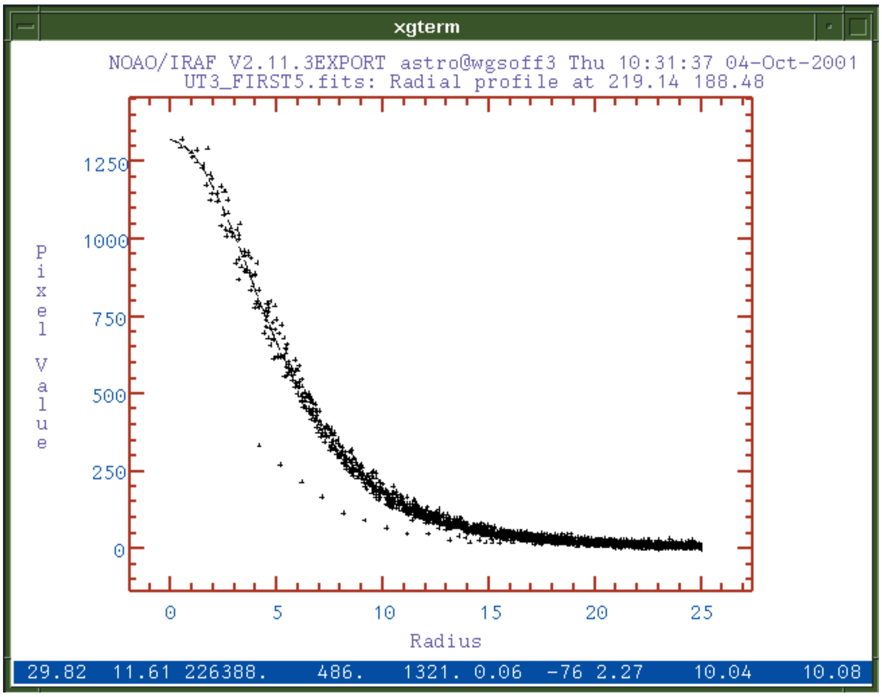
## 2. First Fringes

The night of October 29/30 started with tests of the Coudé Optical Trains and the Relay Optics, converting the light from the Coudé focus to a parallel beam in the Delay Line Tunnel. For the history books it should be noted that one of these mirrors (M9) arrived only on the very same night at Paranal, and a small dummy mirror with a diameter of 40 mm – albeit of very good optical quality – on a temporary mount had to be used for First Fringes.

Around midnight, when the UT team finished the tests and the search for fringes could start, not everybody on the mountain would have bet how quickly the search was successful. Before actually seeing fringes with a new baseline, a number of assumptions has to be taken on the internal path lengths in each arm of the interferometer and on the distance between the telescopes. When distances between individual mirrors can be measured with very high precision (some 10 microns), the distance between the telescopes, i.e. the baseline, is only known with a precision of some 10 millimetres. These uncertainties can be corrected after fringes are found on different stars, and the so-called OPD (Optical Path Difference) model of the interferometer is refined. Depending on the discrepancy between the assumed baseline and the real baseline, the first search for fringes can take several hours since the scan for OPD zero position where fringes can be found has to be done at speeds of about 1 mm per minute.

However, barely one hour after we had started, the automatic fringe search routine in VINCI reported ‘flecos en el cielo’, and the fringes appeared on the screen. We found that the baseline of 102.5 m between ANTU and MELIPAL differed by only 28 mm from their nominal length. After refinement of the OPD model, fringes were subsequently found within 0.4 mm of their calculated position.



```
NOAO/IRAF V2.11.3EXPORT astro@wgsoff3 Thu 10:31:37 04-Oct-2001
UT3_FIRST5.fits: Radial profile at 219.14 188.48
```

```
29.82   11.61 226388.     486.     1321. 0.06  -76 2.27      10.04     10.08
```

*Figure 2: The radial plot of the first stellar image on a CCD at the VLTI focus collected with the 8-m telescopes. After 28 reflections and 200 m of optical path inside the VLTI, the image size of 0.45 arcsec was limited only by the seeing.*

With the experience that we had gathered over the last six months of commissioning, ’routine operation’ with the 8-m telescopes started almost immediately with a number of scientific observations: the first measurements of the diameter of red dwarfs (Kapteyns star, HD 217987 and HD36395), the precise determination of the diameter of Cepheids (Beta Dor and Zeta Gem), the so-called light houses of the universe, and the first measurement of the core of Eta Carinae (for details see the press release). A total of 17 different stars was observed during this observing run. The technical downtime was less than two hours per night.

