The VLT Science Cases: a Test for the VLT

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Introduction

In preparation for VLT operations, ESO is gearing up its interaction with its astronomical community. It is important for ESO to understand the needs and requirements of future users and to accomplish as high a standard of service as possible. In addition, we have got to know the most demanding needs of the community in order to *verify* at the earliest possible stage that the VLT will actually meet such expectations. To this end, we have been actively seeking input from future observers.

We asked several astronomers to provide us with 'VLT Science Cases' (SC), potential programmes of high scientific interest and especially demanding in terms of required performance. In parallel, a set of 'Reference Observing Proposals' (ROP) have been created at ESO to cover some more technical aspects. The SC and ROP are used as a conceptual test of the VLT, of its first-generation instrumentation (ESO Technical Preprint No. 72), and of the VLT science data flow (P. Quinn, *The Messenger* No. 84). They are meant to help us to achieve a quantitative understanding of the expectations concerning the scientific performance of the VLT, and identify possible improvements of the project. This should provide an early appreciation of potential shortcomings that could be eliminated before the VLT is offered to the community, and/or an early identification of needs that may be satisfied by appropriate upgrades in the instrumentation plan and VLT operations. The ROP were also established for tests of the VLT operational system (cf. P. Quinn, *The Messenger* No. 84, and J. Spyromilio, *The Messenger* No. 85). The SC were analysed by the 'Science Performance Group' co-ordinated by the VLT Programme Scientist (A. Renzini) with the goal to identify actions which could improve the scientific performance of the VLT. This approach is complementing the other user interaction channels through the standing oversight ESO Committees, and the VLT/VLTI workshops held over the last few years.

Up to now 28 SC and 7 ROP have been completed (Tables 1 and 2). The collection of VLT Science Cases illustrates the wide involvement of ESO's user community. More than 90 astronomers from all ESO member countries have contributed in one form or another. To this are added over 20 ESO/ECF staff astronomers in Garching and in Chile. The effect is to strengthen the ties between ESO and its scientific community on a rather informal, but direct, level. In effect, through the SC a 'network' has started to be established within the community which can be rapidly accessed for specific scientific questions and to explore the relative effectiveness of various options concerning the VLT. We are very grateful to all the astronomers that have participated in the SC, and believe they deserve the gratitude of the community for having spent some of their time for the common benefit. There will be indeed no privilege or tangible reward for them, with the exclusion perhaps of what may come from having started thinking about VLT observations in a more precise and practical way. With VLT first light being already so close, the VLT has to become a much stronger reality in many European astronomers' mind in this and the coming year. The SC were also meant to stimulate and assist this process.

The size of this SC network has been so far limited only by our capacity to maintain interactions with it and to fruitfully analyse its input. Yet, the exercise is not over and we plan to "call" for a new set of SC this year. The selection of the topics of the SC was done to cover some of the most active areas of astronomical research for which we believe the VLT will become a major contributor. To this we added observational techniques we

TABLE 1: VLT Science Cases

- Evolution of galaxies from $z = 0.6$ to $z = 4.3$
- Testing the redshift evolution of potential wells and scaling relations of galaxies
- The evolution of cluster galaxies
- A search for binaries in globular cluster cores
- High redshift radio galaxies:
  - (a) Their stellar content and surrounding clusters
  - (b) Gas kinematics and jet/cloud interactions
  - (c) Imaging- and spectro-polarimetry to identify and separate the scattered component
  - (d) UV nebular diagnostics of the extended gas
  - (e) Absorption studies of Lyα and C IV as probes of the circumnuclear gas particularly the cold component
- Distant cluster of galaxies
- Measuring Ω with weak gravitational lensing
- Dark matter searches with weak gravitational lensing from a drift-scan image
- Measuring Ω_Λ from (weak and strong) lensing modelling of rich clusters
- The star formation history of ultra-low surface-brightness galaxies
- Extending extragalactic PN as probes of galaxies out to 50 Mpc
- Astronomy of isolated neutron stars
- Spectroscopy and photometry of very distant supernovae
- Chemical evolution and star formation history in nearby galaxies
- A complete sample of 1000 active galactic nuclei to $R = 23.5$
- Dynamics of the Carina dwarf spheroidal galaxy
- Properties of compact emission line galaxies up to $z = 1.2$: velocity dispersions and emission line ratios
- Chemical abundances of stars in globular clusters
- Physics of main-sequence and slightly evolved stars in young open clusters
- RR Lyrae stars in the LMC: tracers of the structure and the metallicity of the old population
- The galaxy population in the redshift interval $0.5 < z < 5$
- Redshift evolution of chemical abundances in damped Lyman-α system
- Dynamics of galaxies at the VLT with FUEGOS/ARGUS
- Optical identification of gamma-ray burst sources

