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PARANAL OBSERVATORY INSTRUMENTATION: CURRENT STATUS

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RESUMEN

El 12 de agosto del 2001, los cuatro telescopios de 8 m del Observatorio del ESO en Paranal: Antu, Kueyen, Melipal y Yepun empezaron a producir simultáneamente datos científicos para la comunidad. De los cuatro, Antu fue el primero en iniciar el ciclo rutinario de operaciones en Paranal. En la actualidad, cuatro instrumentos, FORS1, ISAAC, UVES y FORS2, uno por cada telescopio, están sirviendo a la comunidad bajo dos modos de observación: clásico y de servicio. La proporción de tiempo de telescopio en modo de servicio es un mínimo del 50% en cada uno de los instrumentos. Este artículo presenta una descripción resumida de la instrumentación del VLT y su interferómetro VLTI, los comienzos, logros más importantes obtenidos y planes futuros.

ABSTRACT

Since 2001 August 12, ESO's four 8 m telescopes (Antu, Kueyen, Melipal, and Yepun) have been simultaneously delivering scientific data to the astronomical community at large. Antu was the pioneer, starting its routine science operations life in 1999 March. Currently, four instruments—FORS1, ISAAC, UVES and FORS2—one per telescope, are available to the community under two modes of observation: visitor and service. The proportion of time used in each mode since the opening of Paranal Science Operations is a minimum of 50% in service mode for all instruments. This paper gives a brief description of the VLT and VLTI instrumentation, its beginnings, current achievements, and future plans.

Key Words: **INSTRUMENTATION : TELESCOPES**

1. VLT INSTRUMENTS: OVERALL VIEW

Most Paranal instrumentation is built by external consortia within the ESO (European Southern Observatory) community. On the VLT(I), the exceptions so far are the two infrared (IR) instruments ISAAC and CRIRES and the high resolution UVES spectrograph, which are almost entirely built by ESO. On the other hand, we are practically always directly contributing to some key aspects and in particular those that directly interface with the overall observing "process flow". This includes most detector systems and part of the control electronics hardware and software, as well as special parts or components (e.g., volume phase holographic grisms).

Based on experience, the typical timescales for a full-fledged VLT instrument, from kick-off to preliminary acceptance in Europe, varies between 50 months (based on NAOS and VIMOS) to about 56 months (based on ISAAC), the larger duration being associated with the added complexity of a fully cryogenic instrument. Yet, for complex and innovative instruments that require significant R&D, timescales are known to become indefinite (sometimes infinite!). Overall, experiences shows that fast and successful instrument construction demands: a fast-track design phase, a reasonable-track construction phase (with corner cutting, such as at leat ordering optical glass before the final design review), but a "very extensive" assembly and integration (AIT) phase. In the process, one should expect at least one optical crisis (coating problems, glass availability, alignment problem, etc.) and a exercise a great deal of patience with the mechanics which usually requires multiple iterations in the design to the construction to the AIT phase.

The distribution by telescope of the first generation instruments for the VLT and VLTI is shown in the Figure 1, which shows the four unit telescopes (UTs), the delay lines for the VLTI, and the survey-devoted telescopes VST and VISTA; the distribution of instruments as currently planed is indicated next to each facility. UT1 (Antu) will carry the two imaging spectrographs, ISAAC (near-IR) and FORS1 (optical)—both currently operating on UT1 and UT3 respectively—plus CRIRES (a high resolution echelle spectrometer for the near-IR); UT2 (Kueyen) will have FORS2 (twin of FORS1) at the Cassegrain focus, and UVES (a high resolution optical spectrograph, the equivalent of CRIRES but in the visible), and FLAMES (the VLT wide field fiber facility that will feed GIRAFFE—high and intermediate resolution optical spectrograph—UVES,

