VERY LARGE TELESCOPE INTERFEROMETER

Scientific User Requirements for a next generation ESO/JMMC calibrator tool

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CHANGE RECORD

Issue	Date	Section/Page affected	Reason/Initiation/Remarks
0.1	8 April 2008	All	First Draft MWI & DBo. In parts based on a previous draft from 28 Feb 2007 by ARi, PBa, MWi, & JMe; on a draft from 2 Apr 2007 by GDu; and on meeting notes of the 26 Oct 2007 ESO/JMMC meeting and following discussions.
0.2	14 April 2008	All	JMe comments.
0.3	9 May 2008	All	MWI: first adjustments after meeting
0.4	8 July 2008	All	Revision by DBo and Mwi after the workshop
1.0	18 August 2008	All	Removed specification on calibrator list; corrected a few typos. Version to be released.

1 INTRODUCTION

1.1 SCOPE

This document lists and describes the scientific requirements for a next generation calibrator tool that supports a user of the VLTI to prepare calibrator observations.

Currently, ESO supports the preparation of observations at the VLTI through tools available from its ETC web page http://www.eso.org/observing/etc/. In particular, it offers the tool CalVin, which allows the selection of suitable calibration stars for VLTI observations. CalVin suggests suitable calibrators from an underlying list of stars based on different user-defined criteria such as angular distance on sky, magnitude, angular diameter, spectral type, luminosity class, quality flag, and desired visibility. It returns several quantities to assess whether a suggested calibrator is suitable and feasible, such as the normalized visibility (average/minimum/maximum over the feasible observation time during the night), loss of correlated magnitude, indication of shadowing, rise time/set time/duration, maximum altitude. The strategy to preferably select calibration stars from the limited underlying lists of calibration stars preserves objects, which have already been studied. Currently, the underlying CalVin list of calibration stars for MIDI is based on the catalogue of calibration stars that has been established by the MIDI instrument consortium by spectro-photometric observations of candidate stars fitting the data to atmosphere models (B. Stecklum, ESO calibrator workshop 2003; Verhoelst 2005, http://www.ster.kuleuven.ac.be/~tijl/MIDI_calibration/mcc.txt). The underlying list of CalVin calibration stars for AMBER is currently based on the catalogues of Borde et al. (2002, A&A, 393, 183) and Merand et al. (2005, A&A, 433, 1155).

The JMMC has developed the utility SearchCal (Bonneau et al., 2006 A&A 456, 789), to help VLTI users to find the best calibrator at hand during the planned observations, based on a series of constraints, especially the sky distance, the closeness in magnitude or spectral type, etc… It builds a dynamical catalogue of stars with all useful information for the selection of the calibrators most adapted to the requirement of the astrophysical program. SearchCal extract the required astronomical information from a set of stellar catalogs available at the CDS. Compared to the static or closed-list approach, the merit of this strategy is first to take into account any enrichment of the catalogs by new observational data and secondly to evolve naturally with the increase of limiting magnitudes and baseline lengths of the interferometric facilities. SearchCal extracts astrometric and spectro-photometric parameters of the objects around the science object, creating an initial list of stars. This list is enriched by the stars present in Bordé et al. (2002) and Mérand et al. (2005). If available, the measured angular diameter is obtained through the data of the *Catalog of High Angular Resolution Measurements* (Richichi et al. 2005). Then, for each star on the initial list, calculations are made to correct the interstellar absorption and to compute missing magnitudes. The photometric angular diameter and its associated accuracy are estimated using a surface brightness method based on the (*B*-*V*), (*V*-*R*) and (*V*-*K*) color index. Then, the expected visibility and its error are computed. The list of possible calibrators is finally proposed to the user and the final choice can be made

by changing the selection criteria: accuracy on the calibrator visibility, size of the field, magnitude range, spectral type and luminosity class, variability and multiplicity flags.

ESO and JMMC have agreed on a collaboration to develop a next generation calibrator tool that supports users of the VLTI in planning and preparing their calibrator observations. The next generation calibrator tool will be a successor of both ESO/VisCalc and JMMC/SearchCal.