TABLE 2: VLT Reference Observing Proposals

- Quasar absorption lines
- Gravitational arcs in clusters of galaxies
- The nature of AGNs
- Dynamics of dwarf galaxies
- Stellar winds on the AGB
- Comet impact on Jupiter
- Gravitational shear in clusters of galaxies

expect to be essential for the success of VLT observation, i.e. demanding programmes in terms of preparations and observational skills. We are fully aware that the current set of SC does not cover all of astronomy, but it is the purpose of the next rounds to start filling in the gaps. The scientific contents of the SC are treated confidentially.

The VLTI has been excluded from the current science cases. The Interferometry Science Advisory Group has indeed provided very valuable input to the definition of the VLTI programme (cf. Paresce et al., *The Messenger* No. 83), and further science cases at this stage would have unnecessarily duplicated this effort. One emerging field of astronomy, extra-solar planets, has also been set aside as this area has been judged so rapidly expanding and crucial for the VLT/VLTI that a special working group was created at the beginning of 1996. The reports of this working group are complementary to the SC.

While several useful indications for further improvements have been produced by the SC exercise, it is reassuring to note that no major drawback has emerged, while most SC can be served adequately with the telescopes and instruments as they are specified at this point. In a few cases with very special requirements (e.g. fast reaction time to targets of opportunity – possibly through direct outside access) the proposed experiment does not lie within the specifications for the telescope. Such cases are studied further to explore the possibility of future implementation.

Almost all SC demonstrate that VLT science will not be possible without the preparatory and supporting work at other telescopes. This is true for target selection as well as target characterisation. A direct response to this need is the ESO Imaging Survey which is to be carried out at the NTT (cf. Renzini and da Costa article in this *Messenger*, see also the ESO WEB site).

The extraordinary advantages of the connection with HST has been amply demonstrated by results combining Keck and HST data. The presence of the ECF at ESO/Garching offers the ESO community a unique opportunity for productive combination of VLT and HST data, and several SC are directly built up on such combinations.

Perhaps not surprisingly, it has been found that most demands from the SC have been placed on the instrumentation. This may be due to a self-imposed limitation of many astronomers to currently available telescope hardware. The VLT science cases offer the possibility to ask for more than just the proposed instrumentation and possibly refine the instrumentation programme. It is clearly understandable that most people restrict themselves to the possible rather than develop dreams; however, it is also evident that only by asking for the ‘ideal’ experiment can we try to push hardware to the limit and learn what to do next.

Many SC need massive multiplexing capabilities for the VLT to be competitive in the corresponding scientific areas. Besides this, capabilities to be included in the instrumentation programme highlighted by the SC are adaptive optics supported by artificial guide stars, integral field spectroscopy in the optical and IR, high-speed CCD photometry, and coronography. There are other parts of the instrumental parameter space which are not covered by the VLT instrumentation. However, no SC was designed to demand a capability which could not be served within the current instrumentation plan.

The Science Cases
Pseudo-proposals

The VLT Science Cases solicited by the SPG were meant to address fundamental problems in different areas of astronomical research. By no means is it expected that these SC cover all of the most relevant current astrophysical issues, but they are rather indicative of the type of scientific operations the VLT will be asked to perform. Each PI was asked to fill out a standard VLT Science Case form to obtain relevant and detailed information about the VLT requirements for the proposed research. The form – nicknamed *pseudo-proposal* – was split into five main sections.