The faintest star that could be observed had a magnitude of K = 6.3, and this is all the more remarkable as the 8-m telescopes were used without any adaptive optics correction. The star light in VINCI has to be fed into an optical fibre with a diameter of 6.5 microns which is the diameter of the diffraction limited Airy disk and, thus, a perfect match if the telescopes produced diffraction limited images. Without adaptive optics, this optical fibre is merely fishing for photons in the middle of the speckle cloud with a diameter of about 0.6 arcsec which is 10 times the diffraction limit. The number of photons entering the fibre is then about 100 times or 5 stellar magnitudes smaller than what could be expected with adaptive optics.

We are now looking forward to improving the performance for the following UT observing runs by implementing the tip-tilt correction in the Coudé foci and by tuning the infrared camera readout mode. The general planning for the following years is described in *The Messenger* No. 104, p. 2 (June 2001).

# The VLTI Data Flow System: From Observation Preparation to Data Processing

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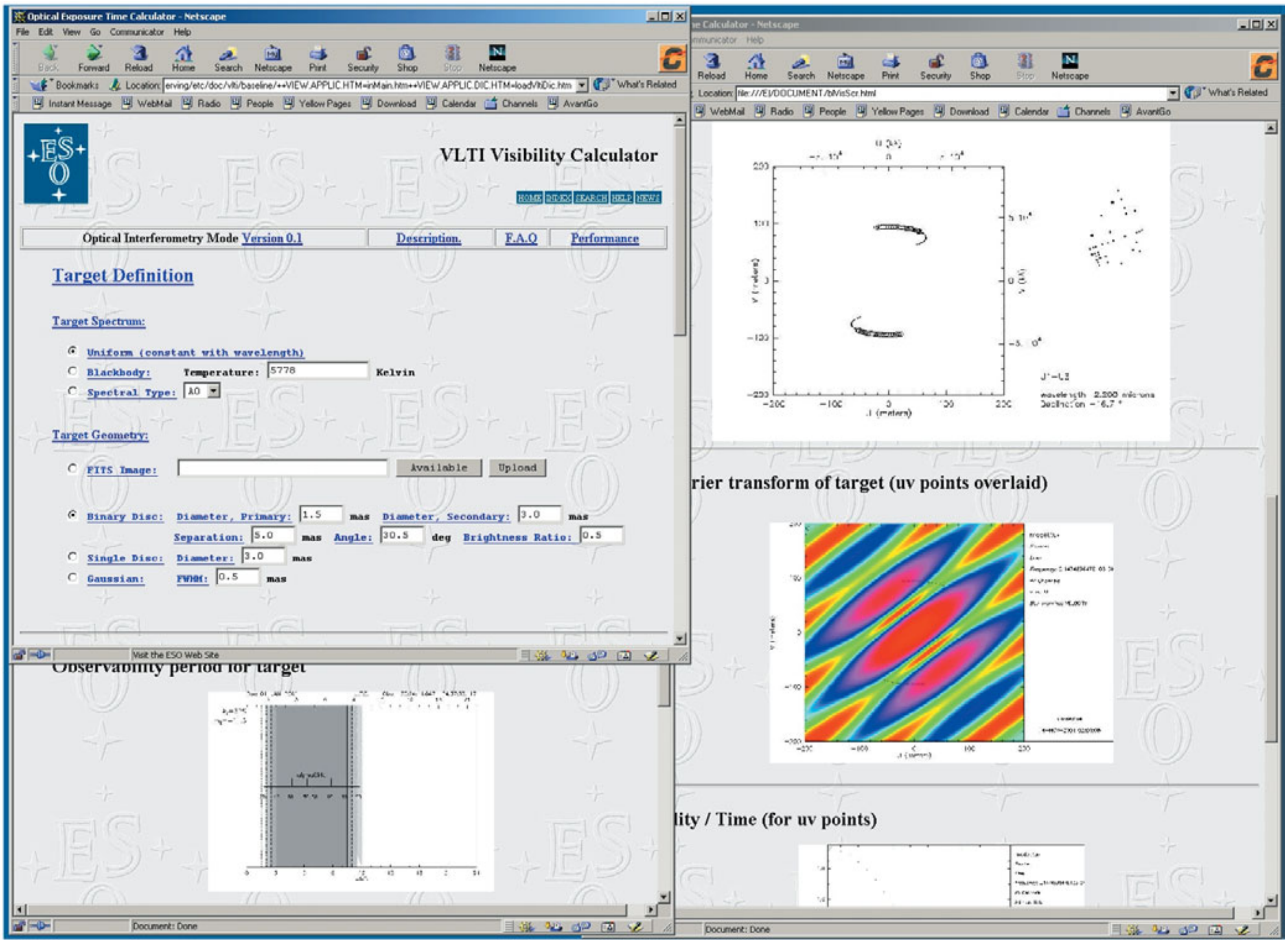
In this article we present the Data Flow System (DFS) for the VLT Interferometer (VLTI) that is analogous with that of other telescopes of the VLT. The DFS was first installed for VLTI first fringes utilising the siderostats together with the VINCI instrument and is constantly being upgraded in phase with the VLTI commissioning. A recent VLTI achievement has been the first fringes with the Unit Telescopes (see article on page 1). For this milestone the VLTI



