AMBER, the Near-Infrared / Red VLTI Focal Instrument

R.G. PETROV [1], F. MALBET [2], A. RICHICHI [3], K.-H. HOFMANN [4]

[1]*Université de Nice – Sophia Antipolis, and Département Fresnel, Observatoire de la Côte d'Azur, France (OCA)*
[2]*Laboratoire d'Astrophysique, Observatoire de Grenoble, France (LAOG)*
[3]*Osservatorio Astrofisico di Arcetri, Italy (OAA)*
[4]*Max-Planck-Institut für Radioastronomie, Germany (MPIfR)*

Abstract

The near-infrared / red focal instrument of the VLTI, called AMBER, will operate between 1 and 2.5 µm in a first phase (2001–2003) with two UTs. This instrument has been designed for three beams to be able to perform images through phase closure techniques. The wavelength coverage will be extended in a second phase down to 0.6 µm at the time the ATs become operational. The magnitude limit of AMBER is expected to reach $K = 20$ when a bright reference star is available and $K = 14$ otherwise. The main scientific objectives are the investigation at very high angular resolution of disks and jets around young stellar objects and AGN dust tori with a spectral resolution up to 10,000.

1. Introduction

The interferometric mode of the VLT (VLTI) has always been present in the VLT project. In the last *Messenger* issue (No. 91, March 1998), the ESO Director General, Riccardo Giacconi, has presented the role of ESO in European Astronomy by stressing the important and unique scientific contribution expected from the VLTI. The VLTI implementation plan has been reviewed in 1995–1996 by ISAC, the Interferometry Science Advisory Committee, who gave its recommendation to the ESO community in *The Messenger* No. 83 (March 1996). The committee recommended early operations of the VLTI as well as a phased development that would focus in the infrared wavelength range (1–20 µm). A new plan has then been proposed by the ESO VLTI team with an updated timetable: operations with two 8-m unit telescopes (UTs) before the end of 2000, with two 1.8-m auxiliary telescopes (ATs) before the end of 2002 and the full complement of 4 UTs and 3 ATs starting in 2003. In 1997, three instruments were proposed:

• AMBER, Astronomical Multi BEam combineR: a near infrared / red instrument (0.6–2.5 µm). At this time, AMBER included adaptive optics.

• MIDI, MID-infrared Interferometric instrument: a thermal infrared instrument (10–20 µm).

• PRIMA, Phase Referencing Imaging and Micro-arcsecond Astrometry: an instrument based on the simultaneous operation of two fields.

On 14 April 1998, the VLTI Steering Committee recommended that ESO take the lead to deliver a dual field and stabilised beams (adaptive optics and fringe tracking), in order to boost the performance of AMBER and MIDI, as early as in 2001, much earlier than expected in the first version of the instrumentation plan.

AMBER intends to combine the main advantages of the interferometric instruments for which Europe has acquired experience: the FLUOR instrument [1, 2] and the GIST interferometer [6].

This paper presents a preliminary report on AMBER, where we detail the science drivers, the concept, the expected performance and the overall project organisation. The work presented here is the result of two preliminary working groups [4, 5] in addition to the AMBER present group [7].

2. Science Objectives

Of course, a major role in the science operation of AMBER will be played by the limiting magnitude that the system will permit (see Section 4). With such sensitivities, there is a wealth of scientific issues that AMBER will allow us to tackle. Within the project, it has been decided that, at least at an initial phase, the instrument should be dedicated to relatively few topics. An investigation based on criteria of feasibility on one side, and strong interest in the scientific community on the other side, has resulted in a few selected areas which are listed, with a list of typical parameters, in Table 1.

It is important to note that AMBER will allow us in principle to cover a wide range of scientific objectives including:

• the search of hot exoplanets
• the formation and evolution of stars
• extragalactic studies

which will be our first scientific targets. A detailed description of the scientific rationale cannot be given in full here, but the reader is referred for instance to the proceedings of the workshops organised by ESO (*Science with the VLT,* Walsh and Danziger eds.; and *Science with the VLT Interferometer,* Paresce ed.).

