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VLTI OBSERVING PREPARATION SEQUENCE

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Abstract. Optical interferometers are instruments that combine the light coming from separated optical telescopes in order to get information with the spatial resolution of the telescope array. One of the major interferometer is the *Very Large Telescope Interferometer (VLTI)*. To observe an astronomical target with the VLTI, like with any other interferometers, one needs to carefully prepare the observations because of the numerous parameters to be fixed. In addition, the VLTI is being developed in the framework of the data flow system created for the *Very Large telescopes (VLT)* at the *European Southern Observatory (ESO)*. I recall the philosophy of the ESO/VLT data flow system and its adaptation to the VLTI data and then I describe the various steps required to prepare a VLTI observation. Finally, I illustrate the various steps of this preparation with an example focused in the observations of the young binary system Z CMa.

1 Introduction

Observing an astronomical object with an interferometer requires a careful preparation. The objective of this school and also of this book is to introduce the astronomers to the different steps in this preparation phase in order to be ready to submit a proposal for the *Very Large Telescope Interferometer (VLTI)* and eventually obtain interferometric data. This contribution summarizes the various stages of the preparation sequence in the framework of the ESO/VLT data flow philosophy.

Section 2 recalls briefly the various elements of the VLTI involved in the observation preparation. Section 3 describes the VLT data flow system and Sect. 4 emphasizes the main differences encountered when observing with the VLTI. Section 5 describes the various steps required for the preparation of an observing sequence with the VLTI and I present a practical example in Sect. 6.

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2 The Very Large Telescope Interferometer

The *Very Large Telescope Interferometer* is being built by the *European Southern Observatory (ESO)* at the top of Cerro Paranal in North Chile with the help of European institutes. It consists of an infrastructure that can host up to 8 telescopes. For the initial phase, it will be able to accommodate 3 telescopes among the 4 × 8m unit telescopes (UTs) or the 3 × 1.8m auxiliary telescopes (ATs). The UTs are installed at a fixed position whereas the ATs can be placed on 30 different positions over a 200-m wide platform . Four delay lines allow to compensate for the optical delay due to the sidereal motion of the target and the atmospheric turbulence. Adaptive optics or tip-tilt compensation systems allow the system to correct partially for the wavefront atmospheric corrugation on each aperture and fringe trackers permit to freeze the position of the interference fringes. Three instruments will eventually be placed at the VLTI focus: VINCI the VLTI commissioning instrument, AMBER the near-infrared 3-way beam combiner and MIDI the mid-infrared 2-way beam combiner.

Further details about the VLTI can be found in this volume in contributions from A. Glindemann, R. Petrov and G. Perrin.

3 The VLT data flow system

Observing with modern telescopes requires an appropriate control of all phases from the preparation of the observations to the final data reduction process through a careful management of the observations. The idea behind the construction of the VLT is to be as close as possible to the concept of the control of a space telescope where no manual interventions are possible. This philosophy was required by the fact that ESO will at the end operate 4 large identical telescopes but with different instruments and wanted to ease the use of these telescopes for the community. The *Data Flow System (DFS)* is the name of the global system that handles the observations and finally the data in the ESO/VLT control implementation (see chapter 10 of Giacconi et al. 1998). ESO aims at incorporating the VLTI observations in the same data flow system even if it has to be slightly modified to accept interferometric data. In this section, I present the overall data flow system to give the context of VLT observations and therefore to the VLTI ones that are described in the next section.