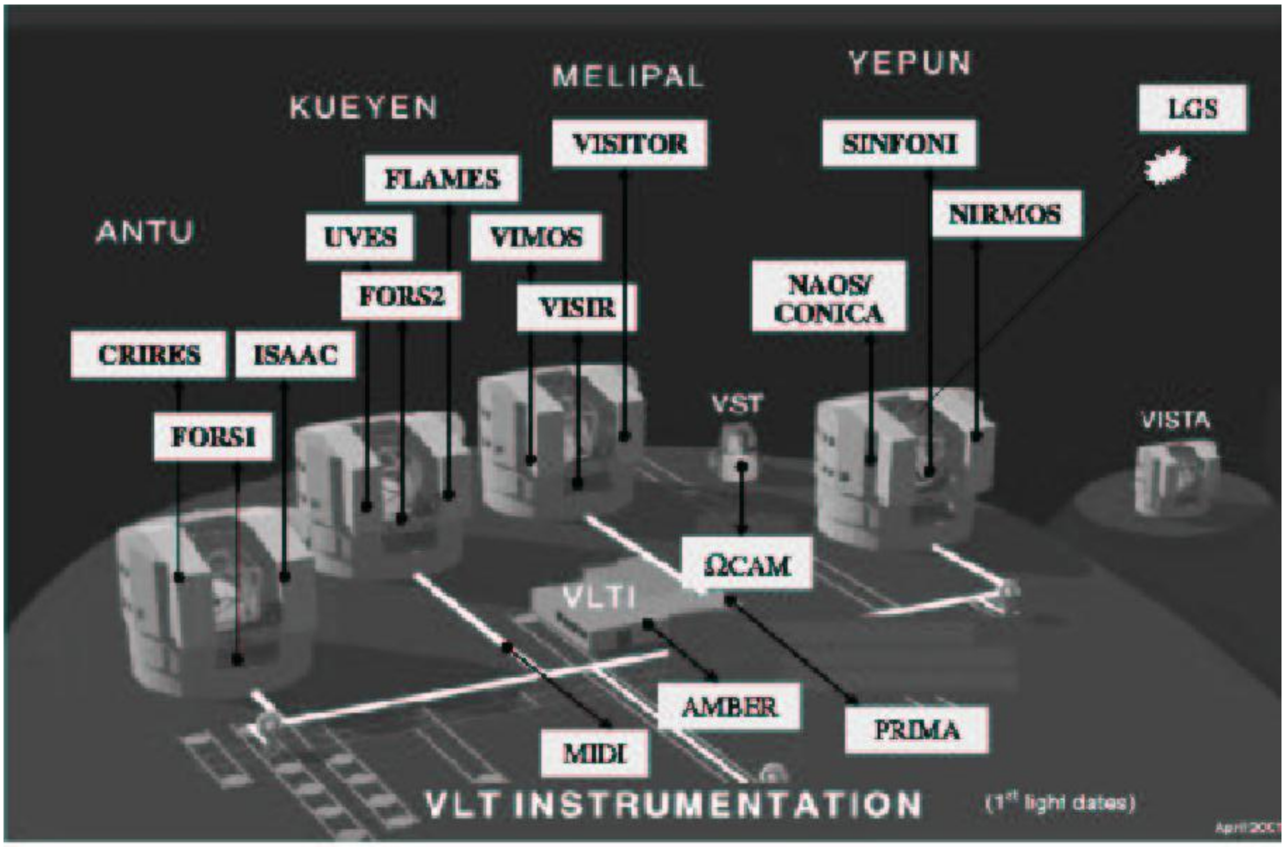

Fig. 1. Foreseen distribution of VLT(I) instruments per telescope unit at Paranal.

