N (with 5 as the default value) pointings on the sky. Although this will nearly cover all the gaps in the focal plane and maximizes the sky coverage, the context map of such data is complex. An advantage is that it will be relatively easy to couple the photometry among the individual CCDs.

• *Jitter* has offsets matching the smallest gaps in CCDs ~ 5 pixels. This mode optimizes the homogeneity of the context map and will be used during observations for which the wide gaps are not critical, but which, for instance, require a well-mapped smoothly varying PSF.

• *Stare* allows re-observing one fixed pointing position multiple times. It is the main workhorse for monitoring the instrument and allows detection of optical transients.

• *SSO* is the mode for observing Solar System Objects, which requires non-sidereal tracking.

For all these modes dedicated observing templates are being developed.

An observing strategy employs one or a combination of the basic observing modes. It also defines a number of additional instructions for scheduling of the observations. We distinguish the following strategies:

• *Standard* which consists of a single observation (observation block)

• *Deep* which does deep integrations, possibly taken at selected atmospheric conditions over several nights

• *Freq* which frequently visits (monitors) the same field on time scales ranging from minutes to months and has overriding priority on the telescope schedule

• *Mosaic* maps areas of the sky larger than 1 degree, which is essentially an item for the scheduling, as the pipeline has to produce uniform quality data anyway. The combination of various field centres into one image is not considered a standard pipeline task.

The observing modes and strategies are fully integrated with the data reduction software being developed by the OmegaCAM consortium. We distinguish between a calibration pipeline producing and qualifying calibration files, and an image pipeline that applies the calibration files to raw data and transforms them into astrometrically and photometrically calibrated images. ESO users will be provided with the output of the image pipeline, run in Garching, on the data contained in a single OB. The nominal photometric accuracy of this pipeline will be ± 0.05 mag, exceptionally ± 0.01 mag. The nominal accuracy for the astrometry is ± 0.1 arcsec rms over the entire field of view.

As part of the contract, the OmegaCAM consortium will deliver software modules that ESO will integrate into the image pipeline. In addition, a project has been set up among European wide-field imaging groups to provide a 'wide-field imaging survey system' that will combine pipeline processing of image data with archiving and data mining tools. Further details can be found on http://www.astro-wise.org, and in Valentijn & Kuijken (2002).

The development of the analysis software is being done by a team based in Groningen and Leiden, led by E. Valentijn.

5. Current Status

The OmegaCAM project is now well into in the manufacturing phase. Most of the CCDs have been delivered and tested; most of the mechanics exist and are ready to be integrated; instrument control and data analysis software is being coded. Extensive tests in Europe are foreseen for the second half of 2003, and the camera should see first light early in 2004. Exciting times!

Acknowledgements

The consortium was formed in 1998 in response to an announcement of opportunity from ESO, and comprises institutes in the Netherlands (NOVA, in particular the Kapteyn Institute Groningen and Leiden Observatory), Germany (in particular University Observatories of Munich, Göttingen and Bonn) and Italy (INAF, in particular Padua and Naples observatories). The ESO Optical Detector Team provides the detector system at cost to the consortium. OmegaCAM is headed by PI K. Kuijken (Groningen and Leiden University) and co-PI's R. Bender (Munich USM/MPE) and Cappellaro (INAF Naples/Padua), and project management is done by B. Muschielok and R. Häfner (USM).

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The VLTI – 20 Months after First Fringes

A. GLINDEMANN, ESO

1. Introduction

In 2002, the second year of fringes at Paranal, the VLTI has made substantial progress. The highlight was the completion of the combination in pairs of all four Unit Telescopes on September 15/16 and 16/17 using a total of five different baselines. Only the combination MELIPAL – YEPUN could not be provided due to the current configuration of delay lines in the interferometric tunnel.

Of equal importance was the start of a total of 150 hours shared risk science operations with the VLTI in October. Forty proposals from the community were received representing about 10% of all proposals submitted to ESO for the VLT observatory. A summary of the first semester with VLTI science operations will be given at the end of this semester. For Period 71, the shared risk science operations became a part of the ESO Call for Proposals with 25 proposals submitted for the VLTI. A number of observation preparation tools have been developed in collaboration with the Jean-Marie Mariotti Centre for Interferometry (JMMC) in Grenoble. Two of them are now available on the web (http://www.eso.org/observing/etc/ preview.html). In the course of the year, all science data between First Fringes in March 2001 and September 2002 have been released through the archive resulting in first scientific results which are described in [1]–[4]. A summary of the first results is given in [5]. In the context of science operations, the results of the on-going observations of calibrator stars are reported in [6], in collaboration with the NOVA ESO VLTI Expertise Centre (NEVEC) in Leiden.

