Astron. Astrophys. 343, L1–L4 (1999)

ASTRONOMY
AND
ASTROPHYSICS

Letter to the Editor

Science verification of the Unit Telescope 1 of the ESO Very Large Telescope*

Riccardo Giacconi, Roberto Gilmozzi, Bruno Leibundgut, Alvio Renzini, Jason Spyromilio, and Massimo Tarenghi

European Southern Observatory, Karl-Schwarzschild-Strasse 2, D-85784 Garching bei München, Germany

Received 14 December 1998 / Accepted 11 January 1999

Abstract. Science Verification observations with the VLT Unit Telescope No. 1 have provided the first publicly available scientific data from the VLT. This paper describes the preparation, observations, and reductions of the imaging data obtained during this Science Verification phase. Also given is a description of the status of the telescope at the time of the observations and of the instrument, the VLT Test Camera. The reductions procedures to which the data have been submitted are outlined. Data analyses and their astrophysical interpretations are presented in other papers in this issue.

Key words: telescopes – surveys

1. Introduction

Early in the construction of the VLT it was decided to include a brief period of scientific observations during the commissioning phase of the first VLT Unit Telescope (VLT–UT1). These *Science Verification* (SV) observations for the VLT–UT1 were effectively performed from August 17 through September 1, 1998. All the data obtained during SV were then released to the ESO astronomy community on October 2, 1998. This special issue of Astronomy & Astrophysics Letters collects the first papers resulting from the investigations of these data.

The original SV observing plans and an outline of the programs were presented before the actual observations (Leibundgut, de Marchi, & Renzini 1998). Information on the observations and the data can also be accessed through the ESO Web pages (http://www.eso.org). A brief, early, summary of the observations was presented by the SV team in the September 1998 issue of The Messenger (No. 93, 1). All SV data are available in raw or flat-fielded form from the ESO archive. In October 1998 a CD-ROM set was also distributed to all astronomical institutes within ESO member states and Chile. The data on the Hubble Deep Field South were made available world-wide.

In this article we briefly outline the concept and policy of VLT Science Verification (Sect. 2), give a description of the VLT telescope status during SV (Sect. 3) and the Test Camera, which was the instrument used for the observations (Sect. 4), and report the actual observations and conditions during the SV period and the preparation of the data for the public release (Sect. 5). Finally, a brief outlook is given over the future plans of VLT Science Verifications.

2. Science verification policy

The goals that ESO intended to reach with these SV observations were manifold: i) experiment a first scientific observing run of the VLT, including the first end to end use of the VLT Science Data Flow (Silva & Quinn 1997, Quinn 1996), ii) offer science grade VLT data and involve ESO users in their scientific analysis at an early stage, iii) foster an early scientific return from the VLT, and iv) gather feedback on the telescope performance and operational procedures.

Within this framework, it was the aim of the Science Verification program to submit the VLT-UT1 to the scrutiny implied by actual scientific observations. A set of diverse SV programmes was planned, with observations in each programme being sufficiently complete to achieve a well defined scientific goal. Therefore, SV was *not* designed to test the technical specifications of the VLT, such as e.g. the VLT Level 1 Requirements, as this was the the primary task of the Telescope Commissioning. The SV observations were instead designed from science objectives asking for the most demanding observations with the available instrument, the VLT Test Camera. An attempt was made to include a wide range of scientific observations so as to allow the involvement of as many astronomers in the process as possible. The selection thus included a broad range of targets from the solar system to the Hubble Deep Field South (Table 1). Despite all attempts for fairness, the final selection may have been biased, as possibly any other conceivable choice. A further selection had to be made at the telescope to match the actual observing conditions to the observational requirements, which resulted in a few SV programmes not getting data at all.

Send offprint requests to: B. Leibundgut

* Based on observations collected for Science Verification of UT1 at the European Southern Observatory, Paranal, Chile. Invited introductory paper to this special Letter section.

Correspondence to: bleibundgut@eso.org

Table 1. Targets observed during UT1 SV.