and eventually a future intermediate resolution IR spectrograph), at each Nasmyth focus. FLAMES is already in its integration phase at Paranal; UVES and FORS2 are also currently operating instruments on UT2 and UT4, respectively. UT3 (Melipal) will have VISIR (an imaging spectrometer equivalent to ISAAC but in the mid-IR) and VIMOS (a multiobject spectrograph in the optical, currently in its commissioning phase at Paranal); the second Nasmyth focus is devoted to a visitor instrument. Finally, UT4 (Yepun) will receive NIRMOS (the counterpart of VIMOS but in the 1–1.8 μm) and two AO-assisted near-IR instruments: SINFONI (the VLT 3D spectrograph to be assisted by the curvature AO system MACAO) and NAOS/CONICA (or NACO, a high resolution near-IR camera assisted by the AO Shack–Hartmann module NAOS). NACO is currently undergoing the "Paranalization" phase and is expected to be released to the community by the end of 2002. In addition, UT4 will receive next year a sodium laser guide star projector (LGS) to enlarge the sky coverage of SINFONI and NACO, which is currently restricted to the availability of a bright natural guide star within a field of view (FOV) of less than 1 arcminute.

The VLT interferometer (VLTI)—the great future promise of the VLT—will have MIDI (a mid-infrared instrument optimized at 10 μm, expected to provide 20 mas resolution for a baseline of 100 m; shipment to Paranal is foreseen by the end of 2002) and AMBER (a near-infrared closure-phase imaging spectrometer aimed at providing a resolution of 10 mas for a baseline of 200 m and a spectral resolution down to 10000). PRIMA is the third projected instrument for the VLTI. This is an astrometric and phase-reference instrument aimed at providing accurate astrometry down to 10 μas and resolution down to 10 mas.

Last but not least, two additional 2.5 and 4 m telescopes, VST and VISTA respectively, will be installed at Paranal. These auxiliary telescopes will be devoted to optical and near-IR imaging surveys to find faint targets for following up with the VLT. VST is currently in its integration phase and will have Omega Cam, an optical wide field camera with a FOV of 1×1 deg^2.

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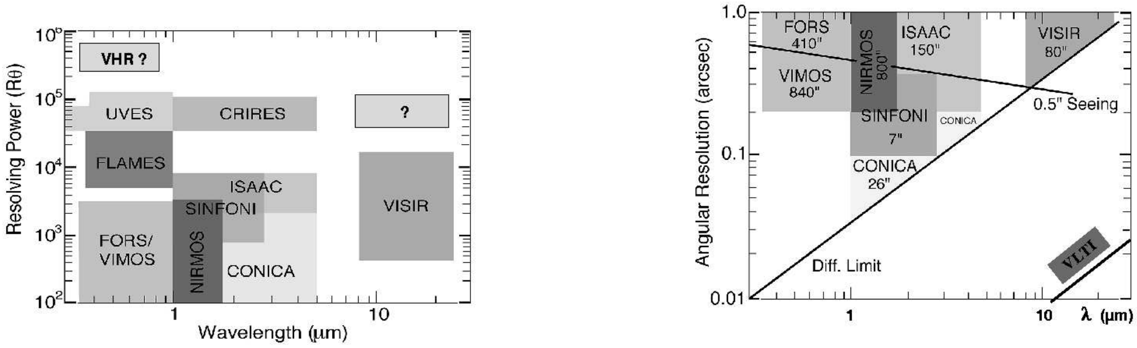

Fig. 2. Spectral and spatial resolution coverage by the VLT(I) first generation instruments. For comparison, the maximum FOV covered by instruments with imaging capabilities is indicated next to each instrument in the right-hand graph).

More detailed information on all the VLT(I) instruments mentioned above, their current status, and planned commissioning dates can be found on the ESO web page.[1]

2. WELL-SAMPLED COVERAGE IN THE SPECTRAL AND SPATIAL RESOLUTIONS

Figure 2 shows the range in spatial and spectral resolutions covered by the first-generation VLT instruments within the reachable spectral range of 0.3 to 25 μm. Spectral resolution coverage is fairly extensive in basically all spectral domains. Note that the spatial and spectral resolutions of VIMOS are very similar to those of the two FORSs, but with four times higher area coverage on the sky and a corresponding gain in the number of multislits.