(1) The scientific rationale, also addressing the possible impact of current research before the VLT will start operating; (2) a description of the proposed observations, including an estimate of the total observing time required to achieve the scientific goal (preparatory La Silla observations were also mentioned and quantified); (3) a detailed list of the technical requirements to accomplish the scientific goal (e.g., pointing, tracking, image quality, throughput, etc.); (4) identification and a quantitative discussion of the performance of the VLT and the instruments required to achieve the science goal and the associated calibration requirements; and finally (5) proposers were asked to briefly identify the limits of first-generation instruments for the specific SC, all the way from simple items (e.g., the filter list) to the whole instrumentation plan.

In a parallel development, several ROP were created in house. Their purpose was specifically to test the operational concepts proposed for the VLT. To provide a semirealistic scenario, they also contain a scientific rationale appropriate for an 8-m project, but the emphasis was put on the technical aspects of the proposals. Since they were planned for realistic checks of the data flow and the operational system, they assumed the approved instrumentation and were developed to cover as wide a parameter space as possible. Operationally simple observations are included as well as complicated and delicate projects which require a very high level of planning and agility of the system, even the combination of individual telescopes for the simultaneous coverage of particular events. There is some overlap between VLT science cases and the reference proposals. We included the reference proposals as they describe the operational requirements in greater detail.

Each SC and ROP was analysed by a member of the SPG. The main observational elements and their requirements were addressed. All proposed observations were assessed with a particular view on technological and operational aspects. The results are now currently used in discussions on the scientific needs of the VLT project, and to quantitatively investigate instrumental options, optimisation, and telescope/instrument combinations.

Discussion

All VLT science cases were broken down to the level of individual types of observation and the relative instrument(s) (imaging, spectroscopy, optical, near-IR, high-resolution, low-resolution, etc.). We have concentrated the investigation on some specific topics, since we are interested on the impact of the realistic programmes on the observing modes and the operations. All observations were assessed for the image quality requirements, the importance of temporal resolution, spectral resolution and coverage, and typical flux levels to judge the amount of observing time.

On the operations side we checked from where the target catalogues for the proposal would be drawn. The VLT will work at flux levels for which no whole sky survey is available. Preparation is the key to the success of VLT observations. Almost all SC are based on extensions of current data sets (e.g. the ESO Imaging Survey) and only very few projects will build their catalogues directly from VLT imaging data. The requirement for the logistic support of the VLT in terms of object catalogues and supporting observations at other (smaller) telescopes is evident. The need to find faint and/or rare but interesting objects for study with the VLT in statistically significant quantities has spawned the ESO Imaging Survey, and many other observatories are gearing up for large-field-of-view instruments. The wide-field capabilities planned at ESO will become crucial for the VLT. Multi-object spectroscopy depends on very good positional information which has to be provided ahead of the VLT observations (to set up slitlet arrays in FORS, fiber positioning for FUEGOS, or provide masks for VMOS and NIRMOS). This information has to be available either from observations with smaller telescopes or imaging with the VLT itself.

There are many different factors which determine the detailed scheduling of an observation. All SC were assessed for their constraints on the schedule. Exceptional atmospheric conditions (e.g. seeing, low IR background) can be critical as well as the absolute timing (co-ordination with other observatories), or the dependence on earlier observations. Most importantly for VLT operations, such factors directly influence whether a programme can be carried out by means of service observations, or whether the presence of the astronomer at the telescope is required. This will still be possible in the 'classical' observing mode. Note that there might be programmes which require excellent conditions, yet are delicate enough to demand the astronomer's direct interaction. Situations like these will have to be resolved and it was one of the aims to learn how many such programmes might emerge in a realistic schedule. Another aspect of importance for the VLT operations is the data rate which will have to be handled at the observatory. Estimates of typical data volumes were derived for each SC. A related topic is the format in which data are archived. For certain observations it will be impossible to maintain all raw data and some preliminary reduction procedures will have to be applied (typically IR data will have to be combined 'on the fly'). Data storage and handling will not pose a critical problem with the possible exception of some special programmes (speckle, high-speed photometry). The current data-flow schemes should be able to cope with the amount of data delivered by the instruments. The SC provide ground examples for decisions to be taken soon. A few SC require specialised observing techniques, e.g. drift scans offer flatfield quality which may be essential for some applications.

