Report on the workshop on

The power of optical/IR interferometry: recent scientific results and second-generation VLTI instrumentation

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This Workshop was held in Garching from April 4 through April 8, 2005, with 2.5 days dedicated to science from interferometers, and 2.5 days dedicated to concepts of second-generation instrumentation for the VLTI. With about 170 registered participants from a large number of countries and institutions, it can be safely stated that the workshop was a huge success. This massive participation forced the organizers to abandon the idea of holding the workshop inside the ESO headquarters, and accept the generous offer of a vast meeting room at the MPE, made by Prof. R. Genzel. Similarly overwhelming was the number of contributions. The number of requests for just the scientific part of the workshop could have easily filled a full week-long schedule with interesting oral presentations, and difficult selections were necessary.

Naturally, the VLTI was in the spotlight, and with good justification. More than half of the total of the world's interferometric refereed publications in 2004 originated from VLTI results, and at the Workshop about two thirds of the 39 oral presentations were similarly centred on recent VLTI results. Next to the well-known VINCI and MIDI, the newly arrived AMBER instrument could also be showcased. AMBER is in fact still under commissioning, and will start its open time observations in October 2005. In spite of the venue and of the implicit focus on the VLTI, a large number of speakers were not directly associated with the ESO interferometric community, and many of the presentations also gave results obtained at other facilities.

At the beginning and midway through the Workshop, the audience was fascinated by historical perspectives, spanning about two decades, on the initial ideas, development and implementation of the VLTI, as presented by two major players in the project, P. Léna and J. Beckers. Also fascinating was the outlook on the future of VLTI (and beyond) provided at the closing of the science part by A. Quirrenbach and T. Henning. The final format of the scientific part of the Workshop consisted of six sessions on four main topics. Some selected highlights are summarized below.

A. Richichi reviewed the statistics on measurements of angular diameters. About 650 sources have at least one direct measurement, but in fact only half of them have repeated measures and only about one third are of sufficient accuracy to constrain theoretical models significantly. Breakthroughs are quietly occurring in this field, such as very accurate measurements of second-order quantities (flattening, limb-darkening), and angular diameters of important, but not well-studied, objects such as main-sequence and pre-main-sequence stars. G. Perrin reviewed the subject of interferometric measurements of late-type stars, concentrating in particular on narrow spectral-band measurements of Mira stars, on the subject of fundamental or overtone pulsation, and on the circumstellar components.

Perhaps one of the most exciting subjects was that of Cepheid stars, with interferometers now able to directly measure the angular variations of the diameters and thus to calibrate precisely the Period-Luminosity relationship. Speakers on this topic included P. Kervella, A. Mérand and J. Davis, with results from the VLTI, CHARA and SUSI interferometers. Impressive illustrations of the progress in this field are provided in Figures 1 and 2.

An outstanding target was Eta Car. Both O. Chesneau and T. Gull devoted their presentations to this exotic object, reporting on observations with MIDI, as well as with HST and VLT. Also R. Petrov reported, among his survey of AMBER results, some brand new observations of Eta Car which, although of very preliminary nature, are sure to fuel much interpretative work (see Figure 3).