Object class	Target	α	δ	filters[a]	comments
		(2000.0)		(s)	
HDF-S NICMOS Field	. . .	22 32 52	-60 38.8	UBVRI	
HDF-S STIS Field	. . .	22 33 38	-60 33.5	BR 392/7	
Lensed QSO	ER0047-2808	00 49 43	-27 52.7	BVR 557/6	
Galaxy Clusters	EIS0046-2930	00 46 28	-29 30.7	VRI	
	EIS0046-2951	00 46 07	-29 51.6	VI	
Host Galaxy of GRB	GRB970228	05 01 48	$+11$ 47.0	BVR	
Edge-on Galaxies	ESO 342-G017	21 12 13	-37 38.0	BVR	
	FGCE 1703	22 09 11	-44 12.0	BR	short exposures
	FGCE 1847	23 43 27	-38 55.6	BR	
Globular Clusters	NGC 6440	17 48 53	-20 21.5	BR	
	NGC 6712	18 53	-08 42	UBVR	several fields
Pulsars	PSR 1706$-$44	17 09 42	-44 29.0	V	
Trans-Neptunian Objects	1993 RO	. . .	. . .	VRI	
	1996 KV1	. . .	. . .	BVRI	
	1996 TL66	. . .	. . .	BVRI	
	1996 TP66	. . .	. . .	BVRI	

[a] The narrow band filters are given with their central wavelength (in nm) and the band width (in nm).

3. The telescope

The VLT UT-1 had first light on the 25. May, 1998 (see The Messenger No. 92). A full description of the telescope can be found in the VLT White Book (1998; http://www.eso.org/outreach/info-events/ut1fl/whitebook). For SV the telescope was used at the Cassegrain focus which provides a plate scale of 528 microns per arcsecond at $f13.6$. The complete optical train was in place including the Linear Atmospheric Dispersion Compensator (LADC) which is located above the focal plane and is always in the beam. For the Science Verification observations described here the LADC was maintained in the closed position.

The telescope pointing during SV was of order 2-3 arcseconds RMS depending on the exact Alt-Az position of the main axes. The telescope was run in closed loop active optics mode including defocus corrections using the off-axis guide star as the reference. Field aberrations are removed before the residual aberrations are calculated. Typically a new correction is calculated and applied every 30 seconds to both the primary mirror and the secondary. The secondary corrects for residual decentering coma (the bulk of decentering coma is taken out by passively correcting the position of the primary mirror) and defocus. On the primary the rest of the first 15 Zernicke terms was corrected with the exclusion of tilt. Since focus is automatically corrected, no overheads for focusing the telescope are incurred. It should be noted that the image quality delivered by the telescope systematically surpassed the seeing as measured by the outside seeing monitor.

Light from the same guide star is used (with a dichroic) to feed the guide probe. Rapid guiding corrections are calculated from the CCD and sent to the secondary mirror unit, which provides the field stabilization through tip-tilt. The update frequency to the secondary was between 10 and 20 Hz depending the magnitude of the guide star.

With the exception of periods of strong wind (>12 m s^{-1}) the tracking performance with rapid guiding active was better than 0.2 arcseconds peak to peak. Operational overheads for the telescope permitted 180 seconds per preset before the telescope moved on to target. Following that the acquisition of the guide star and the first active optics correction typically require 30 to 60 seconds more. No other overhead is presented by the telescope itself. Offsetting the telescope is done during readout of the CCD. We note that the telescope SV phase was purposefully placed in the middle of the commissioning of the telescope. The figures presented here are indicative of the performance of the telescope at the time of SV. We expect improvements as a better understanding of the telescope develops in the second part of commissioning.

4. The VLT test camera

The VLT Test Camera was not meant to be a scientific instrument, it was specifically designed for the commissioning of the telescope. Therefore, its characteristics have been determined almost entirely by technical rather than scientific requirements. The Test Camera has two modules, an imaging module and an analysis module. The latter provides a pupil imager and a wavefront sensor using a Shack-Hartmann analyzer. During SV the imaging module was used. This is a Offner optical system which re-images the telescope image plane onto a Tektronix 2k$\times$2k CCD at unit magnification. A wheel located ahead of the re-imaging optics provides 7 positions for different filters.

Re-imaging is accomplished by four reflections off three mirrors which are coated with high-reflectivity dielectric coatings yielding a total throughput of larger than 70% above

350nm and more than 90% above 550nm out to 1μm. The pixel size of the CCD being 24μ, the actual pixel scale was then 0.0455$''$/pixel. All SV frames, however, were obtained in a binned (2×2) mode, hence with a pixel size of $0''.091$.

A set of regular broad-band $UBVRI$ filters in the system of Bessell (1990) was available together with two special narrow-band filters; a filter isolating the Lyα emission line of QSO J2233$-$606 ($z = 2.22$), the QSO at the center of the HDF-S STIS field, and a narrow-band filter tuned to the Lyα emission line of the Einstein Ring ER0047$-$2808 at $z = 3.595$.

