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SearchCal: a Virtual Observatory tool for searching calibrators in optical long baseline interferometry

I: The bright object case

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ABSTRACT

Context. In long baseline interferometry, the raw fringe contrast must be calibrated to obtain the true visibility and then those observables that can be interpreted in terms of astrophysical parameters. The selection of suitable calibration stars is crucial for obtaining the ultimate precision of interferometric instruments like the VLTI. Potential calibrators must have spectro-photometric properties and a sky location close to those of the scientific target.
Aims. We have developed software (*SearchCal*) that builds an evolutive catalog of stars suitable as calibrators within any given user-defined angular distance and magnitude around the scientific target. We present the first version of *SearchCal* dedicated to the bright-object case (V≤10; K≤5).
Methods. Star catalogs available at the CDS are consulted via web requests. They provide all the useful information for selecting of calibrators. Missing photometries are computed with an accuracy of 0.1 mag and the missing angular diameters are calculated with a precision better than 10%. For each star the squared visibility is computed by taking the wavelength and the maximum baseline of the foreseen observation into account.
Results. *SearchCal* is integrated into ASPRO, the interferometric observing preparation software developed by the JMMC, available at the address: http://mariotti.fr.

Key words. Techniques:high angular resolution – Techniques:interferometric– Stars: fundamentals parameters – Catalogs – Astronomical database: miscellaneous

1. Introduction

A long baseline optical interferometer measures the spatio-temporal coherence (i.e. the visibility) of the target. This measure is directly related to the Fourier transform of the object's intensity map at the spatial frequencies $\frac{\boldsymbol{B}}{\lambda}$, $\boldsymbol{B}$ being the baseline vector between two telescopes. Optical interferometry provides a powerful tool for determining the morphology of astronomical sources at high angular resolution. The modulus and the phase of the visibility are derived respectively from the contrast and the position of the fringes resulting from the recombination process.

The atmospheric turbulence and instrumental instabilities induce long-term and short-term drifts that distort the phase and decrease the amplitude of the target's visibility V_{target} by a factor Γ called the instrumental response. The observed visibility μ_{target} could then be written as

$$\mu^2{}_{target} = V^2{}_{target}\Gamma^2. \tag{1}$$

In order to take these effects into account and to convert the observed fringe contrast into true visibility, the observation of the scientific target is usually bracketed by observations of calibration stars. In practice, observing a calibration star whose visibility V_{cal} can be accurately deduced from direct or indirect determination of its angular diameter leads to a determination of Γ:

$$\Gamma = \frac{|\mu_{cal}|}{|V_{cal}|}. \tag{2}$$

It is then possible to calculate the accuracy on the target's visibility:

$$\frac{\Delta V^2_{target}}{V^2_{target}} \simeq \frac{\Delta V^2_{cal}}{V^2_{cal}} + \frac{\Delta\mu^2}{\Gamma^2}(\frac{1}{V^2_{cal}} + \frac{1}{V^2_{target}}) \tag{3}$$

where $\Delta\mu^2 \simeq \Delta\mu^2{}_{target} \simeq \Delta\mu^2{}_{cal}$ is the uncertainty on the measurement of the visibility amplitudes. Equation 3 shows that the expected accuracy on the target visibility strongly depends on the accuracy of the calibrator visibility.

A calibrator is a star for which the visibility is known (or can be predicted) with high accuracy. It should have physical properties (magnitude, spectral-type, colors) and a sky location close to those of the scientific target, so that the instrumental response during the calibrator-target-calibrator sequence could be considered as independent of the object.

The selection of suitable calibration stars is crucial to obtain the ultimate precision of the interferometric instruments. Until now, each interferometric group has had its own strategy for calibrating the observations either by using reference stars chosen case by case or using specific tools of selection. In 2002, Bordé et al. published a catalog of 374 reference stars selected from the initial list of Cohen's spectro-photometric calibrators (Cohen et al. 1999) using selection criteria adapted to infrared interferometry up to a 200 m baseline. More recently, an observing program (Percheron et al. 2003) was set up to create a list of reference stars with accurate measured angular diameters suitable for calibrating the infrared interferometric observations of the Very Large Telescope Interferometer (VLTI) instruments (VINCI, MIDI, AMBER). To prepare interferometric observations with the Palomar Testbed Interferometer (PTI) and Keck Interferometer (KI), an interferometric observation planning software *GetCal* has been developed (Boden 2003), including a tool to compute the visibility of potential reference stars taken in the Hipparcos catalog and extracting astronomical and spectro-photometric parameters from the Simbad database at the Centre de Données Astronomiques de Strasbourg (CDS)(Genova et al., 2000).

