Paranal Instrumentation Programme: 2013–2020 Development Plan

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The development plan for instrumentation at the Paranal Observatory was presented to the ESO Scientific Technical Committee (STC) in April 2013. Its overall goal is to keep Paranal at the forefront of ground-based astronomy. In addition to the completion of the current second generation instruments, the installation of the Adaptive Optics Facility with the imager and spectrometer ERIS, and execution of the Very Large Telescope Interferometer (VLT/I) mid-term implementation plan, it will allow one new instrument, or instrument upgrade, to be initiated per year (provided current projects are completed). The plan is divided into two phases. Over 2013–2017, instruments are selected and developed with the criteria of filling the VLT capabilities and maintaining the balance between dedicated and general purpose facilities. Beyond 2018, the instruments will be deployed in the era of maturity of the European Extremely Large Telescope (E-ELT). The strategy for the second phase derives from analysis of VLT science in the E-ELT era, to be fully shaped in the coming five years. One new instrument is also proposed for the New Technology Telescope at La Silla, fully funded by the community.

Strategic Overview

With the construction of the E-ELT, ESO will offer two main observatories to its community after 2020: Paranal (integrating the VLT and the E-ELT) and the Atacama Large Millimeter/submillimeter Array (ALMA). The fundamental goals for the Paranal instrumentation strategy can be summarised by quoting the strategic goals for ESO formulated by Council in 2004 and 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 instrumentation development plan does not define the long term strategy for the Paranal Observatory, but rather provides a framework within which to implement new instrumentation in the years 2013–2020, bearing in mind that, for the next ten years, the Paranal Observatory will be the main source of ground-based optical and infrared data for the ESO community. The long-term strategic view is being developed in a white paper, “Paranal in the era of E-ELT”. This white paper, and the process of its development over the coming years, has been recently discussed with STC. This strategy will be fully developed after the E-ELT funding decision, and its development will profit from a thorough discussion with the community at large.

When considering the VLT instrumentation projects currently under construction, in 2018 the second generation VLT and VLT interferometer (VLTI) instruments and the Adaptive Optics Facility (AOF) will be complete, and all VLT/I instruments, but five, will either be new or recently upgraded. This complement of instruments will cover most options in imaging (including adaptive optics [AO] and VLTI working at the diffraction limit) and spectroscopy in the 300–24 000 nm range (c.f. Figure 1). Four integral field unit (IFU) instruments (two AO-assisted) and at least four multi-object spectrographs will be in operation (none AO-assisted). The Paranal Observatory will provide polarimetry, high contrast imaging and coronography, fast photometry and superb astrometry, and also the finest instruments for precise radial velocity (RV) determination. In order to keep the Paranal Observatory competitive, however, a continuous initiative regarding new instrumentation development is planned from 2014.

Considering an overall instrument development time of six to seven years, the plan is separated into two phases, with a cross-over in ~ 2018. The first phase is devoted to providing the VLT with instrumentation that maintains a balance between general purpose and dedicated

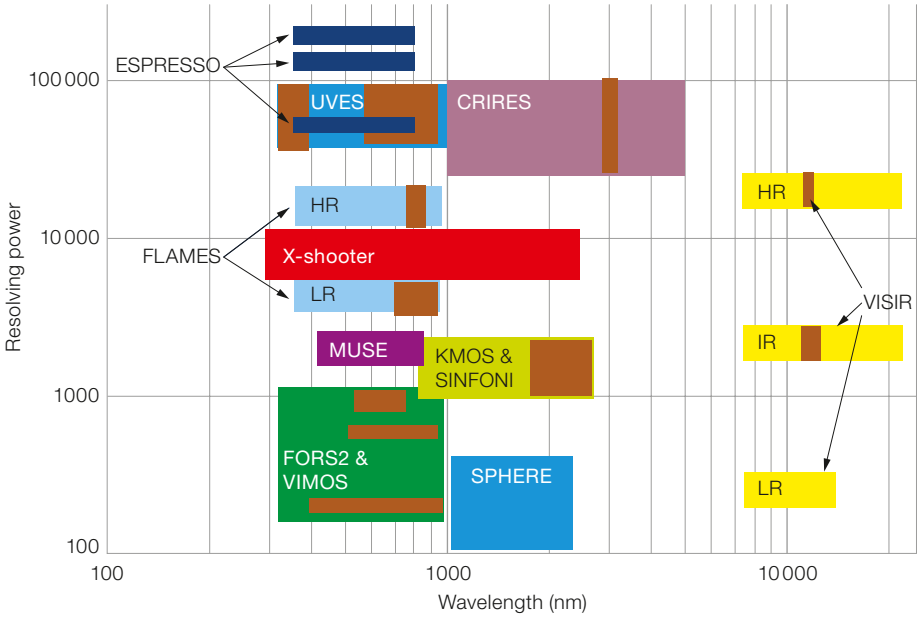

Figure 1. The wavelength–spectral resolving power domain for the VLT instruments (including those at the telescope and those in construction phase).

instruments. The second phase is dictated by the strategy of how the VLT will be used in the E-ELT era.