Amongst the runners-up for achievements are the integrated optics beam combiner IONIC for VINCI, the acceptance of the science instrument MIDI in Heidelberg in September (currently being integrated at Paranal), and three new contracts to extend the VLTI infrastructure: Delay Lines 4, 5 and 6 were ordered at Fokker Space in Leiden, and the installation of the required rail systems in the Delay Line Tunnel started in August. The contract for the fourth Auxiliary Telescope was signed with AMOS in Liège at the beginning of September (see [7]). The first PRIMA contract for the delivery of the fringe sensor unit was signed with ALENIA Spazio, Torino, in July, and the second contract for the star separator unit will follow soon. The PRIMA laser metrology system will be an in-house development. These three subsystems will form the first phase of PRIMA.

IONIC was provided by the Observatoire de Grenoble. IONIC is a beam combiner for VINCI that can be used instead of VINCI's fibre beam combiner MONA. In IONIC, the beams are guided through two silicon fibres into an integrated optics (IO) component where the beam combination takes place. At the exit of the IO component, fibers are attached guiding the light to the infrared detector. Since the fibre connectors are identical to those used in MONA, the optical integration was just a matter of deconnecting and connecting a few fibres. Unlike the K-band beam combiner MONA, IONIC, having silicon fibres and substrates, works in the H-band. The VLTI had first fringes with IONIC on July 18, producing an interferometric transfer function above 80% with an accuracy of 1% which is as good as MONA (see [8]).

Last but not least there is also progress with the adaptive optics systems for the VLTI. The Paranalization of the tip-tilt sensors STRAP on two Unit Telescopes is finished, and MACAO, the high-order adaptive optics system (see [9]), saw first light in the laboratory in Garching in August, closing the loop on an artificial star.

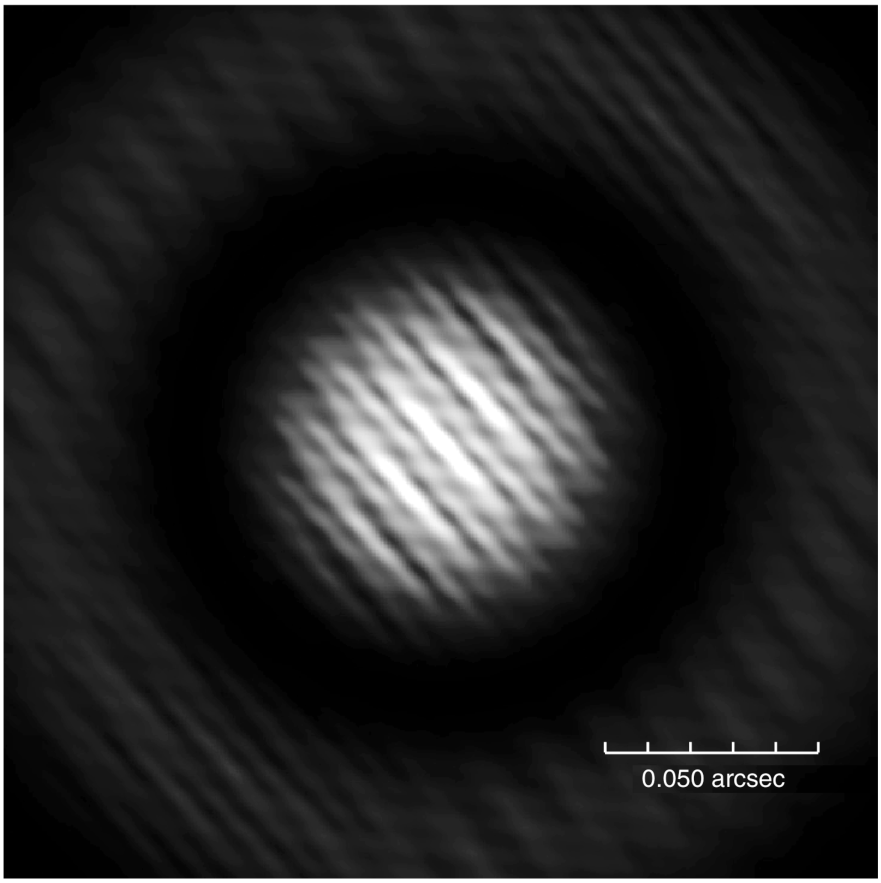


Figure 1: The reconstructed, two-dimensional interferometric point spread function (PSF) of the star Achernar observed in the K-band. The width of the central fringe is 3 by 15 milli-arcsec indicating the angular resolution limit of the VLTI for the baseline distribution shown in Figure 2. On the largest scale, the image is enveloped by the Airy disk of a single 8-m Unit Telescope. Its first minimum at 57 milli-arcsec off the centre can be clearly seen. The image provides a dramatic illustration of the 20-fold increase in resolution of the VLTI over a single 8.2-m telescope.

