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JRA4 Work Package 1.2

ADVANCED INSTRUMENTS

COPHASING AND FRINGE TRACKING

PROGRESS REPORT

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1 Introduction

This is a report about Work Package 1.2 - Cophasing and Fringe Tracking progress.
Operation of interferometric instrumentation is critically based on Cophasing and Fringe Tracking (CFT) functions. The former brings the Optical Path Difference (OPD) among different telescope beams sufficiently close to zero, ensuring their coherence, whereas the latter stabilises such situation against perturbations, mainly associated to atmospheric turbulence. Different regions of the source wavefront are affected by independent (random) phase contributions, evolving with time.
Interferometry needs adaptive optics (AO) to achieve low residual wavefront errors (WFE) on each beam; however, an additional control layer is required to manage the phase relation (piston) among beams. When the disturbances from the environment and instrument are reduced to sufficiently low levels, it is possible to perform long exposures on a nearby source to achieve information on its structure by visibility and phase measurements, as a function of wavelength, baseline length and orientation.
Phase referenced observations in the near IR, with baseline ranging from few tens to few hundred metres, have the potential of resolution at the mas level, and of astrometric precision at the 10 μas level, depending on SNR, visibility and calibration.
The most appealing applications for the current instruments, up to and including the PRIMA facility for the ESO VLTI, and relevant also for next generation ground based instruments, are (phase-referenced) imaging, high precision narrow angle astrometry, and nulling experiments (e.g. in the perspective of GENIE for DARWIN).
The CFT system aims at increasing the integration time on the scientific instruments from the atmospheric coherence time (few ten to few hundred ms) to a few minutes, e.g. by a factor 1e4 from 10 ms to 100 s; this results in an improvement by several magnitudes on sensitivity, or by a large factor in the phase / visibility precision.
The key components of a CFT system, in the VLTI nomenclature, are the Fringe Sensor Unit (FSU), the actuator of the control loop; the Delay Line (DL), used to set the internal delay matching the target position and its sidereal motion; and the dual feed device, selecting the reference and secondary sources, the Star Separator (STS). The latter is required for exposures on astrophysical sources which are intrinsically too faint to allow CFT, in the same way as an off-axis guide star for pointing or AO. An internal metrology system, as foreseen in PRIMA, is usually convenient to reduce instrumental disturbances.
The sky coverage depends upon the desired measurement precision, defining the limiting magnitude for reference stars, and the AO / STS field of view.
The current CFT setup is basically adequate for the present scientific instruments, and for some extension of their concept and architecture.
A number of new concepts have been considered for investigation, also within this JRA, and some of them also require significant development on CFT. For example, the VLTI FSUs available in the next few years are FINITO (3 beams, delivered at Paranal, in commissioning) and the two PRIMA FSUs (2 beams each, in construction); they could be used in pair-wise combination to link up to five (3+1+1) telescopes, with a limited upgrade of the external beam distribution optics.
Simultaneous combination of six to eight telescopes will require a new CFT device. Pair-wise combination is sufficiently well understood, but it might not be the best solution for multiple-beam instruments, in which alternative schemes for direct multiple-beam combination might provide higher sensitivity. Coherencing (i.e. long range cophasing, required for initial fringe acquisition) should also be optimised.

1.1 WP1.2 overview

Current CFT concepts are reasonably well established, and their extrapolation to a number of new implementation cases is reasonably straightforward. Adoption of new technologies, as integrated optics, may provide significant benefits on performance for future instruments; their characteristics can be included in detailed CFT simulations as soon as the specific device parameters and instrument concepts are defined.
The Work Package 1.2 is focused on analysis and optimisation in three areas:

1. current cophasing instrumentation performance,
2. measurement operations and
3. cophasing schemes for future instruments.