The scientific user requirements for this next generation calibrator tool, which are listed and described in this document, are based on the experience of the first years of VLTI operations and data analysis, the experience in using the CalVin and SearchCal tools, and the requirements originating from new observing modes at the VLTI instruments and facility, and from 2nd generation VLTI instruments. A preliminary version of this document has been discussed during the “Workshop on an ESO/JMMC tool for calibrator search”, held on May 5&6, 2008 in Nice, France. Conclusions from this workshop were integrated into the document.

Technical requirements and design issues are not part of this document and will be described elsewhere.

1.2 ACRONYMS FREQUENTLY USED AT ESO/VLTI

AMBER	Astronomical Multi-BEam Recombiner
ASPRO	Astronomical Software to PRepare Observations
AO	Adaptive Optics
ASTO	Archive Storage System
AT	Auxiliary Telescope (1.8m)
CALVIN	VLTI Calibrator Selector
CNRS	Centre National de la Recherche Scientifique (France)
DFS	Data Flow System
DHS	Data Handling System
DICB	Data Interface Control Board
DID	Data Interface Dictionary
DAS	Data Analysis Software
DRS	Data Reduction Software
ETC	Exposure Time Calculator
FITS	Flexible Image Transport System
FSU	Fringe Sensor Unit
GTO	Guaranteed Time Observations
ICD	Interface Control Document
ITF	Interferometric Task Force
JMMC	Jean-Marie Mariotti Center
MIDI	Mid-Infrared interferometric instrument
OB	Observation Block
OPC	Observing Program Committee
OPD	Optical Path Difference
OS	Observation Software
P2PP	Phase 2 Proposal Preparation
PAOS	Prima Astrometric Observation Software
PRIMA	Phase-Referenced Imaging and Microarcsecond Astrometry
QC	Quality Control
QC1	Quality Control Level 1
STC	ESO Science and Technology Committee
SW	Software
TBD	To Be Defined
UT	Unit Telescope of VLT
VCM	Variable Curvature Mirror
VISCALC	VLTI Visibility Calculator
VLT	Very Large Telescope
VLTI	Very Large Telescope Interferometer

2 THE VLTI ENVIRONMENT AND THE VLT/I OPERATIONS SCHEME

2.1 THE VLTI ENVIRONMENT

The VLTI comprises four fixed 8 m Unit Telescopes (UTs) and four movable 1.8 m Auxiliary Telescopes (ATs). The ATs can in principle be positioned on 30 different stations. The Coude foci of the UTs are equipped with MACAO (Multi Application Curvature Adaptive Optics) units, which can be used with natural guide stars (1<*V*<17, seeing <1.5 arcsec, coherence time > 1.5 ms, airmass < 2, distance of the guide star from the science target < 57.5 arcsec). The ATs are equipped with STRAP units, which provide tip-tilt correction with natural guide stars (-1.7<*V*<13.5, distance of the guide star from the science target < 57.5 arcsec). The VLTI facility further comprises a laboratory tip-tilt system (IRIS) working in the near-infrared *K* band that corrects for slow (<1 Hz) tip-tilt motion of the beams (caused by tunnel seeing effects), and an external fringe tracking system (FINITO) which allows, for certain limiting magnitudes and under certain conditions, the astronomer to use longer DITs by freezing the fringes on the detector.
Two science instruments are currently offered to the astronomical community, a 3-beam near-infrared instrument (AMBER) and a 2-beam mid-infrared instrument (MIDI). For each instrument, different instrument modes are available, each with different limiting magnitudes and useable under certain conditions. In the most sensitive modes offered, the limiting magnitude of AMBER is currently (P82) *K*=7 on the UTs and *K*=5 on the ATs, and that of MIDI is *N*=4 on the UTs and *N*=0.74 on the ATs. The detailed information on the currently offered modes is available from the latest call for proposals (http://www.eso.org/sci/observing/proposals) and the instrument WebPages (http://www.eso.org/instruments/amber and http://www.eso.org/instruments/midi). In particular for AMBER, not all foreseen instrument modes are yet fully commissioned and offered. MIDI is currently (P80-P82) offered with 10 different 2-telescope baseline configurations, and AMBER with 4 different 3-telescope baseline configurations.

