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KICK-OFF MEETING - DESCRIPTION OF WP 1.2

ADVANCED INSTRUMENTS:
CO-PHASING AND FRINGE TRACKING

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CHANGE RECORD

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1.0	14/12/2003	Mario Gai	All
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	Added reference and reformatted based on JRA4 document template		

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1. Objectives of the work package

The sensitivity of interferometric instrumentation is critically based on the performance of cophasing and fringe tracking (CFT) sub-systems, because it is necessary to bring the telescope beams sufficiently close to the zero Optical Path Difference (OPD) condition to retain their coherence, and stabilise such situation against the evolution associated to atmospheric turbulence. The physical sources of disturbance are the same as those degrading the diffraction-limited performance of current large telescopes, so that different regions of the luminous wavefront from astrophysical sources are affected by random phase contributions, evolving with time. Therefore, on one side, interferometry needs adaptive optics (AO) as a pre-requisite, in order to achieve low residual wavefront errors on each beam; moreover, an additional level of control is required on the phase relation (piston) among beams.
Only when the disturbances induced by the environment (and instrument) are reduced to sufficiently low levels it is possible to exploit the astrophysical information encoded in the wavefront structure, i.e. the signature of the source structure. At this point, the interferometer is able to perform actual measurements at the resolution corresponding to an aperture of few tens to few hundred metres. The most appealing techniques applicable on the current generation of instruments, up to and including the PRIMA facility for the ESO VLTI, are (phase-referenced) imaging, high precision narrow angle astrometry, and nulling experiments; whilst the first two cases are most relevant also for next generation ground based instruments, the latter is primarily focused on the perspective of future space missions (e.g. GENIE for DARWIN).

The statistics driving AO instrumentation defines the potentiality and limitations of interferometers and beam combining instruments. Without fringe tracking, the integration time is limited to the coherence time of the atmosphere, i.e. from few ms in the near IR up to few hundred ms in the thermal IR (depending also upon observing conditions and measurement requirements). A CFT system able to retain stable observing conditions for periods of few minutes increases the integration time by several orders of magnitude, e.g. by a factor 1e4 scaling from 10 ms to 100 s; this results in an improvement on limiting magnitude, in given conditions, by five magnitudes, or, conversely, an improvement by a factor 100 in the visibility precision at given magnitude.
The key components of a CFT system, borrowing the VLTI nomenclature, are the Fringe Sensor Unit (FSU), the actuator of the control loop proper, often installed into the Delay Line (DL) system, and a device for selection of targets around the position of the selected reference source, 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 targeted measurement precision, restricting the set of available reference stars within the corresponding limiting magnitude, and the STS field of view (also limited by the natural angular extension of correlated atmospheric turbulence).
The current CFT instruments are basically adequate for the present scientific instruments, and for some extension of their concept and architecture. Besides, 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. Combinations of six to eight telescopes will require construction of a new CFT device. Besides, 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, but the aspects of coherencing (i.e. long range cophasing, required for initial fringe acquisition) might be less easily manageable.

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 or new detectors (as spectrally-resolved superconducting devices in the near IR), may provide significant benefits on performance for future instruments; their characteristics can be included in detailed CFT simulations as soon as the specific technologic advancements are achieved, yielding definite device parameters, and the specific needs of new instruments are defined.
However, due to current limitations on manpower and budget, an extensive development campaign does not appear to be a practical approach in the immediate future.
In our opinion, the best usage of the available resources lies in the optimisation of current (and near future, e.g. PRIMA) instrumentation and consolidation of the design for the new instruments.

The main objectives of WP1.2 are currently identified as follows:
1) Optimisation of current cophasing instrumentation performance;
2) Optimisation of measurement operations;
3) Cophasing schemes for advanced instruments (multi-beam, LBT, ...);

The first two tasks 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.

Task 1 arises from the potential performance gain achievable by 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 optimised for the particular operating conditions of large facilities (e.g. VLTI, LBT) will improve the co-phasing ability beyond those of the current adaptations from small-aperture interferometers. 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 with respect to Fizeau interferometry and to 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.
Also, it is possible to identify a number of areas in which current CFT equipment may benefit from technology studies and prototypes, to investigate specific upgrade paths to the benefit of all current interferometric instrumentation. This represents a link with task C of WP1.1.

