ASPRO-VLTI: a JMMC software dedicated to the preparation of VLTI observations

Gaspard Duchêne[a], Jean-Philippe Berger[a], Gilles Duvert[a], Gérard Zins[a] & Guillaume Mella[a]

[a]Laboratoire d'Astrophysique - Observatoire de Grenoble - BP 53 - 38041 Grenoble Cedex 9 - FRANCE

ABSTRACT

We present ASPRO-VLTI, the newly developed JMMC software that will allow astronomers to prepare observations with both first-generation VLTI instruments, AMBER and MIDI. This software has been specifically designed to hide as much as possible instrument complexity and should permit to focus primarily on the science objectives. The targeted users are all astronomers interested in observing with VLTI but with limited interferometric background. It should be particularly well suited for the preparation of ESO-VLTI Phase I proposals. The user can define its target model, choose observational parameters and check if the observations will match its scientific goals. Output quantities and plots can be used for observation proposals.

Keywords: VLTI - software - JMMC

1. INTRODUCTION

Long-baseline optical interferometers have been in use and have produced ground-breaking results for several years now, as illustrated in many contributions in this volume. Because these first arrays (CHARA, COAST, GI2T, IOTA, NPOI, PTI) have been limited to small-sized telescopes, observations were limited to relatively bright sources so far. The recent advent of arrays of 8–10 m telescopes (VLTI, Keck Interferometer) now opens an entirely new window of opportunity for optical interferometers in which the number of potential targets will increase by several orders of magnitudes, including many extragalactic objects. This sensitivity leap is such that interferometry will very likely become, in the next few years, a widely used and extremely powerful observational mode.

However, the broad communities that have now access to optical interferometers are mostly constituted of astronomers who are not familiar with the technical details associated with this type of observations. While optical interferometry could provide crucial observations for a wide variety of astrophysical problems, very few astronomers ("experts") are currently able to envision, prepare, conduct and analyze interferometric observations due to their intrinsic complexity. The optical interferometry community is now faced with the critical task of producing tools to promote and ease the use of these interferometers so that many "non-expert" astronomers can use the full potential of these instruments. In particular, this task includes developing softwares to prepare, reduce and/or analyze interferometric observations.

In 2000, the Jean-Marie Mariotti Center (JMMC[1]), led by the Observatoire des Sciences de l'Univers de Grenoble and the Observatoire de la Côte d'Azur, was created in France by the Institut National des Sciences de l'Univers in order to bring together the extensive interferometric experience of French astronomers. One of the main goals of JMMC is to produce and distribute the softwares necessary for a wide astronomical community to take full advantage of long-baseline interferometers, particularly of VLTI, as well as to provide a support service to their users.

JMMC has already created a software to help astronomers prepare a wide range of interferometric observations: ASPRO,[2] the Astronomical Software for PrepaRing Observations. This software allows to simulate observations with many optical interferometers, not just VLTI. Users can describe their target with simple geometric models, for which visibilities are calculated following the (u, v) sampling specified by the choice of array. Model fitting on the calculated visibilities allow the user to estimate the quantitative constraints observations would place on a specific model. This software is useful, for instance, to select which interferometer is best suited to achieve a given scientific goal, and it also allows experts to fine tune many details of the technical set-up.

Due to its generality (the same formalism applies to all interferometers) and its relatively high level of details, the use of ASPRO is not optimal for very specific interferometers (e.g., the subset of VLTI offered by ESO for a given observing Period) and/or for non-expert astronomers.

On VLTI, ESO now routinely operates the mid-infrared instrument MIDI[3] and will soon publish the first call for proposal to the general community on the near-infrared instrument AMBER,[4] which has very recently obtained its first fringes on astronomical targets. Over the next few semesters, the use of these instruments will increase dramatically, particularly when the Auxiliary Telescopes of VLTI are installed, and a wide community, including non-experts, will be willing to use them. JMMC has therefore decided to develop a VLTI-specific version of ASPRO, nicknamed ASPRO-VLTI, in order to help all astronomers prepare their AMBER and MIDI proposals and observations. This software, which will be maintained up-to-date with ESO announcements, will only allow the user to make array/instrument choices that are supported by ESO, hide as much as possible of the high-level technical details by setting many parameters to default values, and provide exportable outputs (tables and plots) to be used while preparing observing proposals. The first version of ASPRO-VLTI will be released at the end of the summer, in time for the next call for proposal from ESO.

This paper describes some general properties of ASPRO-VLTI (§ 2), its various modules (§ 3), the outputs it will provide the user with (§ 4) and the support services that will be provided by JMMC to help ASPRO-VLTI users (§ 5).

