

Searching for Calibrators

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Abstract

This chapter focusses on the selection of a good calibrator for interferometric observations. A few software tools are available to help the astronomer in this task. We use as an example the *SearchCal* webservice that automates most of the process.

Key words: Interferometry, calibration

1 Foreword

In stellar interferometry, the raw fringe contrast must be calibrated to obtain the true object visibility which will give the object parameters that can be interpreted in term of astrophysical parameters. Calibration is usually done by measuring with the same apparatus, and as simultaneously as possible, the fringe contrast of an object of known visibility: a calibrator. Ideally, a calibrator should be a point source, unresolved at all baselines. In practice, small angular size objects, unresolved by the longest baseline used, or objects of a very well-known (or predicted) angular size can be used as calibrators.

To allow a good calibration of the visibility measurements, the instrumental response must not change during the time necessary to observe the target and the calibrator. Usually, the instrumental response will change as fast as the atmospheric conditions changes (including the change in airmass due to diurnal motion). Most frequently, the instrumental response is also dependent to the observed source flux. Thus, the calibrator should have a brightness and a sky location close to those of the scientific target.

Atmospheric turbulence calls for elevations of the object and calibrator to be as similar as possible at the time of their respective observations. For example, a difference of about 5° in DEC gives a 10% variation in airmass at 40° elevation. For bright calibrators, the difference in RA between the calibrator and the

target is less critical (180 min in RA is tolerable). To allow observations with comparable SNR, the calibrator should not be too weak compared to the target and a maximum magnitude difference of 1 mag seems reasonable.

With the installation of AMBER and MIDI instruments at the VLTI, the selection of suitable calibration stars was deemed crucial to reach the ultimate precision of their interferometric observations. The JMMC calibrators group, building on the experience acquired with the GI2T interferometer, designed a “search calibrator tool” (*SearchCal*¹) to assist the astronomer in this calibrator selection process.

The tool is available in the JMMC’s ASPRO preparation software and has been driven by the objective to create a dynamical catalog of calibration stars, using mostly “virtual observatory” techniques. A complete reference to the scientific background of *SearchCal* is described in [1]. The design can be summarized as follows:

- Input: Astrophysical requirements on the scientific object.
- Method: Search of the potential calibrators in a field around the scientific object. An interface to the CDS data center is used to retrieve the astrometric and spectro-photometric parameters present in the CDS stellar catalogs. Follows the computations of suitable parameters (correction for interstellar absorption, angular diameter, visibility). Finally, an automatic selection of stars based on astrophysical and instrumental requirements is performed.
- Output: list of possible calibrators. A final list of calibrators is obtained after a manual selection by the user, based on astrophysics criteria.

2 Setup

We will use the *SearchCal* tool hosted on the JMMC server (<http://www.mariotti.fr>). At the time of writing, *SearchCal* is available as a plugin in the preparation tool *ASPRO*. From a Web Browser with java enabled, go to the ASPRO web page (http://www.mariotti.fr/aspro_page.htm) and follow instructions there to start *ASPRO*. We will choose the "Full ASPRO Interface" item in the menu that *ASPRO* present us. A menubar titled "JAVA XMLBased GUI" appears.

¹ The documentation for *SearchCal* is included in the ASPRO documentation and available on-line at <http://www.mariotti.fr/doc/approved/JMMC-MAN-2100-0002.pdf>.

3 starting *SearchCal*

In the "JAVA XMLBased GUI" window we will use two menus:

- The menu "WHERE" to choose the interferometer used for the observation.
- The menu "WHAT" to select the scientific target of the interferometric observations and to open the calibrator search.

The "VLT, 2 Telescopes" item in the menu "WHERE" will be used for this practice. We will choose first to find the calibrators for the star Achernar in the K band ($2.1\mu\text{m}$).

Achernar (α Eridani, HD 10144) is a Be star. Spectral type B3 Vpe, magnitudes $V=0.50$, $K=0.88$