VLTI Visibility Calculator

Optical Interferometry Mode Version 0.1 | Description. | F.A.Q | Performance

Target Definition

Target Spectrum:

● Uniform (constant with wavelength)
○ Blackbody: Temperature: 5778 Kelvin
○ Spectral Type: A0

Target Geometry:

○ FITS Image: Available Upload

● Binary Disc: Diameter, Primary: 1.5 mas Diameter, Secondary: 3.0 mas Separation: 5.0 mas Angle: 30.5 deg Brightness Ratio: 0.5
○ Single Disc: Diameter: 3.0 mas
○ Gaussian: FWHM: 0.5 mas

*Figure 1: The VLTI Visibility Calculator (preliminary design). The VLTI Visibility Calculator will be an Internet application similar to the ESO Exposure Time Calculators. The prototype is using the ASPRO/JMMC software as a calculation engine.*

DFS was also present and operating. Observations of objects with some scientific interest are already being carried out in the framework of the VLTI commissioning, making it possible to test tools under realistic conditions. These tools comprise observation preparation, pipeline processing and further analysis systems. Work is in progress for the commissioning of other VLTI science instruments such as MIDI and AMBER. These are planned for the second half of 2002 and first half of 2003 respectively. The DFS will be especially useful for service observing. This is expected to be an important mode of observation for the VLTI, which is required to cope with numerous observation constraints and the need for observations spread over extended periods of time.

## Preparing VLTI Observations

Preparing an interferometric observation involves successive stages, each with specific constraints. In order to assess the technical feasibility of an interferometric observation one needs adequate tools to model the complete interferometer behaviour and to take into account for example shadowing effects, or the range of the delay lines. A typical suite of actions involved in the preparation of an interferometric observation involves the following steps:

- An assumption must be made concerning the intensity distribution of the source. Usually this will be in the form of a model with a uniform or limb-darkened disk, a Gaussian profile, a multiple system or any other shape that can be analytically described or has been obtained by techniques like radiation transfer calculations. The final goal is then to constrain the object parameters by model fitting or image reconstruction.
- The Fourier transform of the source intensity distribution that is the complex visibility function, is calculated. A set of spatial frequencies is identified which is suitable to obtain the required information on the object. A configuration of the interferometer array is selected among the available ones that will make it possible to sample the Fourier space in the adequate domain of spatial frequencies.
- One must make sure that the target is visible from the VLTI platform by all telescopes involved in the observation, taking into account possible shadowing effects. Shadowing effects can be caused for instance by the Unit Telescopes which obscure parts of the sky as seen by the Auxiliary Telescopes.
- The optical path difference must be estimated, in order to evaluate the total time that will be available for the observation.
- Suitable calibrators must be selected for the science object. An interferometric calibrator is a target of (supposedly) known properties that will give a reference value for the measured visibility. Since the transfer function of the interferometer varies with time, calibrators and science objects must be observed alternatively within the finite stroke of the delay lines.
- The visibility amplitude (i.e. the modulus of the Fourier transform) of the target and calibrators can be estimated as well as the required exposure times. Note that in interferometry, it is not just the magnitude of the source that matters, but also the product of the total flux (in the resolution element) and the visibility[1]. For example, between two sources of magnitude 1 and 2, and with visibilities 0.1 and 0.5 respectively, the former will look “fainter” to an interferometer than the latter.
- Once several series of targets and calibrators have been selected, they

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[1] Visibility is a measure of the contrast of the interferometric fringes, as a function of the separation between the telescopes. (An unresolved source will have maximum fringe contrast: visibility will be 1. A completely resolved source will have no fringes, and the visibility will be 0.)

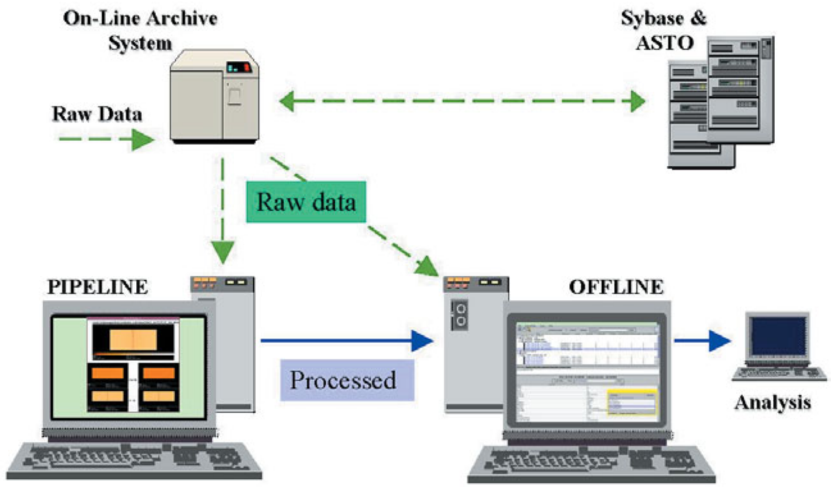

*Figure 2: VLTI Data Flow System at Paranal.*

must be organised in a schedule of observations, where one will try to optimise the time spent in acquiring data taking into account priorities and observational constraints.

As can be seen from the above list, preparing an interferometric observation requires adequate tools that can handle the geometrical configuration of the array and target/calibrator positions. Most observations in interferometry will involve measurements for different spatial frequencies and are likely to require different configurations and spread over extended periods of time, several weeks or several months. It is therefore expected that service observing will be a dominant mode at the VLTI. The geometrical constraints on the observation of the science and calibrator targets and the limited observability of the objects due to both the range of delay lines and shadowing effects will make it necessary to assess the technical feasibility of observations at both stages of phase 1 and phase 2 preparation. During phase 1, general tools like the WEB-based visibility calculator and exposure time calculators will be provided. In phase 2, the details of the observation can be validated more accurately.

### *VLTI Visibility Calculator*

The VLTI Visibility Calculator is the tool used for such calculations. It computes the fringe visibility as a function of the object model parameters and the array configuration. It takes into account the horizon map of the observatory and shadowing effects induced by telescope domes and structures on the observatory platform. It computes the optical path length, the optical path difference and takes into account the range of the Delay Lines to estimate the period of observation for a given target.