3. Preliminary Optical Layout

Figure 1 shows a possible optical layout of AMBER which is mainly intended to illustrate the functions of the different modules of the instrument. Three parts must be distinguished. Firstly, each beam is processed independently (1–4 in the figure); then they are combined (5–8); and finally a spectrograph and a detector (9–13) analyse the combination focus. The figure represents a layout for three telescopes.

The incoming beams have their wavefronts corrected by low-mode adaptive optics modules provided by ESO for the UTs and by the AMBER consortium for visible wavelengths. The expected Strehl

TABLE 1: Scientific characteristics for AMBER

Target	Visibility Accuracy	Minimum *K* magnitude	Wavelength coverage	Spectral resolution	Polarisation useful	3 beams useful	Wide-field useful
Exozodi / Hot exoplanets	10^{-4}	5	*K*	50	N	N	Y / N
Star-forming regions	10^{-2}	7	*JHK*+lines	1000	Y	Y	Y
AGN dust tori	10^{-2}	11	*K*	50	Y	Y	Y
Circumstellar matter	10^{-2}	4	*JHK*+lines	1000	Y	Y	Y
Binaries	10^{-2}	4	*K*	50	N	N	Y
Stellar structure	10^{-4}	1	lines	10000	N	Y	N

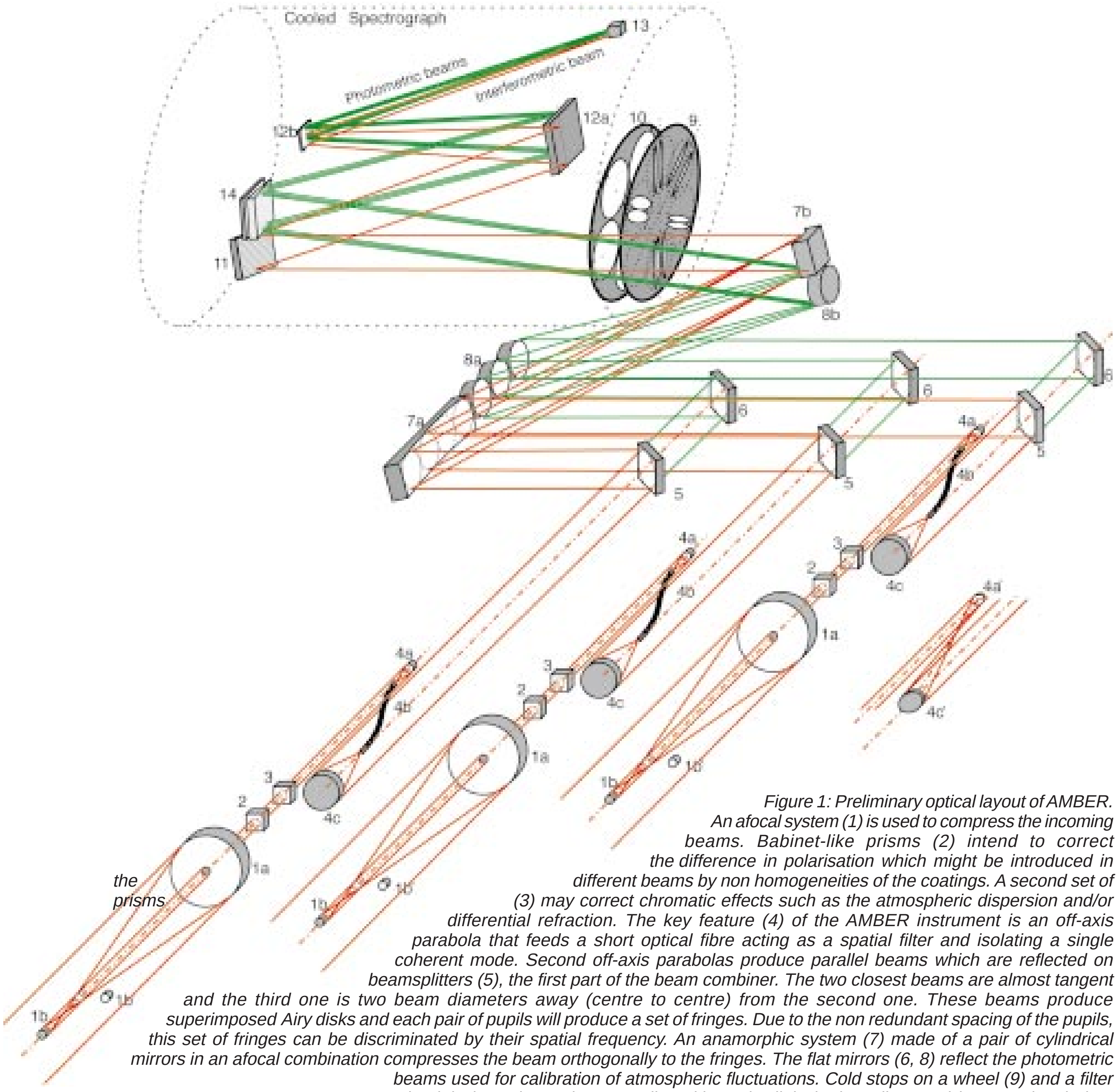


Figure 1: Preliminary optical layout of AMBER. An afocal system (1) is used to compress the incoming beams. Babinet-like prisms (2) intend to correct the difference in polarisation which might be introduced in different beams by non homogeneities of the coatings. A second set of (3) may correct chromatic effects such as the atmospheric dispersion and/or differential refraction. The key feature (4) of the AMBER instrument is an off-axis parabola that feeds a short optical fibre acting as a spatial filter and isolating a single coherent mode. Second off-axis parabolas produce parallel beams which are reflected on beamsplitters (5), the first part of the beam combiner. The two closest beams are almost tangent and the third one is two beam diameters away (centre to centre) from the second one. These beams produce superimposed Airy disks and each pair of pupils will produce a set of fringes. Due to the non redundant spacing of the pupils, this set of fringes can be discriminated by their spatial frequency. An anamorphic system (7) made of a pair of cylindrical mirrors in an afocal combination compresses the beam orthogonally to the fringes. The flat mirrors (6, 8) reflect the photometric beams used for calibration of atmospheric fluctuations. Cold stops on a wheel (9) and a filter wheel (10) are located at a pupil position. The light is then dispersed by a grating (11). A compact