# Result of The Phase A Study for the VLT Mid-Infrared Instrument: VISIR

*P.O. LAGAGE, Y. RIO, D. DUBREUIL, CEA/DSM/DAPNIA/Service d'Astrophysique, CE Saclay, Gif-sur-Yvette, France*
*TH. DE GRAAUW, SRON, Groningen, the Netherlands*
*J.W. PEL, T. SHOEMAKER, Kapteyn Observatory, Roden, the Netherlands*

In March 1993, a contract for a Phase A study concerning the mid-IR instrument to be mounted on the VLT unit 2 (Refs. [4] and [5]) was signed between ESO and DAPNIA/CE Saclay, with as partners SRON at Groningen and the Kapteyn Observatory at Roden. The study is now finished and the main conclusions are outlined here[1]. Various observing modes are foreseen both in the N and Q atmospheric windows (10 and 20 μm):

- imaging over a field up to about 1 arcmin with various magnifications (< 0.08 arcsec per pixel to 0.3 arcsec per pixel),
- long (> 30 arcsec)-slit spectroscopy with various spectral resolutions (350, 2500, 25,000 at 10 μm and 1250, 12,500 at 20 μm),
- limited polarimetry.

The instrument will be an excellent tool for ISO follow-up studies. Even if its sensitivity will not compete with ISO, except for the high spectral resolution mode, its high angular resolution (diffraction limited) will make it very attractive.

## 1. Scientific Needs

Designing an instrument is not an easy task because many parameters (sometimes not completely rational!) have to be taken into consideration and trade off has to be made between scientific desiderata, technical and operational constraints, cost limitation, etc.

The easiest part is to get the scientific desiderata. If a large enough community is consulted, the answer is simple: *all.* More seriously, general tendencies of the observing programmes and associated observing modes can be cleared up[2].

First, we recall that the use of a mid-IR instrument on a large telescope will lead to a dramatic improvement in sensitivity. Indeed, the size difference between the VLT and a 3.6-m telescope leads immediately to an increase in sensitivity by a factor 5 for point source observations; this means that the same signal-to-noise ratio can be reached 25 times faster. When taking into account improvements in detector performances, telescope emissivity and image quality, "dome" seeing, etc., we can expect a gain in sensitivity by a factor 50 compared to the actual TIMMI sensitivity (Refs. [2] and [3]). Although the VLT mid-IR instrument will be much more sensitive than IRAS (band 1 and 2), it will not compete with the instruments on board the cryogenic cooled Infrared Space Observatory (ISO), except for the high spectral resolution mode. However, ground-based mid-IR instruments on a large telescope allows for a diffraction-limited angular resolution of 0.3 arcsec at 10 μm (1.22 λ/D), inaccessible with the small ISO telescope (60 cm). Thus, ground-based and space observations are complementary and we can foresee a lot of ISO follow-up observations. *This perspective leads us to stress the need for such an instrument soon after ISO.*

To be more explicit on the observing modes, we now discuss two types of observations: observations of dust and gas.

### *1.1 Dust Studies*

The two mid-IR atmospheric windows are key domains to study relatively "warm" dust (400 K – 140 K). Indeed, a black body at 400 K has its peak of thermal emission at 7.5 μm (the beginning of the 10 μm atmospheric window), while a black body at 140 K has its emission peak at 28 μm (about the end of the 20 μm atmospheric window). Dust as cold as 50 K should still be detectable at 20 μm. The warm dust is an important component of the Universe, as shown by the IRAS satellite. The study of this dust is related to actual astrophysical problems dealing with star formation, planet formation, stellar evolution, AGN unified scheme, etc. and concerns various astronomical objects ranging from comets to quasars.

The observing modes related to these programmes are:

- diffraction-limited imaging both at 10 and 20 μm to locate the dust, measure its temperature,
- low spectral resolution ($R = \lambda/\delta\lambda = 400$) to constrain the composition of the grains (for example looking for the silicate dust features at 10 and 18 μm).
- polarisation to learn about grain size.