The first two items concern the consolidation of current interferometric instrumentation, with the aim of improving their performance and ease their accessibility to the astronomical community at large. The third is related to the future development perspective. The fundamental pre-requisite to all of them is the detailed modelling of current CFT devices.
The first area concerns the potential performance improvement from more robust detection algorithms and data filtering methods. Given different observing conditions, and consequent different distributions of disturbances, it is possible to optimise both elementary measurement duration and signal processing to best match the noise PSD.
Fringe tracking algorithms must be optimised for the particular operating conditions of large facilities (e.g. VLTI, LBT). WP1.2 will analyse current CFT instruments and their operating algorithms (in particular, the VLTI FINITO and PRIMA FSUs), in order to achieve a more detailed modelling of their characteristics and derive adequate performance estimate in different operating conditions.
It will then be possible to develop and implement advanced fringe-tracking algorithms, also for Fizeau interferometry, and to test predictive algorithms, taking full advantage of our knowledge of the statistics of atmospheric turbulence. In the case of LBT, with baseline below the outer coherence length in most conditions, predictive algorithms may induce significant benefits.
The second area addresses the whole measurement chain, rather than only CFT, e.g. searching for optimal observation and calibration sequences, and analysing the measurement sensitivity to a range of environmental and instrumental limitations. An immediate impact can be expected on the astrometry measurement of PRIMA.
The third area takes advantage of the results of analysis of current fringe tracking systems and their operation, to evaluate CFT requirements and performance for possible future interferometers and combiners, in particular with reference to the concept studies developed within WP1.1.

2 Organisation of the project

An initial version of the WP1.2 task list, with a call for interest, was circulated among the EII participants on January, 2004. The list of participants below is composed from the answer to the initial call.
The current list of study areas is:

T1. Analysis of performance of current fringe tracking systems
T2. Fringe sensors hardware improvements

T3. High sensitivity operation
T4. Fringe sensors detection schemes
T5. OPD measurement filtering
T6. High precision astrometric calibration
T7. Baseline and wavelength bootstrap
T8. Multi-beam fringe sensor concepts
T9. Identification of technology development requirements
T10. Analysis of applicability of advanced detector (e.g. NIR STJ)
T11. Analysis of applicability of integrated optics (in bands J, K, ...)

The task list, in the form of a management plan, will be updated and circulated once a year, based on the inputs generated within the working group, and from the EII. The changes will be based on the results of ongoing research activity within the WP1.2 and the inputs / requests from other EII groups (e.g. need for specific analyses concerning specific instrument concept studies). The definition of new deliverables (e.g. reports), if required, and their schedule, will be included in the activity planning.
Decisions will be managed within the working group, by the WP leader, after discussion with the interested parties; in case of controversial issues the EII Extended Board will take charge of the problems.
Regular progress reports will be required after October, 2004, due also to the internal organisation constraints of several groups and the delay in EU funding. The definition of the reporting mechanism is in progress.

2.1.1 Personnel and responsibilities

Table of groups and tasks

Institute	Contact point	Tasks	# members	FTE [months]
INAF-OATo	M. Gai	T1, T3, T5; T2, T4, T6	7	18
Obs. Haute-Provence	V. Borkowski	T4, T5, T6, T7, T8	4	10
Cologne (Köln, D)	C. Straubmeier	T1, T4, T5	4	22
Technion	E. Ribak	T4, T7, T8, T9, T11	2	4
ONERA	F. Cassaing	T8; T4	(1)	2
Obs. Bordeaux	G. Daigne	T1, T3, T6, T8, T9	(1)	2
MRAO (Cambridge, GB)	J. Young	All	(3)	3

2.1.2 Work breakdown

The WP1.2 is supported by a working group managed by M. Gai (INAF-OATo), taking advantage of the Web resources supported by the Grenoble team (WP2.1).
The INAF-OATo group is working on the VLTI fringe sensors FINITO and PRIMA FSU, and plans tests in the lab and at Paranal. The work in progress was focused mainly on the design and analysis activity for the PRIMA FSU and in setup optimisation for FINITO.
The Technion group aims at in-depth practice on interferometric techniques, and multiple beam combination concepts in particular. In the framework of the Exchange

Visitor Program, E. Ribak (Technion) was in Torino in August, 2004, for analysis of implementation issues of current instruments and evaluation of future multi-beam instrument concepts.
The LISE team (OHP) is carrying on the analysis and laboratory activity aimed at testing the "dispersed speckle" method.
The Köln group is working on the LINC-NIRVANA Fringe-And-Flexure-Tracker for LBT.
The ONERA group proposes to work in strict collaboration with some of the WP1.1 groups, on future simulations and lab tests.
The Obs. Bordeaux group is interested in Group Delay Tracking, astrometric measurements, and in phase-coherencing.
The Cambridge group proposes to provide comments on the activity reports and documents generated within WP1.2.

3 Progress report

The groups involved in current experiments carried on the ongoing activity, with the results documented in the literature. Below we provide details on the activity of each group.