Phase 1 (Projects initiated before 2018/ deployed before ~ 2025).
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 the scientific use and output of Paranal instruments should be optimised. It is important to preserve a balance between specialised instruments and workhorse instruments, with the latter covering a wide range of scientific interests.

Phase 2 (Long-term opportunities in the E-ELT era, after ~ 2025).
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 per year to a single problem. This approach could open up new perspectives in astronomical research. The last two instruments of the decade (deployed in 2018/2019), should be fully integrated into this long-term perspective. Their selection will occur after a careful reflection on the scientific use and role of the VLT in the E-ELT era. To this purpose, several scientific conferences will be held in the coming years to direct the choices and finalise the strategy and its implementation.

Programmatic drivers

The instrumentation development plan follows from consideration of a number of basic drivers:

Paranal and E-ELT
The E-ELT will be an additional telescope at the Paranal Observatory, and the strengths of each unit should be maximised. Synergy and the ability to complement E-ELT capabilities are therefore important criteria for the VLT.

Paranal, HST and JWST
By 2018 the Hubble Space Telescope (HST) will most likely no longer be in operation, and the James Webb Space Telescope (JWST) will be about to enter operations. HST capabilities that will be unavailable include ultraviolet (UV) spectroscopy and high-resolution imaging in the *B*- to *R*-bands. An instrument able to provide 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 between the VLT and the JWST in the areas of high resolution spectroscopy, observation of bright sources, diffraction-limited observation at short wavelengths, flexible operations, wide wavelength coverage and use of wide field can be mentioned. It may also be advantageous to provide some overlapping capabilities with JWST.

Paranal and 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.

Maximisation of efficiency/optimal use of observing time
Optimisation can be achieved by concentrating on three main aspects: improved efficiency (throughput and duty cycle); extending the spectral coverage; exploring the possibilities for sharing the available foci. This goal could include the concept (new for the VLT) of instruments designed to be exchanged with a regular cadence.

Instrument development duration
The typical development time for second generation VLT instruments has been almost ten years from the time of conception. This long lead time should not be assumed to be inevitable, and the programme could develop instruments on shorter construction times if this becomes an agreed goal. One interesting possibility would be to create a new class of visitor instrument, operated by the construction team, but also including proposals from the community at large (in the manner of the VLTI instrument PIONIER).

Focus occupancy
With the arrival of ESPRESSO in 2016, all VLT/I foci will be occupied, including the incoherent combined focus. Some instruments (e.g., ISAAC and MIDI) will have been decommissioned as early as 2013–2014 and replaced by second generation instruments (SPHERE, MUSE and GRAVITY). Each time a new instrument is accepted, the instrument to be decommissioned will be identified on the basis of a grid of criteria that includes: scientific potential, complementarity with new instruments, instrument status and future perspectives.

Role of La Silla
It is clear that today the success of 4-metre-class telescopes is often linked to the ability to occupy scientific niches. HARPS at the ESO 3.6-metre telescope is a good example of such a success story. The specific added value of the La Silla 4-metre-class telescopes for ESO can be summarised:
- La Silla continues to be a competitive site in the southern hemisphere providing unique opportunities to its users;
- the ESO community continues to request the ESO 3.6-metre telescope and the New Technology Telescope (NTT) at reasonable to high oversubscription rates and both telescopes continue to produce good publication rates (105 refereed publications from the NTT in 2012, 69 from the ESO 3.6-metre);
- the ESO 3.6-metre telescope and the NTT are maintained to VLT technical standards and provide excellent image quality and efficiency at negligible technical down time;
- a minority of Member States have access to national 4-metre-class telescopes;
- La Silla provides the opportunity to dedicate a 4-metre-class telescope to one, or a few, scientific questions;
- 4-metre-class telescopes with state-of-the-art (workhorse) instrumentation release pressure on the observing time at the VLT (and in the future, possibly for the E-ELT).