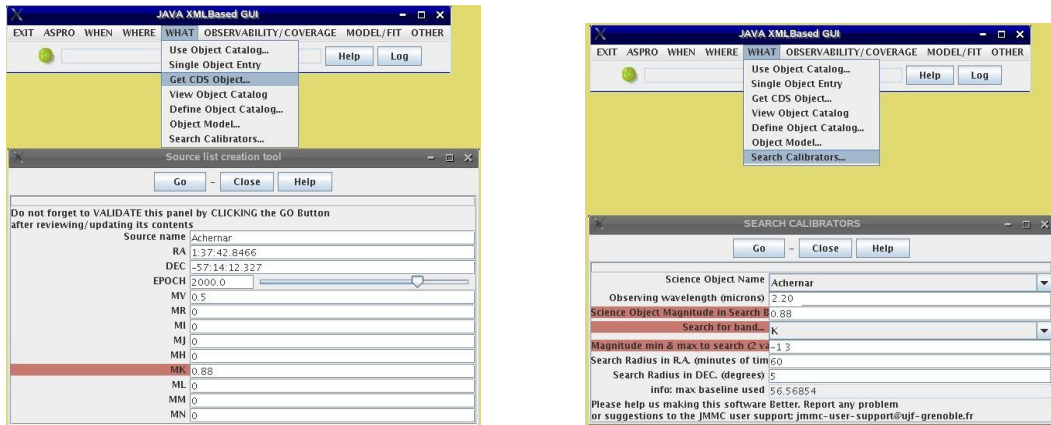


Fig. 1. Left: The ASPRO ToolBar and the panel returning the coordinates of Achernar from CDS. Right: the same, with the panel for entry of *SearchCal* parameters. Entries recently modified by the user are signaled by red labels.

In the menu "WHAT":

- Select the "Get CDS Object..." item to retrieve the coordinates of the star Achernar from the window "Get Source Catalogue". The values of the parameters returned from CDS appears in the window "Source list creation tool". Acknowledge the values (button GO).
- Select the "Search Calibrators..." item to open the "SEARCH CALIBRATORS" panel.

This panel (fig. 1, bottom right) contains all parameters needed to find the calibrators around the scientific target via the web request to star catalogs available at the CDS. These parameters will be updated following the selected photometric observing band, the corresponding object magnitude and the differences in magnitude and position allowed between scientific target and the

calibrators.

- In this example, we will select the "Search for band" to "K" and set a compatible "Observing wavelength" of 2.2 microns. We will keep the size of default field on the sky: the maximum distance of the calibrator will be ± 60 minutes of time in right ascension (RA) and ± 5 degrees in declination (DEC).
- The minimum and maximum magnitudes of the calibrators will be changed to -1 3 to bracket the object's magnitude. Why?

The magnitudes of the object and the calibrator must be close so that they can be observed with the same instrumental configuration.

- Note that the max baseline length is given as an information. Since we did not modify ASPRO's default setup beforehand, the value indicated (56.56 m) corresponds to the UT1-UT2 baseline.
- Click "GO"

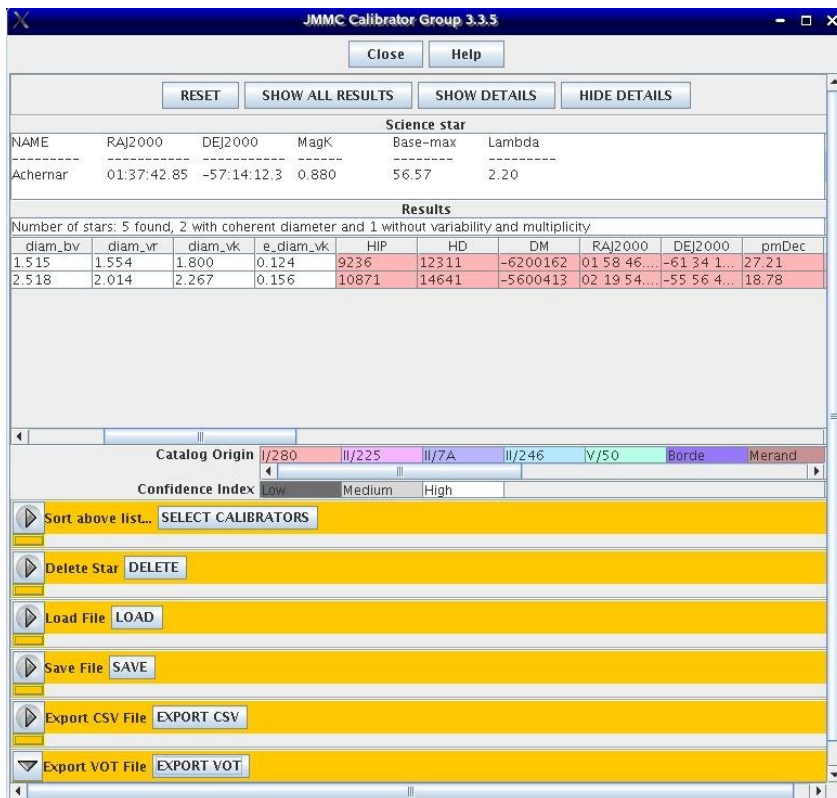


Fig. 2. The *SearchCal* result panel (current version), with results for Achernar, K-band search

The server side of the program queries the various catalogs. During this connexion with the CDS, the names of the catalogs accessed are briefly displayed in the "JAVA XMLBased GUI" window (above the ASPRO menuBar). Once all the CDS requests have been performed, the results are computed and presented in a new panel. Depending on the version of *SearchCal* used, this result

panel may differ in shape and content. The panel displayed in fig. 2 is the panel in use at the time of writing, the one displayed in fig. 3 (section 6) the future *SearchCal* result panel.