In the near-IR, ISAAC gives imaging (2.5 arcmin FOV), low and medium resolution slit spectroscopy in the 1 to 5 μm range. The SINFONI integral field spectrometer covers the 1 to 2.5 μm range, with a much smaller FOV (7 arcsec maximum) but with spatial resolution up to the diffraction limit. NIRMOS extends the capabilities of VIMOS in the J and H bands in imaging and the J band in spectroscopy. CONICA (with its NAOS adaptive optics system) provides diffraction-limited 1 to 5 μm imaging and low resolution slit spectroscopy. CRIRES extends the high spectral resolution capability of UVES in the 1 to 5 μm range.

Finally, the mid-IR from 10 to 25 μm is covered by VISIR, which provides higher spectral resolutions than ISAAC, an important aspect in guaranteeing accurate removal of the large number of atmospheric features present in this range. CRIRES uses an adaptive optics system input to shrink stellar images down to the 8 m $\sim$ 0.26 arcsec diffraction limit. Spatial resolutions about 30 higher will be delivered at 10 μm with MIDI and PRIMA on the VLTI.

3. CURRENT VLT(I) INSTRUMENT ACHIEVEMENTS

In 1999 March, Antu (UT1) and the imaging spectrographs ISAAC in the IR and FORS1 in the optical started to deliver scientific data to the community, thus opening the Science Operations lifecycle of Paranal. From 2001 August on four instruments, one per telescope, have been simultaneously executing scientific programs for the community at large. The current distribution of instruments is as follows: ISAAC on UT1, FORS1 on UT3, UVES on UT2, and FORS2 in UT4. On average, Paranal operations are characterized by a low technical downtime (about 2.5% on UT1, 2.1% on UT2, 0.8% on UT3, and 2.1% on UT4) and a high shutter open efficiency (ISAAC has the lowest efficiency [67%], mainly because of the intrinsic nature of IR short observations; FORS1 and 2 have comparable efficiencies of 73%, UVES being the most efficient of the four [85%], mainly because of the long exposures—hours—used with this instrument). Furthermore, since the beginning of Paranal operations, starting with both ISAAC and FORS1 on UT1, ESO is handling a minimum of 50% of the telescope time in service mode. As such, Paranal is the first ground-based observatory sustaining service mode observations routinely on a large scale. This has allowed the observatory the unique opportunity to tailor atmospheric conditions, lunar phase, and instrument availability to the specific science needs of our community.

Some of the main achievements so far obtained by the instruments on board VLT are summarized next.

[1] At http://http.hq.eso.org/instruments/.

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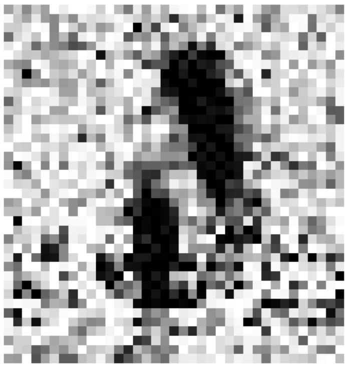

Fig. 3. "Rotation" curve of a $z = 2.3$ galaxy resolved in the [O III] 5007 Åline by ISAAC. The spectrum is a 6 hr exposure, and the image quality corresponds to 0.4 arcsec.

FORS is characterized by high image quality and exceptional image stability. FORS has so far delivered 0.18 arcsec-resolution images in seconds of integration and 0.25 arcsec in minutes of integration. This is critical for imaging faint companions next to bright stars, which usually requires short integration time frames to avoid saturation (Neuhauser et al. 2000). FORS also provides exceptional image stability, well inside one pixel for any duration exposure. This is achieved through the combination of the VLT active optics system, which runs continuously in closed loop, and of the passive flexure correction system incorporated in the two FORS instruments. The impressive image quality delivered by VLT + FORS may be judged from the first ever spatially resolved images of a hot-spot region in a radio galaxy (Prieto, Brunetti, & Mack 2002).