3.1 INAF-OATo (I)

The work in progress in INAF-OATo (I) was focused mainly on the design and analysis activity for the PRIMA FSU (PM9, 25-26 March 2004, and ongoing algorithm / performance implementation), and in setup optimisation for FINITO (alignment refinement in July 2004; first two commissioning nights on UTs in 3-4 August 2004). The status was described in contributions to the SPIE conference (Glasgow, UK, June 2004) and to the ESO-EII Workshop (Garching, D, April 2005).
In the framework of the Exchange Visitor Program, E. Ribak was in Torino between July, 31st and August, 21st, for analysis of implementation issues of current instruments and evaluation of future multi-beam instrument concepts.
In 2005, the work on integration of the PRIMA FSU A and B is progressing, with preliminary acceptance in Europe and delivery to ESO planned for end July.
On February, 2005, ESO appointed a team composed of Mario Gai, Pierre Kervella, David Mozurkewich, Mark Swain, and Gautam Vasisht, with the purpose of assessing the current performance limitations of fringe tracking with FINITO and recommend actions necessary for achieving requirement-level performance, reviewing the design, performance tests and plans for a test run. The final meeting was held in Garching in May, 2005.
The main conclusions are that primary limitation to fringe tracking on UTs is OPD vibrations in the telescope and beam transport (on ATs it is flux drop-outs due to poor coupling onto the FINITO fibres), and that, although it needs improvements, fringe tracking with FINITO essentially has the potential to deliver stable fringes to instruments.
The proposed improvements are vibration and tunnel seeing mitigation, variable curvature mirrors commissioning, and improvements to the algorithms of FINITO and delay line control. Noise sources are to be investigated in more detail and minimised.

3.1.1 Interferometric science

Several interferometry-related activities have been undertaken, as detailed below; although not strictly dependent on fringe tracking issues, they are relevant to definition of the scientific application context.

A preliminary evaluation on feasibility and performance of an interferometer in Antarctica was performed for INAF, in 2004. The team collaborated to the proposal to ESO on the PRIMA Reference Mission, coordinated by G. Perrin.

INAF-OATo submitted two VLTI Science Demonstration Time (SDT) proposals and in one of these, an attempt has been made to obtain, for the first time, a direct measurement of asteroid sizes by means of interferometric observations. Although technically not successful (since no fringes have been detected), these observations have set an important limit to the object albedo and underlined a potentially interesting new field of application for optical interferometry. The results are being prepared for publication.

In order to support the efficient use of the VLTI facilities, an effort is under way to collect and install a suite of software tools which will be essential to plan and prepare observations with the VLTI instruments, and to subsequently reduce the data obtained.

Several proposals have been submitted for open time during the coming ESO Period 76 (October 2005- March 2006).

3.2 LISE - Obs. Haute-Provence (F)

The LISE group is working on a laboratory prototype to test the “dispersed speckle” method (Borkowski et al. 2002, Borkowski et al. 2003,). This method consists in measuring piston errors among apertures of a multi-aperture interferometer using three dimensional Fourier transforms. See references below for more details on this method. The sensitivity and accuracy of this method should allow doing direct imaging and even coronagraphy in space. The prototype is under construction, and it is planned to be tested on the sky.

In the presence of turbulence there are speckles on the multi-prism. The pupil and optics have been chosen in order to have one speckle per multi-prism facet. On the camera, 100 channelled spectra can be seen. Each corresponds to one column of the input cube. The optical element called multi-prism has been developed in the LISE laboratory. Piston values as large as 20 μm can be detected in the lab.

Further testing and analysis in planned for the coming period.

The dispersed speckle method can be used in multi-aperture interferometers or hypertelescopes to determine piston errors from multi-spectral speckled images. It consists of calculating the 3-dimensional Fourier transform of a data cube built with stacked recorded monochromatic speckled images. The resulting output cube gives the piston errors by measuring the dot heights inside columns located at the positions of the pupil autocorrelation peaks.

Simulations showed that, for an interferometer composed of four 8 m sub-apertures (as in the VLTI case), 2.6e6 photons are required to reach the precision of $\lambda/100$ for visible wavelengths. This magnitude corresponds to magnitude of 4.28 (Borkowski V. et al. 2005). An optical setup has been built (Borkowski V. et al. 2004) and it is still in tests to validate this method. The current results are described in a contribution to the ESO-EII Workshop (Garching, D, April 2005).