The Test Camera CCD is not a science-grade device and is affected by major, extended blemishes. A large region near the center of the chip shows a markedly different sensitivity with a very strong color dependence. Regular bias frames were obtained to check for any drift in bias level. No significant drift was detected. Dark frames were also acquired on four different nights equally spaced throughout the SV observing period. No corrections for dark current were applied as the CCD was measured to have about 7 e^-/pixel/hour, which is negligible compared to the average sky levels reached. The gain and the readout noise of the CCD were measured in the laboratory and confirmed at the telescope to be 2.5 e^-/ADU and 7.9 e^- RMS, respectively. The shutter accuracy was determined by a series of short exposures with the dome lights on, which where then compared to long exposures. The shutter map shows the typical structure of an iris shutter. The variation between the center and the edge of the field for a 1 second exposure is about 4%. The uniformity for a 5 second exposure is better than 1% across the whole field with a small area close to the center enhanced by 0.8%.

Flat-fielding of the images proved to be very difficult. Twilight flats were obtained whenever the conditions allowed us, but they did not produce good results on the science data. The best results were achieved by combining a number of science exposures in a median stack, thereby removing signal from any astronomical sources. Two sets of such flatfields for each broad-band filter were produced and applied to the science frames. The large CCD blemishes could be corrected to better than about 1%, but dust features, which moved between nights could not be eliminated from some of the frames. For the narrow-band observations, the twilight flats were used. The accuracy here is better than 2% for the 392/7 filter. The 557/6 filter was vignetting the field considerably and the combined image shows a strong radial gradient.

A bad pixel map was generated from a series of low-level dome flatfields which was compared to a series of high-level flats. There are only very few pixels which deviate by more than 5 σ from the mean. These are located in small sections (10-15 pixels) of five columns.

5. The observations

SV observations were prepared with the same tools which are to become standard for the regular operations of the VLT, and which are already used for observing with the NTT and the 3.6m telescopes on La Silla. In particular, all the observation blocks (OBs) were prepared with the Phase 2 Proposal Preparation Tool (P2PP) in Garching ahead of the observing period. At Paranal we modified the observation blocks only in exceptional cases, e.g. to streamline the observations of standard stars. It is envisaged that visiting astronomers using the VLT will proceed in a similar way, by producing the OBs at home ahead of time and modifying them at Paranal.

The telescope performed very well for the complete SV period with a global loss equivalent to about two nights due to technical problems. The telescope operations worked very smoothly and did not provide any problems.

The observations themselves were arranged in a fashion mimicking the *Service Mode* of operation, i.e. several programs were mixed together in a single observing night with attention to the specific filter combinations, the appropriate calibration data, the observing conditions, and the sky background. The SV period included new moon, but lasted until two days into the second quarter with moon illuminations up to 70% during the last night. For most programs the observations were broken into integrations of typically 10 to 15 minutes exposure time to guarantee sufficient background illumination. The individual exposures were also offset by about 5$''$. Standard stars were observed every photometric night.

The data were transferred to Garching shortly after the observations. Preliminary reductions were performed by the SV team in Garching and the results (and problems) reported to the observers. In particular, the progress and quality of the observations from the HDF-S observations were monitored in Garching. In this way, it was possible to optimize the observations according to the observing conditions and the scientific priorities of the programs.

The weather has been very unusual for Paranal and highly variable during the whole SV phase, perhaps an indication that the turmoil generated by the 1997 El Niño had not settled yet. While the fraction of photometric nights has been within expectation ($\sim$70%), the seeing has been much worse than usual. Actually, with a monthly seeing average of $\sim$1$''$, August 1998 turned out to be the worst month since the beginning of the seeing measurements on Paranal in 1988. Together with the limitations of the Test Camera this means that the SV data are not optimal. The future dedicated VLT instruments will provide a much better match for the capabilities of the VLT telescopes. In spite of these limitations, exciting science results have still been obtained, as demonstrated by the papers included in this Letters issue.

The final data reductions had to await a detailed analysis of the flat-fielding problem. The best solution was to combine the science data to produce a flat frame which matched the color of the sky. This was mostly due to the strong color sensitivity of the large blemish of the CCD. Two sets of flatfield frames were produced for each broad-band filter. The reductions of the science images were attempted with both flatfields and the results examined visually. The better result was then kept. In case of several exposures the images were combined using integer pixel shifts. Given the small pixel size and the large over-sampling, this did not limit the resolution in the result image. The com-

Table 2. Broad band average photometric solutions

Filter	zero-point	color term	color combination	extinction coefficient
U	$-24.56(08)$	$-0.24(06)$	(U-B)	0.50(03)
B	$-26.87(03)$	$-0.13(02)$	(B-V)	0.26(01)
V	$-26.74(03)$	$0.07(01)$	(B-V)	0.17(01)
R	$-26.91(04)$	$0.06(01)$	(V-R)	0.13(01)
I	$-26.60(05)$	$-0.02(02)$	(V-I)	0.07(02)

bined images, together with the raw data, were made available as a data product to the community. All raw data were further archived in the VLT data archive in Garching.