The VLT Data Flow System is schematically presented under the form of a flow diagram in Fig. 1. An observation starts at the left of the diagram by the first preparation phase called the *Programme Handling*. It consists for the user in defining the programme of the future observations and to submit it to the time allocation committee called at ESO, the Observing Programmes Committee (OPC). If accepted, the programme is transformed in a set of small entities called **Observing Blocks (OBs)**. OBs are the smallest schedulable units of telescope resources or in other words quanta of data that flows within the DFS. This second phase in the preparation of the observations is called *Observation Handling*. When ready the OBs can be executed by the telescope and instrument control system and

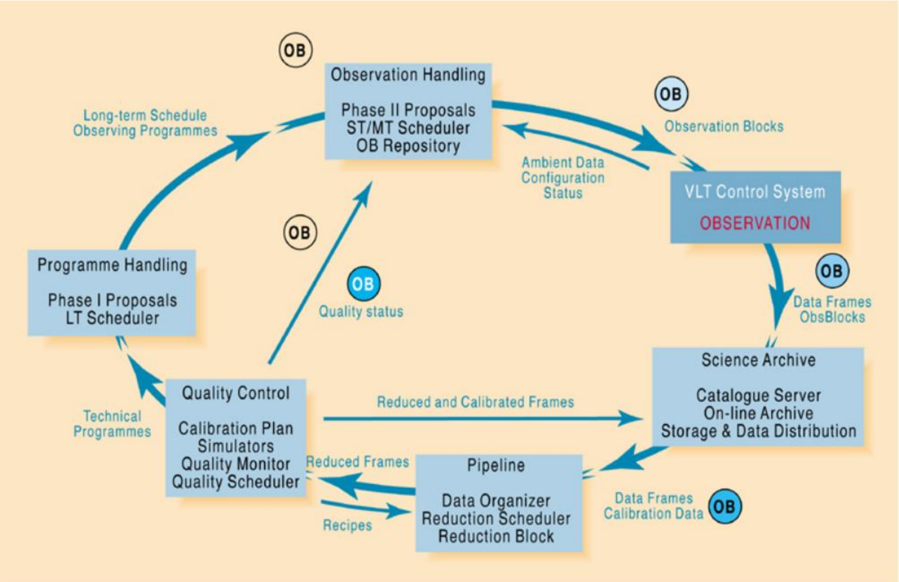


Fig. 1. Flow diagram of the VLT data flow system.

transform in observing scripts that send orders to the various parts of the telescope or the instrument. The raw data corresponding to the OBs is then stored in the *Science Archive*, then processed in the *Data Reduction Pipeline*. Of course the output data is used by the astronomer for his own scientific purpose, but also is processed by a *Quality Control* stage to check that the quality of the output data of each OBs is within the observing criteria of the programme specifications. These criteria can include for example requirements for the maximum seeing or the atmosphere transparency. If the resulting data is not acceptable, the corresponding OBs can be reprocessed.

The scope of this paper is not to go into the details of the various steps of the DFS. We focus our attention to the first steps of the proposal preparation.

3.1 Phase 1 proposal preparation: Programme Handling

In this phase, the astronomer is requested to write a proposal so that it can be ranked with the other proposals by the OPC. It includes a detailed description of the programme:

- *Scientific rationale* describes the scientific background of the project with relevant references and a justification for the present proposal;
- *Immediate objectives* specifies what is actually going to be observed and what information will be extracted from these observations in order to assess the proposal feasibility

- *Instrument configuration* defines which telescopes are used, and which instrument setup is chosen (or several if required).
- *Technical feasibility* gives the elements to the OPC to estimate that the proposal is realistic and can be performed with the chosen telescope and instrument.
- *Estimation of required time* defines the number of nights or hours required to fulfill the project.

In order to answer to these various questions the proposer needs also information on the telescope and the instrument. It has access to the VLT user guide, the instrument manual and if available an Exposure Time Calculator (ETC) that provides estimates of the expected signal-to-noise ratio for a given setup and a given astronomical source. These ETCs are available at the following address:

`http://www.eso.org/observing/etc`

Finally the proposer submits the proposal before the deadline (twice a year: beginning of April and beginning of October) and the proposal is being reviewed by the OPC that ranks it in one of the 3 categories: A, B or C. Proposals ranked A will be observed during the semester, and some of the B proposals too if there are some opportunities, for example if they do not require very good atmospheric conditions and whenever A observations cannot be performed.