2. Four Eyes Are Better

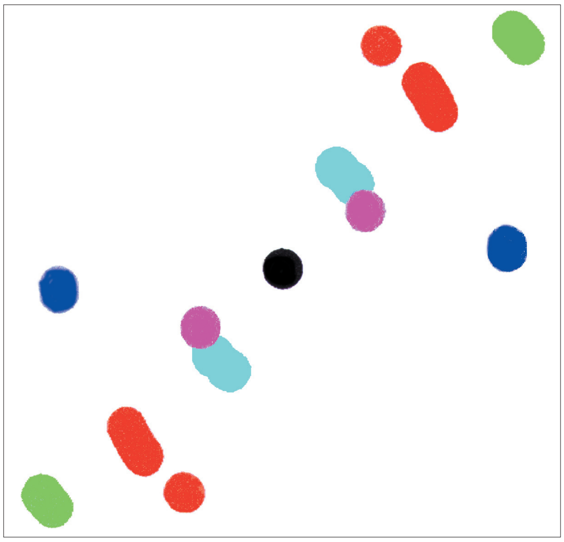
Why should one attempt to use more than two telescopes if the interferometric instrument can only combine two beams? First of all, this exercise demonstrated the ability to provide multiple beams in the VLTI laboratory without losing time for mirror realignment or for other reconfigurations. In 2003, AMBER, the near infrared science instrument, will see first fringes. Then we will have an instrument combining up to three telescopes simultaneously.

In addition, multiple baselines are the key to efficient interferometric imaging. The result of the observations of the star Achernar in September, shown in Figure 1, gives an impression of the angular resolution capability of the VLTI with the Unit Telescopes. The intensity distribution was reconstructed from the measurements with individual baselines by Fourier transforming the distribution of values displayed in Figure 2. Every balloon in that figure represents the result of a visibility measurement with one baseline vector. It is important to properly refer to baselines as baseline vectors in order to understand why the distribution of the balloons is considerably different from the distribution of Unit Telescopes at Paranal (see Fig. 3). The visibility function depends on the difference of telescope coordinates (projected perpendicular to the viewing direction of the star). For instance, two telescopes separated by 100 m along the north-south direction have exactly the same baseline vector as two other telescopes a few kilometres away that are also separated by 100 m along north-south.

The baseline vectors are displayed in the 'uv-plane', where the measured visibility forms the function value at the coordinate given by the length and the orientation of the baseline vector. Since the visibilities are derived from the intensity, a real and positive quantity, the visibility function is point symmetric; one visibility measurement delivers two function values, at (u, v) and at (-u, -v).

The balloons representing the measured visibilities in the uv-plane are small disks although a point would be expected when observing with an individual baseline. The reason is that the telescope is not a pinhole but an 8-m aperture allowing for a small variation of baselines around the 'centre-to-centre' baseline. Inside VINCI, optical fibres are used as spatial filters. The size of the optical fibres is exactly an Airy disk of the telescope, i.e. the field of view is one Airy disk. This spatial filtering is equivalent to performing an average over the visibilities inside the disk represented by the balloons.

For imaging it is important to note that one measures as many independent image points inside the Airy disk as one has baselines, i.e. as one has degrees of freedom. Fortunately, the number of baselines is not only determined by the number of telescopes but also by the duration of the observation. Due to the sidereal motion, the baseline projected onto the viewing direction changes all the time in length and orientation depending on the object coordinates. Some of the baselines that are displayed in Figure 2 have a slight peanut



▲ *Figure 2: The set of baselines used for observing Achernar with the four Unit Telescopes. Each baseline is represented by two opposite, short arcs, symmetric around the origin (centre) of the diagram. The colour-coded pattern reflects the telescope pairs (ANTU-KUEYEN = magenta, ANTU-MELIPAL = red, ANTU-YEPUN = green, KUEYEN-MELIPAL = cyan, KUEYEN-YEPUN = blue).*