2. BASIC PROPERTIES OF ASPRO-VLTI

ASPRO-VLTI is a software that simulates proposed observations of a modeled astronomical object with VLTI and its first-generation instruments, AMBER and MIDI. Its main outputs consist in visibility and closure phase (for AMBER) measurements sampling the (u, v) plane according to the selected array configuration and time coverage of the source. ASPRO-VLTI also allows to adjust models on these simulated visibilities and closure phases.

ASPRO-VLTI is primarily intended for users who are not experts in long baseline optical interferometry but are trying to prepare an observing program with VLTI. Consequently, as much as possible of the technical details of the interferometer will not be asked from the user, many parameters being set to default values appropriate for most projects. However, ASPRO-VLTI can also be valuable to expert interferometrists whose VLTI programs are relatively straightforward and do not require a fine level of details. For more advanced observing preparation tests, experts should use ASPRO.

ASPRO-VLTI will first and foremost be a web-based tool that can be accessed through the main webpage of JMMC (`http://mariotti.ujf-grenoble.fr/`). This will allow for transparent upgrades of the software since the user will not need to download a newer version every time. More and more choices will simply become available without changes in the appearance of the software. An additional portable version of ASPRO-VLTI, that could be installed on a variety of common operating systems, may also be developed in the future.

A critical aspect of ASPRO-VLTI is that it will be maintained up-to-date with the sets of choices officially offered to the community by ESO for a given observing Period (available VLTI stations, resolution modes for the instruments, ...), as well as with on-sky measured sensitivities for both instruments as they become available. Realistic observing overheads, as set by ESO and by practical experience, will also be incorporated in ASPRO-VLTI.

Most importantly, ASPRO-VLTI will be a science-oriented software. This means that the user will start using the software with a specific problem (an object and its possible model to be tested) in mind and with the goals of i) determining which VLTI array/instrument set-ups allow the observation of his target, ii) deciding which of them (if any) are actually useful in constraining this problem, and iii) quantitatively predicting how constraining the proposed observations would be. Therefore, after using ASPRO-VLTI, the user can easily decide whether his program should be conducted and, if so, use robust quantitative arguments to justify such observations.

3. GENERAL DESCRIPTION OF ASPRO-VLTI

In short, ASPRO-VLTI will successively ask the user to define the astronomical target (coordinates, brightness, model of its structure), select the desired instrument and VLTI configuration and define the observing conditions (e.g., time coverage). A series of consistency checks regarding the sensitivity and observability of the source will then be performed. If a problem is identified at this stage, the user will be advised or requested, depending on the seriousness of the issue, to make some changes in his choices. If (or once) the user's choices are considered satisfying, the (u, v) coverage of the object will be calculated and the visibilities and closure phases estimated at each sampled spatial frequency. A realistic signal-to-noise calculator that includes a treatment of the visibility calibrator will be used to estimate uncertainties. Finally, model fitting options will be available. In the following, we briefly describe the main features of each of these modules.

3.1. Target definition

Before choosing an instrumental set-up and simulating observations, the user will first describe the object he is interested in getting interferometric data on. A target is first defined by its name, celestial coordinates and its brightness (in the visible for acquisition/guiding and in the infrared for the interferometric measurements). ASPRO-VLTI will offer the option of searching web-based databases, such as Simbad, to retrieve the object's coordinates and brightness.

The second part of the object's definition consists in assigning a geometrical structure to it, usually inferred from other observations. In ASPRO-VLTI, it will be possible to define the object's model in two ways. First, the model can be defined as one or the sum of two analytical model(s) that span a wide variety of structures (point sources, uniform and limb-darkened disks, elliptical gaussian profiles, power-law surface brightness distributions, binary systems, ...). Each analytical model can be defined by a small number of parameters, including their relative position and fraction of the total flux.

The other option for specifying the object's structure is to download an homemade model as a FITS file. With this second option, the observation of any astrophysical object can be simulated with ASPRO-VLTI, even if it is not possible to represent it by a simple analytical model.

The goal of the simulated VLTI observations is to constrain quantitatively the parameters of the model describing the object (if the model is analytical) and/or to test whether significant visibility and closure phase changes as function of time, baseline orientation or projected baseline can be measured with VLTI.

3.2. Observational set-up

The second step in defining the observations consists in specifying the requested instrument, spectral resolution and operating wavelength. In most cases, all of these parameters will be largely dictated by the goal of the observations.

One of the most important part of the instrumental set-up is the array configuration. Depending on the instrument, choices between Unit and Auxiliary Telescopes and between two or three interferometric beams have to be made. Then the individual VLTI stations have to be selected. This selection process, which will be facilitated by a graphical representation of the array, will offer only ESO-supported configurations. To help users who are not familiar with the handling of baselines in the (u, v) plane, it will be possible to visualize a representative point spread function corresponding to the requested array configuration and object's coordinates.