3.2 Phase 2 proposal preparation: Observation Handling

Once the proposal has been accepted, the user must prepare the observations by actually building observation blocks (OBs). The VLT can be operated either in visitor mode or service mode. In visitor mode, a given number of nights are allocated to the astronomer who comes on site to conduct the observations. If the weather is bad or if the telescope / instrument do not work, the time is lost. In service mode, the proposal is performed by an ESO operator who, in a given night, schedules several proposals which have been translated in OBs. Whenever the OBs are completed, the user receives the data at home. Of course, service mode is more flexible and allow to provide very good seeing for specific observations.

In service mode, OBs are stored in an OB repository from where a schedule can be constructed over the night but also over the week and even over the semester. For this step, ESO provides a tool called P2PP for Phase 2 Proposal Preparation. It allows the user to specify the target, the exposure time, setup the different parameter of the instrument.

3.3 Other steps

I will not go into details for the other steps since it does not necessarily involve the user. It includes:

- execution of observing blocks,

- data archiving,
- data reduction pipeline,
- quality control including quick-look tools and off-line analysis.

If the quality of the data are not compliant with the specifications of the proposal, then the OBs can be executed again.

It is important to realize that this is the ideal scheme for VLT instruments. However, it takes time to provide all these tools and therefore for the new instruments, some part of the global chain can be missing.

4 The data flow system with the VLTI

The ESO goal is to stick as close as possible to the scheme described in the previous section. The data flow system however needs to be adapted in order to accept VLTI observations and data. The description of the DFS adapted for the VLTI can be found in Ballester et al. (2001). The motivations are three fold:

- VLTI observations are complex with several telescopes, delay lines servo system,... and requires to be performed by qualified personnel,
- the high level of automation of the VLTI can be handled by the DFS,
- the VLTI should be considered as part of the VLT in particular for maintenance.

However there are undoubtedly some differences:

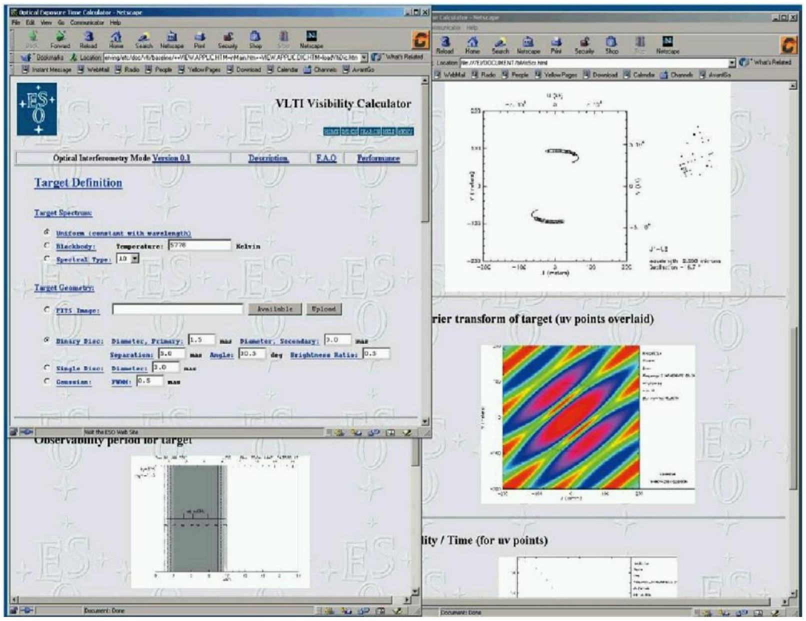
- the VLTI array configuration with many telescopes, delay lines, ...,
- the instrument configurations,
- valid observations do require calibration stars (like for adaptive optics).

One should keep in mind that this is an improving process and not everything has been yet completely finalized.