With the startup of long-baseline and large-aperture optical interferometers, such as VLTI, KI, or the CHARA array, and with the increase in the accuracy or in the range in sensitivity and angular resolution, the calibration of interferometric data requires definiting new strategies for seeking suitable calibrators and developing of selection tools usable by a larger community of astronomers.

In Sect. 2, we present our method for creating a dynamical list of stars fulfilling the requirements of interferometric calibrators for a bright scientific target($K \leq 5$). Section 3 briefly depicts the different scenarii of request to the CDS database, in order to extract the useful parameters from stellar catalogs and to sort out the initial list of possible calibration stars. Section 4 deals with the major steps in the calculations (interstellar absorption, angular diameters, visibility) for each star on the list. Some technical aspects are mentioned in Sect. 5. Finally, the current limitations of *SearchCal* and its evolution to in case of faint targets are discussed in the last section.

2. Our original method

The design of a search calibrator tool available in ASPRO (Duvert et al., 2002, Duchene et al., 2004) was guided by the goal of creating a dynamical catalog of calibration stars suitable for each scientific target. The goal was to provide a list of potential calibration stars for which the visibilities are calculated from their angular diameters and the maximum spatial frequency ($\frac{\boldsymbol{B}}{\lambda}$) of the interferometric observation. The search for calibrators must work as well for long baseline interferometric observations carried out in the visible (V band), the near infrared (J, H, or K bands), or the mid infrared (N band).

The "*Virtual Observatory*" techniques were adopted to 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 be much more adapted to the limits in magnitude of the coming interferometric facilities (VLTI with four 8 m or KI with two 10 m telescopes).

To minimize the effects of temporal and spatial variations of the seeing on the calibration process, a calibrator must be as close as possible to the scientific target. The field size on the sky is defined by the maximum difference in right ascension and declination. To be observable with the same instrumental configuration, the magnitude of the calibrator must be in a narrow range of value around the target magnitude in the observing photometric band. In order to select stars as potential calibrators, a certain number of astronomical parameters must be known for each star. These parameters are given in Table 1.

Table 1. Astronomical parameters for calibration stars

Identifiers	HIP, HD, DM numbers
Astrometry	coordinates (RAJ2000, DEJ2000), proper motion, parallax, galactic coordinates
Spectral Type	temperature and luminosity class
Photometry	magnitudes $U, B, V, R, I, J, H, K, L, M, N$
Angular diameter	measured or computed angular diameter
Miscellaneous	variability and multiplicity flags, radial velocity, rotational velocity

An on-line interface with the VizieR data base (Ochsenbein et al., 2000) at the CDS was created to extract astrometric and spectro-photometric parameters of the sources in the defined box and to obtain the initial list of stars (see details in the next section). This list is enriched by the stars present in the *Catalogue of calibrators for long baseline stellar interferometry* (Bordé et al., 2002) and the *Catalog of bright calibrator stars for 200-m baseline near-infrared stellar interferometry* (Mérand et al., 2005). If available, the measured angular diameter is obtained through the data of the *Catalog of High*

Angular Resolution Measurements (Richichi, Percheron and Khristoforova, 2005).

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.

3. The CDS interrogation

To build a dynamical list of stars, we chose to extract the information from catalogs available at the CDS. Different scenarii were implemented depending on the photometric band selected for the interferometric observations, i.e. in the visible (V band) or the near infrared (K band). For each star the astronomical parameters were extracted from the following catalogs:

- I/280: All-sky Compiled Catalog of 2.5 million stars (Kharchenko, 2001)
- II/7A: UBVRIJKLMNH Photoelectric Catalog (Morel et al., 1978)
- II/225: Catalog of Infrared Observations, Edition 5 (Gezari et al., 1999)
- II/246/out: The 2MASS all-sky survey Catalog of Point Sources (Cutri et al., 2003)
- J/A+A/413/1037: catalog J-K DENIS photometry of bright southern stars ((S. Kimeswenger et al.,2004)
- I/196/main: Hipparcos Input Catalog, Version 2 (Turon et al., 1993)
- V/50: Bright Star Catalog, 5th Revised Ed. (Hoffleit et al., 1991)
- V/36B: Supplement to the Bright Star Catalog (Hoffleit et al., 1983)
- J/A+A/393/183: Catalog of calibrator stars for LBSI (Bordé et al., 2002)
- J/A+A/433/1155: Calibrator stars for 200-m baseline interferometry (Merand et al., 2005)
- J/A+A/431/773/charm2: Catalog of High Angular Resolution Measurements (Richichi et al., 2005)