4 Result panel

This panel mainly consists of three sections:

- The science star window,
- The results window,
- A set of selection tools used to refine the list of calibrators and load/save the results.

The top border of the panel presents some useful buttons.

- Use the "SHOW DETAILS" button to see all information.
 - Use the "SHOW ALL RESULTS" to see a complementary list of stars that were not selected as good calibrators because of their multiplicity or variability flags.
- How many stars were found? How many selected?
 - What was the reasons several stars were not selected?
 - Why such a small number of calibrators?

5 stars are found.

- 3 stars are rejected because the lack of photometric data prevents the computation of the angular diameter.
- 2 stars are found to be potential calibrators with a consistent diameter: HD12311 (angular distance 5.0°) and HD14641 (angular distance 5.9°).
- 1 calibrator (HD14641) is selected without variability or multiplicity flag.

The star HD12311 is rejected because it is suspected to be variable and multiple in the I/280 catalog.

The scarcity of bright stars (magnitude $K \leq 5$) explains the very small number of calibrators. This happens more than often. In this case, it is advised to widen first the RA interval (which amounts to comparable elevation and airmasses). Then the DEC difference can be increase up to 10 degrees if the elevation is more than, say, 45° . If this does not yet suffice, the range in magnitude can be extended provided the largest magnitude does not come close to the limiting magnitude of the instrument.

- Colors in list: they have a meaning.
- For example, what is the originating catalog for the J, H and K magnitudes of HD14641?
 - What is the confidence index of the corresponding visibility?
 - Why such a low (far from $V= 1.0$) visibility?

- The infrared magnitude of HD14641 are from the Bordé catalog i.e. “A catalogue of calibrator stars for long baseline interferometry” [2]
- A high confidence index is associated with the computed visibility for HD14641 because the photometry is directly extracted from a catalog (see color code of the entry in the table).
- The squared visibility (0.822) is quite low but very precise (0.5%) because its value is obtained with the angular diameter given in the Bordé catalog ($UDDK = 2.140$ mas) with a relative accuracy of 1%.

- What does the V2 uncertainty listed by SearchCal include? Only uncertainties from fitting the photometric information? How do measurement uncertainties on the calibrators affect the calibration process? What maximum degree of uncertainty on the calibrator should be tolerated?

The error on the value of V2 given by SearchCal takes into account the uncertainty on the value of the angular diameter of the calibrator. Except for stars having published value of the angular diameter, this uncertainty reflects the fitting of the photometric data.

For very small calibrators (diameter < 0.5 mas), the estimated visibility is always very close to 1.0 and an large error (say up to 50%) on the angular diameter have quite a negligible effect on the value of the visibility

In any case, the user will have to select the value of the angular diameter of his calibrator (and his error) from a critical analysis of the published values or by his photometry and by comparing the results given by the various methods of calculation of photometric diameter available in the literature.

The degree of uncertainty tolerable on the angular diameter depends on the value of the estimated visibility. The more the calibrator will be unresolved, the larger will be the uncertainty on his angular diameter.

5 MIDI calibrator

We will now find the calibrators for Achernar, but observed with MIDI at $10\mu\text{m}$.

Close the "Results" and the "SEARCH CALIBRATORS" panels and Select the "MIDI" item in the "WHERE" menu.

Recall the "Search Calibrators..." item in the "WHAT" menu to open a new and slightly different "SEARCH CALIBRATORS" panel.

Enter the Achernar $10\mu\text{m}$ magnitude: -1.0. Get the result. Discuss.

- The calibrators are extracted from the list of stars characterized by the absence of circumstellar dust and a flux at $12\mu\text{m}$ more than 5 Jy. This list is used by the ESO Calvin tool (<http://eso.org/instruments/midi/index.html#calvin>).

- 1 calibrator is found: HD10052 (angular distance 1.0°) with a squared visibility of 0.983.

The calibrator found is closer than at K, and has a better visibility. Why?

VLTI observations in the mid-infrared N band ($\lambda \sim 10\mu\text{m}$) allows an angular resolution 5 time less than in the near-infrared K band ($\lambda \sim 2\mu\text{m}$) and then gives a fringe visibility much higher for a given angular diameter of the source. In other words, unresolved stars are more numerous at N than at K, at constant baseline length.

6 Fainter Star, K band

Let's go back to VLTI+AMBER, in K band, but with a fainter star, Gl551.