One good example of the changes that are required to the DFS in order to include VLTI operation is for the Programme Handling phase. Users will have to deal with visibilities which are not quantities often used in the astronomical community. ESO plans to provide therefore a *Visibility Calculator*, inspired by the ASPRO program used during this school, which is displayed on Fig. 2

5 Observing preparation sequence

I list here the different steps needed to prepare an observation with the VLTI. The flow diagram extracted from the AMBER User's Manual (Malbet 2001) gives a good example (see Fig. 3) and details the various steps needed to prepare a VLTI observation.



VLTI Visibility Calculator

Optical Interferometry Mode Version 0.1 | Description | F.A.Q | Performance

Target Definition

Target Spectrum:

● Uniform (constant with wavelength)
○ Blackbody: Temperature: 5778 Kelvin
○ Spectral Type: A0

Target Geometry:

○ FITS Image: Available Upload
● Binary Disc: Diameter, Primary: 1.5 mas Diameter, Secondary: 3.0 mas Separation: 5.0 mas Angle: 30.3 deg Brightness Ratio: 0.3
○ Single Disc: Diameter: 3.0 mas
○ Gaussian: FWHM: 0.5 mas

Observability period for target

rier transform of target (uv points overlaid)

lity / Time (for uv points)

Fig. 2. A preliminary view of the VLTI visibility calculator (Ballester et al. 2001)

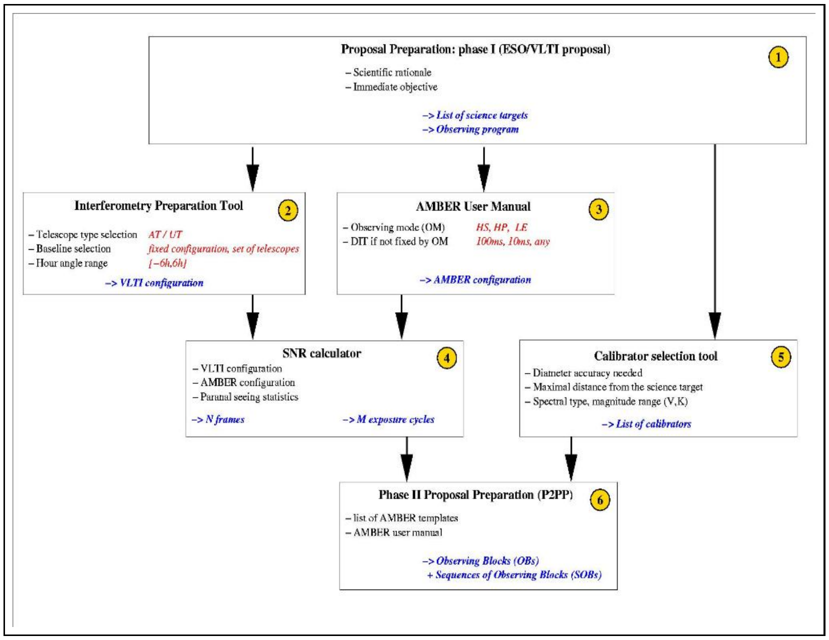


Fig. 3. Example of steps required to prepare an observation sequence with AMBER (from AMBER User's Manual, Malbet 2001)

The main difference in preparing a proposal for a VLT instrument compared to a proposal for the VLTI is that the observing data will be complex visibilities. One needs to **think in Fourier space**. The observables for the VLTI instruments are respectively: the *visibility amplitudes*: AMBER and MIDI (cf. Berger, Ségransan in this volume); the *differential phases*: AMBER and MIDI (cf. Stee in this volume); and the *closure phases*: AMBER (cf. Buscher, Monnier in this volume).