The next addition to the VLTI will be the dual-feed facility PRIMA. The objective of PRIMA is to enable simultaneous interferometric observations of two objects - each with a maximum size of 2 arcsec - that are separated by up to 1 arcmin, without requiring a large continuous field of view. PRIMA enhances the VLTI in three key areas: (1) an improved sensitivity by using the PRIMA fringe sensor units (FSUs) and by using an off-axis star for fringe tracking, (2) imaging of faint objects with high angular resolution, and (3) high precision astrometry. For the first two areas, PRIMA is used as an additional facility to enhance the capabilities of the instruments AMBER and MIDI. Using the FSUs in the near-infrared, higher limiting magnitudes of tentatively *K*~8 and *N*~5-6 can be reached on the UTs for the primary star. The limiting magnitude for the secondary star with AMBER is tentatively *K*~15. For the third area, the high precision astrometry, PRIMA is used as a stand-alone instrument.

Second-generation instruments for the VLTI are also already being designed, which will be more versatile, and will enhance the scientific capabilities of the VLTI (cf. Richichi & Moorwood, 2006, The Messenger, 125, 35).

As a result, the suit of different instrument modes at the VLTI, each with its own limiting magnitudes and operational conditions, is becoming more and more complex. It is thus important to offer a calibrator tool that helps a user of the VLTI to find the best suitable calibrator for a certain instrument mode and scientific goal, and to prepare the calibration star observations.

2.2 THE VLTI OPERATIONS SCHEME

The VLTI operations scheme is fully integrated into the well-established operations scheme of all VLT instruments. The VLT scheme allows astronomers to submit visitor mode or service mode observation programmes. In visitor mode, the astronomer is present at the telescope and can adopt the programme to specific requirements at the time of observation. In service mode, the observation details and constraints are submitted to ESO beforehand, and the observations are scheduled and carried out by ESO staff.

The standard calibration plan of VLTI observations in service mode currently consists of pairs of one science target observation and one calibration star observation ("sci-cal" sequence). This pair is only considered successfully completed if both observations of the pair were executed successfully and close in time. It is also possible to request one additional calibration star observation per science target observation ("cal-sci-cal" sequence). The observations have to be prepared in such a way that there is a feasible (fulfilling the limiting magnitudes and available on sky considering shadowing effects and delay line limitations) calibration star available at any time of the chosen LST (local sidereal time) interval of the science target.
In visitor mode, more complex sequences of science targets and calibration stars can be realized, and the strategy can be modified during the night following the needs.

The preparation tools for the VLTI thus have to support both visitor mode and service mode observations. In visitor mode the date of observation is known at the time of preparing the observation details. The astronomer is present at the telescope and may like to change or add calibrator observations during the night.
In service mode, the exact date of observation is not known at the time when the observation is prepared, but will be scheduled by ESO staff according to the required constraints and the priorities. In service mode, there is no immediate feedback of the data quality to the astronomer, and no possibility for the astronomer to change or add calibrator observations during the night. It is thus of essential importance for service mode observations that the preparation of the calibration star observations is done beforehand as well as possible, and that a well known calibration source of high quality is selected that fits well to the scientific purpose of the programme, and that is feasible (and optimized) for the chosen instrument mode.

3 SOURCES FOR CALIBRATION STARS

The next generation calibrator tool shall have the option to search within a (large) fixed underlying list of calibration stars. This list shall be created once per observing period based on a dynamic query to CDS catalogues, and shall include estimated or measured angular diameters.

The requested catalogs must be selected to be able to provide all useful information to find and to select for the calibrators

- Identifiers	HIP,HD, 2MASS, DM numbers
- Astrometry	equatorial coordinates, proper motion, parallax, galactic coordinates
- Spectral type	temperature, luminosity class, surface gravity
- Photometry	magnitudes in various photometric bands (B,V, R, I, J, H, K, L, M, N)
- Angular diameter	Limb-darkened/Rosseland angular diameter measured or computed
- Miscellaneous	variability and multiplicity flags, radial velocity, rotational velocity

These catalogs must be able to provide sources with astrometric and astrophysical parameters up to the limits (limiting magnitude, astrometric precision) of the VLTI instruments for the current observing period.

A list of known bad calibrators provided by the IAU commission shall be taken into account.