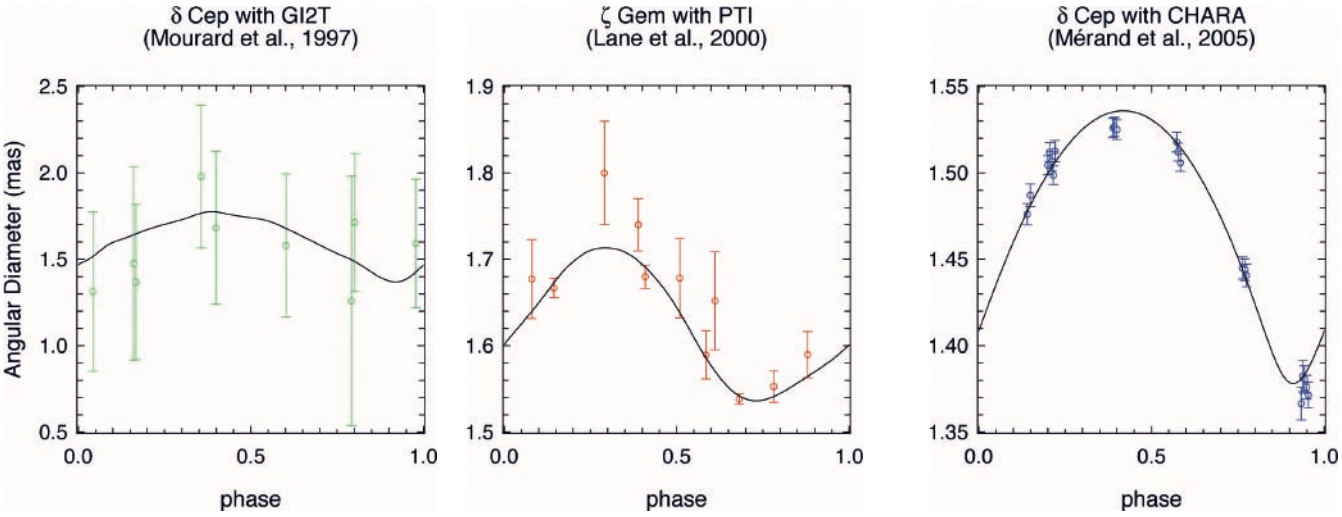


Figure 1: Progress in detecting angular-diameter variations in Cepheids by interferometry (presented by Mérand). **Left:** first attempt (Mourard et al. 1997, Science with the VLT Interferometer, Proceedings of the ESO workshop, p. 334). **Centre:** first detection (Lane et al. 2000, Nature 407, 485). **Right:** recent results by Merand et al. (submitted).

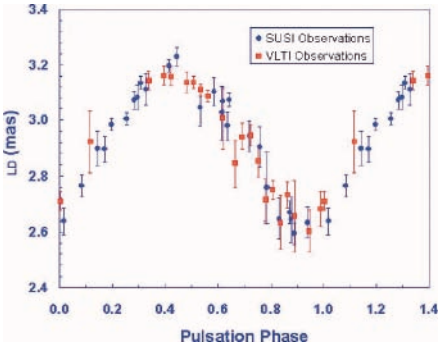


Figure 2: Comparison of SUSI and VLTI measurements (optical and near-IR, respectively) on the Cepheid star l Car (presented by J. Davis, VLTI measurements by Kervella et al. 2003, Semaine de l'Astrophysique Française, Conference Series, p. 531).

Next to the single giant stars and their circumstellar environments, a staple food of interferometry is represented by binary and multiple stars on one side, and by young stellar objects on the other: it was certainly interesting to note that the amount of results, some of which very recent and yet unpublished, was comparable across these areas. C. Hummel reviewed the subject of interferometric measurements of binary and multiple stars, highlighting the precision which is now obtained in the orbital results also for systems with just a few milliarcsecond separation (see Figure 3).

A. Boden reported a preliminary physical orbit for the pre-main-sequence star HD 98800 B. He obtains masses for the two components of ~ 0.5 and ~ 0.4 solar mass, with an accuracy of 5 % which is unprecedented among the very rare determinations of this kind for pre-main-sequence stars (see Figure 3).

The last part of the workshop took the audience from the familiar subjects of stellar astrophysics to more exotic areas. K. Meisenheimer reviewed the subject of interferometric measurements on AGNs, a field which did not exist until two years ago and that now already has several observations, mostly obtained at the VLTI. He detailed in particular the ground-breaking observations obtained by MIDI on NGC 1068 first (Figure 6, see next page), and then on Circinus A. A. Poncelet further illustrated the diversity of theoretical models available and how the data can constrain them.

The subject of the Galactic Centre also took a share of the spotlight, with recent MIDI/VLTI observations of IRS3 presented by A. Eckart, representing the first observation by interferometry of a mid-IR source in this region. A. Eckart concluded that the observations, when analyzed in combination with other photometric and spectroscopic data, will permit one to assess the size, geometry and grain composition of this source. Modelling is currently in progress. Even more intriguing were the prospects for future