### *1.2 Gas Studies*

A wealth of information about the gaseous component in a large number of various objects can also be provided by

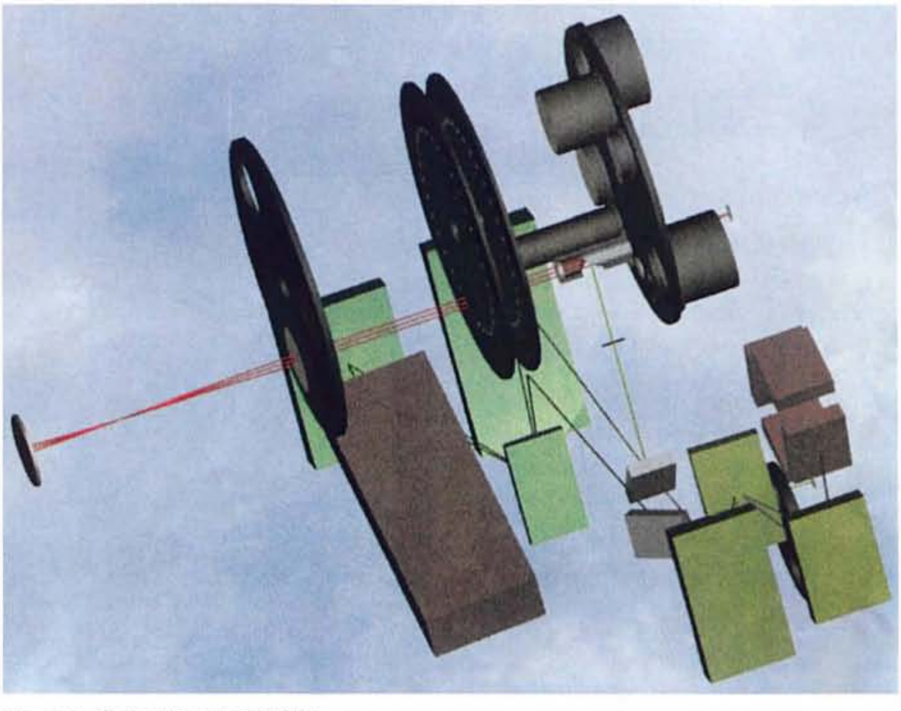

Figure 1: *Optical layout of VISIR.*

---

[1] The complete report is available upon request at LAGAGE@sapvxa.Saclay.cea.fr.

[2] Specific programmes can be found in the Phase A report, in the proceedings of the French meeting "L'exploitation astrophysique des fenêtres 10 et 20 μm avec le VLT", October 1993, D. Alloin and P.O. Lagage Eds., and in the proceedings of the ESO workshop about "Science with the VLT", June 1994, Danziger and Walsh Eds.

observations in the thermal infrared. Indeed, many molecular, atomic and ionic spectral lines are present in this wavelength range. Of special interest are several key interstellar and circumstellar symmetrical molecules ($H_2$, $CH_4$, $CO_2$, etc.) which have to be detected through observations of the (vibration-)rotation lines in the infrared. The linewidth varies from a few km/s in stars to a few hundreds of km/s in active galaxies.

Several spectral resolutions ranging from a few thousands to about 100,000 are needed to cover the various cases. Here again, observations both at 10 and 20 µm are interesting. For example, from the ratio of the $H_2$ lines intensity at 12 and 17 µm, the gas temperature can be derived. We have set two regimes, one for medium-resolution (2500 at 10 µm) and one for high spectral resolution, limited to 25,000 (at 10 µm) to avoid technical configurations which appear too risky.

## 2. Instrument Design

The optical arrangement of VISIR, an instrument which fulfills the previous scientific requirements, is shown in Figure 1. VISIR stands for **V**LT **I**mager **S**pectrograph in the **IR**. It is made of two sub-units: an imager and a spectrograph. The spectrograph has two arms, one for the low and medium spectral resolution, the other for the high spectral resolution. The whole optical bench is enclosed in a cryogenic/vacuum vessel to prevent internal background; (a black body at room temperature has its peak emission at . . . 10 µm). The vessel is a cylinder, 1.1 m long and 1.7 m in diameter. The total instrument weight is 1.5 tons. Closed-cycle coolers are foreseen to maintain the optical bench at the required temperature: 45 K for most of it and 15 K for the parts near the detector. The detector itself has to be cooled down to about 5 K (to prevent dark current). The same array will cover both the N and Q bands. The detector array used for the imager and the spectrograph will be different in order to be adapted to the quite different background flux received when observing in broad-band or at high spectral resolution.