Concerning the immediate objectives, one needs to describe what type of observations by defining:

- the *wavelength*: $1 - 2.5\ \mu$m for AMBER or $8 - 12\ \mu$m for MIDI;
- the *number of targets*: a few ones or a survey;
- the *magnitude* of the objects to determine if one needs the UTs or the ATs, if one can use the fringe trackers with an implication on the exposure time for high spectral resolution;
- the *type of object structure* one is looking for in order to identify the best observables:
  - simple structure like a binary or a photosphere → visibility amplitudes
  - asymmetric objects → closure phases
  - objects with spectral signature → differential phases
  - structure with high contrast → high accuracy measurements
- the type of (u, v) coverage: few points (for a diameter determination), few tracks (binary parameters) or full coverage (image).

The best way to teach the different steps is to go through a complete example that could have been one proposal for the last practice work session. This is the purpose of next section.

6 A practical example

I have chosen to follow the different steps of the observing preparation sequence in a concrete case: *Detection of the binary Z Canis Majoris at 10 microns.* All the steps will be briefly described in the following paragraphs to illustrate this approach.

6.1 Scientific rationale

Z Canis Majoris is a well known binary belonging to the class of young stellar systems (YSOs). Investigating the close environment of young stars is of importance to understand the precise mechanisms of star and planet formation. Young stars are believed to form through an accretion disk that can go in state of high accretion rate, called FU Orionis state. Z CMa is one of these systems that have the peculiarity to be double. One of the components is supposed to host the FU Ori disk and the second one is probably an infrared photosphere. However this interpretation comes from observation with speckle interferometry and adaptive optics at visible and near-infrared wavelengths (Koresko et al. 1991; Malbet et al. 1993; Barth, Weigelt, & Zinnecker 1994; Thiébaut et al. 1995). Getting additional clues for this system will help us to understand the accretion process.

6.2 Immediate objective

The separation and the position angle measured by speckle interferometry and adaptive optics in the near infrared and visible domains (Koresko et al. 1991; Malbet et al. 1993) are respectively 0.1” and 120°. The two components have never been separated at 10 μm since the spatial resolution at this wavelength of a 4-m telescope is not high enough. The flux ratio has not been measured yet at this wavelength. An estimation of this flux ratio will permit to complete the spectral energy distribution for each component. Eventually one might be able to detect the presence of the accretion disk around the visible or the IR component by measuring a decline of the visibility amplitude with the baseline length.

6.3 Observability

We have to check a few things:

- A SIMBAD query[1] shows that the Z CMa V magnitude is about 10, allowing tip-tilt correction on the UTs
- The Z CMa flux is within the MIDI sensitivity. The N magnitude given by the Catalogue of Infrared Observations (Gezari, Pitts, & Schmitz 1999) accessible on the VizieR web site[2] is about -1.
- In the same catalogue, one can check that the H magnitude for the fringe tracker is about 4, allowing fringe tracking.

In conclusion, Z CMa itself can be used as a reference for tip-tilt correction and fringe tracking.

Using the observability function of ASPRO, one can verify that the object is visible during the entire night at the beginning of January.

6.4 VLTI configuration

We have the choice between UTs and ATs. For this example, we choose the ATs, since we are within the sensitivity of MIDI with the ATs (cf. Perrin in this volume) and it provides more possibilities for the baseline choice.

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[1] `http://simbad.u-strasbg.fr`