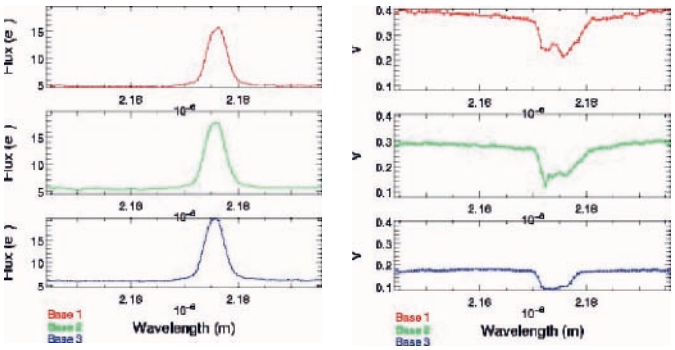
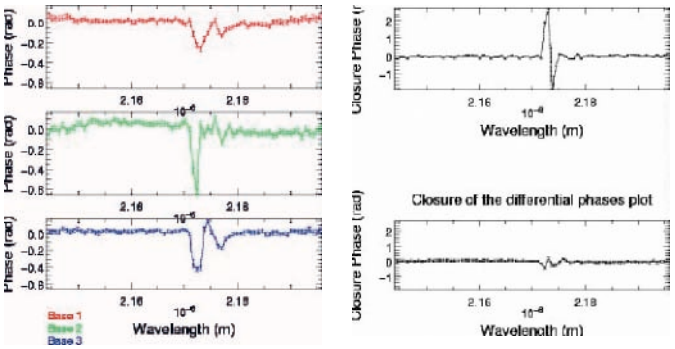


Figure 3: AMBER observations of Eta Car on a 3-UT combination. **Left:** the spectrally dispersed visibilities on the 3 baselines. **Right:** same, for the differential phases (presented by R. Petrov).



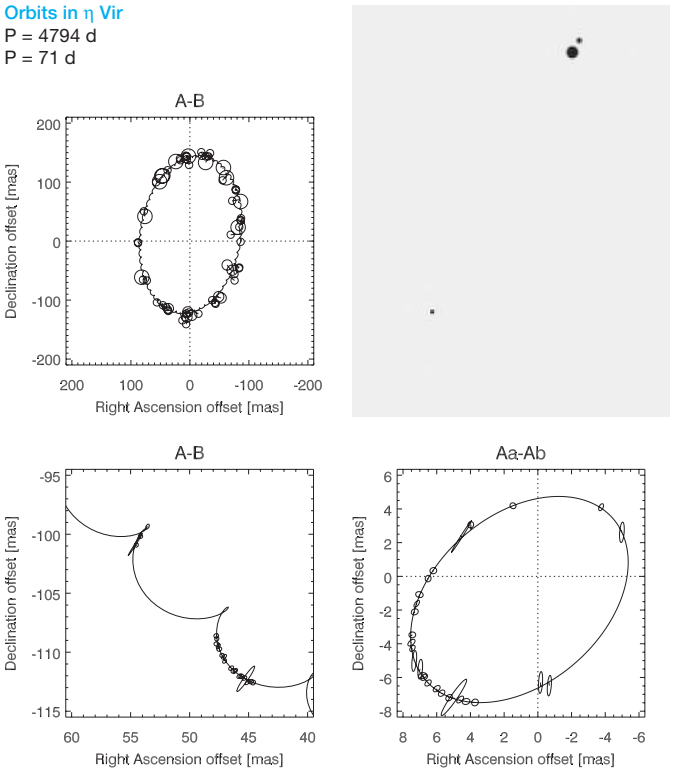


Figure 4: Orbits in the triple system Eta Vir (presented by C. Hummel). The image shows the constellation of the three stars with A, accompanied by Ab, in the upper right and B in the lower left. The other curves show: the A-B orbit, a zoom-in on the orbit of B displaying loops due to the motion of the photocentre around the centre of mass of component A, and (note the scale) the Aa-Ab orbit.