### 2.1 Imager

The imager design is classical and based on lenses, in order to easily implement various magnifications. Indeed, given the state of the art in detector complexity (256 × 256), it is not possible to have both a large field and over-sampling of the diffraction pattern, while one or the other is required according to the programmes. For example, programmes aiming at detecting faint extensions around stars will prefer over-sampling of the airy pattern (PFoV < 0.1

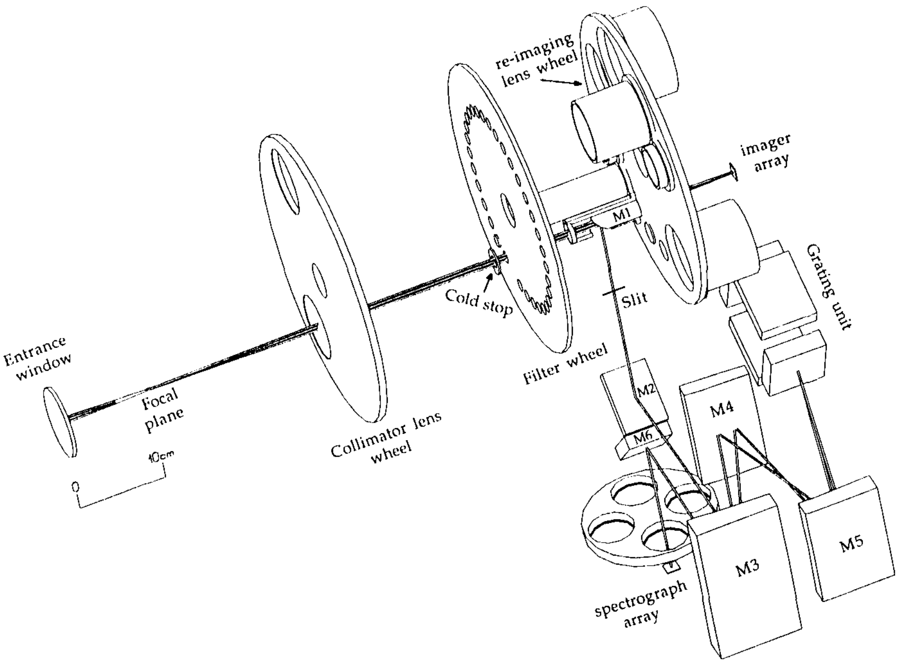

Figure 2: *Optical arrangement of the camera and the low and medium spectral resolution modes. In the imaging mode, the light goes first through a collimator lens which images the telescope secondary mirror onto a cold pupil stop. After passing the filter, the light is re-imaged on the detector array with various magnifications, thanks to one of the lenses of the second lens wheel. This wheel also holds a lens followed by a folding mirror to image the focal plane onto the slit unit with a magnification of 0.8. After the slit, a folding mirror, M2, selects one of the two spectrograph arms. Then the light enters a 3-mirror collimator of the ISAAC type, which produces a collimated beam of 55 mm on the selected grating. The selection and scan of the gratings are based on the mechanisms made for the ISO/SWS instrument. After reflection/dispersion on the gratings the light goes back throughout the 3 mirrors, which are now used to image the spectrum on the array, via the folding mirror M6. The magnification of the system is 1. (Note that in Figure 1, M6 has been inclined differently so that the spectrograph detector is near the imager detector for cryogenics reasons; a filter wheel cooled at 15 K has been included in front of the spectrograph array to limit the internal photon background emitted by the spectrograph optics cooled at 45 K.)*

