VLT/VLTI Second-Generation Instrumentation: Lessons Learned

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The five second-generation instruments already delivered for the Very Large Telescope (VLT) represent worthy successors to the first generation of instrumentation development. Despite this success, it is still possible to learn many lessons for the future. A review, preceded by a workshop, on the lessons learned from the second-generation instrumentation for the VLT and VLT Interferometer took place in November 2015, following a previous review twelve years ago on lessons learned from the first-generation instruments. The aim of the workshop was to identify lessons in order to help define/refine good practice and make recommendations for the future. This article briefly reports on the workshop and summarises the findings of the review panel, their recommendations and some of the steps to implement them.

The five second-generation instruments already delivered for the VLT have been a great success and taken as a whole they represent a worthy successor to the first generation of instrumentation developed for the VLT. Despite this it is still possible to learn many lessons for the future. A review of the second-generation VLT/VLTI instrumentation lessons learned took place in Garching between 25 and 27 November 2015. The first two days of the review were in the form of a workshop, with the third day devoted to drafting the report. The aim of the workshop was to identify lessons to help define/refine good practice and to make recommendations for the future. The workshop focused on four main areas:

– interaction between partner institutes/consortia and ESO (both Europe and Chile);
– design, construction, test in Europe, shipment, integration, commissioning, verification on site;
– operational aspects, post-delivery support, maintenance, training, upgrades;
– overall cost, schedule and performance of each project.

Five second-generation instruments now in operation[1] were discussed: X-shooter (Vernet et al., 2011), KMOS (Sharples et al., 2013), MUSE (Bacon et al., 2010), SPHERE (Beuzit et al., 2008) and PIONIER (Le Bouquin et al., 2011).

The review panel consisted of a representative of the ESO Council (Christoffel Waelkens, vice-chair), Hans Van Winckel as representative of the ESO Scientific Technical Committee (STC), the chair of the STC at the time when much of the second-generation instrumentation was approved (Linda Tacconi) and two past directors of the Paranal Observatory — Roberto Gilmozzi, who acted as chair of the panel, and Jason Spyromilio. The panel was supported by a panel secretary (Fabio Biancat Marchet). This article summarises the findings of the panel, their recommendations and some of the steps already taken in response.

The workshop

Members of the consortia that built the instruments, as well as the ESO Project Managers (PMs), were invited to present their experiences and the collective input from their teams. The chair of the Users Committee (Stefano Covino) also presented input from the user community. Paranal instrumentation and Paranal science operations also made general and per-instrument presentations. The workshop was organised such that each instrument was presented separately and each round of presentations was followed by a round-table discussion involving all present. The meeting took place in a very collaborative and constructive spirit and the panel stressed that they had been particularly impressed with the openness of the workshop and the inter-consortium discussions.

The panel report, after summarising the sessions and the issues of interest for each instrument, details 26 lessons learned by the panel, from which 12 recommendations were distilled (i.e., not all lessons resulted in recommendations). A comparison between the recommendations resulting from the lessons learned from the VLT first-generation instrumentation and their implementation, during the time of the second-generation instrumentation, is included. The report ends with a number of instrument-specific lessons learned at Paranal, with recommendations to avoid recurrence in future projects. This article summarises aspects of the report and provides the community with a first reaction from the management of the ESO Programmes Directorate to the report.

Lessons learned and recommendations

The second-generation instruments arrived over a timespan of seven years, during which time several aspects of instrumentation procurement have evolved, in particular the implementation of the lessons learned from the first-generation instruments (see Monnet & Bacon, 2003). In addition, the second-generation instruments were developed in a variety of configurations: X-shooter was led by ESO with the support of external consortia; KMOS, MUSE and SPHERE were led by consortia with ESO supervision and support; while PIONIER was fully developed in the community and arrived at ESO as a visitor instrument first. On account of this variety, some of the lessons learned were specific to an instrument or mode of procurement rather than being general.

The following sections summarise the broad findings of the panel report.