The available VLT science cases span a wide range in project size. There are a few SC which, if implemented at the proposed scale, would take up a major fraction of the available time, while other programmes are estimated to take only a few nights for completion. Interestingly, the majority of the projects would request more than 100 hours observing time. Thus it should not be expected that observing projects at the VLT will be of smaller scale or be completed in less time than current programmes at La Silla.

Many projects are suitable for service observing, some completely depend on it to catch the excellent image quality required for the experiment. The option to make full use of co-ordinated observations, however, is not explored yet. Only few projects try to combine various observing techniques for a more complete picture of the science object.

There are certainly limitations in the current set of SC. There is an obvious bias towards observational cosmology. The large statistical samples of faint objects required for this type of research drives the demand for high multiplexing facilities at the large telescopes. Another often requested facility is outstanding imaging quality stable for very weak objects over a large wide-field of view (weak gravitational lensing, statistical lensing).

A few science areas are missing completely, e.g. there are no SC for the thermal IR or adaptive optics with IR wavefront sensor. No studies of the interstellar medium or of gas in general have been provided. High-resolution studies of stars, mapping of stellar surfaces (e.g. through Doppler mapping), stellar outflow, stellar environments, or the whole area of star formation and pre-main-sequence evolution have not yet been considered. Other stellar topics, like initial mass functions, low-metallicity stars, stars in nearby galaxies, will have to be addressed in the future. No science case for the solar system (e.g. trans-Neptunian objects) is available.

Summary

The VLT Science Cases have opened a new channel of user interaction with ESO. They were meant to have a two-way effect; first to raise the awareness within the community by stimulating European astronomers to think about the forthcoming capabilities of the VLT 8-m telescopes and entice them to prepare for the exciting opportunities they will provide. Besides this, they were meant to set elements for a concrete scientific platform for future developments in the VLT project. They also were meant to better identify what the astronomical community is expecting from ESO.

It is gratifying to see that there seem to be no major shortcomings in the VLT programme, and the instrumental resources for most planned observations will become available in due time. Yet we have identified improvements in the instrumentation plan like the massive multiplexing spectroscopy needs or the possible fiber feed boosting the multiplex capability of the high-resolution instruments (e.g. UVES).

With the experience gained from this first set of SC we now feel confident to ask interested astronomers to submit a science case to ESO. While we cannot guarantee that every pseudo-proposal can be included into our list, we do encourage all ESO astronomers to think about their plans for VLT observing, whether they submit a science case to us or not. Anybody interested in providing a VLT Science Case should contact one of the authors of this article. We are particularly interested in projects which cover research areas not represented in the current sample, and instrumental capabilities which are poorly represented in the first set of SC. These include the mid-infrared spectral range, near-infrared high resolution spectroscopy, and projects which require adaptive optics with and without artificial reference star.

We believe it is timely to think about the capabilities of the VLT now and ask for the necessary preparatory observations with La Silla telescopes. The OPC has specifically set guidelines to devote some of the available time to preparatory programmes (cf. Call for Proposals). The work on a Science Case may also provide stimulus to check out the developments in the VLT project (see the WWW VLT page http://www.eso.org/vlt/ and the descriptions of the instruments). It certainly will prepare you for the occasions when the VLT will be 'your' telescope. On the other hand, soon real VLT proposals will take the place of SC pseudo-proposals, and some of the questions in the pseudo-proposals may be transferred to real ones, for ESO to keep active an ongoing monitoring of the needs and expectations of the community.

The ESO Imaging Survey

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1. Introduction

During 1997 (July–November), ESO plans to carry out a wide-angle, multicolour imaging survey using EMMI on the NTT, followed by a deeper, narrow-angle survey using SUSI2 and SOFI, early in 1998. A summary of the expected characteristics of the survey is shown in Table 1. This project, hereafter referred to as the ESO Imaging Survey (EIS), is meant to generate moderate-size statistical samples for a variety of astronomical applications, ranging from candidate objects at the outer edge of the Solar System all the way to galaxies and quasars at extremely high redshift. EIS data should provide a suitable database from which targets can be drawn for observations with the VLT, in its early phase of scientific operation (from the