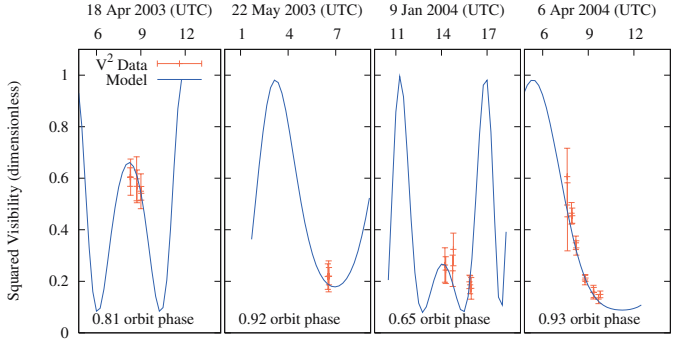


Figure 5: Orbital measurements of HD 98800B, obtained with the Keck Interferometer (presented by A. Boden).

studies of the inner parts of the Galactic Centre presented by T. Paumard. The speaker showed that the mass and mass distribution in the GC can be studied by following the orbits of stars in a region smaller by about one order of magnitude of what is currently possible. Such orbits would have periods of about one year, and with their high ellipticity and precession would permit one to infer the relativistic effects of the strong gravity connected with the black hole at the centre of our own Galaxy.

Interferometric studies of exoplanets are another subject which will keep us waiting for 1–2 more years, but equally rich in exciting perspectives. The issue was reviewed by D. Queloz, who compared the RV, transit and interferometric methods for the study of exoplanets. He argued that the VLTI will provide invaluable information on these systems starting with the first results from PRIMA, and suggested a strategy of massive surveys with this facility. He also advocated that stability and accuracy should be the first requisites of second-generation VLTI instruments.

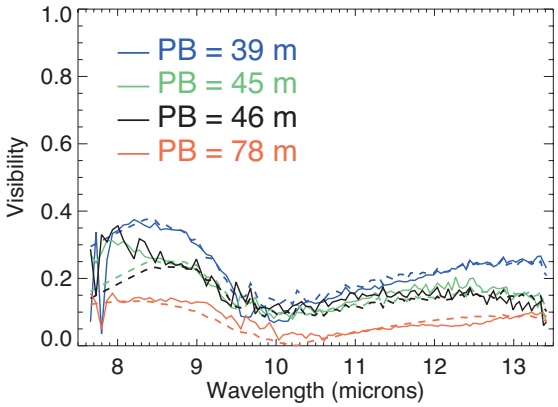


Figure 6: MIDI/VLTI observations of NGC 1068 (various baselines) and the comparison with theoretical models (presented by A. Poncelet).

Second-Generation Instrumentation for the VLTI

The second part of the workshop continued with the same enthusiasm as the first part. M. Schöller, R. Petrov and Ch. Leinert discussed the lessons learned during the implementation of the VLTI and its instruments. The stage was then given to the instrument proposals, which we summarize briefly below. Most of the proposals required the so-called VLTI '4 × 4' box, with four UTs and four ATs equipped with PRIMA star separators, a 4-beam Fringe Sensor Unit, four Differential Delay Line Units (two more than currently foreseen) and improved Metrology. In addition, there were presentations of general concepts for multi beam fringe tracking (M. Gai and F. Cassaing), for multiple anamorphic beam combination (E. Ribak), for the combination of VISTA with the VLTI (G. Perrin) and for the use of heterodyne detection in the *N*-band (R. Schieder). A large number of posters covered an even wider area of instrumental and technical topics.

The **Après-MIDI** concept was proposed by the former MIDI Consortium presented by B. Lopez (OCA, Nice) and S. Wolf (MPIA, Heidelberg). Their approach is to upgrade MIDI by adding a 4-beam imaging mode with filters to complement its current spectroscopic mode with two beams only. Prime science targets are the study of the complex circumstellar environment of (young or evolved, single or multiple) stars and of the detailed structure of AGN tori. The upgrade involves adding an opto-mechanical subsystem in front of MIDI and exchanging a few optical pieces inside the Dewar.

Two competing concepts – **VITRUV** and **CavCam** – that could lead to a successor to AMBER were introduced. They permit multi-beam (four, six or even eight) combination instead of the current 3-beam only with AMBER. Prime science targets are stellar surfaces, circumstellar environments, microquasars, and the central part of AGNs. Both instruments have roughly the same footprint as AMBER in the VLTI Laboratory.

VITRUV, a four- to eight-beam near-IR instrument, was proposed by a Consortium presented by F. Malbet (LAOG, Grenoble) and P. Garcia (CAUP, Porto). In their technical concept integrated optics is used to provide a compact maintenance-free beam recombiner. Extensions to the *I*- and *L*-bands, plus the addition of a medium spectral resolution mode (for e.g. stellar jets/winds and stellar dynamics around super-massive black holes) were also discussed.