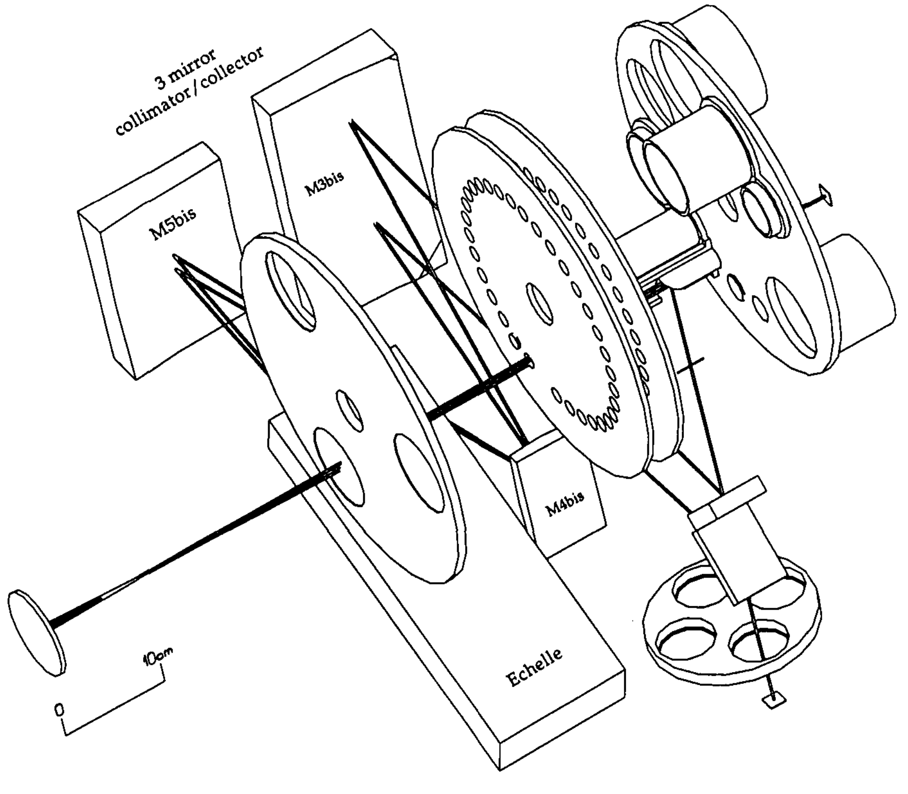

Figure 3: *Optical arrangement in the high-resolution mode. The beam goes through the imager as in the low and medium spectroscopic mode. The folding mirror M2 has been flipped by 90 degrees to deviate the light into the high spectral resolution arm, also made of a 3-mirror collimator/collector of the ISAAC type; the collimator beam is now 110 mm. The grating unit is made of two nearly similar echelles, mounted back to back. A second filter wheel has been included in the imager to sort out the various orders. The mirror M6 has also been flipped by 90 degrees to send the spectrum on the same detector array as in the low and medium spectroscopic modes.*

arcsec at 10 μm), even if the field will be limited to less than 25 arcsec. On the other hand, observations of objects quite extended or survey-type observations will require a larger field. With a simple two lenses design (see Fig. 2), it was possible to implement a field up to 80 arcsec with diffraction-limited optical quality.

In our two-lenses design, the first lens images the pupil of the secondary mirror of the telescope on a cold stop to prevent extra external background (as usual in ground-based IR instruments). The lens also acts as a collimator, so that the filter wheel located near the cold stop is in a parallel beam. Such a configuration relaxes the tolerances on the spatial homogeneity of the filters and leads to a focalisation which is independent on the filter whatever its thickness is. But the drawback of this configuration is a slight change in the wavelength transmission of the filter according to the position in the field (different angle of incidence on the filter). To avoid prohibitive shifts in wavelength for narrow-band filters (R = 50), the cold stop has been fixed to 15 mm. There is actually no good optical material that covers both the N and Q bands. We will use Germanium for 10 μm and CdTe for 20 μm; the two collimators will be mounted on a wheel. A second wheel will hold the lenses which re-images the focal plane onto the detector with various magnifications (0.08 arcsec, 0.16 arcsec, 0.3 arcsec). The antireflective coatings on the optical materials considered are very good (a few per cent of reflection), so that the efficiency of the optics will mainly be determined by the filter transmission. By an appropriate design, the ghosts resulting from light reflection on the lenses can be made negligible.

Limited polarimetry capability will be provided by 3 analysers in the filter wheel.

Several firms (LETI/LIR in France and now Rockwell and SBRC in the US) have developed detectors optimised for broad-band observations from the ground. In these detectors, the storage capacity of a pixel has been pushed to its maximum (> 3 $10^7$ electrons) in order to "absorb" the huge photon background generated by the telescope and the atmosphere (1500 Jy/arcsec$^2$), without being saturated.

### *2.2 Spectrograph*

The design of the spectrograph and especially its high-resolution mode was the subject of many debates. To the 3 optical pre-designs internally made at ESO (Ref. [1] and references therein), we added a couple of alternative designs. Hereafter, we will only describe the final one (we should say the last one). The slit option with gratings was eventually found to be on the safer side.

When working at 10 μm, we are in a world where diffraction is around. To avoid diffraction at the slit, we have considered a 2 λ F-ratio entrance slit. Even with such a slit width, the optical elements of the spectrograph have to be oversized to avoid diffraction losses. It is also better to have the cold pupil stop in front of the slit because, behind it, the pupil is fuzzy. In Figure 1, the cold stop of the imager is also used for the spectrograph. In a previous design, a separate cold stop/re-imaging unit based on two off-axis paraboloids and two folding mirrors was considered. Both options are open. Note that the use of a re-imaging unit in front of the spectrograph has additional advantages; it provides the possibility to move the spectrograph entrance slit to a more convenient location; it allows to reduce the F-ratio (from 13.6 to 11) to keep the spectrograph dimensions within limits; it allows to inject the parallel beam of the internal (wavelength) calibration source, which will be quite similar to the source used for the ISO/SWS instrument.