A prototype of the VLTI Visibility Calculator is shown in Figure 1. The current prototype uses as a computation engine the ASPRO software (Duvert & Berio, 2001) provided by the Jean-Marie Mariotti Centre (JMMC) supported by INSU (CNRS and Ministère de la Recherche, France). The prototype is used to identify an efficient and user-friendly procedure for dealing with the numerous interferometric observation constraints. The user-interface of the VLTI Visibility Calculator uses the same technology as the ESO Exposure Time Calculators (ETCs). It will therefore be an Internet tool like the existing VLT ETCs.

An important feature of this Web-based prototype is that the user is provided not only with a visibility map of the source under consideration, but also with the so-called u-v tracks for the chosen VLTI configuration[2]. This enables the user to see immediately which parts of the visibility map can be studied and thereby estimate the usefulness and impact of such measurements.

### *VLTI Exposure Time Calculators*

Observation preparation tools have been provided for the VLT instruments in the form of Exposure Time Calculators accessible over the Internet (http://www.eso.org/observing/etc). The system provides a uniform access to the ETCs provided for the different VLT instruments. Several solutions have been designed to make it possible to efficiently develop and maintain these applications. For instance HTML templates and dictionaries are used to generate the pages on the fly, a macro language is used for prototyping and a database system is utilised to simplify the adjustment of instrument characteristics.

The ETC interface consists of two main pages, the input page and the result page. On the input page, the instrument se-tup and the target of the observations are defined. An HTML form is used to forward this information to a model application, which then performs the calculations and generates the result page. The result page summarises the input parameters and presents the results of the calculations, such as detected number of electrons of the object and sky, as well as various other information. The main result is the signal to noise for the observation, or alternatively, the number of integrations needed to achieve a specified signal to noise. In interferometry the signal-to-noise computations are significantly different from those required for a standard image or spectrum as done so far in the ETCs. The VLTI instruments ETCs will be interfaced to the Visibility Calculator.

## VLTI Data Flow System at Paranal

The hardware system handling the VLTI data is similar to the system installed at the Unit Telescopes (Ballester et al., 2001). Figure 2 shows the logical structure of the VLTI DFS system at Paranal: the instrument data are transferred from the instrument workstation to the On-Line Archive System machine, where they are kept on a Redundant Array of Independent Disks (RAID) system. The Data Handling Server takes care of distributing the data to the pipeline, off-line and archive workstations. Two machines are reserved for archive operations. One is dedicated to the Sybase server, where critical information about the operations is stored in various databases. The other Archive Storage (ASTO) machine is dedicated to media production, in particular CDs and DVDs. The pipeline workstation usually runs in automatic mode, receiving and processing the data, displaying the results and transferring the processed data to the off-line workstation. On the off-line workstation, interactive tools are available for reprocessing and analysing the data for the purpose of commissioning and scientific evaluation.

In the Data Flow system, the instrument parameters are grouped in high-level structures called Templates and Observation Blocks. Templates and Observation Blocks are assembled with P2PP, the Phase 2 Proposal Preparation tool. This Java tool provides a uniform graphical user interface to all VLT and VLTI instruments. In visitor mode the OBs are loaded using P2PP directly at the VLTI. In service mode, the Observation Blocks are ingested in a repository in Garching. The Template activates a standard operation mode of an instrument, for instance for the purpose of internal calibration, observation of calibration objects or scientific observations. Templates are grouped in Observation

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[2] u-v plane: also known as Fourier plane or Fourier space, is the counterpart (or inverse) of the image plane in which we measure separations in angles in arcseconds. The coordinates in the u-v plane are in metres and the points that are measured are defined by the baseline vectors (the vectors 'between' the telescopes of the interferometer).

Blocks, which in the Data Flow correspond to an unbreakable unit of observation. For the interferometry, a prototype template has been tested which integrates the acquisition and observation of science and calibrator targets. This concept should make it possible to keep track of related observations in the archive and for pipeline processing.