spectrograph design requires two chamber mirrors (12). The detector (13) will probably be 1024 × 1024 HAWAII Rockwell array. With three telescopes, the fringes are analysed within a strip of 12 × n pixels, where n is the number of spectral channels (n > 1024). The photometric beams are slightly dispersed by a fixed prism (14) to take into account the chromatic variations of the Strehl ratio and the spatial filter efficiency. For some objects, we plan to use the 2″ non-vignetted field available in the VLTI laboratory. This is achieved by replacing the spatial filter unit by an afocal system without spatial filter (4a′, 4c′) which maintains the direction of the output beam but divides its diameter by two. The figure roughly respects the proportion between the elements. The size of the spectrograph is 45 cm × 30 cm.

ratio should reach 0.5 for the Unit Telescopes in the *K* band and should remain as high as 0.25 for reference stars of magnitude $V \approx 15$. The optical path differences between the beams are compensated by an ESO fringe tracker. Thanks to the dual field, wavefront correction and fringe stabilisation can be performed on a star up to 25 arcseconds away from the scientific target.

The compressed pupil after the cylindrical optics has the same shape whatever the number of telescopes. We plan to use the same spectrograph and detector in all cases. Therefore, increasing the number of telescopes from two to three, and then to four, requires only the addition of one incoming beam with the corresponding optics and the modification of the anamorphic system without changing anything in the already existing beams.

The effect of the spatial filter is to reduce the wavefront perturbations to a flux variation in the fibre [3]. If these photometric fluctuations are measured with a good precision, and if the fringe exposure times are short enough, then the fringe visibility can be measured with no experimental bias as has been demonstrated by the FLUOR experiment. The spatial filter and the photometric calibration are therefore necessary to measure visibilities with extremely high accuracy (our ambitious target is 10^{-4}) on relatively bright sources (up to $K \approx 9$). With the spatial filter, the instrument has a field limited by the size of the Airy disk of the individual telescopes.

4. Expected Performances

At this stage of the project, this parameter is still subject to several uncertain-

TABLE 2: Expected limiting magnitude for two UTs (left) and two ATs (right). See text for details.