The spectrograph is based on the 3-mirror collimator/collector design developed by ESO for the ISAAC instrument, one of the near IR instruments to be mounted on the VLT unit 1 (Moorwood et al., 1993). The light entering the slit goes through the three mirrors, which produce a collimated beam on the gratings; once diffracted/reflected by the gratings, the beam goes back through the 3 mirrors which now act as a collector to image the spectrum. The 3-mirror ISAAC collimator/collector has many advantages in terms of compactness, optical quality, straylight rejection, grating efficiency (grating in Littrow configuration), which overcomes the relatively large number of mirror reflections.

The compactness of the three-mirror ISAAC collimator led us to consider two arms for the spectrograph, one for the low and medium resolution with a collimator beam of 55 mm, and the other for the high resolution with a collimator beam of 110 mm (see Figs. 2 and 3). Four gratings are planned for the low- and medium-resolution modes; for efficiency reasons, two gratings are needed for a band (Q or N); but the same gratings are used for the Q and N sub-bands (1st order for Q, 2nd order for N). The high-resolution mode is also based on gratings, but used at high orders (echelle mode). Again for efficiency reasons, we plan to use the "duo-echelle" concept: two nearly similar echelles, mounted back to back, where the orders of one fit between the orders of the other echelle. It is worth mentioning the size of the gratings: 35 cm! The efficiency of the optics (including order sorting filters) should be around 40% for the low and medium spectral resolution and 30% for the high spectral resolution.

The detector array used for the spectrograph will be optimised for low background conditions. Indeed the flux received by the spectrograph can be up to $10^5$ fainter than in the imager. It is more in the range of the flux received when imaging from space, and detector arrays have been optimised for these conditions. The pixel pitch of these detectors range from 30 to 50 μm. In the spectrum focal plane, 50 μm represent 0.115 arcsec on the sky, which samples correctly the airy pattern at 10 μm. To avoid additional complexity, we have not considered, at the present stage, a re-imaging system after the spectrograph. Note that the good image quality of the ISAAC 3 mirror system allows for the implementation of a detector up to 1024 × 1024 pixels.

The mechanical tolerances on the spectrograph are quite tight for a cryogenic cooled instrument. A finite-element mechanical study was made for the previous optical design studied in detail. The tolerances on the present design are tighter by a factor 3; (for example, the tilt between the 3-mirror collimator and the detector should vary by less than 1 arcsec when moving the telescope). We are in the range of the ISAAC tolerances, but we are not at the same focus (Cassegrain instead of Nasmyth), so that we have to wait for very detailed finite element calculations to fully address the mechanical question.

## 3. Sensitivity

The goal is to achieve the theoretical expectations based on background noise limited performances and a telescope emissivity of 10%. The sensitivity of the imager in broad-band observations of point sources should tend towards 1 mJy 10 σ 1 hour at 10 μm (or magnitude 11.5) and 10 mJy 10 σ 1 hour for the Q band. The theoretical sensitivity of the spectrograph is given in Table 1:

The high spectral resolution is driving the specifications in many domains: detector noise, internal background,

*TABLE 1. SPECTROGRAPH SENSITIVITY (Signal/noise in 1000 s for a 1 Jy point source)*

| *Mode* | N band | Q band |
|---|---|---|
| *High resolution* | 14 | 3 |
| *Medium resolution* | 24 | 5 |
| *Low resolution* | 80 | 18 |

mechanical tolerances, . . . The performances of this mode are the most difficult to achieve.

## 4. Perspectives

VISIR is an ambitious instrument which will require a total work of 100 man years with some hard time.

Rendez-vous in five years to report on the first telescope tests of VISIR, . . . hopefully.

**Acknowledgements:** We wish to thank the various colleagues who have contributed to the phase A study, either technically or scientifically and which are too numerous to be quoted here. We also would like to thank the ESO staff and especially A. Moorwood, B. Delabre, H. Käufl, J.-L. Lizon à l'Allemand for their valuable comments all along the study.

### *References*

[1] Käufl H. and Delabre B.: 1994, "Improved Design and Prototyping for a 10/20 µm Camera/Spectrograph for ESO's VLT" in *Instrumentation in Astronomy VIII*, SPIE volume **2198**, p. 1036–1047, Crawford D.R. and Craine E.R. Eds.