To define of the extracted data and the limitation of the number of returns, we used for each catalog the data fields defined by UCDs (Unified Content Descriptors) and labels and the limits on the data's values. Our strategy is based on two sequences of requests on the VizieR data base.

3.1. Primary request

An on-line interface with the CDS has been created to obtain the initial list of stars present in the calibrator field and with magnitudes according to the specified magnitude range. This request is done on catalog(s) called "primary catalog(s)" depending on the scenario. The primary catalogs were selected with respect to the quality of the equatorial coordinates and of the available photometry. In the case of the "visible" scenario, the choice was thus made on the compiled catalog I/280 because of the need to have a reliable value for the magnitude V and precise coordinates for stars brighter than typically $Vmag \leq 10$. For the "near infrared" scenario, it was mandatory to have the K magnitude of a star brighter than typically $Kmag \leq 5$, and the choice was made to take the compiled catalogs I/225, II/7A, and II/246 as primary catalogs. The output of this first sequence of requests is a list of star coordinates having magnitude values as specified in the defined calibrator field.

3.2. Secondary request

The second sequence of requests is done on the stars contained in the previous list and with the goal of extracting astrometric and spectro-photometric parameters. The secondary catalogs were selected because of the relevance and the reliability of the parameters of interest for our purpose. In the current version of *SearchCal*, the identifiers, the equatorial coordinates, the proper motions, the parallaxes, spectral type, and variability or multiplicity flags are extracted from the I/280 catalog. For bright stars, the visible photometry comes from I/280, whereas infrared photometry is taken from the II/7A, II/225 and II/246 catalogs. The galactic coordinates are taken from the I/196 or II/246 catalogs. The radial velocity and rotational velocity are extracted from the I/196, V/50 or V26B catalogs, respectively.

3.3. Setting the list of possible calibrators

We then parse and merge all the results in a single array of stars with all the astronomical parameters. The catalogs are first linked according to the HD number if provided and with the equatorial coordinates found in the different catalogs if they are coherent at the level of 1 arc second. The V magnitude (for V band) or the K magnitude (for infrared bands) is also used to confirm that the star present in the different catalogs is the same. The final result is a single list containing stars for which the suitable astronomical parameters have been extracted from the selected catalogs.

4. The central engine of the calibrator's parameters calculation

For the stars contained in the final list of the CDS requests, we need to compute their apparent diameters (except if they have already been measured) to determine their visibilities in the interferometric configuration. This is done in several stages: first we correct the photometry from interstellar absorption, then we compute the possible missing photometric data, and finally the apparent diameter is obtained from surface brightness relation.

4.1. Interstellar absorption

We must correct the photometric data for the wavelength-dependent effects of the galactic interstellar extinction. In the current version of *SearchCal*, all the calibrators are bright enough to have a measurement of their trigonometric parallax. For each star, the visual absorption A_V is computed as a function of the galactic coordinates (longitude l and latitude b) and of the distance d. As all calibration stars currently selected by *SearchCal* have $d \leq 1000pc$, we have used the analytic expression for the interstellar extinction in the solar neighborhood given by Chen et al. (1998).

The observed magnitudes $mag[\lambda]$ are then corrected for interstellar absorption using:

$$mag[\lambda]_0 = mag[\lambda] - A_\lambda \tag{4}$$

$$R_\lambda = A_\lambda / E(B-V) \tag{5}$$

$$A_\lambda = A_V R_\lambda / R_V \tag{6}$$

with $R_V = 3.10$ and the values of R_λ given by Fitzpatrick (1999).

4.2. Rebuilding missing photometries

The knowledge of all the $BVRIJHK$ photometry of the calibrator is useful for the interferometric observation. In particular, it could be important to have a calibrator with similar brightness to the scientific target at the observing wavelength, and the photometry will be mandatory for computing the angular diameter of the calibrator. In addition, the value of the magnitude of the calibrators in some photometric bands must be known for the needs of some housekeeping operations (fringe tracking for example).