Considering that the current NTT instrumentation is reaching the end of its life cycle (EFOSC2 went into operation in 1990, SOFI in 1998), ESO will launch a call in 2014 for a new instrument for the

NTT to be built in the community. This new instrument could replace either SOFI or EFOSC2 or both, and would be available to the ESO community for 50% of the time until 2021. Additional observing time with the new instrument will be available for interested groups through the co-funding of NTT operations.

The NTT call will be open for both specialised instruments, taking advantage of the large amount of dedicated observing time, as well as state-of-the-art workhorse instruments addressing broad needs within the ESO community. Such an instrument is required to be at negligible cost to ESO.

Instrument definition and procurement procedure

Scientific input for the new instruments is provided to the instrumentation programme manager through:
– the "Paranal in the E-ELT era" white paper, as well as other inputs from the VLT programme scientist;
– the community, by either contacting the instrumentation programme manager directly, via the STC, or via *ad hoc* scientific conference(s).

Each proposal will be scientifically evaluated by the VLT programme scientist. In order to ensure community input to the definition of the Paranal instruments, scientific workshops will be organised to address the scientific needs for the VLT in the next decade. The emphasis will be on 8-metre telescope science rather than instruments or technological concepts. These workshops, organised in the period 2013–2017, will define the instrumental capabilities to be developed after ~ 2018.

A working group of about 15 people (five from ESO, five composed of STC members and five community experts) will evaluate the best sequence in which to deploy the 2015–2018 projects. A non-exhaustive list of instrument options, which has emerged so far from the different inputs, is presented in the following sections.

After the various inputs have been collected and elaborated, a proposal consisting of the top-level characteristics for the instruments will be presented to the STC. Once the concept has been recommended a call for tenders for Phase A study will follow.

The Paranal instrumentation programme will not be static, and must be able to react to the evolving scientific and technological landscape and to re-assign priorities. New proposals will be evaluated by the programme manager, in collaboration with ESO management and 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.

New instruments for the VLT

Following a series of Phase A studies and recommendations by the STC, the following new instruments are now in process.

CUBES

In UV spectroscopy from the ground (i.e., 300–380 nm spectral range), a large increase of efficiency with respect to the existing instruments (UVES and X-shooter) is possible. In addition, this spectral range complements that of the E-ELT and JWST. An efficient UV spectrograph can cover a broad science case and could be a world-leading instrument for many years to come. Located at the Cassegrain focus, it could be easily exchanged. The CUBES concept will be developed by a consortium of Brazilian institutes and ESO. The project has passed Phase A review and has been recommended by the STC. The detailed design is ongoing, and construction will commence following the ratification of Brazilian accession to ESO.

CRIRES upgrade

CRIRES is equipped with a pre-disperser and currently delivers a fraction of one echelle order per observation. A cross-disperser could increase the simultaneous wavelength range by a large factor. An upgrade that considers the installation of a set of cross-dispersers and new detectors has passed Phase A and, after positive STC recommendation, is now in the design and construction phase (Oliva et al., 2012). It will answer a number of scientifically pressing questions, and will, in addition, satisfy several of the above considerations (such as complementarity with JWST and improvement of efficiency).

MOONS and 4MOST

The proposal to build a new, powerful multi-object spectrograph (MOS) has been strongly endorsed by the ESO community and advocated in several instances by the STC. After a call for ideas, two competitive MOS Phase A studies were awarded: 4MOST (de Jong et al., 2011) and MOONS (Cirasuolo et al., 2011).

MOONS is a near infrared facility (0.8–1.8 μm) which can host up to 1000 fibres at the Nasmyth focus of the VLT. The field of view is about 500 square arcminutes. It can operate either at lower resolution (R ~ 5000) or at higher resolution (R ~ 20 000) in two selected spectral regions.

4MOST is proposed for the 4-metre VISTA telescope, with a field of view of more than 3 square degrees. It will host up to 2400 fibres and will work in the optical (0.3–0.9 μm). Sixteen hundred fibres will feed two lower resolution spectrographs (R ~ 5000), with 800 fibres to two higher resolution spectrographs (R ~ 20 000).

These two instruments are largely complementary in almost all aspects: spectral coverage, telescope used, field of view and scientific aims. Given the outstanding science cases presented by the two consortia, the enormous range of applications of large field spectroscopy and the strong push by the community to increase ESO's MOS capabilities, together with the strong complementarity with JWST and E-ELT, both instruments have been recommended for design and construction by STC. The work for MOONS has started in 2013 and 4MOST will start in 2014.

Potential new instruments 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. This list is not intended to be exhaustive.

