tr>
<tr>
<td>6. ESPRESSO</td>
<td>High Resolution 1UT &amp; 4UT</td>
<td>Integration Europe</td>
</tr>
<tr>
<td>7. ERIS</td>
<td>AOF Imager and Spectrograph</td>
<td>Design</td>
</tr>
<tr>
<td>8. NACO</td>
<td>Spare parts for NACO Survival</td>
<td>Ongoing</td>
</tr>
<tr>
<td>9. CUBES</td>
<td>UV Spectrograph</td>
<td>Awaiting Brazilian ratification</td>
</tr>
<tr>
<td>10. CRIRES+</td>
<td>Upgrade, X-disperser, new detectors</td>
<td>Design</td>
</tr>
<tr>
<td>11. MOONS</td>
<td>IR Multi-Object Spectrograph for VLT</td>
<td>Design</td>
</tr>
<tr>
<td>12. 4MOST</td>
<td>Optical Multi-Object Spectrograph for VISTA</td>
<td>Design, Contract agreement pending</td>
</tr>
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<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>VLTI Facility</strong></td>
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<tr>
<td>13. PR1</td>
<td>AT Service Station</td>
<td>Completed</td>
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<tr>
<td>14. PR2 – PRIMA</td>
<td>PRIMA Astrometry</td>
<td>Discontinued</td>
</tr>
<tr>
<td>15. PR3</td>
<td>NAOMI (AO for ATs)</td>
<td>Detailed Design</td>
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<tr>
<td>16. PR4</td>
<td>Infrastructure for MATISSE &amp; GRAVITY</td>
<td>Construction</td>
</tr>
<tr>
<td>17. PR5</td>
<td>MATISSE Fringe Tracker</td>
<td>Phase A follow-up</td>
</tr>
<tr>
<td>18. PR6</td>
<td>Coordination, System,</td>
<td>Design</td>
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<td></td>
<td></td>
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<tr>
<td><strong>AOF</strong></td>
<td></td>
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<tr>
<td>19. 4Lasers</td>
<td>AOF Lasers &amp; Launch telescope</td>
<td>Acceptance Europe</td>
</tr>
<tr>
<td>20. DSM</td>
<td>Deformable Secondary Mirror</td>
<td>PAE passed</td>
</tr>
<tr>
<td>21. GALACSI</td>
<td>AO module for MUSE</td>
<td>PAE</td>
</tr>
<tr>
<td>22. GRAAL</td>
<td>AO module for HAWK-I</td>
<td>Installed on UT4</td>
</tr>
<tr>
<td>23. UT4 Upgrade</td>
<td>UT4 Preparation &amp; modification</td>
<td>Complete</td>
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<td></td>
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<tr>
<td><strong>LA SILLA</strong></td>
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<tr>
<td>24. LFC for HARPS</td>
<td>Laser Frequency Comb</td>
<td>Testing La Silla</td>
</tr>
<tr>
<td>25. SOXS @ NTT</td>
<td>X-shooter – for NTT</td>
<td>Definition</td>
</tr>
<tr>
<td>26. <a href="mailto:NIRPS@3.6m">NIRPS@3.6m</a></td>
<td>IR Planet RV and atmospheres</td>
<td>Definition</td>
</tr>
</tbody>
</table>

Table 1: List and summary description of running Paranal Instrumentation projects. VLTI infrastructure and AOF facilities have been split into their main projects and subsystems. Delivery dates are given in Table 2.
Table 2 shows the planned development timetable. For the new projects, one year of Phase A is foreseen for all instruments plus a development time of 5 years. This duration is on the short side when compared to 2nd generation instruments such as MUSE, KMOS, SPHERE, but not unrealistic.

<table>
<thead>
<tr>
<th>Yr</th>
<th>Phase A</th>
<th>Design &amp; Constr.</th>
<th>Delivered</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td></td>
<td>CRIRES+ MOONS</td>
<td>MUSE</td>
</tr>
<tr>
<td>2014</td>
<td>NTT Call for Ideas</td>
<td>4MOST</td>
<td>SPHERE PRIMA Astrometry (discontinued)</td>
</tr>
<tr>
<td>2015</td>
<td>NTT (New I)</td>
<td>SOXS&amp;NIRPS (New I)</td>
<td>VISIR Upgrade LFC for HARPS VLTI PR1 GRAVITY BCI</td>
</tr>
<tr>
<td>2016</td>
<td></td>
<td></td>
<td>GRAVITY CIAO VLTI PR4 NACO MATISSE ESPRESSO</td>
</tr>
<tr>
<td>2017</td>
<td>New I</td>
<td>CUBES(?)</td>
<td>CRIRES+</td>
</tr>
<tr>
<td>2018</td>
<td>New III</td>
<td>New II</td>
<td>VLTI PR5 (?) AOF VLTI PR3 (NAOMI) SOXS&amp;NIRPS(?)</td>
</tr>
<tr>
<td>2019</td>
<td>New IV</td>
<td>New III</td>
<td>MOONS</td>
</tr>
<tr>
<td>2020</td>
<td>New V</td>
<td>New IV</td>
<td>ERIS CUBES(?) 4MOST</td>
</tr>
<tr>
<td>2021</td>
<td>New VI</td>
<td>New V</td>
<td></td>
</tr>
</tbody>
</table>