[2] `http://vizier.u-strasbg.fr`

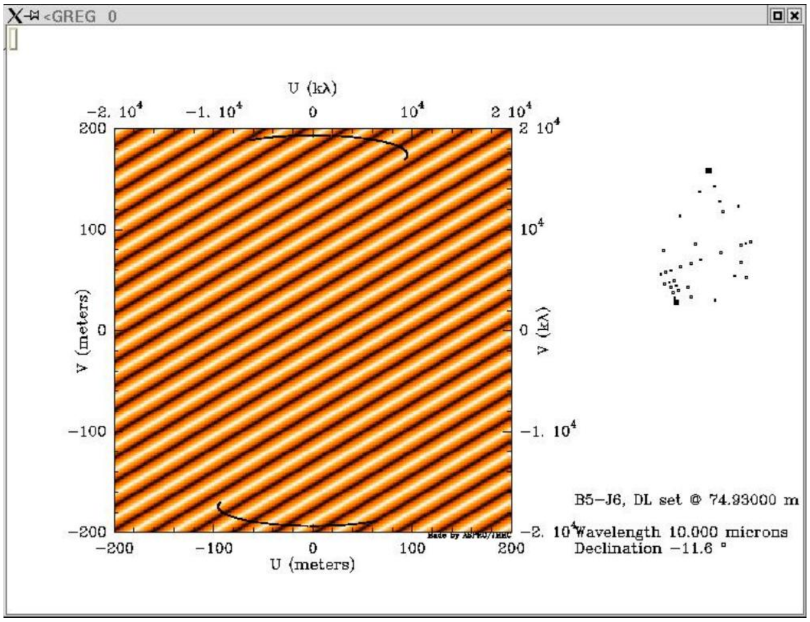


Fig. 4. (u, v) coverage corresponding to the B5-J6 baseline computed with the ASPRO software for the MIDI instrument.

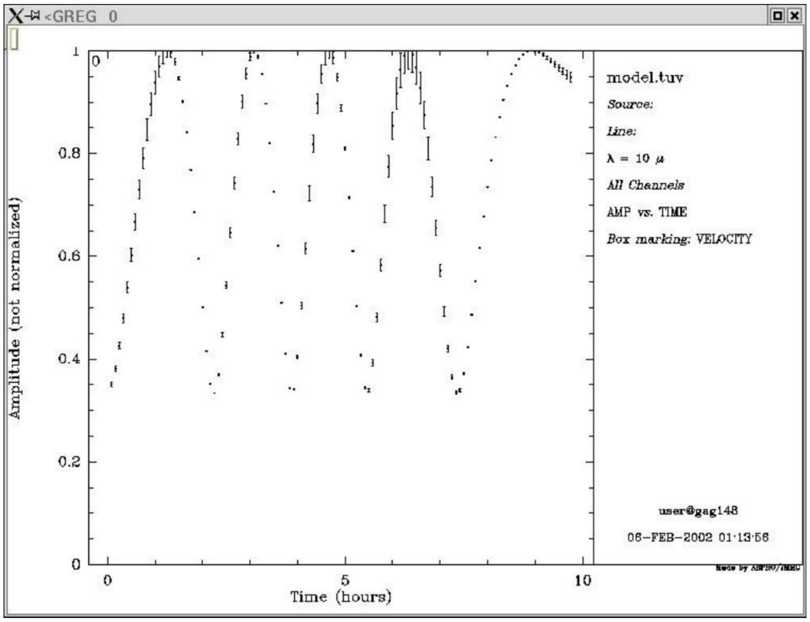
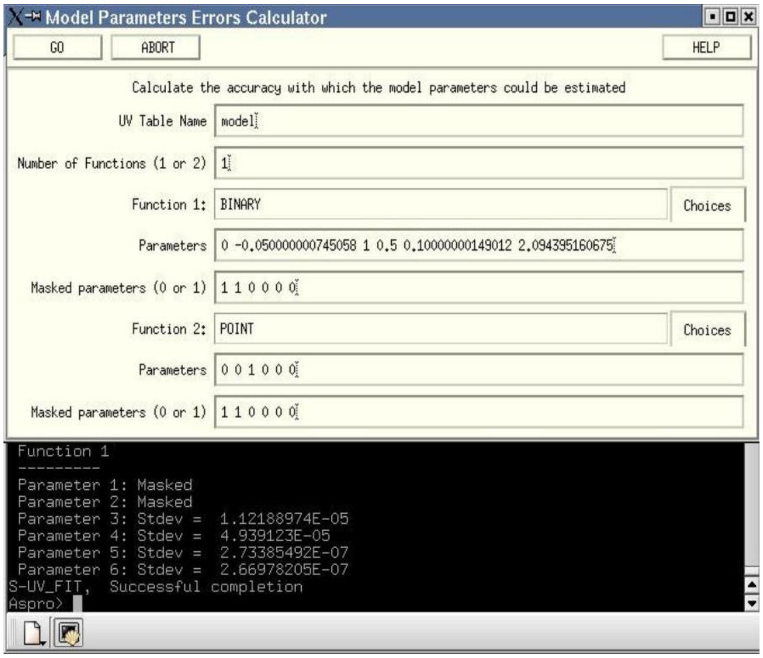