Workhorse instrument to complement/support FORS2 and X-shooter

FORS2, X-shooter and ISAAC (and also EFOSC at the 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, infrared spectroscopy in the 2.4–5 μm regime will no longer be 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 will be debated by the ESO/STC/community working group.

New Instrument for the AOF

In answer to the STC request for a plan for AO instruments at the VLT, ESO has proposed a development in two phases: ERIS, that will follow-up NACO and feed SPIFFI, the SINFONI spectrograph; a new, ambitious instrument, still to be decided, to fully exploit the potential of the AOF, in the focus occupied by GRAAL and HAWK-I. A high Strehl *B*- to *R*-band imager would be one attractive possibility. A multi-IFU, AO-assisted, large field spectrograph would also be unique, and its scientific merits should be studied.

In either case, the instrument may require a considerable amount of research and development. The scientific discussion about a new AO-assisted instrument of this type should start soon.

New VLTI instrument

The VLTI will continue to provide the highest angular resolution, even in the E-ELT era. The rising demand for imaging capability of stellar surfaces, close circumstellar environments and extragalactic sources sets a clear path for the VLTI medium-term development plan. PIONIER, GRAVITY, MATISSE and the second generation fringe tracker are, and will be, the immediate answers to that request. The continuous and successful effort to improve the VLTI's robustness and performance will be essential too.

However, improving the spectral coverage (visible to mid-infrared) and the imaging capability of VLTI should remain a high priority in the years to come. PIONIER already provides this and GRAVITY will provide observing modes close to the most demanded AMBER ones, but with greater sensitivity and much improved Fourier uv-plane coverage.

While it seems premature to start a new project given the enormous ongoing effort to complete and operate PRIMA, GRAVITY and MATISSE, some avenues to be explored for the VLTI in the coming years include:

1) Securing the continuity of PIONIER and offering it to the community;
2) Continuing to offer a visitor focus at the VLTI;
3) Exploring the six-telescope imaging capabilities of VLTI with the existing infrastructure.

Potential VLT instrument upgrades

Even if most of the VLT/I instruments will be new or recently upgraded, the 15 years of VLT experience demonstrate that there are frequent requests for upgrades (mostly of detectors) and that these have served the community very well. Upgrades under consideration are:

- X-shooter: Two proposals to upgrade X-shooter have been submitted and have been evaluated.
- FORS2: A proposal to upgrade the FORS2 detector is being prepared. The use of a 4kx4k pixel CCD detector would bring substantial operational benefits.
- SPHERE: The deformable mirror is formally below specification, and a replacement could be needed if its performance deteriorates.

All major upgrades will be treated as any other project, and compared to running or planned instruments in order to decide priorities. It must be clear that starting one project per year implies that either a new instrument or a major upgrade can be initiated, but not both.

Potential new instruments for La Silla

3.6-metre

In 2014 HARPS will be equipped with the Laser Frequency Comb (LFC), but will be out-performed by ESPRESSO at the VLT after ~ 2017. However HARPS has the advantage of using a dedicated telescope and of having built up a long time-series of observations; it should be used for the sources that do not need an 8-metre collecting area. HARPS is highly requested, and its future demand will also depend on the fate of space missions. It is worth recalling that exoplanet science is a young and expanding field.

NTT

The new instrument for the NTT (see above) could either be a dedicated instrument or a multi-function workhorse.

An exciting approach could be to complement HARPS at the ESO 3.6-metre with a near-infrared planet-finder at the NTT, matching the RV precision of HARPS. Several observatories are planning instruments of this kind in the northern hemisphere. High velocity precision could make it unique.

An X-shooter-type instrument for the NTT could be an interesting alternative to EFOSC2 plus SOFI.

Roadmap

Starting from 2013, the resources dedicated to E-ELT instrumentation will progressively increase. This will imply a progressive decrease in the resources available for the Paranal instrumentation programme to a new level that can sustain the "one new start per year" plan. Table 1 shows the proposed timetable. For all instruments, one year of Phase A is foreseen and a development time