Finally, the date and, most importantly, the time coverage (expressed in hour angle before and after the object's transit) of the observations to be simulated must be specified. This will conclude the information-gathering section of ASPRO-VLTI since, at this stage, all calculations can be performed without additional input from the user.

3.3. Feasibility tests

Before getting to the actual observation-simulating stage, ASPRO-VLTI will run a number of simple checks of the consistency and feasibility of the observations. In particular, the brightness of the object will be checked against the actual sensitivity of the instrument in the requested mode. Also, the observability (which may be limited among other things by the capacity of the delay lines to track down the object in some 3-telescope configurations) of the object throughout the selected hour angle range will be checked. The risk of vignetting of the Auxiliary Telescopes by the dome of the Unit Telescopes will also be evaluated.

3.4. Simulation of the observations

If ASPRO-VLTI ascertains that the observations are technically feasible, it will then simulate them. Basically, the model of the object will be transposed in the (u, v) plane, where visibilities and closure phases for each individual spatial frequency can be readily calculated. This will be repeated for each independent measurement and plots of both measurable quantities will be created (see § 4).

Along with the visibilities and closure phases values, ASPRO-VLTI will provide the user with estimates of the uncertainties. These will be determined as the combination of two sources of error: the instrumental sensitivity to the target and a calibrator-induced uncertainties. In many cases, the latter will be comparable to or larger than the former. The instrumental sensitivity will be set to the values determined from actual VLTI observations. The calibrations uncertainties will be defined either as a statistical estimate based on the target's coordinates and brightness or as the result of a specific search engine that will browse databases for adequate calibrators.

Even before adjusting models to the simulated observations, a number of conclusions will be available to the user at this stage: non-unity visibilities confirm that the object is spatially resolved by VLTI, non-zero closure phases reveal that the object is not point-symmetric at the VLTI resolution, and significant changes in visibilities and/or closure phases as a function of time/baseline show that the proposed observations offer the possibility to constrain the object's model. If none of these phenomena occurs, it is unlikely that the proposed observations are useful to the user's scientific goals.

3.5. Adjustment of models

Once the user has verified that the observations he envisions are feasible and are likely to be useful in constraining a specific problem, he needs to obtain quantitative estimates of their usefulness. This will be done in ASPRO-VLTI by adjusting analytical models to the simulated measured quantities using a χ^2 minimization routine. It will be possible to use simulated visibilities, closure phases or both quantities for the model adjustment. As described below, two main model adjustment options will be available to the user.

First, if the user has defined the structure of the object as an (or a sum of) analytical model(s), the same model will be fitted. Any subset of the parameters defining the model can be treated as free parameters in the fit. This will indicate how well the supposed object's model will be constrained by the observations.

Additionally, it will be possible to fit in a similar way a different analytical (sum of) model(s) so that it is possible to determine whether a model ambiguity (e.g., uniform *vs* limb-darkened disk) that is left unsolved by other types of observations can be resolved with VLTI observations. This latter option will also be available if the user has used an homemade model for the target.

4. ASPRO-VLTI OUTPUTS

While using ASPRO-VLTI in defining his target and the desired observational set-up, the user will get an immediate feedback on the feasibility of the observations, as explained above. Explicit error messages, accompanied by illustrative plots, will describe what the exact problem is with the set-up he has chosen, allowing him to modify his choices accordingly.

Once the observations are successfully defined, the user will be able to retrieve useful outputs to help him prepare and strengthen his VLTI proposal. First, it will be possible to download as postscript files all the plots produced by ASPRO-VLTI. This includes plots of the visibility and closure phase measurements (including uncertainties) as a function of hour angle, time or projected baseline as well as two-dimensional (u, v) plots that will contain the representation of the object's model or its best fit along with the spatial frequencies sampled by the requested observational set-up. These plots could be readily included in ESO proposals.

Furthermore, results will be available in a simple tabulated format, with all visibilities/closure phases as a function of time and baselines. This will allow the user to input these quantities into his favorite graphic software to produce more personal plots illustrating the proposed observations.

Finally, for the model adjustment calculations, the user will be provided with the parameters defining the best fit analytical models, their associated uncertainties and the χ^2 values which can be used to decide whether a given fit is acceptable or not.

5. USER SUPPORT

At each step in using ASPRO-VLTI, the user will have the possibility of accessing an help menu which describes the quantities that are being requested in explicit terms, as well as the format and units to be used when entering parameters. A brief explanation of what is being done by the software will also be available. Along with a complete user's manual available on the same webpage as the software, these help menus represent the first level of user support.