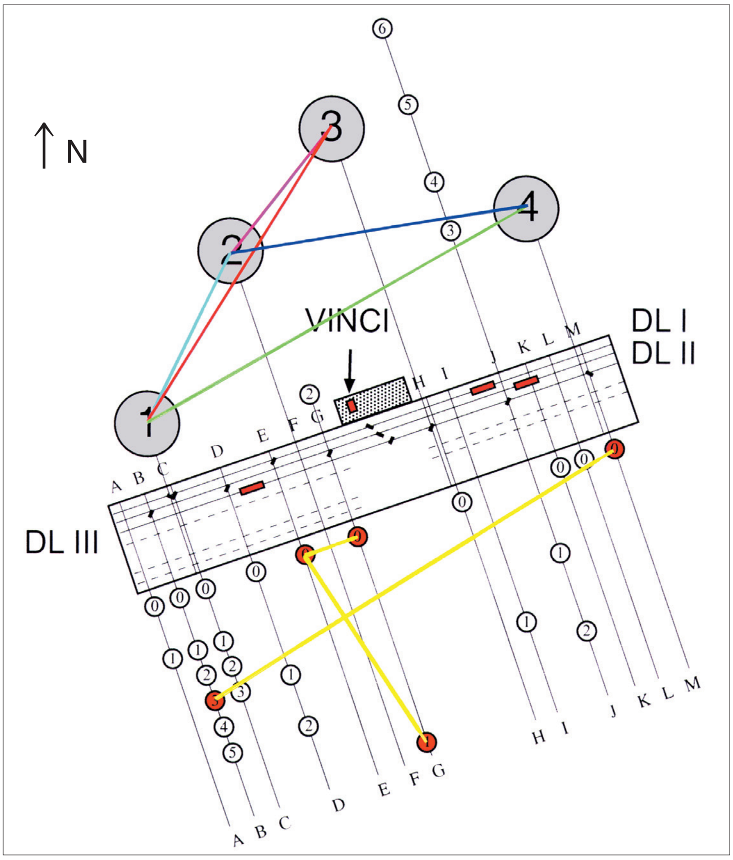


Figure 3: The lines indicate the Unit Telescope and AT stations that have been combined at Paranal to date. The colour scheme for the UTs corresponds to the baselines shown in Figure 2. ▶

shape due to the observing time of a few hours. Several individual measurements were taken during this time. Therefore, the number of individual points in the image will be considerably larger than six when observing with all four Unit Telescopes.

The present observations of Achernar give an impression of the point spread function of the VLTI because Achernar with an angular diameter of 2 milli-arcsec is smaller than the resolution limit of 3 milli-arcsec of the VLTI in the K-band. Due to the moderate number of baselines, the point spread function in Figure 1 shows a mix of a moderate number of individual fringe patterns. A larger number of visibility measurements would make the individual fringe patterns disappear, and only the central fringe would remain as the 'point' in the point spread function.

The particular distribution of baselines in Figure 2 is rather extended in the north-east/south-west direction (the baseline of ANTU-YEPUN) and rather narrow in the perpendicular direction because the baseline MELIPAL-YEPUN is missing. Consequently, the Fourier transform of this distribution is rather narrow in the north-east/south-west direction and rather wide in the perpendicular direction. The terms narrow and wide refer to the width of the central fringe. The central fringe in Figure 1 has a width of about 3 milli-arcsec in the direction of the longest baseline and of about 15 milli-arcsec in the perpendicular direction. Due to the processing technique, the Airy disk of an individual 8-m telescope shows up in the point spread function in Figure 1. The first dark ring of the Airy disk with a radius of 57 milli-arcsec in the K-band is readily apparent. This illustrates the gain in angular resolution with the VLTI compared to an individual Unit Telescope.

However, it is still a long way to go before the VLTI will do imaging of arbitrary objects since this requires measuring the phase of the visibility function in addition to its modulus i.e. its contrast. AMBER in 2003 will be a first step, being able to use three telescopes and performing a phase reconstruction via the closure phase technique. Eventually, from 2005 onwards, PRIMA will allow measuring the phase directly per baseline and, in addition, observe very faint objects. The scientific objectives of the PRIMA facility are described in [10].

3. Outlook

The coming year will be extremely busy, with integrations of new subsystems about every two months. FINITO, the fringe sensor unit, will be first, followed by two MACAO systems, by the first two Auxiliary Telescopes, by AMBER and by the carriages with cat's eyes of the three new Delay Lines. This is a big burden for the integration teams since the VLTI is not the only 'telescope' at Paranal.