Interaction between partner institutes/consortia and ESO

It is evident that ESO is playing various roles in the instrumentation programme: ESO is the contracting authority, the specifier of the programme, the provider of subsystems and the final client and operator. It was clear from the input by the consortia during the workshop that, while in some cases these roles have conflicting interests, ESO staff have been proactive in seeking solutions. The situation, however, has not been uniform, with some instruments being managed as formal agreements and others as if they were partnership agreements.

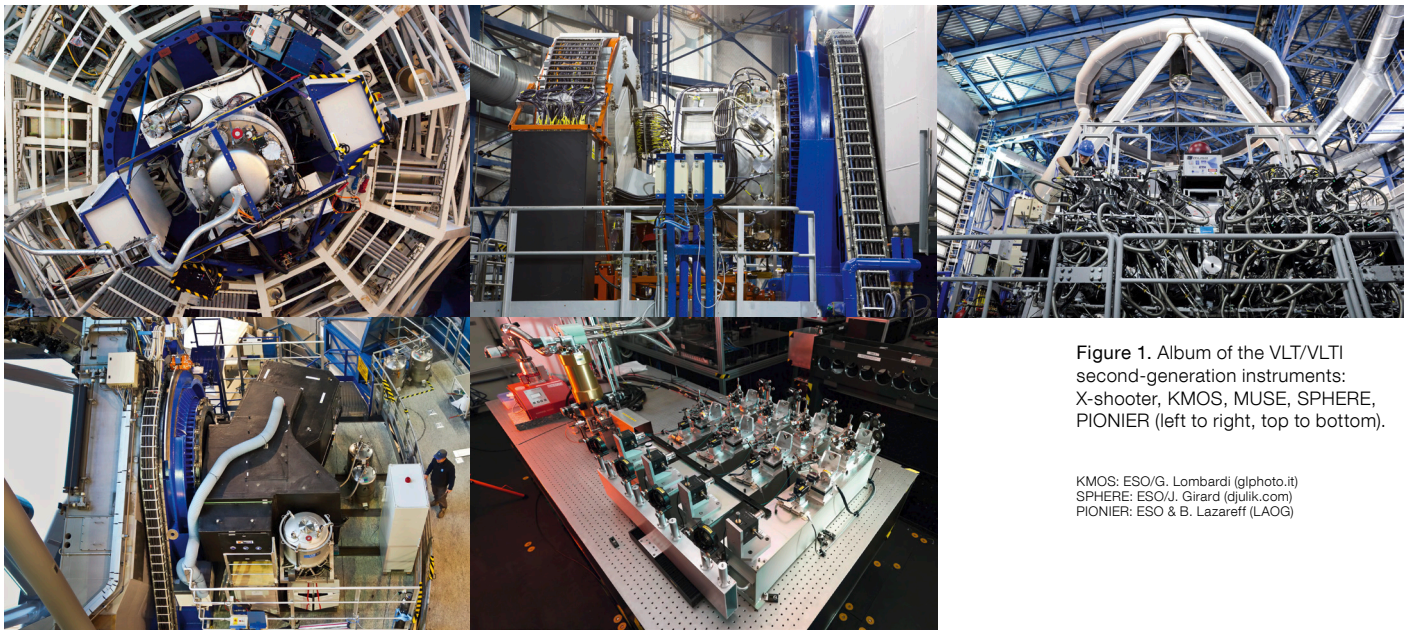

Figure 1. Album of the VLT/VLTI second-generation instruments: X-shooter, KMOS, MUSE, SPHERE, PIONIER (left to right, top to bottom).

KMOS: ESO/G. Lombardi (glphoto.it)
SPHERE: ESO/J. Girard (djulik.com)
PIONIER: ESO & B. Lazareff (LAOG)

As instruments increase in size, complexity and cost, the consortia that are created to build them also increase in size and complexity. This may be an unavoidable consequence of pressure from the community to be involved and a need for resources, both manpower and, in some cases, funds. The skills to manage such large consortia are not yet broadly available in the ground-based astronomical community.

The participation of ESO in the development of instruments was highlighted by the presenters as a key factor in their success, albeit with a request for a more structured input. The panel noted that the depth of ESO's expertise in optics, opto-mechanics, adaptive optics, software and detector systems was considered vital by the consortia, and, in general, greater involvement of ESO engineering staff is welcomed by both the ESO Project Managers and the consortia.