Newly available information on previous observations and the quality of calibrators (cf. Sect. 4) shall be taken into account for the creation of every new version of the calibrator list.

Ideally, additional archival information on the candidate calibration stars shall be used as well.

The latest offered instrument modes with their limits shall be considered for each version of the list.

The exact strategy to find calibrators and to estimate their diameters shall be discussed by an ESO/JMMC working group and regularly revised.

4 INFORMATION ON PREVIOUS OBSERVATIONS AND QUALITY OF CALIBRATORS

For all stars present in the list of calibrators, the calibrator tool shall indicate

i. Whether the star was already observed with the VLTI, and if so with which instrument, which mode, on which date, and with which baseline. Ideally, the tool shall provide a plot of previous VLTI visibility/estimated transfer function measurements for each instrument mode.
ii. As far as available, the same information as for (i.) but for other interferometers.
iii. Whether the star has been resolved by previous (dedicated) measurements (if yes, value of the angular diameter; if no maybe a standard code such as 0 or -1).
iv. The quality (quality flag) of the calibrator (based on the possible detection of a stellar companion or a circumstellar source)
v. If the star appears on a “black list” either from ESO, the IAU, or another interferometer, and if so for which reason.

5 SEARCH CRITERIA

The tool shall allow the user to limit the resulting list of suggested calibrators according to these criteria (single or combined criteria):

- The instrument mode (instrument, mode, baseline configuration, use of FINITO <yes/no>). If mode is specified, the list shall be limited to calibration sources compatible with the limits of the selected mode.
- Characteristics (magnitudes, spectral type, luminosity class) of the science target. In this case, the list shall be limited to sources with a maximum recommended deviation of these characteristics between science target and calibrator as specified in a configuration file and updated once per period according to the recommendations in the latest version of the user manual.
- Observable during a certain night (visitor mode only) taking into account limits on sun altitude, zenith distance, shadowing effects, delay line limits (the latter two for the chosen baseline configuration).
- Observable during a certain LST interval, taking into account limits on zenith distance, shadowing effects, and delay line limits (the latter two for the chosen baseline configuration). The LST interval of the science target observation shall be an optional input so that only those calibrators are shown that fit to the specified science target LST.
- Limits (and/or) on angular distance, magnitude, angular diameter, spectral type, luminosity class, quality criteria (quality flag), averaged visibility over the feasible LST range, correlated magnitude, astrometric stability (proper motion).

In an easy ‘call for proposal mode’ the search shall be based on standard criteria that are a priori defined for each instrument mode by an ESO/JMMC science group.

6 INFORMATION ON THE FEASIBILITY AND SUITABILITY OF THE LISTED CALIBRATOR

The tool shall provide the following information on the finally presented list of calibrators (independently on whether these characteristics were used as a search criteria or not).

Feasibility:

- Feasible LST range compared to the LST range of the science target observation, taking into account standard limits on zenith angle, shadowing effects, delay line limits. In a so called 'CfP version' of the tool, these values are fixed values defined in a configuration file. In an expert version, they are configurable.
- Feasible UT time range (visitor mode only) taking also into account the sun altitude for the date of observation.
- Magnitude at wavelength of observation.
- Correlated magnitude at wavelength of observation
- Magnitude at wavelength of FINITO
- Correlated magnitude at wavelength of FINITO
- Magnitude at wavelength of Coude guiding
- Magnitude at wavelength of IRIS guiding

Suitability:

- Angular diameter (Limb-darkened/Rosseland-mean)
- Distance on sky from science target
- Visibility (maximum, minimum, and average value over the feasible LST range)
- Astrometric stability (proper motion, no starspot activity, etc.).
- Information on previous observations as listed under 4.

Based on the final list, it shall be possible to select one or more of the suggested calibrators, and to transfer relevant information to the OB (paf file).

7 DESIGN GOALS

The new tool shall make use of modern visualizing capabilities and be designed with ease of use in mind.

There shall be a "call for proposal version" of the tool, which is restricted to the modes and limits offered in the current call for proposals (defined in configuration files), and an expert version with freely configurable modes and operational limits.

Both versions (or flavours) shall be able to support service mode observations (exact date not known, results to be based on the LST of the observation), and visitor mode observations (exact date and time of observation to be considered)