If some photometric values are missing, we have chosen to compute them from "spectral type - luminosity class - color" relations and from existing magnitudes. Such relations exist in the literature, but in general each of them covers only certain classes of luminosity, a range of spectral type, or a limited number of photometric index. To obtain a relation linking all spectral types of all luminosity classes to $BVRIJHKLM$ photometry, we compiled the works of Bessel (1979), Bessel and Brett (1988), Fitzgerald (1970) Johnson (1966), Leggett (1992) Schmidt-Kapler et al., (1982), Thé (1990) and Wegner (1994). We adopted the Johnson photometric system according to our main source of accurate photometry (Morel & Magnenat 1978). The relation of Bessel (1983), Glass (1975) and Bessel and Brett (1988) are used to transform the other photometric systems in the Johnson one. Tables A.1, A.2, and A.3 list the adopted value of our "spectral type - luminosity class - color" relations for dwarfs, giants and supergiants stars, respectively. In Fig. 1 we show an example of our relation for the $(B-V)$ and $(V-R)$ color index. The $(B-V)$ relation is also used to check the consistency of the spectral type extracted at the CDS.

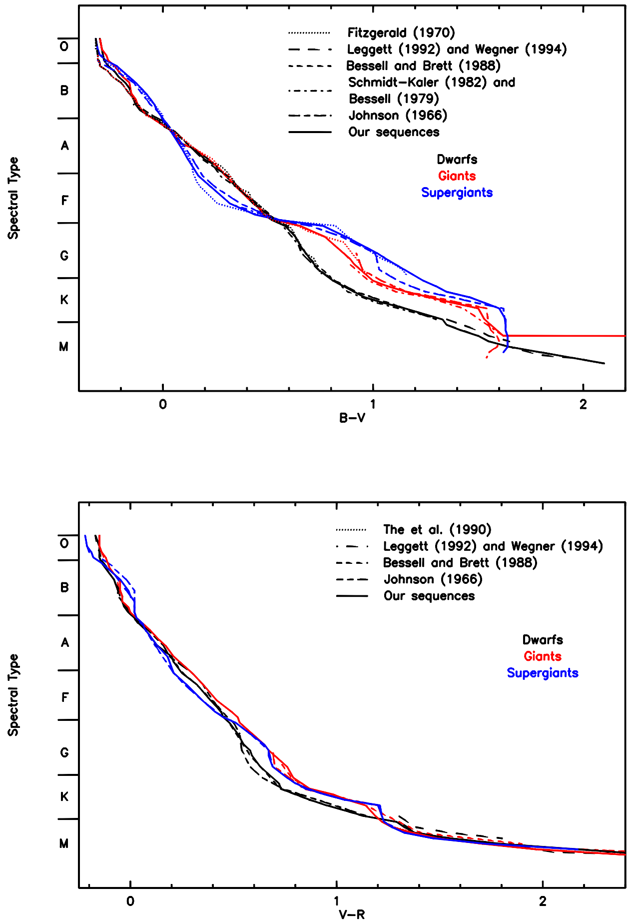


Fig. 1. Example of our "spectral type - luminosity class - color" relations used to compute missed photometry. The relation for dwarfs, giants and supergiants are shown in dark, red, and blue, respectively . Our sequences are plotted in solid lines, when the relation from which they are extracted are in different dashed lines.

To check the accuracy of the rebuilt photometry, we compare the colors of our tables with those of stars in the catalog of Ducati (2002) also in Johnson filters. Figure 2 shows an example of the O-C (difference between the color measured and computed with our relation) as a function of the spectral type. The Ducati (2002) photometry is not corrected for interstellar absorption, so a part of the dispersion is due to reddening, which is visible for the bright (and then distant) OB stars. The dispersion of the O-C is then a superior limit of the accuracy of our computed photometry. Using only the stars in the spectral type range A to K seems a good compromise for estimating our accuracy, since they are closer than OB stars so less reddened and enough bright to reduce the observational errors.