Interferometry data are stored in the form of binary tables. The header of the data follows the ESO Data Interface Control guidelines and provides the FITS keywords necessary for the data handling, processing, archive retrieval and proper documentation of the data.

## *VINCI Pipeline and Data Quality Control*

VINCI (VLT INterferometer Commissioning Instrument) is the beam combiner instrument used to commission the Cerro Paranal VLTI complex (Kervella et al., 2000). The latter is based on the proven concept of FLUOR (Fibre Linked Unit for Optical Recombination) that has been operated since 1995 as a focal instrument of the IOTA interferometer in Arizona. The instrument can receive the beams from the VLTI siderostats or from the Unit Telescopes ANTU and MELIPAL. The Data Flow System to handle VINCI data and the VINCI pipeline were first installed for the VLTI first fringes with the siderostats in March 2001 (Glindemann et al., 2001). The system has been regularly upgraded in particular with the extension of the Data Quality Control facility, which writes a subset of the pipeline results into an operational log-file.

The present VINCI pipeline performs automatically the first stage of processing and prepares FITS files containing the raw visibilities and all the information required for model fitting. The pipeline generates several data products. First the photometry-corrected interferograms are delivered for the purpose of commissioning analysis. This is delivered in ASCII form for further processing. Second, the raw visibilities, together with all the information required for further astrophysical analysis are written in a FITS file.

The pipeline receives the raw data frames from the On-Line Archive system and classifies them in accordance with the specifications given in the pipeline reduction rules. Conditions are evaluated on FITS keywords in order to classify the data. This determines the reduction procedure applied to the data. Before executing the procedure it may be necessary to read additional FITS keywords and to query auxiliary calibration data and tables from the pipeline local calibration database. A reduction block is prepared and sent for execution to a data reduction system. The VINCI measurement set consists of 4 values. These include the Interferometer 1, Interferometer 2, Photometer A and Photometer B measurements at a given time, also corresponding to a given Optical Path Difference (OPD). A scan is a sequence of OPD variation; it typically lasts about 0.1 second with VINCI. Series of scans are taken for different optical configurations: off-source scans, telescope A on-source only, telescope B on-source only, and a longer sequence of interferometric scans with both telescopes on-source. An exposure with VINCI includes the set of 4 batches and all auxiliary information. Each exposure produces a FITS file containing all the information necessary to derive uncalibrated visibilities.

The Quality Control (QC) system includes the tools used inside and outside the pipeline environment in order to control the conditions in which the data have been acquired and processed, in particular the instrumental and observational conditions. Quality control parameters are measured using the data and then written to the log files. The QC parameters have proven to be a very useful method for checking and tracking the health of instruments (Ballester et al., 2000). During the pipeline processing the data quantities characterising the performance of the instrument are measured. These values are written to operational log files. The log files are produced on a daily basis and can be used to produce automatic reports, graphs and summary information. The QC log files are used for diverse applications, for example to establish a catalogue of observed objects, to produce trend graphs of the interferometer transfer function or to verify the quality of the processing by checking the number of scans rejected by the pipeline.

## *Data Reduction Software*

The algorithm for the data processing (Coudé du Foresto et al., 1997) is illustrated in Figure 3. The off-source signal is recorded with both light channels closed. This is processed to estimate the noise power spectral density. The mixed beam signals are recorded while the light passes through telescope A only or telescope B only. They are used to establish the throughput of the interferometer for each beam (transfer matrix) of the interferometer and to calibrate the intensity recorded on each interferometry output with respect to the two photometry signals. Once these preliminary calibrations are performed, it is possible to process the on-source signal. The on-source photometry signal is processed and filtered using information previously collected by the off-source and mixed beam signals. Finally the on-source interferometry signal is processed to yield squared coherence factors together with variance estimates. The processing involves corrections for the dark signal and transfer matrix, and integrating the power spectrum according to the spectral filter.