Taking particular advantage of the seeing-conditions fine tuning offered by the service mode, ISAAC is also delivering exceptional quality images, occasionally approaching the 8 m diffraction limit in the still poorly explored L and M bands. This opens up a really new window that covers a spectrum ranging from detailed studies of the atmospheres of planets (ESO Press Photos 21/01) to the gaining of a deep insight into the cores of AGN (Prieto, Reunanen, & Kotilaniem 2002). But perhaps ISAAC's greatest hit is its spectroscopic sensitivity: Figure 3 shows the rotation curve of a $z = 2.3$ galaxy observed in the [O III] 5007 Å in a 6 hr exposure; the seeing is 0.4 arcsec. The apparently ordered motion revealed by ISAAC on this high redshift galaxy is a promising starting point to begin weighing the mass of the first building blocks of the Universe.

Operationally speaking, UVES is the most efficient instrument on the VLT. Not only is it extremely easy to operate, it also has the best and most complete data reduction pipeline, which allows users to get fully reduced data at once. It is also currently the most sensitive in the blue–UV part of the spectrum. This has been crucial, for example, in deriving Be abundances in old galactic stars (Primas, Molaro, & Bonifacio 2000), finding in optical wavelengths the first sign of a stellar corona (Schmitt & Wichmann 2001) outside the Solar System, and deriving a meaningful lower limit of the age of the Universe from an extremely faint uranium line in an old star (Cayrel et al. 2001). It also gives very high precision radial velocities (RV). Figure 4 illustrates this for two stars, one known to have a constant RV at the 4 m s^{-1} level—UVES brings that limit below 2 m s^{-1}—and another one known to be moderately active, which UVES measures to the level of 2.25 m s^{-1} rms.

A recent newcomer at the VLT is the NACO (formerly NAOS–CONICA) near-IR adaptive optics imager (and low resolution spectrometer). First images delivered by NACO from its commissioning phase already reveal the power of this AO instrument. Figure 5 shows the core region of the cluster NGC 3603 as imaged by NACO in the K band and *Hubble Space Telescope* (*HST*) WFPC2 in the I band. Comparison of the two images speaks for itself. The close to the K band diffraction limit of the NACO image with 56% Strehl reveals a multitude of faint low mass stars on top of a background of extended diffuse emission. These, however, are unseen in the longer *HST* exposure in the I band, which, furthermore, has roughly comparable resolution to that of NACO (ESO Press Release 25/01).

A great revolution in stellar astronomy will take place when the VLTI becomes fully operational. The first fringes from bright stars obtained in 2001 March using two 40 cm siderostats on a baseline of 16 m are impressive. The diameter of the star Alpha Hydrae, for example, could already be determined with a precision of 0.17 mas (previous photometric measurements have a precision of 9 mas). On 2001 October 29, the beams, this time from two VLT units, ANTU and MELIPAL, were successfully combined "in phase", marking the exciting starting point for operations with the VLTI. Diameters of red dwarf stars and pulsating Cepheids, as well as a first interferometric measurement of the core of Eta Carinae could be obtained routinely with precisions down to 0.02 mas (ESO Press Release 23/01)!. Although still in the technical commissioning phase, the scientific data so far obtained VLTI are of such high quality