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 6/7 years. According to the proposed scheme, New I-III are concerned by the first phase. Column “Delivery” refers to shipping to Paranal for instruments and to the end of the integration for infrastructure projects (AOF, VLTI). Dates with question marks 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. The most critical ones are VLTI infrastructure and AOF, which absorb a considerable fraction of the ESO staff effort. Figure 3 shows the status of the Paranal instrumentation in year 2020, according to the present programme plan. In 2020, all but four instruments will be either new or recently upgraded, and in addition four new projects (three for VLT) will be in design or construction to keep the programme active and alive.

![Diagram of Paranal Instrumentation configuration in 2020](image)

*Figure 3: Paranal Instrumentation configuration in 2020, according to the present plan. All but four instruments are new or recently upgraded, 5 new instruments (NEW II-VI in table 2) will be in different phases of completion.*

### 4.6 Milestones for the coming projects

The plan described in this section was first introduced in Oct 2011 to the Paranal sub-committee and in April 2012 to the STC. The first version of this plan was presented at the STC in April 2013 (ESO/STC-514), it was presented to the wider community in the December 2013 ESO Messenger and in 2014 became a Council document. The following table summarizes the approval and definition milestones for the next period. As seen from the table below, after the positive answer to the NTT call for proposals (and therefore NEW I is SOXS+NIRPS), the sequence of instruments and TLRs for the first new VLT project (NEW II) should be ready in next year to allow the Call for Tenders.
<table>
<thead>
<tr>
<th>Date</th>
<th>4MOST</th>
<th>NEW I SOXS &amp; NIRPS</th>
<th>CUBES</th>
<th>NEW II</th>
<th>NEW III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q2 14</td>
<td></td>
<td>Proposals</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q1 15</td>
<td></td>
<td></td>
<td>CFP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q2 15</td>
<td></td>
<td>Council GTO approval</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q4 15</td>
<td></td>
<td>Contract agreement</td>
<td>GTO Approval</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q2 16</td>
<td></td>
<td>Contract Agreement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q4 16</td>
<td></td>
<td>[GTO approval]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q1 17</td>
<td></td>
<td>[Contract Agreement]</td>
<td>Phase A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q2 17</td>
<td></td>
<td></td>
<td>CFT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q1 18</td>
<td></td>
<td>Approval</td>
<td>Selection &amp; Phase A</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: The table summarizes the expected milestones for the coming projects. New I will be an instrument for the NTT. CUBES approval is pending Brazilian ratification.

The Table below shows in more details the upcoming milestones for the major projects.
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 VLTI.

5.1 Resources

Resources (cash and effort) are allocated to the programme according to the Budget Forward Look. Each project has an allocated budget and cash expenditure profile, and accepted deviations must be balanced within the programme. Project managers request resources from the ESO matrix through the standard ESO process. A stricter concept (and associated process) of project cost to completion, that includes capital costs and staff effort for all projects from approval to completion, is being elaborated in collaboration with Finance department. It will also include small projects.

A table summarizing costs for the major projects is given in Table 5. This will be updated and extended to all projects in the next issue of this document.

A limited contingency is included, but is not assigned to each project, rather it is 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 organization, 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 2016 BFL. The overall resources and expenditure profile is shown in Figures 4 and 5. After the completion of VLTI and AOF, overall funding (including staff effort) decreases to reach a roughly constant value of approximately 3.8 MEUR/yr cash plus 27.5 FTEs/yr of staff effort. This is less than half of the presently used resources and reflects the transition from the 2nd Generation of multiple projects in parallel to the new programme. After 2019 the programme should reach a steady state of ~6-8 projects running at any time.

Figure 4: Paranal instrumentation programme capital expenditure profile (staff effort not included), according to past real expenditures and actual projections. The high values in years 2016-17 are due to carry-over from previous years.
Figure 5: Paranal instrumentation programme staff effort (ESO staff effort only).

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 now at a level where further reductions have a damaging impact. For example, the need for increased staff effort in the coming years has brought the need to ensure external fundings for the SPHERE HODM spare, and to use some of the capital for future projects. It should be noted that the new instruments for the NTT and 3.6m (NEW I) and CUBES are possible because both instruments are planned at a very low cost to ESO.