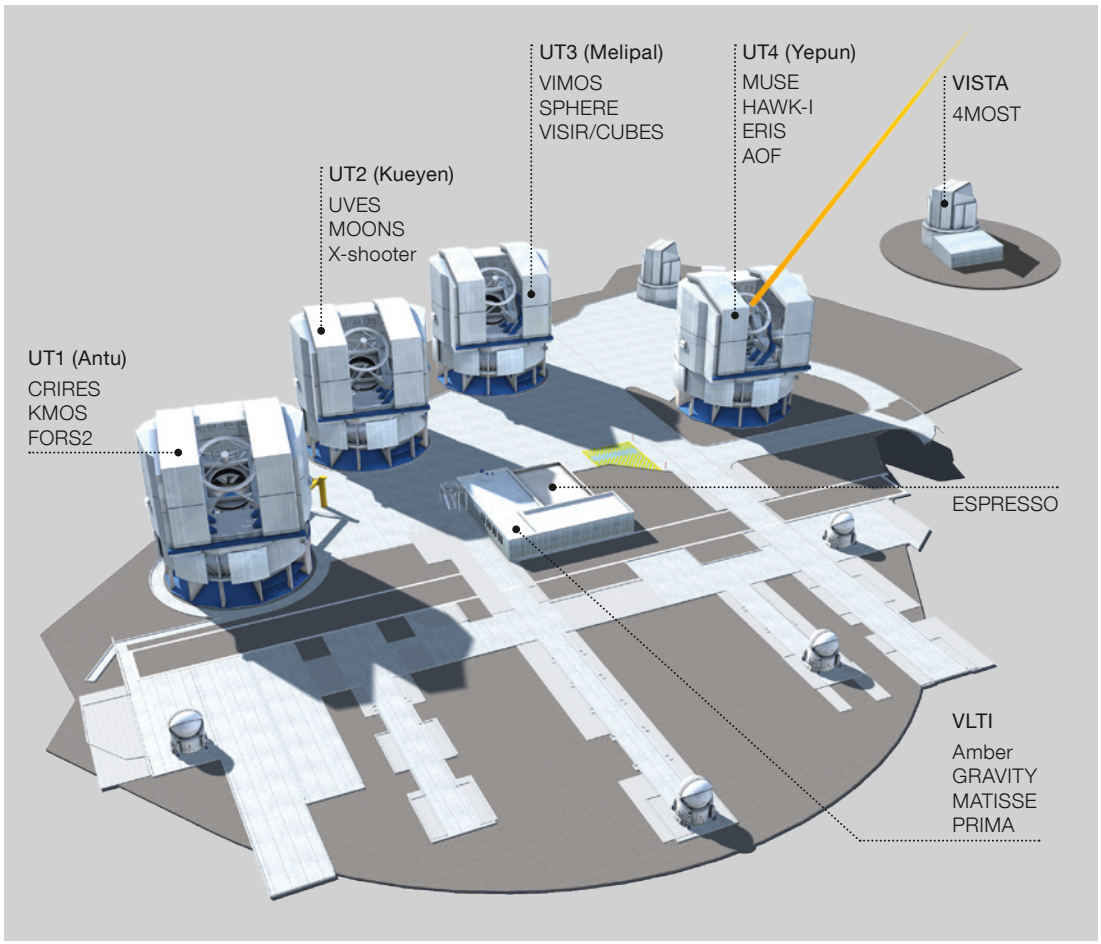

Figure 2. Planned Paranal instrumentation in 2019. One new instrument in integration, four in design and construction and one in Phase A are also planned at this time (see Table 1).

of five years. This is on the short side, but not unrealistic. Figure 2 shows the Paranal instrumentation and the project development in 2019 according to the present plan. In a resource-constrained environment, the beginning of new projects will also have to be subject to satisfactory completion of existing projects. If existing projects run late, the new ones will be re-planned accordingly.

References

Cirasuolo, M. et al. 2011, The Messenger, 145, 11
de Jong, R. et al. 2011, The Messenger, 145, 14
Oliva, E. et al. 2012, Proc. SPIE, 84462N

Links

The agendas of Council and STC meetings can be found on the ESO web pages: http://www.eso.org/public/about-eso/committees/

Year	Phase A	Design & Construction	Delivery
2012	CUBES CRIRES upgrade	ERIS	KMOS VIMOS upgrade
2013		MOONS CRIRES upgrade	MUSE SPHERE
2014	Letter of interest NTT	4MOST	VISIR upgrade PRIMA astrometry GRAVITY LFC for HARPS
2015	New I (NTT?)	CUBES (?)	AOF MATISSE
2016	New II	New I (NTT?)	ESPRESSO VLTI
2017	New III	New II	CRIRES upgrade
2018	New IV	New III	CUBES(?) MOONS
2019	New V	New IV	ERIS 4MOST
2020	New VI	New V	New I (NTT?)

Table 1. Proposed development plan for the Paranal instrumentation programme. One year of Phase A is expected to be carried out, and the overall duration is typically estimated as six to seven years. Delivery in the last column refers to start of integration in Paranal for instruments or to the end of the integration for infrastructure projects (such as the AOF and VLTI).