The photometric calibration was achieved through the observations of Landolt standard stars. The large oversampling of the test camera allowed us to integrate on these bright star for 10 seconds in all broad band filters thus avoiding any problems with uneven illumination due to the shutter speed. We took care to observe a significant color range for the standards to measure the color terms adequately. A photometric solution was established for every night in which sufficient standard star observations were available. Typically we observed four fields several times throughout the night averaging about 10 standard star observations in total. The coefficients were determined by measuring the total flux in a $11''$ diameter aperture around the star. The average zero-points, color terms and extinction coefficients are summarized in Table 2. These values are only indicative as the photometric conditions for each of the science observations has to be established independently. The scatter around the mean for all nights in which a photometric solution was determined is given in units of 0.01 magnitudes in parentheses. These solutions should be used with great caution as they are averages over several nights. While this is a fair assumption for the color term, which is instrument dependent, this is not true for the photometric zero-point and the extinction coefficients. For individual applications it has to be made sure that the data obtained were indeed taken under photometric conditions. Some of the SV data do not fulfill this condition. The average values for the zero-point and the extinction coefficients are also not an accurate determination for an individual night. These values are available from ESO. However, we measured a very small scatter in the zero-point as well as in the extinction term, which is an indication of the stable atmospheric conditions at Paranal. The absolute range for the zero-points is always less <0.20 magnitudes and <0.14 magnitudes for the extinction coefficient. These values give an indication of the accuracy which can be achieved by applying the average photometry parameters. For the narrow-band filters we also observed two spectroscopic standard stars (Feige 110 and EG 21; Hamuy et al. 1992, 1994).

6. Science verification – a glimpse of the future

For this first science run the VLT telescope performed fully within the expectations, while still at an early stage of its commissioning. Aspects of both the *Visitor Mode* as well as of the *Service Mode* of operation have been experimented and tested, proving the validity of the VLT operations concept. Lessons have been learned that will help the implementation of the regular operations.

SV observation runs are now planned for the actual scientific instruments of UT1, i.e. FORS1 and ISAAC. SV of the instruments is expected to be particularly valuable, given their high performance, and the much enhanced capabilities compared to the small instrument available for this first experiment. All the science grade data obtained during future SV runs will be publicly released following the same procedures used for the VLT-UT1 SV data. This will provide the VLT users with an early chance to examine and experiment with the kind of VLT data that will be produced during the regular operations. instrument commissioning.

The VLT-UT1 will start regular operations on 1. April 1999. Nearly at the same time, the second telescope shall see it first light, and shall enter into operations one year later.

Acknowledgements. Many people at ESO have contributed to science verification for UT1. A science verification team was established for the planning early on. Team members were F. Bresolin, M. Cullum, G. De Marchi, M. Ferrari, F. Paresce, B. Pirenne, P. Quinn, P. Rosati, E. Tolstoy, and R. Viezzer. Help was provided by ESO's Optical Detector Team and the Test Camera Team under the respective leaderships of J. Beletic and M. Cullum. We received continuous, critical support from the telescope Commissioning Team, lead by JS and including A. Wallander, M. Chiesa, K. Wirenstrand, and S. Sandrock. The observations were further supported by the Paranal Engineering Department headed by P. Gray and the Paranal Facilities Department lead by J. Eschwey. Additional aid with image processing was provided by R. Fosbury and R. Hook (ST-ECF).

References

Bessell, M. S. 1990, PASP, 102, 1181
Hamuy, M., Walker, A. R., Suntzeff, N. B., Gigoux, P., Heathcote, S. R., & Phillips, M. M. 1992, PASP, 104, 533
Hamuy, M., Suntzeff, N. B., Heathcote, S. R., Walker, A. R., Gigoux, R. & Phillips, M. M. 1992, PASP, 106, 566
Leibundgut, B., de Marchi, G., & Renzini, A. 1998, The Messenger, 92, 5
Quinn, P. J. 1996, The Messenger, 84, 4
Silva, D. &Quinn, P. J. 1997, The Messenger, 90, 12
The VLT White Book 1998, Garching: ESO