The table below summarizes Cost to Completion costs for the major PIP projects. In the future all approved projects will be included.
Table 5: Summary costs of Major Paranal Instrumentation Projects. It shall be noticed that the “VLTI Facility” costs cover all VLTI infrastructure expenses made in the past, in addition to the running project, which uses only a minor fractions of the reported resources. (*) SPHERE and AOF are funded by the EC in the amount of 900 k€ and 680 k€ respectively (Ref.: OPTICON Contract No. RII3-CT-2004-001566 dated 26 April 2004)

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 that adopted ESO–wide and similar to the E-ELT. A programme risk register is being prepared. A description of the top three Programme risks is given below.

<table>
<thead>
<tr>
<th>Risk</th>
<th>Description</th>
<th>Impact</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost Increase IR Detectors</td>
<td>MOONS need 4 IR 4k4k. Sudden increase in the costs</td>
<td>~2 ME costs increase</td>
<td>De-scope Instrument Use best VIRCAM detectors, seek additional funding in Consortium</td>
</tr>
<tr>
<td>Availability of staff effort at ESO</td>
<td>FTE requests for 2016 and 2017 severely exceed FTE assigned by BFL</td>
<td>Overheating of the programme, feasibility and delays in projects, loss of reputation</td>
<td>Several: delay AOF, allocate higher staff complement, finance the resources needed</td>
</tr>
<tr>
<td>Exchange rates unfavourable</td>
<td>US$, UK £ exchange rate higher than planned</td>
<td>Detectors are usually procured in these currencies ~ 1.5 ME</td>
<td>Escalated to Corporate level</td>
</tr>
</tbody>
</table>

5.3 Schedule and Coordination

The need for a higher level of schedule coordination for the Programme has been recognized, especially to better manage the many interventions at Paranal and the use
of common resources and facilities (telescope, integration hall, etc.). The planning of every PIP project has therefore been inserted into a common data-base, that will allow an overview and Programme-wide consolidation. A link to each schedule is also now available through the PIP project summary in the PIP intranet.

5.4 Lessons Learned

Following the successful exercise carried on for the first generation of the VLT instruments and for PRIMA, and following the advice of the STC, Visiting Committee and Council, the Directorate of Programmes is planning to routinely carry out lessons learned exercises. A lessons learned workshop for the second generation instruments in operations (X-Shooter, PIONIER, KMOS, MUSE, SPHERE) will be held at ESO in November 2015 and its outcome will be separately reported.
APPENDIX A: Characteristics tables of Paranal instruments in 2020

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Wavelength Range</th>
<th>Field of View</th>
</tr>
</thead>
<tbody>
<tr>
<td>VST + QCAM</td>
<td>0.3-1 μm 1x1 Degree</td>
<td>1x1 Degree</td>
</tr>
<tr>
<td>VISTA(?)</td>
<td>0.8-2.5 μm eq. 46x46 arcmin</td>
<td>46x46 arcmin</td>
</tr>
<tr>
<td>FORS2</td>
<td>0.3-1 μm, 6.8x6.8 arcmin</td>
<td>6.8x6.8 arcmin</td>
</tr>
<tr>
<td>VIMOS</td>
<td>0.35-1 μm, 4x7x8 arcmin</td>
<td>4x7x8 arcmin</td>
</tr>
<tr>
<td>WIFI, GROND, SOFI, EFOSC(?)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**AO assisted**

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Wavelength Range</th>
<th>Field of View</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAWK-I + AOF (GLAO)</td>
<td>0.8-2.4 μm 7x7 arcmin</td>
<td>7x7 arcmin</td>
</tr>
</tbody>
</table>

**Diffraction limit (1 UT)**

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Wavelength Range</th>
<th>Field of View</th>
</tr>
</thead>
<tbody>
<tr>
<td>VISIR</td>
<td>0.8-24 μm 32x32 arcsec</td>
<td>32x32 arcsec</td>
</tr>
<tr>
<td>ERIS</td>
<td>1-5 μm 2x2 arcmin</td>
<td>2x2 arcmin</td>
</tr>
<tr>
<td>SPHERE</td>
<td>0.6-2.3 μm 11x11 arcsec</td>
<td>11x11 arcsec</td>
</tr>
</tbody>
</table>

**Diffraction limit (VLTI)**

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Wavelength Range</th>
<th>Field of View</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATISSE</td>
<td>3.5-12 μm, ~1 arcsec</td>
<td>3.5-12 arcsec</td>
</tr>
<tr>
<td>GRAVITY</td>
<td>2-2.4 μm, 2 arcsec</td>
<td>2 arcsec</td>
</tr>
</tbody>
</table>

Table 6 Imagers at Paranal in 2018.