Fig. 5. Visibility square amplitude in function of time with the B5-J6 baseline computed with the ASPRO software for the MIDI instrument.



Calculate the accuracy with which the model parameters could be estimated

UV Table Name: model

Number of Functions (1 or 2): 1

Function 1: BINARY

Parameters: 0 -0.050000000745058 1 0.5 0.10000000149012 2.094395160675

Masked parameters (0 or 1): 1 1 0 0 0 0

Function 2: POINT

Parameters: 0 0 1 0 0 0

Masked parameters (0 or 1): 1 1 0 0 0 0

```
 Function 1
 ---------
 Parameter 1: Masked
 Parameter 2: Masked
 Parameter 3: Stdev =  1.12188974E-05
 Parameter 4: Stdev =  4.939123E-05
 Parameter 5: Stdev =  2.73385492E-07
 Parameter 6: Stdev =  2.66978205E-07
S-UV_FIT,  Successful completion
Aspro>
```

Fig. 6. Determination of the error bars on Z CMa binary parameters using the simulated data with the ASPRO software.

The expected visibility map of Z CMa is a ripple pattern characteristic of a binary. The amplitude of the ripple corresponds to the flux ratio. Figures 4 and 5 show that with the longest baseline B5-J6 for a 4 hour transit, the visibility goes up and down 4-5 times allowing a good fit of the binary parameters.

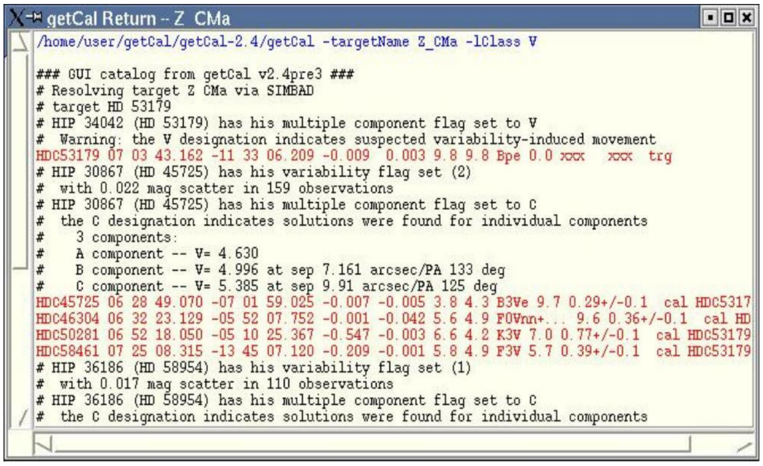
6.5 *MIDI configuration*

The choice of configurations of MIDI is limited (see Perrin in this volume). We request the standard configuration with 250 spectral resolution. A visibility accuracy of 5% is sufficient as shows Fig. 5. The computation of the error bars was performed with ASPRO.

Figure 6 shows the screen copy of the ASPRO model parameter error calculator. Using 50% flux ratio and the known binary parameters, one find that with the data simulated in Fig. 5 we obtain very small errors.