The calibration of visibilities of interferometry data involves two stages. First the raw visibilities are estimated on both the science and calibrator data. This is the most computing intensive step, during which science and calibrator data are processed in a similar way. Second, the calibrator information is used to estimate the instrument transfer function. This transfer function is then interpolated as a function of time. In interferometry a particular emphasis is placed on the statistical analysis of the data and the accurate estimation of the error bars. This second stage of calibration involves a limited amount of data as it applies to time averaged data. It may also require user interaction for the identification and rejection of calibration points. The calibrated visibilities with error estimates can then be used to determine the science object parameters.

The VINCI data reduction software and pipeline is also an excellent exercise in preparation for the two scientific instruments MIDI and AMBER. MIDI will be the first scientific instrument installed at the VLTI. It will cover the mid-infrared range between 10 and 20 microns. It records spectrally dispersed fringes and at 10 mm can reach a resolution of the order of 20 milli-arc-second. AMBER, which can combine up to three beams will be the first VLTI instrument with some imaging capability. It delivers spectrally dispersed fringes covering the three near-infrared bands J, H and K. Three spectral resolutions of approximately 35, 1000 and 10,000 are supported. By interfering three beams at once it will be possible to obtain images through phase closure

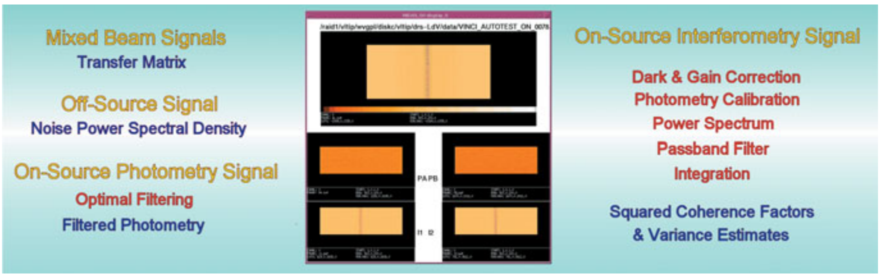

*Figure 3: Main processing steps of the VINCI Data Reduction Software.*

techniques eliminating the influence of atmospheric turbulence on the fringe position. The system can also be used in differential interferometry mode in order to estimate the phase difference between two spectral channels. Handling dispersed data and three-beam combination will be among the new methods to be installed for the VLTI pipelines.

The data rate for the first VLTI instrument VINCI is less than 1 gigabyte per night. The data rates will be higher for AMBER (0.7 MB/s) and MIDI (2.3 MB/s). For MIDI this translates into more than 40 gigabytes of data per night. The handling of such data volumes brings the current system to its limits, in terms of overall throughput. For example, the DVD production is limited by the media capacity and writing speed. For this reason a new archive technology, based on magnetic disks rather than DVDs, is being evaluated and seems quite promising (Wicenec et al., 2001). The science VLTI instruments like MIDI will set very high requirements in terms of pipeline computation speed. Presently the VINCI pipeline can process data at about the same rate as they are acquired. MIDI will require two orders of magnitude in computation speed to perform this real-time data acquisition and processing. Solutions are being investigated using large VINCI data sets and MIDI simulated data.

### *Off-Line Processing and Analysis*

For the scientific analysis of data, different interactive tools are provided on the off-line workstation, based on commercial data-analysis packages. The data can be browsed and organised by Observation Blocks with the Gasgano tool, which provides means of organising large amounts of data, classify them, view headers and call scripts on selected files. Gasgano can be used as a front-end graphical interface to the data reduction software.

Commands are provided to perform a second stage of calibration on the pipeline results. First the data are glued together and grouped by instrument modes. The calibration information can be tuned and the instrument transfer function is evaluated on the calibrator and interpolated with time. Finally it is possible to apply the calibration to science data and to model the intensity distribution of the source.