	Two UTs			
Fringe accuracy	$\lambda/4$		$\lambda/40$	
Self-reference	14		9.7	
Spectral resolution	Broad-band	100	1000	10000
Off-axis reference	20.7	17.7	15.2	12.7

	Two ATs			
Fringe accuracy	$\lambda/4$		$\lambda/40$	
Self-reference	11.3		7	
Spectral resolution	Broad-band	100	1000	10000
Off-axis reference	18	15	12.5	10

ties linked to exact specifications of optics throughput, detector and electronics characteristics, as well as fringe tracker and adaptive optics performance. At present (see Table 2), we estimate that AMBER coupled to the VLT UT telescopes should allow us to reach, when a bright star reference is available, $K \lesssim 20$ in broad band and $K \lesssim 15$ at a resolution of 1000. When the interferometer uses the object as a reference, the limiting magnitude is rather $K \lesssim 14$. At the 1.8-m AT telescopes these limits drop by about 2.7 mag.

The upper half of Table 2 gives the limiting magnitudes of AMBER when the instrument detects fringes on the scientific source (self-reference mode). These numbers would also be the limits for the fringe sensor (for example the ESO/OCA Prototype Fringe Sensor Unit equipped with PICNIC detector with 18 electrons read out noise, Rabbia et al., 1996). In this mode, AMBER can detect fringes with $\lambda/4$ accuracy on stars up to $K = 14$ with 25-ms exposure time. For stars brighter than $K = 9.7$, the fringes can be detected at $\lambda/40$ accuracy with 4-ms exposure time. In this self-referencing mode, the limiting magnitudes are valid for all spectral resolutions.

The dual field allows for off-axis reference stars. The limiting magnitude for these references are the same as the ones quoted above. The lower half of Table 2 gives the limiting magnitudes on the science object in order to reach a 1% visibility accuracy within 4 hours of observation sliced into 100-second individual exposures.

These numbers are given for poorly resolved objects producing maximum fringe contrast in the fringe sensing spectral band. A 0.1 object visibility would lead to a 2.5 mag penalty.

5. Organisation

5.1 Institutes involved

The AMBER consortium is composed of four institutes:

• Laboratoire d'Astrophysique, Observatoire de Grenoble (LAOG, France).

• Observatoire de la Côte d'Azur (OCA, France)

• Osservatorio Astrofisico di Arcetri in Firenze (OAA, Italy)

• Max-Planck-Institut für Radioastronomie in Bonn (MPIfR, Germany).

Other institutes provide expert scientists or engineers but do not build or integrate hardware. They are:

• Institut de Recherche en Communications Optiques et Microondes in Limoges (IRCOM, France)

• Université de Nice – Sophia Antipolis (France)

• Office National d'Études et de Recherches Aerospatiales in Paris (ONERA, France),

• Centre de Recherche Astronomique de Lyon (CRAL, France).

5.2 Project structure

The AMBER project includes a principal investigator (PI: R. Petrov OCA), a project scientist (PS: F. Malbet LAOG), a chairman of the science group (SGC: A. Richichi OAA), a project manager (PM: P. Kern LAOG), a system engineer (SE: S. Ménardi OCA) and a co-investigator (CoI: K.-H. Hofmann MPIfR). AMBER has been divided in a set of working groups, each one in charge of one AMBER subsystem.

In addition to the ESO ISAC (Interferometry Science Advisory Committee), there is a science group for each VLTI instrument with the task of identifying and prioritising the key targets in order to maximise the scientific return of the instrument, especially during early operations. In the case of AMBER, the science group (SGR) includes scientists working on star formation, galaxies, AGN, exoplanets, low-mass stars, AGB stars, Be stars and circumstellar medium. The project scientist (PS) is in charge of translating the scientific needs in terms of instrument specifications. He is helped by an interferometry group (IGR), for interferometry offers a large range of observing modes and procedures, whose priorities must be analysed and specified by specialists.

The subsystem working groups of the AMBER instrument are:

• Optomechanics

• Cooled spectrograph

• Detector and associated electronics

• Instrument control (VLTI interface included)

• Observations support (observation preparation, data reduction)

• Testing, integrating equipment and performance tests.