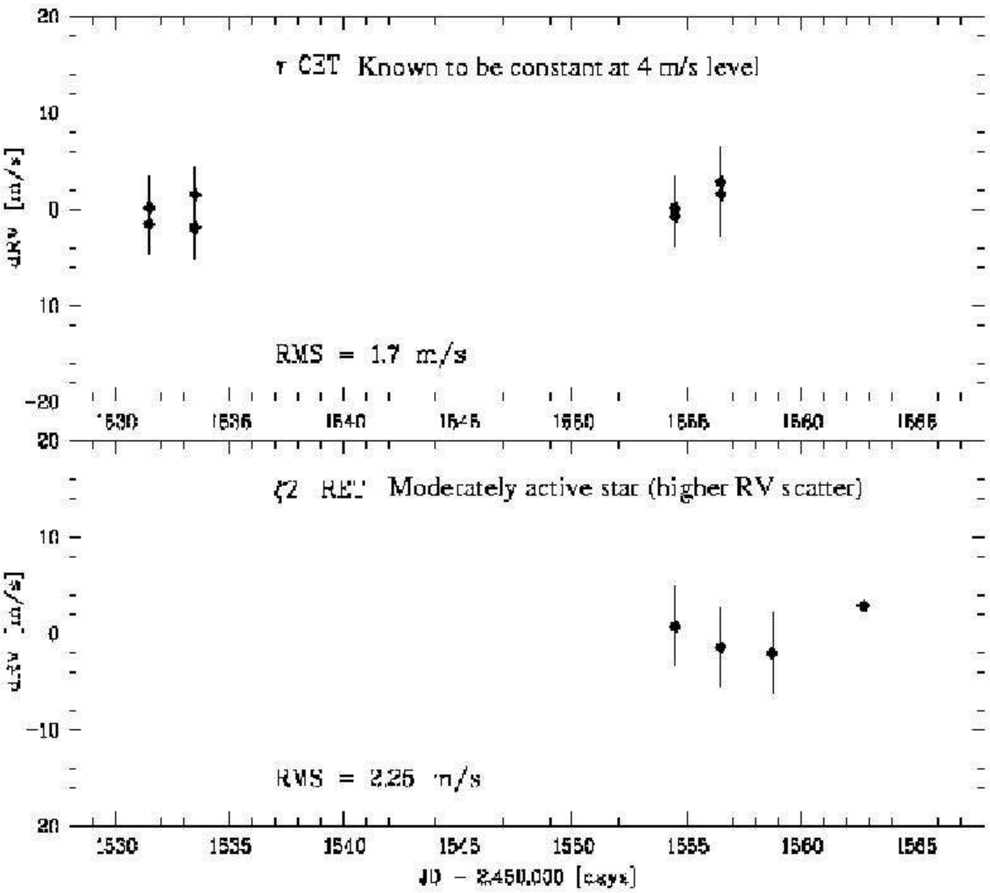

Fig. 4. High precision radial velocity (RV) measurements obtained with UVES + iodine cell on two stars: γ Cet and ζ^2 Ret. The long-term achievable precision is expected to be better than 2 m s^{-1}. Results from commissioning data, 1999 Dec–2000 Jan, courtesy of M. Kuerster.

that ESO decided in 2002 April to make them available to the community through its archive for immediate scientific exploitation (http://www.eso.org/projects/vlti/).

4. PROSPECTS FOR SECOND GENERATION VLT(I) INSTRUMENTS

In 2001 June, ESO issued a call to the international community for a Workshop on *Science Drivers for Future VLT/VLTI Instrumentation*. Out of this conference, three main scientific drivers were identified: 1) the determination of high redshift mass assembly, weighing the first building blocks of the Universe; 2) detailed spectroscopy of individual targets (fast follow-up of SNe, γ rays bursts, etc; and 3) planet finding. To tackle these goals in a far more efficient manner than that envisaged with current VLT instrumentation, four new VLT instrumental capabilities were identified. These included: 1) a cryogenic multiobject spectrometer in the 1 to 2.4 μm range (KMOS); 2) a wide field 3D optical spectrometer ("3D deep-field surveyor"); 3) a medium resolution wide band (0.32 to 2.4 μm) spectrometer ("x-shooter"); and 4) a high contrast, adaptive optics-assisted, imager ("planet finder"). To start involving the community in the design of these instruments, in 2001 November ESO issued a Call for Preliminary Proposals for second-generation instruments; twelve proposals were received and are currently under evaluation. Three preliminary conclusions can already be outlined: the diversity and audacity of the proposals received show that a) no lack of imagination is present in the community; b) all but some of the fast-shooter proposals require at least very substantial and sometimes formidable R&D, from often conceptual to always the prototyping phase; and c) severe choices have to be made because of point b) and resource limitations.