In the case of near infrared observations, we impose the knowledge of the photometry in V and K, and our

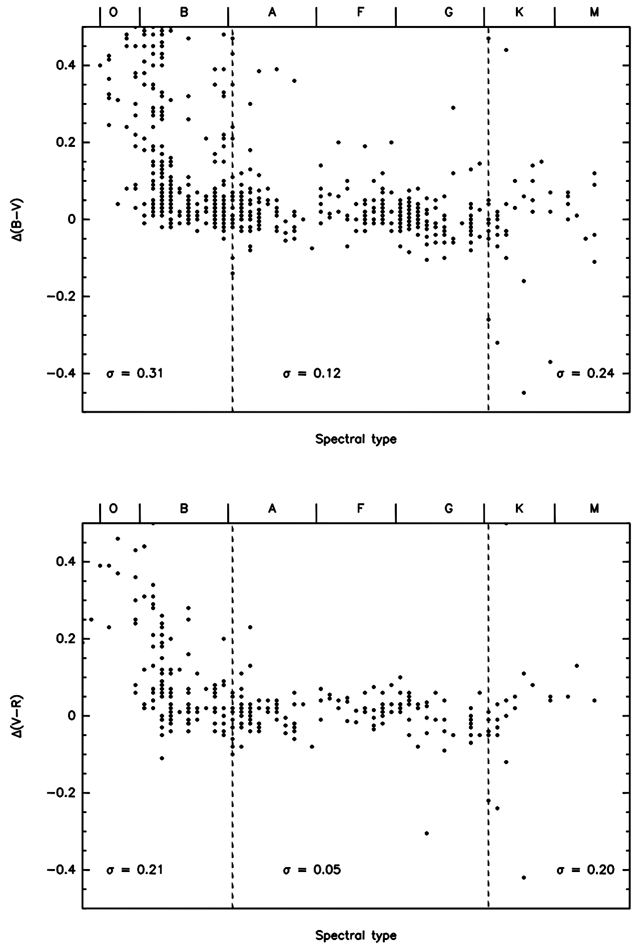


Fig. 2. Difference between measured colors of the stars in the Ducati catalog (2002) and that computed for the same spectral type and luminosity class. The rms of this O-C are given for three ranges of spectral type. Only the dwarfs are plotted in this figure, as an example.

computed complementary photometry has an accuracy of 0.1 mag or better. For visible observations, only the B and V magnitudes are mandatory, so that the determination of the missing J, H, and K has an accuracy of 0.2 mag.

4.3. Determination of the angular diameter

Since the goal was to calculate the visibility for each possible calibrator, it was necessary to know the value of its angular diameter. In some particular cases this parameter is either a measured value taken from catalog CHARM (Richichi et al., 2005) or an estimated value taken from the lists of stars of reference published by Bordé et al. (2002) or Mérand et al. (2005). These catalogs are indeed included in *SearchCal*. But in the general case no object in these catalogs complies with the specific requests of ASPRO in coordinates and magnitude range, and then the angular diameter is usually not known. A surface-brightness versus color-index relation should be used to compute angular diameter from photometry. Such relations exist in the literature (di Benedetto 1998; van Belle 1999; Kervella et al. 2004) but are determined only for a particular luminosity class or only for few a photometric indices.

Our goal was then to obtain a universal relation working for the all luminosity classes. For that purpose we used, on one hand, linear diameters and an absolute magnitude determined in eclipsing binaries (which are in general dwarfs) and, on the other, angular diameters measured from interferometry or lunar occultation (generally for giants) and apparent magnitude.

The angular diameter θ of a star of linear diameter D_* (in unit of solar diameter $D_\odot$) at the distance d (in pc) is given by:

$$\theta = Cst\frac{D_*}{d} \tag{7}$$

where Cst = 9.306 mas corresponds to the angular diameter of the sun seen at 1 pc. The distance of the star is usually a function of the apparent m_V and absolute M_V magnitudes:

$$d = 10^{(m_V - M_V + 5)/5}. \tag{8}$$

Then, we define the quantity ψ_V as:

$$\psi_V = \frac{D_*}{10^{(5-M_V)/5}} = \frac{\theta}{9.306.10^{-m_V/5}}, \tag{9}$$

where ψ_V is computed as a function of θ and m_V for stars with angular diameter measured from interferometry or lunar occultation and as function of D_* and M_v for eclipsing binary components. Then, ψ_V-versus-color-index relations were determined for the whole index of $BVRIJHK$ system using a polynomial fit for each color index (CI).

$$\psi_V = \Sigma_k a_k CI^k. \tag{10}$$

To determine our relations we compiled (i) the stellar diameter (from interferometric measurements, lunar occultation and eclipsing binaries) from Barnes et al. (1978), Andersen (1991), Ségransan et al. (2003), and Mozurkewich et al. (2003) and (ii) $BVRIJHK$ photometry (from Ducati 2002 and Gezari et al. 1999 catalogs) for a large sample of stars of spectral type O to M and for the whole luminosity class. We plan to regularly add new and more accurate measurements in our compilation, and to refresh our relation in *SearchCal*. Such relations are also very useful for other studies and will be described in detail in a forthcoming paper.