Gl 551 (Proxima Centauri, HIP 70890) is a red dwarf.
spectral type M5.5 Ve, magnitudes V= 11.0, K= 4.4.

Fainter stars are more numerous², we will restrict ourselves to a search zone of 20 minutes of time in RA and 2 degrees in declination. We bracket the magnitude range from 3 to 6.

Same questions as in section 4.

² For the search of very faint calibrators (magnitude $K \gg 5$) the most serious problem can be encountered in the vicinity of a bright star. In this case, the catalogs can contain a "blind spot" and SearchCal will not possibly find all the potential calibrators. The only solution in this case is to make a specific research on a small field around the target.

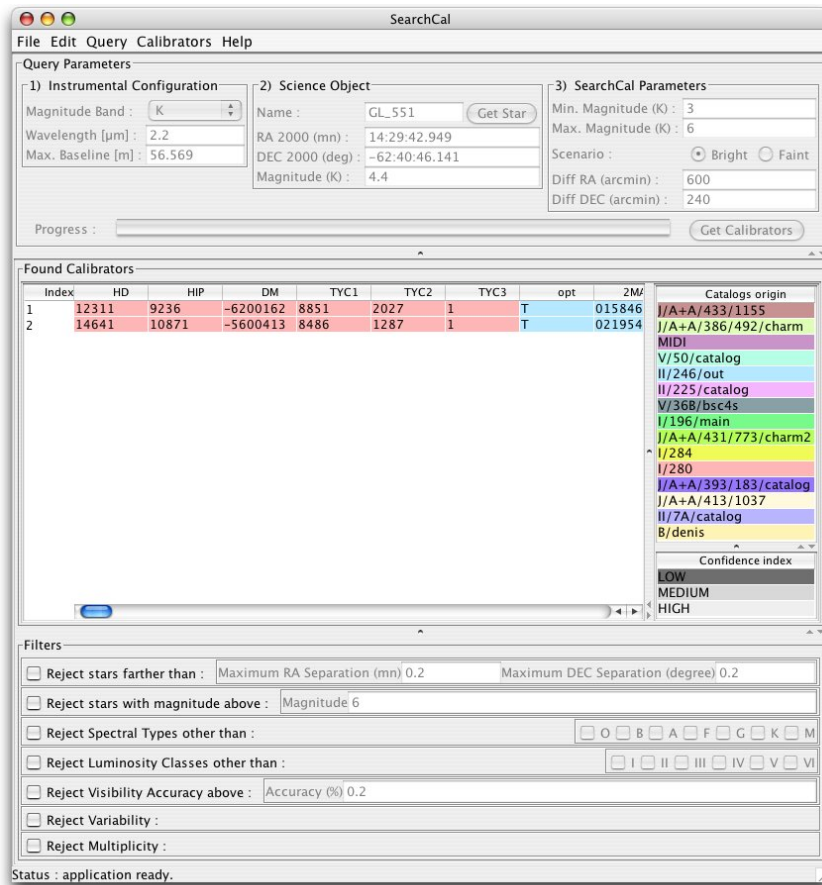


Fig. 3. The *SearchCal* result panel (new version), with results for GL 551, K-band search

7 stars are found.

- 3 stars are found to be potential calibrators with consistent diameter: HD127996 (angular distance 0.9°), HD 125881 (angular distance 1.2°) and HD125158 (angular distance 1.8°).
- 1 calibrator (HD125158) is selected without variability or multiplicity flag.

The star HD127996 is rejected because it is suspected to be variable and multiple in the I/280 catalog but for star HD125881 the varflag3 = C ("constant") indicates that no variability was detected by Hipparcos.

The visibilities are now better (for a calibrator). Why?

What would be your final choice in that list for the GL551 star?

- The selected stars being fainter, their angular diameters are smaller that gives a larger fringe visibility for a given base length.
- To privilege a strong value of the visibility , the star HD125881 is a good choice of calibrator since it gives the largest visibility. If the priority is given to the brightness of the calibrator, then star HD125158 must be selected.
- Usually, if one has the choice between several calibrators, one will have to take the brighter calibrator (to guarantee a good SNR of the data) but only if its visibility is either near 1.0 (unresolved calibrator) or known with a high precision (resolved calibrator).

Use the "**SELECT CALIBRATOR**" command of the "sort above list" subpanel to sort the list according to the various sorting parameters. From the final list of potential calibrators, the user can refine the choice of its calibrators by changing, a posteriori, the selection criteria:

- field around the science object,
- object - calibrator magnitude difference,
- spectral type and luminosity class,
- accuracy on the calibrator visibility,
- indications about variability and multiplicity

7 Bibliography

- [1] Bonneau, D. *et al*, 2006, A & A, 456, 789.
- [2] Bordé, P. *et al.*, 2002, A & A, 393,183.