5.3 Budget

Many elements still have to be defined in the present system definition phase. Therefore, the final budget cannot be completely defined before the Preliminary Design Review (PDR) in November 1998. The estimated final budget for the hardware of the infrared part of AMBER for two beams (phase 1) is 4 MF ±10%. Extension to three beams and to visible wavelengths (phase 2) require additionally 4 MF ±30% including the adaptive optics modules for two ATs (1 MF each).

The preliminary and still approximate general timetable combines the planning for each subsystem and integrates them in a general planning with the following important dates:

• July 1998: Full definition of the project (Final Concept Review). Problems have been identified and a concept has been selected.

• November 1998: Preliminary Design Review. Problems have been solved, detailed system analysis is finished. All interfaces are analysed. Precise timetable is known.

• April 1999: Final Design Review. All orders can be issued.

• July 2000: Manufacturing and Integration Review. All subsystems have been integrated and tested and it is possible to start the global integration and tests.

• December 2000: Shipment to Paranal where, after 3 months of laboratory and siderostat tests on site, we expect to start observations.

• April 2001: Observations with the UTs.

Note:

The AMBER documentation is available on the following Web site:

http: //www-laog. obs.ujf-grenoble.fr/amber

References

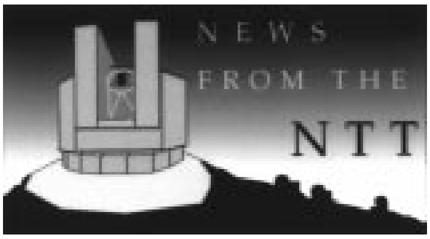
[1] Coudé du Foresto V., Ridgway S. 1991, FLUOR: a Stellar Interferometer Using Single-Mode Infrared Fibers. In: Beckers J., Merkle F. (eds.) Proc. ESO Conf., *High-resolution imaging by interferometry II*. ESO, Garching, 731.

[2] Coudé du Foresto V., Perrin G., Mariotti J.-M., Lacasse M., Traub W. 1996, The FLUOR/IOTA Fiber Stellar Interferometer. In: Kern P., Malbet F. (eds) Proc. AstroFib'96, *Integrated Optics for Astronomical Interferometry*. Bastianelli-Guirimand, Grenoble, p. 115.

[3] Coudé du Foresto V. 1996, Fringe Benefits: the Spatial Filtering Advantages of Single-

Mode Fibers. In: Kern P., Malbet F. (eds) Proc. AstroFib'96, *Integrated Optics for Astronomical Interferometry.* Bastianelli-Guirimand, Grenoble, p. 27.
[4] Malbet F., Coudé du Foresto V., Mékarnia D., Petrov R., Reynaud F., Tallon M. 1997a, *Étude préliminaire de l'instrument proche-infrarouge / rouge du VLTI et de GI2T*, available on the AMBER Web (AMB-REP-001).
[5] Malbet F., Perrin G., Petrov R., Richichi A., Schöller M. 1997b, *AMBER Report 2 – The imaging and spectroscopic VLTI focal instrument,* available on the AMBER Web (AMB-REP-002).
[6] Mourard D., Tallon-Bosc I., Blazit A., Bonneau D., Merlin G., Morand F., Vakili F., Labeyrie A. 1994, *A&AS* **283**, 705.
[7] Petrov R., Malbet F., Antonelli P., Feautrier Ph., Gennari S., Kern P., Lisi F., Monin J.-L., Mouillet D., Puget P., Richichi A., Rousset G. 1998, *AMBER, The near infrared / red VLTI focal instrument,* Report for the Steering Committee meeting, 30 January 1998. Available on the AMBER Web (AMB-REP-003).
[8] Rabbia Y., Ménardi S., Reynaud F., Delage L. 1996, The ESO-VLTI Fringe Sensor. In: Kern P., Malbet F. (eds) Proc. AstroFib'96, *Integrated Optics for Astronomical Interferometry.* Bastianelli-Guirimand, Grenoble, p. 175.