A technically different approach was advocated by D. Buscher from Cavendish Laboratory (hence the provisory instrument name '**CavCam**') at University of Cambridge. He proposed a four- to six-beam beam combiner with an Envelope Sensor Unit, i.e. not tracking the individual fringe like an FSU but instead the fringe package envelope given by the group delay. The use of bulk optics ensures optimal efficiency (~ 25 % improved transparency compared to integrated optics) but less accurate visibility measurements since the fringes are not calibrated in flux. The use of group delay tracking also is less accurate compared to fringe tracking, but observations would be more sensitive and could be obtained on many science objects lacking a bright enough reference source required for fringe tracking.

VIDA, a potential additional mode to VITRUV, was presented by O. Lardière (Collège de France) and J. Schneider (Observatoire de Paris). Here, a densified pupil is used providing high sensitivity and high dynamic range at the cost of an extremely small field of view. Prime science targets are exoplanets (Hot Jupiters may be detectable), stellar surface imaging, gravitational lenses and AGNs. A VIDA test bench is currently under development at OCA.

R. Neuhaeuser (University of Jena) introduced the **NIFI** instrument aiming – on the technical side – at investigating integrated optics based subsystems (beam recombination and Delay Lines) in the *J*-, *H*- and perhaps *K*-band. The scientific impetus is to detect close companions to young stars and directly image stellar convection.

VEGA was proposed by D. Mourard (OCA, Calern). This would be essentially a remake of the REGAIN instrument that is installed at the GI2T (Calern). Operating in the 0.5–0.9 µm region, with a spectral resolution ~ 5 000, it would combine up to four telescopes. Photon-counting detectors with 30 % Q. E. are used to obtain a good sensitivity. Two modes are foreseen, x-λ spectroscopy with polarimetric information and multi-band pass imaging. Prime science targets are spots on magnetic stars, AGN, Cepheids and astroseismology.

A. Quirrenbach (University of Leiden) discussed **I-UVES**, linking the existing UVES instrument with a beam combiner in the VLTI Laboratory via 150-m long incoherent fibers. This provides high-resolution (R ~ 60 000) single-baseline interferometric data in the visible, λ = 0.6–0.9 µm. Without adaptive optics on the Auxiliary Telescopes they would have to be stopped down to about 50 cm. This instrument would essentially be dedicated to the precise testing of stellar models via diameter versus wavelength, oscillation mapping and direct measurement of star differential rotation.

With all the instruments discussed so far serving more general science cases, F. Eisenhauer (MPE, Garching) presented a dedicated single-topic science facility for the VLTI. The approach is to develop a low spectral resolution (~ 30) large efficiency (fully optimized for the *K*-band), high accuracy (dedicated AO system with an IR wave-front sensor, internal differential delay lines, cryogenic enclosure) system combining up to six beams. Preliminarily dubbed **GRAVITY**, it was essentially conceived to probe strong General Relativity effects by observations of close stellar orbits and differential astrometry of flashes in the Galactic Centre, plus possibly photometric detection of hot Jupiters.

GENIE, the Darwin ground demonstrator was presented by P. Gondoin (ESA). It is based on 2-beam interferometry in the *L*-band

and would offer both a nulling and a constructive mode. The science case covers in particular the survey and detection of possible exo-solar zodiacal dust discs, as well as Pegasides. Other applications include stellar formation, circumstellar environments, and AGNs. The Genie Science Team (co-sponsored by ESA and ESO) has produced a comprehensive report on the scientific prospects of this concept. After two ESA-funded Phase A studies were performed in 2004 by ALCATEL and ASTRIUM, the decision has to be taken which concept to choose.

Conclusions: towards Second-Generation Instrumentation and Infrastructure

The quality of the presented instrument concepts was remarkably high. While in the mid-infrared Après-MIDI was basically without competition except for the fact that one could ask for a more powerful spectroscopic mode, the near-infrared had a dense field of competitors. Here the choices to be made are between bulk optics vs. integrated optics and envelope tracking vs. fringe tracking on the technical side, and wide vs. narrow scope on the scientific side. But with such an enthusiastic and knowledgeable community, there should be no doubt that whatever choice is taken we will have a second generation of VLTI instruments that will ensure further workshops like this one.