The concept can be extended to the case of a large number of sub-apertures, and an analysis is performed for the possible application of the ESO OverWhelmingly Large Telescope (OWL), with the purpose of cophasing the whole array.
Also, the dispersed speckle method is investigated in the framework of the Carlina project. Preliminary results will be presented at the JENAM meeting in July in Liege. Carlina is a diluted version of the Arecibo radio telescope. The primary mirror is made of spherical fixed mirrors above which a balloon carries a gondola with the recombination optics and detector. A prototype has been built at the Observatory of Haute Provence.
The main advantage is that Carlina doesn't use delay lines; a method for coherencing and phasing the mirrors is described in Le Coroller H. et al, AA, 2004, 426.

3.3 Köln group

The Köln group presented the current results on the LBT Fringe and Flexure Tracker at the SPIE conference (Glasgow, UK, June 2004).
The correction of atmospherical differential piston and instrumental flexure effects is mandatory for full interferometric performance of the LBT NIR interferometric imaging camera LINC-NIRVANA (developed and built by MPIA Heidelberg, INAF-Osservatorio di Arcetri, University of Cologne, and MPIfR Bonn). This is the task of the Fringe and Flexure Tracking System (FFTS), which is part of the contribution of the I. Physikalische Institut of the University of Cologne to the project. Differential piston and flexure effects will be detected and corrected in a real-time closed loop.
Being a Fizeau-Interferometer, the LBT provides a FoV, which is much larger than the region that can be exploited by the science detector due to financial constraints. The FFTS can make use of the large FoV (1arcmin x 1.5arcmin in diameter) and increase the sky coverage of the overall instrument, if it is able to acquire the light of a suitable fringe tracking reference star. For this purpose, the FFTS detector needs to be moved to the position of the reference star PSF in the focal plane and needs to precisely follow its trajectory as the field rotates.
Subpixel (1pixel = 18.5 μm) positioning accuracy is required over a travel range of 200mm x 300mm. Strong are the constraints imposed by the need of a cryogenic environment for the moving detector. We have finalized a mechanical design and started prototyping and testing of the various mechanical components of the FFTS.
In the fringe tracking concept implemented in the FFTS, differential piston information is gathered in the image plane. We have developed and tested a fast PSF analysis algorithm that allows to clearly identify differential piston even in PSF images with low S/N ratios. In addition to simulated fringes, the fitting algorithm proved successful on real fringes. A scaled model of the LINC-NIRVANA optics as a laboratory experiment allowed us to generate LBT-like PSFs with arbitrary differential piston between the two channels.
As mentioned before, the FFTS may not necessarily operate on the science target, but will use a suitable reference star at a certain angular distance to the science target. In this case, differences between piston values at the position of the science target and at the position of the FFTS reference star can not be determined and add to the residual piston of the FFTS. We have dealt with the question of differential piston angular anisoplanatism and studied a possible improvement of the isopistonic patch size by the use of multi conjugate adaptive optics (MCAO). In its final stage LINC-NIRVANA will be equipped with such a system.

3.4 Technion group (IL)

3.4.1 Interferometric science

Most of the activity carried out during the first part of the research concentrated on finding ways to reduce errors in co-phasing different interferometer beams (see Tasks below). This was performed under the assumption that the common beam combination method is of the Michelson sort. A severe problem there is the calibration and vibration problem, which result from a few sources.

Dealing here with the beam combination side of the interferometer, it is difficult to correct errors in misalignment and vibration in the interferometer before the beams arrive at the combination station. Here there are many beam splitters which also add to the problems light loss and complex geometry. Vibrations of the splitters and combiners are doubled in path length difference, and are also different from beam pair to another. In some solutions, there is a need to move optical elements in order to combine different pairs, complicating the system even more. Also, unequal reflection and transmission ratios add to the complexity of the intensity calibration, there being again pair dependent.

Thus it would be nice if all beams could be treated as one unit, suffering exactly the same vibrations and intensity variations, which can then be calibrated out easier. A possible solution is to go back to the wave front division principle in interferometry, as similar to returning to Young's experiment back from Michelson's approach. The principle is to divide each beam many ways across its aperture or image domain, then mix these pair wise. A way to do that is to stretch the beams anamorphically, and take slices of the wave front and interfer them with slices from other beams. The principle is that of a table: all beams are lined up, stretched in the orthogonal direction into a comb of beams, and that comb is now interfered with itself rotated at normal angle.