However, this greater involvement has clashed with the work within the Organisation. One of the main factors behind several reported problems was the limited ESO manpower available to cover unforeseen needs of the instrumentation projects. In particular, when the consortia wanted to include ESO technical and engineering expertise into their designs and development processes, this seemed to be addressed on a best effort basis. The panel recognised that, in order to mitigate this problem, ESO has adopted stricter planning and resource controls, and that VLT instruments, including those developed by external consortia, will continue to have an associated follow-up team internal to ESO.

ESO participation in consortium-led instruments sets a requirement for a clear separation between ESO as "customer" and ESO as "partner". In practice, since ESO the customer cannot find fault with ESO the supplier, complex issues arise.

As the operator, ESO maintains the authority and technical competence to guide the consortia in areas associated with operations, whether scientific or technical. ESO will need to retain the ability and credibility to guide consortia in technical matters associated with the development of new instruments. This issue will be exacerbated in the European Extremely Large Telescope (ELT) first-generation era, where ESO is not leading any of the instrumentation. Two recommendations explicitly addressed these aspects:

1. ESO should partner with the consortia in the development of instrumentation whenever possible. The customer–supplier relationship often hinders this process, and the context in which the development takes place should be reconsidered in light of the reports from the consortia.

2. If ESO is to provide support in the future, as it has done for the second-generation instrumentation, then it must retain the in-house expertise for managing and constructing large complex instrumentation, built according to the same rules that apply to external consortia.

In the course of the review, it was also noticed that the Instrument Science Teams (ISTs), the teams of scientists from the community who meet about once a year to provide input to the ESO instrument scientists on instrument development and requirements, had a limited role. On this topic the panel recommended that:

3. The ISTs for the second-generation instruments have had limited input and authority. Either the role should be abolished or strengthened with a direct mandate and resources.

Independent of the fate of ISTs, it seems good practice to regularly review (for instance at major design reviews) the instrument science cases and verify the validity of the original requirements and specifications.

ESO/ESO relationship

One important aspect of the organisation of projects is the relationship between the two ESO sites, at Garching and Paranal. This aspect is also addressed in the section below on Operations. It was clear that communication channels within ESO had not always operated correctly. The consortia and the ESO presenters indicated that sometimes Paranal had been presented with a *fait accompli* and often Garching had been unaware of the requirements and restrictions (operational implementations) on Paranal. The Garching-based presenters were found to be keen to bring the Paranal expertise into the projects at an earlier stage, while the Paranal experience was that input during the design was not always satisfactorily taken on board. The panel recommendation in this area was that:

1. Communications between Paranal and Garching should be evaluated institutionally and regularly.

Instrument development

This section covered a fairly broad range of aspects, including the use of development standards, the effectiveness of reviews, the timing of specific developments and the evolution of specifications.

There was general praise for the ESO software standards. The presence of engineers in the community with experience of the ESO software is sufficient that the software environment, despite its obvious age (e.g., the use of Tcl/Tk), is considered to be a good platform for the development of instruments.

The positive feeling towards ESO software was not, however, repeated with respect to hardware standards. The consortia have suffered the development of new ESO standards. In particular, but not exclusively, the area of motor controllers was generally felt not to have been a successful endeavour. The consortia pushed strongly for the adoption of industrial off-the-shelf solutions to replace custom ESO systems.

Modelling was used to varying degrees by the consortia. In all cases the advantages of modelling seemed to justify the investment. In some cases it was felt that additional modelling would have been useful, such as for specific cases (for example, thermal modelling), but this was not a global issue.

Early development of pipelines and software was not universally considered to be a useful endeavour. Indeed, the panel noted that, for some teams, early definition led to excess code being generated owing to unstable requirements, and to subsequent difficulties in finding resources by the time the requirements had stabilised.

It was noted that the Paranal science operations staff had not been sufficiently involved in the development process of instruments; Paranal's involvement in the analysis of problems arising during the construction phase of an instrument would help identify issues that could be critical to operations. The list of anomalies and the non-conformance reports should be provided to the project team and reviewed.