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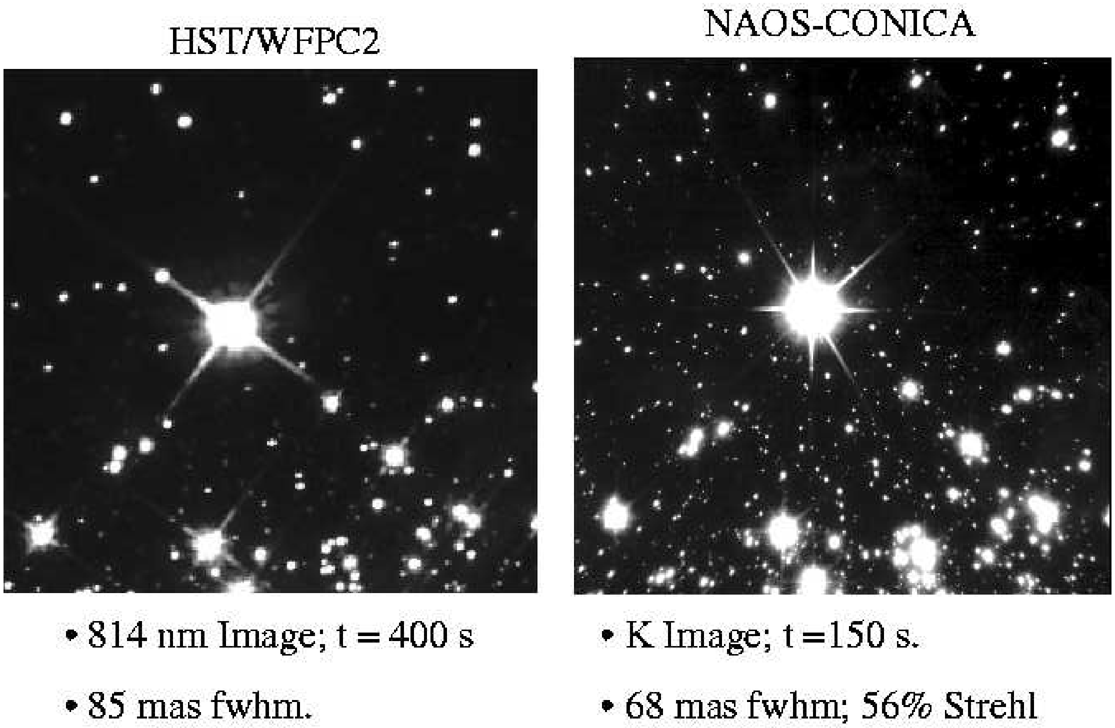

Fig. 5. The core of the cluster NGC 3603 imaged by CONICA-NAOS in the K band (right) and the *HST* WFPC2 I band (left). The diffraction limit and larger aperture of the VLT permit the detection of a multitude of cool low mass stars, which are undetected in the *HST* image. The FOV is 27×27 arcsec^2, north is up, and east to the left.

5. SOME RECOMMENDATIONS FOR THE GTC

In conclusion, we outline three main points that could be of relevance for the GTC and its community.

• Instrument construction phase: a lesson learned at ESO is the importance of the AIT phase. Cutting corners here always results in wasting, never saving, time.

• The use of more than 50% of the VLT time in service mode is a key aspect contributing to the overall success of the VLT observatory. Service mode has become the preferred mode of the ESO community. Yet the overall system is heavy and very demanding. If the main mode of the GTC operations is to be service, the GTC should prepare for it well in advance.

• When the GTC becomes operational, there will be a fleet of 8–10 m class telescopes producing unique results. For the GTC to be competitive, it will be important that the community identify very specific, clear-cut scientific goals and build its second generation instrumentation specifically tailored for these.

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