## Conclusion

In the first phase of system commissioning, most of the calibration and analysis aims at characterising the performance of the interferometer, using two siderostats of 40 cm diameter separated by 16 m. For these tests, the pipeline provides photometry-corrected interferograms, uncalibrated visibilities, and the QC parameters which are instrumental to the assessment of the system performance. After this first stage of processing, data are transferred from the off-line work-station to the dedicated environments used for the performance analysis of each independent subsystem of the VLTI. The prototype tools for observation preparation can be tested for their usability in real conditions of observation.

In particular the interferometer transfer function, environmental parameters such as the atmospheric piston noise or the level of tunnel internal seeing, opto-mechanical performance and sensitivity of the delay lines are being analysed. A number of stars have been measured and a major criterion for stability could be verified: the equivalent point source contrast, i.e. the interferometer transfer function, was measured to be 0.87 with stability of about 1% over three days. This is far better than the required 5% over five hours. Other commissioning tests aim at verifying that fringes are found on any bright star in the specified field of view (60 degrees of zenith) or that low visibilities (down to 5%) can be measured.

After achieving the first fringes from the interferometer using the Unit Telescopes, the system is now used more intensively for the verification of the science performance of the system. More targets are observed and the pipeline is used to perform a preliminary calibration of the visibilities.

## Acknowledgements

Many thanks to Bill Cotton from the National Radio Astronomy Observatory and Walter Jaffe from Leiden Observatory for important contributions to the data-reduction package, to Gilles Duvert from Grenoble Observatory for helping with the VLTI visibility calculator using ASPRO.

### *References*

Ballester, P., Chavan, A.M., Cotton, B., Coudé du Foresto, V., Glindemann, A., Guirao, C., Jaffe, W., Kervella, P., Longinotti, A., Percheron, I., Peron, M., Phan Duc, T., Pirenne, B., Quinn, P.J., Richichi, A., Schöller, M. , Wicenec, A., Wilhelm, R., Wittkowski, M., Zampieri, M., Data Flow System for the VLT Interferometer, *SPIE* Vol. **4477**, Paper No. 31, 2001.

Ballester, P., Modigliani, A., Boitquin, O., Cristiani, S., Hanuschik, R., Kaufer, A., Wolf, S., The UVES Data Reduction Pipeline, *The Messenger* No. **101**, p. 31, Sept. 2000.

Coudé du Foresto, V., Ridgway, S., Mariotti, J.M., Deriving object visibilities from interferograms obtained with a Fibre stellar interferometer, *A&A Suppl*. Vol. **121**, pages 379–392, 1997.

Duvert, G., Berio, P., ASPRO: A Software to PRepare Optical interferometry observations, SF2A-2001: *Semaine de l'Astrophysique Française*, in press.

Glindemann, A., et al., Light at the end of the tunnel – First fringes with the VLTI, *The Messenger* No. **104**, p. 2, June 2001.

Kervella, P., Coudé du Foresto, V., Glindemann, A., Hofmann, R., The VLT INterferometer Commissioning Instrument, in Interferometry in Optical Astronomy, *SPIE* Vol. **4006**, 2000.

Wicenec, A., Knudstrup, J., Johnston, S., 2001, ESO's Next Generation Archive System, *The Messenger* No. **106**, p. 11. Dec. 2001.

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# Volume Phase Holographic Gratings Made in Europe

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This article is a shortened, combined and updated version of papers given at the August 2001 SPIE conference on Gratings in Astronomy (Monnet et al., 2001 and Habraken et al., 2001).

## 1. Grisms at ESO

The mission of the ESO Instrumentation Division is to provide our user community with state-of-the-art, operationally and optically efficient, versatile and stable instruments. Grisms have proven to be devices with which our mission can be carried out exceedingly well.

A grism is a surface-relief transmission grating that is applied to the hypotenuse face of a prism. The angle of the prism is chosen in such a way that the central wavelength of the first order spectrum is passed without deviation. Grisms with groove densities of up to 600 g/mm have an optical efficiency in the visible that is comparable to, or slightly better than, that of ruled gratings. Contrary to gratings, their zero deviation wavelength is nearly invariant with respect to slight orientation errors that may be caused by the insertion mechanism