3.4.2 Technology

The realization of the idea in the lab is made in two stages: an optical design of the beam stretcher, and test of the idea in hardware. Two designs were performed by the Turin group. A lab model was constructed at the Technion, and showed that indeed six or eight beams could easily be stretched, made into an orthogonal table, and the fringes measured. These results were presented at the VLTI Next Generation meeting in 4/2005.

3.4.3 Other Subjects

Four other subjects were tackled in the framework of interferometry, and two were already presented at the SPIE meeting in Glasgow in 2004: utilization of photons for interferometry after adaptive optics correction, and achromatizing beam combination in masked aperture, fibre interferometry. The third subject is to be presented in the near future. The fourth subject is measurement of longitudinal coherence in astronomy, and was also presented at the VLTI Next Generation meeting in 4/2005.

3.4.4 Economics

Most of the money was spent for two purposes. The first is working together, namely travel expenses incurred for cooperation, and for display of results. The second is local labour, mostly spent for student work on interferometry (now at progress but to

be presented soon). The full financial reports have been sent to the OPTICON centre as required.

3.4.5 People Involved

Apart from the PI, four more people were involved in the work above at the Technion: Professor S. G. Lipson (co-author of an upcoming book on stellar interferometry) with the multi-beam combiner described above, and Dr. D. Spektor, with help on the electronics part. A graduate student (from Tel Aviv University) is working on new concepts to be presented soon. P. Parhovnik is an undergraduate student (minimally) involved in general tasks. Cooperation was essentially with Dr. M. Gai and his group from Turin Observatory, and to a lesser extent with S. Lacour and G. Perrin from Meudon Observatory.

3.4.6 Associations With Tasks

Referring to document JRA4_WP1_2_impl_v02, the work above is in fulfillment of the following work group tasks:
T2. Fringe sensors hardware improvements
T3. High sensitivity operation
T4. Fringe sensors detection schemes
T8. Multi-beam fringe sensor concepts

3.5 ONERA

The ONERA group is investigating at laboratory level the concept of focal-plane cophasing and fringe sensing, using the technique of phase retrieval/diversity (3 sub-pupils) for piston/tip/tilt reconstruction, verifying the nanometric repeatability. Current tests include the effects of high-order modes and a larger number of apertures. The concept is proposed for space applications (DARWIN), and could be applied to future VLTI fringe sensors or for other interferometers, with advantages in the case of a variable number of beams, and the capability of accepting resolved objects (imaging mode, VIDA). The concept and lab results were described in a contribution to the ESO-EII Workshop (Garching, D, April 2005).

3.6 Obs. Bordeaux (F)

Main activity: Chromatic phase effects due to diffraction along an interferometer beam path [by G. Daigne]

3.6.1 Problem

Free-space beam propagation along the arms of long baseline optical interferometers undergoes diffraction effects, inducing coherence losses and supposedly interferometric phase perturbations. Diffraction losses have been studied by Horton et al. (MNRAS 327, 217 (2001)), with corrugated wavefronts at the entrance pupils, and various propagation path lengths and beam compression factors.
Perturbations on the interferometric phase have not been considered in this study, as it vanishes in closure phase imaging.
Although the interferometric phase is hardly an “observable” in long baseline optical interferometry, differential phase is certainly most useful for group delay tracking, for

differential astrometry, for co-phasing an interferometer, for color-differential phase measurements, ... Surprisingly enough, all simulations I know about have been performed as if free-space propagation of a (highly) compressed corrugated wavefront was not affecting the mutual coherence at the place where it is really measured, that is at the beam combination. A way to get rid of this effect, and not to have to deal with it, is to carefully re-image the entrance pupil onto the beam combination plate (for pupil plane combination).

In fact, a study on diffraction phase effects is needed, even in the VLTI context, supposed to re-image the entrance pupil with the Variable Curvature Mirror of the main Delay Line, the reasons being:

a) such a re-imaging facility is not yet operational on the VLTI,

b) even if some day operational, sensitivity of phase measurements to pupil offsettings has to be evaluated before implementing an adjustment technique or procedure,

c) more generally the investigation is useful in the design of long baseline optical interferometers with large apertures, and hence large beam compression factors.