It was noted that occasionally reviews failed to catch design errors and not enough time was allocated to discussing issues in depth. Possibly a different format for the reviews (for example, preceded by in-depth engineering meetings) could address some of these issues. It was felt that the design reviews would be more effective if sufficient time were allocated for ESO engineering staff to actively, rather than superficially, engage in the proposed design and analysis.

Changes to specifications during the design phase were a cause of concern, disappointment and extra cost. It is apparent that management of the evolution of ESO standards is lacking. Some issues of obsolescence take a long time to address and the consortia felt that standards were only good when they were directly applicable.

The consortia presenters were unanimous in their praise of the spirit and working relationship that existed once they arrived at Paranal. The panel noted that, although the re-integration, installation and commissioning of the instruments is often a very intense and difficult period, there seemed to be consensus that for the second-generation instruments these were relatively smooth and successful activities. Much credit was given to the support on Paranal and the extensive Provisional Acceptance in Europe (PAE) process.

The panel recommendations in the area of instrument development were:

1. The instrument specific research and development (R&D), for example in the case of slicers, is currently part of instrument Phase A studies, which extends the time needed to build an instrument. ESO should, in collaboration with the community and with a strategic plan for instrumentation, fund more R&D independent of a specific instrument.

2. The final operator of instruments is Paranal and Paranal representatives should comprise a significant part of the executive authority in the reviews.

3. Evolution of the specifications takes place during development. Irrespective of the wisdom of this approach, if it is to continue then the existing procedures for configuration management (e.g., the timely and correct application of change requests [CREs], requests for waiver [RFWs], etc.) should be followed.

4. ESO, in collaboration with the instrumentation community, should determine and clarify the right level of standardisation and the management thereof.

Operations and post-operations

One important finding has been that, in general, neither the start of operations, nor the instrument acceptance in Chile, sees an end to the work needed by the instrument teams and Garching staff and the completion of the handover of an instrument to the Observatory. A longer involvement of the consortia, beyond installation, was considered to be necessary to complete the process. Also, time constraints make it difficult to implement a full training programme on Paranal and therefore the transfer of expertise from

the consortium to the operations team on Paranal was often not satisfactory. This was considered a problem for both Paranal and the consortia, and it was felt that a follow-up by the consortium after handover would help to resolve this issue.

Much discussion focused around the pipelines. The input from the Users Committee was for more emphasis on improvements to the pipelines and documentation. The current agreements do not follow through with pipeline development into the period when improvements from the team and the community can be merged. It is clear that the area of instrument pipelines is one where development (rather than maintenance) beyond the start of operations is key to the success of the instrumentation and gaining the support of the community. In this case, as opposed to hardware and control software, it appears that the formal deliverables by the consortia are not always the products that ESO and its community would prefer. This has been an outstanding issue since the early days of the VLT programme.

The acceptance of the instrument into operation appears to be connected to the formal acceptance of the instrument. This creates obstacles to doing early science. The panel noted that Provisional Acceptance Chile (PAC) appears to have taken on a greater importance, at odds with earlier practices.

One specific point noted is ESO's limited ability to translate some operational aspects into clear requirements and specifications. This, in conjunction with the instrument builders' limited experience of Paranal operations, has produced some unnecessary tensions and duplication of work.

The panel recommendations concerning operations were:

1. The entire operation of the Observatory is complex, and changes that may appear, or even ought to be, trivial (e.g., component or instrument names) have an impact beyond what may be assumed. There appears to be much that is unwritten or unread. The earliest possible involvement in the instrument development by science operations, both from Garching and Paranal, is critical.
2. The "after-sales" period of the agreement (after start of operations/usage of GTO time, whichever comes first) needs more clarity. For complex instrumentation it may be advisable that technical staff of the consortium be seconded to Paranal for a period of time to improve the transfer of expertise and training.

Cost and schedule

The hardware costs of the instrument projects always turned out to be very close to the values originally estimated, so there was not much discussion on this at the workshop (apart from the cost impact of some of the issues discussed above). A common feature with the instruments presented was the occurrence of problems in the manufacture of one or more critical components. This impacted mostly on the project timeline. Several instruments had rather long development times, and were late, leading to an increase in the FTEs needed by the consortia. This cost was not born by ESO and was not part of the review. The general appreciation was that the quality of the instruments is satisfactory and nobody advocated a trade-off between quality and faster development.