Dutch Minister of Science Visits ESO Facilities in Chile

Mrs. Maria van der Hoeven, the Dutch Minister of Education, Culture and Science, who travelled to the Republic of Chile, arrived at the ESO Paranal Observatory on Friday afternoon, May 13, 2005.

The Minister was accompanied, among others, by the Dutch Ambassador to Chile, Mr. Hinkinus Nijenhuis, and Mr. Cornelis van Bochove, the Dutch Director of Science.

The distinguished visitors were able to acquaint themselves with one of the foremost European research facilities, the ESO Very Large Telescope (VLT), during an overnight stay at this remote site, and later, with the next major world facility in sub-millimetre and millimetre astronomy, the Atacama Large Millimeter Array (ALMA).

At Paranal, the guests were welcomed by the ESO Director General, Dr. Catherine Cesarsky; the ESO Council President, Prof. Piet van der Kruit; the ESO representative in Chile, Prof. Felix Mirabel; the Director of the La Silla Paranal Observatory, Dr. Jason Spyromilio; by one of the Dutch members of the ESO Council, Prof. Tim de Zeeuw; by the renowned astrophysicist from Leiden, Prof. Ewine van Dishoek, as well as by ESO staff members.

The visitors were shown the various high-tech installations at the observatory, including many of the large, front-line VLT astronomical instruments that have been built in collaboration between ESO and European research institutes. Explanations were given by ESO astronomers and engineers and the Minister gained a good impression of the wide range of exciting research programmes that are carried out with the VLT.

Having enjoyed the spectacular sunset over the Pacific Ocean from the Paranal deck, the Minister visited the VLT Control Room from where the four 8.2-m Unit Telescopes and the VLT Interferometer (VLTI) are operated. Here, the Minister was invited to follow an observing sequence at the console of the Kueyen (UT2) and Melipal (UT3) telescopes.

The Delegation in front of Kueyen (UT2). From left to right: Prof. T. de Zeeuw, Dr. C. Cesarsky, Dr. C. van Bochove, Minister M. van der Hoeven, Ambassador H. Nijenhuis, Prof. P. van der Kruit, Prof. E. van Dishoeck, Mr. H. van der Vlies, Mrs. van der Kruit, Mr. H. van den Broek, Dr. L. Le Duc, and Prof. F. Mirabel.

"*I was very impressed, not just by the technology and the science, but most of all by all the people involved,*" expressed Mrs. Maria van der Hoeven during her visit. "*An almost unique level of international cooperation is achieved at ESO, and everything is done by those who can do it best, irrespective of their country or institution. This spirit of excellence is an example for all Europe, notably for the new European Research Council.*"

Catherine Cesarsky, ESO Director General, remarked that Dutch astronomers have been part of ESO from the beginning: "*The Dutch astronomy community and industry play a major role in various aspects of the Very Large Telescope, and more particularly in its interferometric mode. With their long-based expertise in radio astronomy, Dutch astronomers greatly contribute in this field, and are now also playing a major role in the construction of ALMA. It is thus a particularly great pleasure to receive Her Excellency, Mrs. Maria van der Hoeven.*"

The delegation spent the night at the Observatory before heading further North in the Chilean Andes to San Pedro de Atacama and from there to the Operation Support Facility of the future ALMA Observatory.

On Sunday, May 15, the delegation went to the 5 000-m Llano de Chajnantor, the future site of the large array of 12-m antennas that is being built there and should be completed by 2013. The Minister visited the 12-m APEX (Atacama Pathfinder Experiment) telescope and saw the technical infrastructure.

"*I am fully confident that the worldwide cooperation in ALMA will be equally successful as the VLT, and I am convinced that the discoveries to be made here are meaningful for the Earth we live in*", said Mrs. van der Hoeven. "*History and future are coming together in the north of Chile, in a very special way,*" she added. "*In the region of the ancient Atacamenos, scientists from all over the world are discovering more and more about the universe and the birth and death of stars. They even find new planets. They do that on Paranal with the VLT and soon will be doing that on the ALMA site.*"

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