6.6 *External calibrator stars*

There is no tools yet dedicated for the search of calibrator stars at 10 microns. Therefore we use the `getCal` software used in the practice work session 3, to look for reference stars for Z CMa.



```
/home/user/getCal/getCal-2.4/getCal -targetName Z_CMa -lClass V

### GUI catalog from getCal v2.4pre3 ###
# Resolving target Z CMa via SIMBAD
# target HD 53179
# HIP 34042 (HD 53179) has his multiple component flag set to V
#  Warning: the V designation indicates suspected variability-induced movement
HDC53179 07 03 43.162 -11 33 06.209 -0.009  0.003 9.8 9.8 Bpe 0.0 xxx   xxx  trg
# HIP 30867 (HD 45725) has his variability flag set (2)
#  with 0.022 mag scatter in 159 observations
# HIP 30867 (HD 45725) has his multiple component flag set to C
#  the C designation indicates solutions were found for individual components
#    3 components:
#    A component -- V= 4.630
#    B component -- V= 4.996 at sep 7.161 arcsec/PA 133 deg
#    C component -- V= 5.385 at sep 9.91 arcsec/PA 125 deg
HDC45725 06 28 49.070 -07 01 59.025 -0.007 -0.005 3.8 4.3 B3Ve 9.7 0.29+/-0.1  cal HDC5317
HDC46304 06 32 23.129 -05 52 07.752 -0.001 -0.042 5.6 4.9 F0Vnn+... 9.6 0.36+/-0.1  cal HD
HDC50281 06 52 18.050 -05 10 25.367 -0.547 -0.003 6.6 4.2 K3V 7.0 0.77+/-0.1  cal HDC53179
HDC58461 07 25 08.315 -13 45 07.120 -0.209 -0.001 5.8 4.9 F3V 5.7 0.39+/-0.1  cal HDC53179
# HIP 36186 (HD 58954) has his variability flag set (1)
#  with 0.017 mag scatter in 110 observations
# HIP 36186 (HD 58954) has his multiple component flag set to C
#  the C designation indicates solutions were found for individual components
```

Fig. 7. Calibrators for Z CMa found with the `getCal` software.

Table 1. External calibrator characteristics for Z CMa

Name	V	K	Distance (°)	Diameter (mas)
HD 46304	5.6	4.9	9.6	0.36
HD 50281	6.6	4.2	7.0	0.77
HD 58461	5.8	4.9	5.7	0.39

We have at least 3 candidates in Fig. 7 (HD 53179 is Z CMa) since HD 45725 is quoted as a potential multiple system by Hipparcos and therefore is not a good calibrator. The characteristics of the remaining calibrators are summarized in Table 1.

6.7 Technical and astrophysical feasibility

In the case of the Z CMa example, the observations require one full transit, maybe two, i.e. two nights. The only unknown is the contrast between the primary and secondary component, but we are also eventually interested by the influence of the accretion disk.

The interpretation plan consists in extracting the exact flux ratio between the two components and using the N magnitude for the total system photometry, one will be able to deduce the N magnitude for both component and includes them in their spectral energy distribution from which using disk models we will be able to identify if the primary component is the FU Ori disk.

A second step would be to analyze the decline of the average visibility amplitudes to find out if one resolves directly the disk structure. Using standard models (see for example Malbet & Bertout 1995), we will able to fit the disk parameters.

7 Summary and conclusion

The sequence for preparing a VLTI observation can be summarized by the following list:

- scientific rationale
- immediate objectives
- list of targets with the appropriate magnitudes (J, H, K for AMBER, N for MIDI) but also the V magnitude and spectral type for active guiding
- requested VLTI configuration:
  - Telescopes: UT/AT
  - Baseline(s)
  - Hour angle range
  - Fringe tracker, dual-feed
- requested instrument configuration (cf. instrument presentations):
  - spectral configuration
  - other parameters
  - required accuracy (visibility or phase)
- calibrators: strategy, list of calibrator stars
- technical feasibility:
  - expected visibility range
  - date of observations
  - Schedule constrains: dark moon, part of the night
  - total observing time
- preparation tasks if any
- plan for interpreting the data
- general conclusion on the exercise

Following these steps should in principle be sufficient to prepare a VLTI proposal. Some examples worked out by some students of the school are also presented in this volume.

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