A very special case was PIONIER, which was the culmination of a rather long R&D process at the Laboratoire d'Astrophysique de Grenoble (LAOG), but then resulted in a very cheap and fast instrument development. The PIONIER experience has shown that very fast, very cheap, specific-goal instruments are still possible.

The recommendations in the area of cost and scheduling were:

1. Faster instrument deployments, based on the PIONIER example, should be encouraged.
2. The availability of a visitor focus across the La Silla Paranal Observatory system is a functionality that should be present to enable novel instruments to be tested.

Additional findings

Guaranteed Time Observations (GTO) formed a large part of the discussion. It is evident that, with very large allocations of GTO time, the rules and procedures to ensure that both the wider community and the consortium get to exercise their rights of access to the instrument and the sky have not reached an equilibrium accepted by all parties. It was noted that the distribution of GTO and instruments on the VLT creates occasional anomalies that reduce the available open time to inadequate levels. The panel recommended that GTO time and target allocation should be subjects for a separate working group.

VLT first-generation instrumentation lessons learned

The follow-up of the previous lessons learned exercise (Monnet & Bacon, 2003) is an important check on the effectiveness of the process. The workshop panel analysed the extent to which the lessons learned from the first-generation instruments have been implemented, compared with the execution of the second-generation instruments, as described during the workshop. The analysis is summarised here.

Simpler instruments, fewer mechanisms and modes

This recommendation has not been followed and the second-generation instruments have, in general, become significantly more complex, encompassing more mechanisms and combining multiple modes. This seems, however, to be an unavoidable consequence of the need for higher performance, exploiting the available technologies to the limit. It is the opinion of the panel that this recommendation should be interpreted in the sense that unnecessary complexity should be avoided, and at least the complexity of the instruments should be reflected in a suitable organisation of the project, including commensurate managerial and technical resources.

More standardisation (for example, for cryo-vacuum systems)

This recommendation has been followed to a reasonable extent. Although, as described above, there have been flaws, it was the general opinion of the participants that the adoption of standards is beneficial, provided they are properly managed. The standards should refer as much as is feasible to solid and proven technologies, be kept up to date, and be communicated to the project teams.

Phase A studies to minimise technical/cost/schedule risk

Phase A studies are now routinely undertaken and are an unavoidable phase in the inception of a project.

Compact consortia

This recommendation has not in general been followed for the second-generation instruments. As with the first point above on simpler instruments, these are major undertakings both in terms of technical challenges and financial exposure, which can only be afforded by consortia with a large number of members. The emphasis should rather be on the proper management of large partnerships.

More ESO/consortium collaboration during development

It has been lamented by some consortia that the attitude of ESO was excessively client-like, and therefore this recommendation has not been completely followed and rather depended on ESO management. On the other hand, there is some pressure internal to ESO to have clean formal relationships.

Stricter provisional acceptance and PAE

For PAE, this recommendation has been followed in general, although with some exceptions.

More involvement of Paranal

During the development of the second-generation instruments, an effort has been made to ensure early and effective involvement of the Paranal staff in the projects. This, however, has been limited by operational priorities and the availability of manpower. When properly accomplished, the benefit for the projects has been evident and therefore the panel strongly recommends increasing such effort for the new projects.

More parallel interaction with the Data Management & Operations Division

An improvement in this interaction has been noted in respect of the second-generation instrumentation.

Increased possibility for early science

On account of their complexity, the second-generation instruments could not really follow this recommendation.

Implementing the lessons learned

Here we report on the reaction of the management of the ESO Programmes Directorate to the second-generation lessons-learned panel report.

Issues relating to the Paranal instrumentation programme

As noted by the panel, the delivery of the second-generation VLT/I instruments has been spread over some seven years, during which the development of instrumentation at ESO has gone through a significant evolution, with the creation of the Directorate of Programmes and the institution of an independent Paranal Instrumentation Programme (Pasquini et al., 2013). Some of the panel findings and recommendations have been (partially) implemented, or at least addressed, in this period, while some of the panel recommendations have triggered a prompt response, and we emphasise them in this section.