[2] Lagage P.O. et al.: 1993, "TIMMI: a 10 µm camera for the ESO 3.6-m telescope" in *Infrared Detectors and Instrumentation*, SPIE volume 1946, p. 655–666, Cormer B. Ed. Moorwood A.: 1993, "IR Instrumentation for the ESO VLT" in *Infrared Detectors and Instrumentation*, SPIE volume 1946, p. 461–471, Cormer B. Ed.

[3] Käufl H.-U., Jouan R., Lagage P.O., Masse P., Mestreau P., Tarrius A.: "TIMMI at the 3.6-m Telescope". *The Messenger* **70**, 67.

[4] Käufl H.-U.: "Phase-A Study Launched for the 10/20-µm Camera/Spectrometer for ESO's VLT". *The Messenger* **72**, 44.

[5] Käufl H.-U.: "Ground-Based Astronomy in the 10 and 20 µm Atmospheric Windows at ESO – Scientific Potential at Present and in the Future". *The Messenger* **73**, 8.

P.O. Lagage
e-mail address: lagage@sapvxg.saclay.cea.fr

---

# NTT BITS & PIXELS

*With this periodically compiled collection of short notes, the NTT Team intends to keep the community informed about changes in performance, configuration, and operation of the NTT and its subsystems.*

## First NTT Team Member To Leave

The first departure of members from their group often marks the transition to a new phase. This is also true for the NTT Team which started to come into existence about one year and a half ago. Since then, a fair number of improvements could be reported, and the operation of the NTT has stabilised considerably. Thanks to his astronomical expertise, Edmond Giraud has had his share in this progress. When Edmond heard about the NTT Upgrade Plan (*The Messenger* 75, 1), he spontaneously offered to spend a year on leave of absence with the NTT Team at La Silla. (Our colleague Miguel Albrecht has suggested the handy acronym "NTT UP" for the NTT Upgrade Plan, which henceforth we shall gladly use). That year has meanwhile become 14 months long, but now it is time for him to return to his home institute, the Observatoire de Marseille.

This is a good example of how ESO's role as a service organisation can be strengthened by the active support of the astronomical community. We thank Edmond for his willingness to help during a critical initial phase and wish him all the best.

## Instrument Operators to Join the Team

On May 16 and June 1, Gabriel Martin and Roberto Aviles, respectively, will take up their duties as instrument operators. This is the first big step towards the operational part of Phase II and beyond of NTT UP which foresees that the NTT will be re-commissioned in service mode, much the same as is planned for the commissioning and operation of the VLT. Since this is a very important and complex type of work, for which there is only limited experience available, Gabriel and Roberto are joining us early in order to insure the proper commissioning of this operating mode.

An important aspect of this early start is that the training of the instrument operators will not be limited to ESO staff. Between now and the 'Big Bang' on April 1, 1996, Gabriel and Roberto will increasingly assist Visiting Astronomers in the operation of EMMI and SUSI. We hereby hope to achieve two goals: (a) The know-how transfer will also take place directly from the community to the instrument operators; (b) Visiting Astronomers can convince themselves that also in service mode their programmes will be in 'good hands'. (The scientific responsibility and supervision will always rest with an astronomer.)

We wish Roberto and Gabriel a successful start with their demanding work.

## Postdoctoral Fellowship Available at La Silla

Given the proto-typical character of the NTT hard- and software and the operations model for the VLT, a few years of work with the NTT Team at La Silla should be the optimal practical and conceptual preparation for young astronomers with strong interest in observational work for the VLT era. Currently, we have an opening for a recent PhD recipient. If you are interested in a challenging job which offers an unusual diversity of experiences and research opportunities at a major observatory, consult the vacancy notice in the *Announcements* section of this issue of *The Messenger*.

## Field Test of Work Component No. 5

During February 18–21, the latest test of another component of the VLT-like control software as defined in NTT UP was successfully completed. It consisted of two parts, (i) the control of the hydraulic system and (ii) the selection of video signals such as from guide probe or slit viewing cameras and their distribution to the requested local or remote destination. Apart from these specific applications, the scope of the tests also included checking the VLT LCU Common (LCC) and Central Control Software (CCS). Once again, no real problems were encountered during the installation so that most of the night time could be used for further optomechanical tests and other work with the telescope. As for all other tests of the new control system, the old control software was fully restored after completion of the tests.