F. Malbet
Fabien.Malbet@obs.ujf-grenoble.fr



NEWS FROM THE NTT

G. MATHYS, ESO

The NTT Upgrade Project has come to an end at the end of March. Over the past 4 years, the readers of this column have been able to follow the progress of this project through its three distinct phases: the stabilisation of the operations of the NTT, the installation at the NTT of the VLT control system, and the use of this refurbished facility for scientific observations within the framework of the VLT operational model (see *The Messenger* Nos. 75 to 91). The upgrade project has fulfilled its objectives of strengthening the NTT as a world leading 4-metre-class telescope and of using it as a testbench for the technical and operational concepts and solutions adopted for the VLT, prior to the entry of its first unit telescope into operations. With consideration for the latter objective, the NTT Upgrade Project has been conducted under the overall responsibility of the ESO VLT Division (but with important resources of other divisions, in particular the La Silla Division). Now that the project is completed, quite naturally, NTT operation has come back since the beginning of Period 61 under the responsibility of the La Silla Division, like all the other ESO telescopes on La Silla.

The end of the NTT Upgrade Project also marks the end of the present series of dedicated articles presenting "News from the NTT", or more specifically, news from the upgrade project: this note is the last one of this series. From the next issue of *The Messenger* on, in line with the above-mentioned reassignment of the responsibilities, information about the NTT will be reintegrated in "The La Silla News Page". The author of these lines will, as a matter of fact, have left the NTT to move to the Paranal Observatory and to participate in the preparation of the operations of UT1. He will be replaced, in his function of NTT Team Leader, by Olivier Hainaut, who has recently joined the NTT Team (see below).

The end of the Upgrade Project

The NTT News published in the last issue of *The Messenger* had been written between the installation and the commissioning of SUSI2. The latter was completed at the end of February, in spite of adverse weather conditions, and a brief report was given in a dedicated article by S. D'Odorico in the previous issue of *The Messenger.*

Bad weather also severely hampered the SOFI commissioning period, in March. In spite of the limited amount of astronomical observations that could be carried out during the latter, its outcome was very positive, with the successful implementation of a number of new features:

– an ATM connection between the Local Control Unit (LCU) of the detector and the instrument control and acquisition workstation *(wsofi).* The use of such a connection in a real-time operational environment is a première at ESO. Until now, at the NTT as well as at the other telescopes on La Silla, data read out from the detectors were transferred to the acquisition computers through an Ethernet link. For its installation at the NTT in December, SOFI also was initially configured in this way. However, with the most recent increases of instrument performance in terms of detector array size and readout speed, Ethernet becomes a bottleneck for the achievable rate of data acquisition (both for the IR and for the visible: SUSI2 also suffers from this). In order to overcome this limitation, the option retained by ESO for new instruments (and existing instrument upgrades) is the replacement of Ethernet by ATM. SOFI is the first instrument to benefit from this new technology. The success of its implementation is a major step for the future of the ESO observatories, as it paves the way for other instruments on La Silla (in particular, the Wide Field Imager and SUSI2) and on Paranal.

– a new version of the Phase 2 Proposal Preparation (P2PP) tool, which supports the preparation of Observation Blocks for SOFI (in addition to EMMI and SUSI2, which were already supported before).

– an on-line reduction pipeline for imaging, through which, in particular, large sets of dithered images can be automatically combined in a very effective manner, taking away a large fraction of the burden typically affecting IR observers. SOFI is the first instrument to come on line which has been designed from the start for use within an end-to-end data flow context: thanks to this, it has been possible to develop for it powerful and effective automatic reduction tools which are far superior to those that could up to now be offered for conceptually older-fashioned instruments such as EMMI.

On the other hand, the end of the Upgrade Project has also marked the end (or, at least, the temporary suspension) of the Service Observing experiment at the NTT. The outcome of the latter and the lessons that can be drawn from it are reported in a separate dedicated article in this issue of *The Messenger.* Here, it should just be pointed out that, in spite of a number of shortcomings and weaknesses in what was primarily a learning period for both ESO and the astronomical community, Service Observing at the NTT has been quite favourably perceived by ESO users, to the extent that ESO has been urged by various of its advisory committees to consider the possibility to keep offering this option at the NTT (and possibly to develop it at other La Silla telescopes)