Much attention has been devoted to relationships with the consortia, which have evolved in the direction of partnerships, and ESO is now directly involved in all projects as a partner institute. At the same time, ESO remains the final client and must guarantee the performance of the instruments to the community and safely operate them for decades; this role cannot be delegated or removed. Nevertheless, the relationships have evolved towards a more collaborative status than pure customer–contractor, focusing on the common aim, which is the success of the projects. This collaborative attitude has been especially evident when major problems occurred, when ESO experts have directly supported the projects at a level beyond what was stipulated in the formal agreement. Some project control aspects have been improved, and a stricter Configuration Management (CRE, RFW, etc.) policy is in place, in order to fully evaluate the impact on the project of proposed changes in specifications or performance.

Paranal–Garching communications have been the subject of intense work over recent years. A tension was recognised quite some time ago, as communications became more and more critical for those projects which heavily impact the existing Observatory infrastructure — such as the Phase-Referenced Imaging and Micro-arcsecond Astrometry (PRIMA) instrument, the VLTI facility, GRAVITY, the Adaptive Optics Faciity (AOF) and the Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations (ESPRESSO) instrument. In order to improve communications, several actions have been taken over the past few years:

- for all major projects it is now standard to temporarily transfer key people from Garching to Paranal for substantial parts of the project lifecycle;
- monthly coordination meetings are held between Paranal and the Instrumentation Programme management;
- a Change Request process is in place and projects need to have CREs submitted and “approved in principle” by Paranal before Provisional Design Review (PDR), and approved in their final form by the Final Design Review (FDR).

It is, however, clear that more effort is needed to improve the communications between the sites, as well as to make the process smoother for the consortia. Managing the relationship between Garching and Paranal, proactively planning and resolving problems, is a major part of the role of the Paranal Instrumentation Programme Engineer in Garching.

It is fully recognised that Paranal staff should continue to form part of the composition of review panels, but the concept of shared executive authority, as recommended by the panel, is not supported by the Programmes Directorate management. We believe that the right balance is achieved by keeping Paranal as the executive authority for all change requests to the infrastructure, whilst maintaining one executive authority with responsibility for the full project in the Paranal Instrumentation Programme.

The recommendation to guarantee strong support after the start of operations has triggered an immediate response: for the Spectro-Polarimetric High-contrast Exoplanet REsearch (SPHERE), Multi Unit Spectroscopic Exlorer (MUSE), AOF, GRAVITY and ESPRESSO, instrument experts have been (or will be) transferred to Paranal for several months after the handover. This will become a standard procedure for the future. These activities are being implemented in the Programmes Directorate's planning, by allocating programme resources beyond the start of operations.

The point about needing to retain in-house instrumentation expertise is fully agreed, and this is discussed further below. ESO has always led and implemented all instrument upgrades, although they can be developed in collaborations with consortia (for example, the CRyogenic high-resolution InfraRed Echelle Spectrograph upgrade, CRIRES+). Clearly ESO's involvement must be compatible with the resources needed to successfully develop and build the ELT and its instrumentation.

Pipelines and science data products have been an outstanding issue since the early days of the VLT programme. Specific projects (for example, MUSE, ESPRESSO and the 4-metre Multi-Object Spectrograph Telescope 4MOST) have agreed to produce science data products, but this is not standard for all instruments. Once science data products are delivered from the consortia, the long-term policy clearly becomes important.

The possibility of making a VLT focus permanently available for visitor instruments has been debated on several occasions and addressed in the Paranal Instrumentation Programme development plan (Pasquini et al., 2013). At that stage a permanently free focus was considered a waste of opportunity, and it was proposed to offer a VLT Cassegrain focus for visitor instruments, in conjunction with the CUBES spectrograph (which will be easy to dismount). Visitor instruments can in the meantime be proposed at any Call for Proposals for the New Technology Telescope (NTT), ESO 3.6-metre telescope and the VLTI. The updated plan, which includes the recommendations for decommissioning VLT instruments (STC-569[2]) foresees that, in about 2019, one Nasmyth focus may become free.