3.6.2 Method

Wavefront propagation along a first order optical system (described by an ABCD matrix) is performed with the help of a Generalized Fresnel Transform. The input corrugated wavefronts are obtained from CAOS (Code for Adaptive Optics Systems) and propagated down the different optical systems of an interferometer arm with pupil re-imaging capabilities.

3.6.3 Results and future work

Different quantities have been evaluated in terms of output pupil offset (relative to the true position of the imaged pupil) , in the AT /VLTI context: coherence loss, chromatic phase perturbations, scintillations on the output pupil ...

Still to be evaluated: effects on the measured Group Delay (for astrometry measurements, cophasing ...).

3.7 MRAO

The MRAO group contributed to discussion of the CFT concepts and of the documents circulated within the mailing list. The study for a general purpose, multiple beam combiner with on-axis fringe sensing capability is described in a contribution to the ESO-EII Workshop (Garching, D, April 2005).

3.8 Status of the project

Activity on several of the tasks enlisted for WP1.2 has started; based on the current status of the activity in the various groups, the definition of the basic tasks of WP1.2 will be reassessed in the planned meeting in Cambridge on October, 2005.

4 Reference documents

4.1 Recent publications

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The LINC-NIRVANA Fringe and Flexure Tracking System: differential piston simulation and detection
Proc. SPIE 5491-167, 2004, in press

Bonino D., Gai M., Corcione L., Massone G.
Models for VLTI fringe sensor units: FINITO and PRIMA FSUs
Proc. SPIE 5491-168, 2004, in press

Borkowski V., Labeyrie A., Martinache F., Lardière O.
The dispersed speckles cophasing system for direct imaging with VIDA
Proc. ESO-EII Workshop on "The Power of Optical/IR Interferometry: Recent Scientific Results and 2nd Generation VLTI Instrumentation", Garching, Germany, 4-8 April 2005, in press

Borkowski V., Labeyrie A., Martinache F., Peterson D.
Sensitivity of a "dispersed-speckles" piston sensor for multi-aperture interferometers and hypertelescopes
2005, A&A vol. 429, pp.747

Borkowski V.
La methode "speckles disperses": mise en phase pour faire de l'imagerie directe avec des interferometres et des hypertelescopes.
2004, PhD Thesis, Obs. Haute-Provence

Borkowski V. et al.
2004, EAS Publications Series, Vol 12, pp.287-291

Buscher D., Baron F., Coyne J., Haniff C., Young J.
A photon-efficient multi-way combiner for the VLTI D. Buscher, F. Baron
Proc. ESO-EII Workshop on "The Power of Optical/IR Interferometry: Recent Scientific Results and 2nd Generation VLTI Instrumentation", Garching, Germany, 4-8 April 2005, in press

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The VLTI Fringe Sensors: FINITO and PRIMA FSU

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Gardiol D., Loreggia D., Mannu S., Mottini S., Perachino L., Gai M., Lattanzi M.G.
End-to-end opto-mechanical simulation for high precision global astrometry
Proc. SPIE 5497-51, 2004, 461.

Loreggia D., Gardiol D., Gai M., Lattanzi M.G., Busonero D.
Fizeau Interferometer for Global Astrometry in Space
2004, Applied Optics, Vol. 43, 4, p. 721

Loreggia D., Gardiol D., Gai M., Lattanzi M.G., Busonero D.
Fizeau Interferometry from Space: a challenging frontier in global astrometry
Proc. SPIE 5491-29, 2004, 255.

Martinache F.
2004, J. Opt. A: Pure Appl. Optics 6, pp.216-220

Ribak E.N., Perrin G., Lacour S.
Multiple beam combination for faint objects
SPIE 5491 1624-9, Ed. W. A. Traub, Glasgow (2004)

Ribak E.N.
Interferometry following adaptive optics
SPIE 5491 1154-9, Ed. W A Traub, Glasgow (2004)

Ribak E.N., Gai M., Gardiol D., Loreggia D. and Lipson S.G.
Multiple anamorphic beam combination
Proc. ESO-EII Workshop on "The Power of Optical/IR Interferometry: Recent Scientific Results and 2nd Generation VLTI Instrumentation", Garching, Germany, 4-8 April 2005, Ed A Richichi, in press.

Straubmeier C., Bertram T., Eckart A., Wang Y., Zealouk L., Herbst T., Andersen D., Ragazzoni R., Weigelt G.
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Proc. SPIE 5491-171, 2004, in press