In addition, JMMC will create an ASPRO-VLTI helpdesk, i.e., an email contact to use when having problems running ASPRO-VLTI. This will allow the user to present issues specific to the observations he is trying to simulate. This helpdesk will be the primary contact to the ASPRO-VLTI support and development teams for the users. An ASPRO-VLTI email list will also be created. Users who subscribe the mailing list will be informed of all news concerning the software, such as updates in the offered configurations after an ESO call for proposal, or releases of newer versions of the software containing additional options to match the users' needs. The ASPRO-VLTI webpage will give access to the entire archive of this mailing list and will also provide a link to a set of Frequently Asked Questions so that the user can get immediate help for the most common problems. Information regarding the helpdesk, mailing list and FAQ page will be posted on the JMMC webpage when ASPRO-VLTI is distributed to the community.

On a longer term, JMMC plans on developing a tutorial version of ASPRO-VLTI. This version will combine a tutorial on long baseline optical interferometry for non-experts with a demo version of ASPRO-VLTI, in which a couple of predetermined observing programs will be simulated step by step with the software. This will help the non-expert user of ASPRO-VLTI better understand the most important concepts of optical interferometric observations and their link to the various menus of and calculations performed by ASPRO-VLTI. With this tutorial, a complete discovery kit will be available to all users to become familiar with optical interferometry, VLTI and its instruments, and the family of ASPRO software developed by JMMC.

6. SUMMARY AND FUTURE DEVELOPMENT

JMMC, a center recently created to support and expand the use and capabilities of long baseline optical interferometers, has developed during the last few years a software, ASPRO, that allows users to simulate interferometric observations. We are now currently developing a related software, ASPRO-VLTI, that will be devoted to the preparation of observations with the first-generation instruments on ESO/VLTI, AMBER and MIDI.

ASPRO-VLTI will be mostly used by astronomers who are not experts of optical interferometry, but experts who need only simple interferometer configurations will also find it a useful tool. Many of the high-level technical details of the interferometer will be set to default values so as to put the emphasis on the science and the usefulness of VLTI to conduct specific programs.

The software will allow the user to define his favorite target, including a geometrical model for its structure, as well as the instrumental and VLTI array configurations. After checking the technical feasibility of the proposed observations, ASPRO-VLTI will simulate them and estimate uncertainties on the interferometric measured quantities (visibilities and closure phases). It will be possible to adjust models to the simulated measurements using χ^2 minimization routines and thereby obtain quantitative estimates of the usefulness of the observations in constraining the astrophysical problem at hand. Numerous outputs (tables and plots) will be available to the user, possibly to include them in observing proposals.

ASPRO-VLTI will be constantly maintained up-to-date with the most recent information from ESO and the instruments' teams to provide the user with the only possible array or instrument configurations and with realistic sensitivity measurements. A multi-tool support service will be available to users, in the form of manuals, help menus, FAQs and mailing list archive and an active helpdesk.

The first version of ASPRO-VLTI is scheduled to be released at the end of the summer, in time for preparing the first community-wide observing proposals with AMBER on VLTI. Over time, a tutorial version of ASPRO-VLTI, that includes detailed explanations of the main concepts of optical interferometry, will be developed. In parallel to this effort, JMMC is working on providing ASPRO-VLTI users with the possibility of including polychromatic models, which will permit simultaneous model adjustment in several bands or in and out of spectral features, for instance.

REFERENCES

1. Chelli, A., Duvert, G., Bonneau, D., Perrin, G. S., Thiébaut, E. M., Mourard, D., Petrov, R. G., Cruzalèbes, P., Lopez, B., Malbet, F., Daigne, G. & Ollivier, M. 2003, in *Interferometry for Optical Astronomy II*, Traub, W. A. ed., SPIE proceedings, 4838, 144
2. Duvert, G., Bério, P. & Malbet, F. 2002, in *Observatory Operations to Optimize Scientific Return III*, Quinn P. J. ed., SPIE proceedings, 4844, 295
3. Leinert, Ch. & Graser, U. 1998, in *Astronomical Interferometry*, Reasenberg, R. D. ed., SPIE proceedings, 3350, 389
4. Petrov, R. G., Malbet, F., Richichi, A., Hofmann, K.-H., Mourard, D., Agabi, K., Antonelli, P., Aristidi, E., Baffa, C., Beckmann, U., Bério, P., Bresson, Y. & Cassaing, F. 2000, in *Interferometry in Optical Astronomy*, Lena P. J. & Quirrenbach, A. eds., SPIE proceedings, 4006, 68