Issues of strategic importance

Two major issues of strategic importance, which transcend the Paranal Instrumentation Programme, came out of the review:

1. ESO's role in ELT instrumentation — both the management of ELT instrumentation and ESO's level of participation in ELT instrumentation;
2. Retaining and developing ESO's in-house expertise.

It is clear from the review that all instrument projects get into difficulties at some point, when it is expected that the Principal Investigator (PI) institute will take the lead in resolving the issues. However, it is also clear that the PI institute needs to be able to find at ESO the strength and depth that will fill holes in the consortium that the PI institute cannot. There is in fact a dual role for ESO — both as partner in the consortium (to fill known gaps as a member of the consortium at the start of the project) and to be able to assist in times of crisis.

ESO's role in ELT instrumentation

The request for ESO's continued involvement in instrument consortia is clear from the review. For the Paranal Instrumentation Programme, this is essentially an endorsement of the current philosophy. For the ELT, however, this will represent a change. It is now clear that ESO should increase its support of the instrument consortia on the ELT. In the first instance this effort should be targeted at the interfaces between the instruments and the telescope, since this is the most critical area. However, we need to be able to help the consortia in times of crisis in the same way as has been the tradition on the VLT. The ELT planning is being updated to meet this objective. Of course a critical issue will be the availability of funding and of key staff.

Retaining and developing ESO's in-house expertise

In order to retain the core skills in instrumentation and be able to develop the next generation of experts, three strategic objectives for ESO have been identified and are discussed in turn below.

1. Instrumentation leadership

With the complexity of modern instrumentation, consortia will continue to be the vehicle for delivery of major new instruments. ESO should continue to participate in the development of instrumentation, delivering major subsystems as a consortium partner, and should in addition have a goal of always leading one major instrument at any time. Presently ESO is leading two major instrumentation initiatives for Paranal — the AOF and the VLTI facility project to prepare for GRAVITY and the Multi-AperTure mid-Infrared SpectroScopic Experiment (MATISSE). Once these are completed, ESO should look to take a leadership role in another new instrument (either on the VLT or the ELT). Such a leadership role will of course depend on available resources, but it is viewed as fundamental to the long term retention and development of ESO staff.

2. Be world class in several areas of technology

One of the best ways to retain and develop experts is through ESO's role in technology development. The immediate r&D (small r, big D) focus should be on those areas which are needed by the ELT. ESO should be the spider at the centre of the web, providing leadership

and (some) funding to influence the direction of the community (who will do big R and small d). For example, ESO will lead and facilitate the technology development needed to bring the ELT Planetary Camera/Spectrograph concept and technology readiness to the level needed to be able to start construction in 2019+.

ESO must have the in-house expertise to drive or facilitate the development of, and later be able to support, the instrumentation activities and the operation of the telescopes. Areas which ESO will target with the objective of being/continuing to be world class are, *inter alia*:

- detectors/controllers;
- adaptive optics (AO) technologies:
  - AO high-order deformable mirrors (DMs);
  - wavefront sensor (WFS) cameras;
  - real-time control (RTC) systems;
  - laser systems;
- wavefront control, phasing and metrology;
- interferometry.

In addition, ESO will continue to develop its expertise in project management, instrument systems engineering and ultra-high-contrast imaging.

3. Retain the basic skills for instrumentation in all disciplines

Finally, ESO should pursue a balance in its overall work to ensure that all the basic skills for instrumentation are retained. This means that the choice of subsystems that ESO delivers to consortia should be cognisant not only of the availability of effort, but of the need to retain core skills. In the short term, ESO will build the ELT Commissioning Test Camera. Although it is a commissioning camera, with no science capability, it will require the full suite of core instrumentation skills. The timing of this work (no significant effort before 2019) is consistent with not increasing the overheating of the current programme.

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Links

[1] List of all VLT/VLTI instruments: http://www.eso.org/sci/facilities/paranal/instruments.html
[2] STC-569 VLT instrument decommissioning guidelines: http://www.eso.org/public/about-eso/committees/stc/stc-87th/public/STC_569_Guidelines_for_decommissioning_of_VLT_instruments_87th_STC_Mtg.pdf

The four Unit Telescopes and three of the Auxilliary Telescopes of the VLT on Paranal.