In 2004, the remaining two MACAO systems and the third and fourth Auxiliary Telescopes will arrive at Paranal so that the VLTI will be able to combine the light from eight different telescopes, four Unit Telescopes and four Auxiliary Telescopes. With six Delay Lines, a common focus of six telescopes can be used at any given moment. To fully exploit the VLTI infrastructure, the first second-generation instrument should clearly be a six-way beam combiner, measuring 15 baselines at once and 28 during a night, without reconfiguring the telescopes.

Amongst all these integration and commissioning activities one must not forget that the success of an observatory depends solely on the scientific output. MIDI will make a start next year, and 2004 will be largely devoted to science operations with the VLTI.

Acknowledgement

Over the last 20 months, the number of people both at ESO and in the community contributing to the VLTI has become too large to name here. I would like to thank not only those with the highest visibility but also the large number of contributors forming the base of the success by ensuring that every little piece of this complex machine works every night.

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The Auxiliary Telescopes for the VLTI: a Status Report

B. KOEHLER[1], C. FLEBUS[2]
P. DIERICKX[1], M. DIMMLER[1], M. DUCHATEAU[1], P. DUHOUX[1], G. EHRENFELD[3], E. GABRIEL[2], P. GLOESENER[2], V. HEINZ[3], R. KARBAN[1], M. KRAUS[1], J.M. MORESMAU[1], N. NINANE[2], O. PIRNAY[2], E. QUERTEMONT[2], J. STRASSER, K. WIRENSTRAND[1]

[1]ESO, Garching, Germany; [2]AMOS, Liège, Belgium; [3]ESO, Paranal, Chile

1. Introduction

In June 1998, ESO signed a contract with the company AMOS (Belgium) for the supply of the Auxiliary Telescope System (ATS) for the VLTI. The original scope covered two movable Auxiliary Telescopes (ATs), as shown in Figure 1, as well as their associated site equipment including rails and interface devices for each observing station. An amendment was signed in September 1999 for the supply of a third AT and, last September, a fourth AT was ordered.

The contract with AMOS is based on top-level performance requirements and includes the design, manufacturing and testing of the complete system including all mirrors and cells, complete mechanical structure, drives, encoders, small mechanisms and low-level electronics. The main sub-contractors of AMOS are FISBA (Switzerland) for the coudé mirrors, PHASE (Italy) for the motors and CSEM (Switzerland) for the M2 hexapod mechanism.

ESO is in charge of the design and development of the telescope control hardware and software, as well as of the two star sensors located at the coudé focus.

After integration of the ESO control hardware and software, the telescope is fully tested in Europe at AMOS with the possibility of sky observation provided by an outside observing station included in the dedicated test facility. After this, ESO transports the ATs to Paranal, re-integrates them in the so-called Mirror Maintenance Building (MMB) and finally commissions them on the sky.

The project entered into manufacturing phase in mid-1999 and is now reaching the end of a very extensive testing and verification phase in Europe on AT#1 before its shipment to Paranal next year.

This article recalls the rationale at the origin of the ATS development, provides a description of the design and finally reports on the performance as measured in Europe so far.

2. Why Does the VLTI Need Auxiliary Telescopes?

The VLTI is primarily intended to combine coherently the four VLT 8-m Unit Telescopes (UTs). Obviously, the ultimate VLTI sensitivity will indeed be obtained when combining the UTs. However, the array of 1.8-m diameter ATs is a key element for the technical and scientific capability of the interferometer. The main reasons are listed below.

• It provides the best imaging capability of VLTI by complementing the array of UTs. It gives access to 30 telescope stations increasing therefore the number of accessible baseline vectors, a fundamental parameter for high-fidelity image reconstruction.

• It gives access to the longest VLTI baseline of B = 200 m versus a maximum of 130 m between UTs. This is needed to reach the ultimate angular resolution of the VLTI that scales as λ/B (i.e. 0.6 milli-arcsec in the visible and 2 milli-arcsec in the K band).

• It enables full-time use of the VLTI facilities, since the ATs are entirely dedicated to interferometric observations. This is an important factor for the VLTI scientific productivity (and for the amortization of its development cost!).

• It is required by the Narrow Angle Astrometry mode of PRIMA that

Figure 1: The first Auxiliary Telescope for the VLTI during final testing at AMOS in Liège (Belgium).