Task 2 extends beyond the fringe tracking loop, to address the whole measurement chain, for example aiming at identification of optimal observation and calibration sequences, analysing the measurement sensitivity to a range of environmental and instrumental limitations (e.g. temperature distribution within the optical train, longitudinal dispersion effects at large zenithal angles, etc.).
An immediate impact can be expected on the astrometry configuration of the VLTI PRIMA facility. Also, this has strict relations with the Networking Activity, in the sense of providing support to interferometry users on the CFT aspects, through the dissemination mechanisms foreseen in the JRP.

Task 3 extends the modelling of current fringe tracking systems, implemented in tasks 1 and 2, to the concept studies developed within WP1.1, towards which strict interaction is required.
The list of projects proposed throughout the development of the EII proposal includes specifically CFT only in some of the items. However, many of them require specific CFT studies to investigate compatibility with current equipment and/or upgrade requirements.
The extreme cases are:

(a) the new instrument concept is intrinsically compatible with current CFT devices (e.g. PRIMA); in this case, the CFT analysis is already part of tasks 1 and 2. Direct participation of representatives from the instrument team into WP1.2 is useful, but not mandatory *(under the assumption that internal information circulation works appropriately, which is a task of the management)*.

(b) the new instrument concept has requirement beyond the current CFT devices (e.g. 6-8+ beam combiners); then, CFT concepts and models require specific development. Direct participation of representatives from the instrument team into WP1.2 is mandatory, to ensure proper understanding of requirements and feasibility of solutions. Alternatively, the CFT issue might be investigated under the total responsibility of the instrument team, if the project peculiarity appears to be best fulfilled with such solution. Then, at least for reasons of clear interfaces towards the funding agency, it is recommended that the CFT issue is clearly identified and documented in the reports.

A number of combinations between (a) and (b) are possible, and might be identified according to needs on a case by case approach. Also, the needs associated to tasks A and B of WP1.1 are potentially different, and their support from WP1.2 shall be agreed upon in the same way.
It is recommended to identify such needs, as far as possible, at kick-off; subsequent modifications, either due to evolution of the design or other new conditions, shall be resolved at the level of the Board / Extended Board.

Here follows a tentative list of study areas which might be allocated among the above three tasks of WP1.2:

a) Analysis of performance of current fringe tracking systems
b) Fringe sensors hardware improvements
c) High sensitivity operation
d) Fringe sensors detection schemes
e) OPD measurement filtering
f) High precision astrometric calibration
g) Baseline and wavelength bootstrap
h) Multi-beam fringe sensor concept
i) Identification of technology development requirements
j) Analysis of applicability of advanced detector (e.g. NIR STJ)
k) Analysis of applicability of integrated optics (in bands J, K, ...)

(to be completed and detailed)

2. Participants and budget

The effort of Torino is clear: most of the manpower and all EU funds are focused on WP1.2.
All participations are welcome.
A call for interest will be circulated prior to kick-off, together with this draft WP1.2 guidelines.

3. Current list of projects

From the list in of D. Mourard (*), in DefWP1_1.pdf, the interests expressed during the definition of the EII proposal are the following:

Project	PI	Collaborators
Fringe concepts and technologies tracking	G. Rousset ONERA	
Advanced fringe sensors based on TES, KID or STJ	A. Quirrenbach NOVA	SRON Utrecht, NOVA, …
Fringe tracking beam combiners	C. Haniff Univ. Cambridge	
Multibeam Fringe sensor and combiner for the VLTI	M. Gai INAF-OATo	

(*): I did not check, since in any case a general call for interest seems to be in order. Thanks to Denis for his previous effort in building up and providing the list.

4. Future work for implementation of WP1.2

Ask for contributions to study areas
Ask for interest in active participation OR info (mailing list / discussion forum)

Definition of EU deliverables:
Reports on specific study areas

Internal activity monitoring and organization:
Reports from contributing groups and individual participants (each 6 months?)

Meetings - Board level + among group representatives, depending on organization and needs

5. Remark

This note is at the level of a working draft. I will take care of correction of errors and omissions.