**IFUs**

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Field of View</th>
</tr>
</thead>
<tbody>
<tr>
<td>MUSE</td>
<td>1x1 arcmin (7.5x7.5 arcsec AO assisted)</td>
</tr>
<tr>
<td>VIMOS(?)</td>
<td>1x1 arcmin IFU discontinued after MUSE?</td>
</tr>
<tr>
<td>FLAMES(?)</td>
<td>7x7 arcsec, 15*2.4x3 arcsec) out if MOONS selected?</td>
</tr>
<tr>
<td>ERIS (SPIFFI)</td>
<td>0.8x0.8, 3.3x3.3 arcsec AO assisted</td>
</tr>
<tr>
<td>KMOS</td>
<td>24* 2.8x2.8 arcsec on 7 arcmin Ø field</td>
</tr>
<tr>
<td>XShooter</td>
<td>1.8x4 arcsec</td>
</tr>
<tr>
<td>SPHERE</td>
<td>1.73x1.73 R=50</td>
</tr>
</tbody>
</table>

**MOS**

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>FORS2</td>
<td>19</td>
</tr>
<tr>
<td>KMOS</td>
<td>24 mini-ifus</td>
</tr>
<tr>
<td>FLAMES(?)</td>
<td>&lt; 130 or 15 mini-ifus + 7 to UVES-RED</td>
</tr>
<tr>
<td>VIMOS</td>
<td>&lt; 500</td>
</tr>
<tr>
<td>4MOST/MOONS</td>
<td>&gt;1500/&gt;250</td>
</tr>
</tbody>
</table>

**No MOS AO assisted**

Table 7 IFUs and MOS at Paranal in 2018.
<table>
<thead>
<tr>
<th>Instrument</th>
<th>Wavelength Range</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRAVITY</td>
<td>2-2.4 μm</td>
<td>R=22,500,4000</td>
</tr>
<tr>
<td>VISIR</td>
<td>8-13 μm</td>
<td>R~500</td>
</tr>
<tr>
<td>FORS2</td>
<td>0.3-1 μm</td>
<td>R=300-3000</td>
</tr>
<tr>
<td>MUSE</td>
<td>0.46-0.93 μm</td>
<td>R~3000</td>
</tr>
<tr>
<td>SINFONI</td>
<td>1.1-2.45 μm</td>
<td>R=2-4000</td>
</tr>
<tr>
<td>VIMOS</td>
<td>0.36-0.9 μm</td>
<td>R=200-2500</td>
</tr>
<tr>
<td>KMOS</td>
<td>0.8-2.5 μm</td>
<td>R~3600</td>
</tr>
<tr>
<td>SPHERE</td>
<td>1-2.3 μm</td>
<td>R=100,-700</td>
</tr>
<tr>
<td>4MOST/MOONS</td>
<td>0.4-0.92/0.8-1.6 μm</td>
<td>R~6000 and ~20000 (both)</td>
</tr>
<tr>
<td>X-Shooter</td>
<td>0.3-2.4 μm</td>
<td>R=6-10000</td>
</tr>
<tr>
<td>FLAMES(?)</td>
<td>0.37-0.9 μm</td>
<td>R=6-20000</td>
</tr>
<tr>
<td>VISIR</td>
<td>10 μm</td>
<td>R=3200, 25000</td>
</tr>
</tbody>
</table>

**No low or Int-R spectroscopy in 2-4 μm**

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Wavelength Range</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRIRES</td>
<td>0.95-5 μm</td>
<td>R=40-100000</td>
</tr>
<tr>
<td>UVES</td>
<td>0.3-1 μm</td>
<td>R=40-120000</td>
</tr>
<tr>
<td>ESPRESSO</td>
<td>0.38-0.8 μm</td>
<td>R=120-220000 *4UT R=60000</td>
</tr>
<tr>
<td>FEROS(?) HARP S</td>
<td>0.37-0.93 μm</td>
<td>R=48000</td>
</tr>
<tr>
<td></td>
<td>0.38-0.68 μm</td>
<td>R=115000</td>
</tr>
</tbody>
</table>

Table 8 spectrographs at Paranal in 2018.

Polarimetry: FORS2 (Circ. and Lin.), HARPS, SPHERE, CRIRES? VISIR?

High Contrast/Coronography: SPHERE, VISIR

RV Precision: ESPRESSO (<0.1 m/s), HARPS (<0.3 m/s), CRIRES (<3 m/s), FEROS? (<25 m/s)

FAST Photometry: VISIR (5ms?), HAWK-I Bust mode (2ms), FORS2 (2ms)

Astrometry: Gravity (30 μarcsec, goal 10), ERIS(300 μarcsec)

Table 9 Summary of some of the special modes present in the Paranal instruments in 2018.