In the top of Fig. 3 we plot one example of the relation for the $(V-K)$ color. The angular diameters could then be computed by using Eqs. 9 and 10. The (O-C) (difference between the measured and the computed angular diameters) are calculated for the stars of Ségransan et al. (2003) and Mozurkewich et al. (2003). The distribution of the relative (O-C) are shown in the bottom of the Fig. 3.

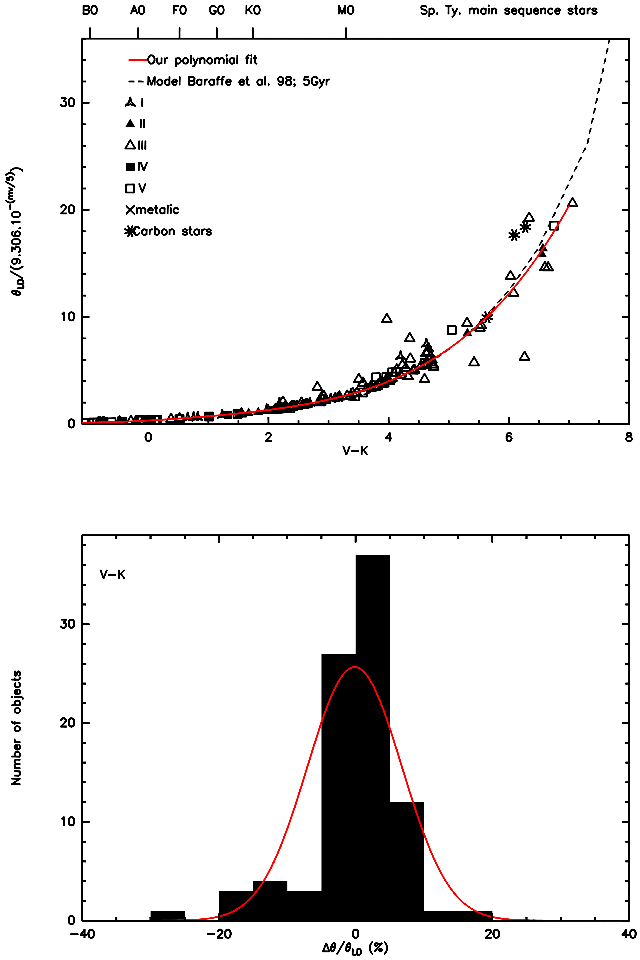


Fig. 3. top: ψ_V as a function of $(V-K)$ color. The red line is our polynomial fit. bottom: Distribution of the angular diameters (O-C) from the ψ_V versus $(V-K)$ colors relation. The red curve is a Gaussian function fitting the distribution of the (O-C). $\Delta\theta$ is the difference between angular diameters computed from our relation and measured angular diameters

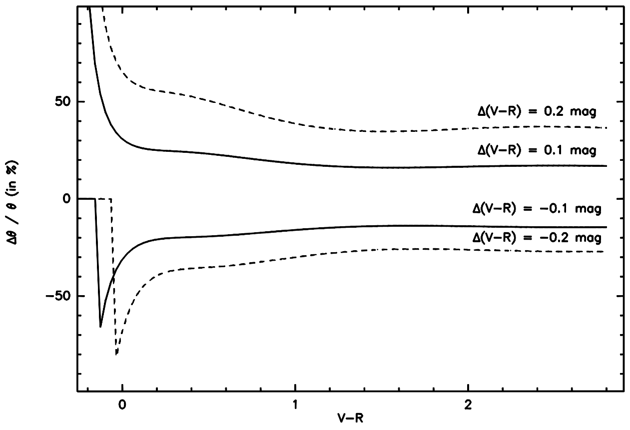


Fig. 4. Error in the determination of the angular diameter when the ψ_V versus $(V-R)$ relation is used and when the $(V-R)$ color have errors of -0.2, -0.1, 0.1, and 0.2 magnitude.

The first cause of uncertainty in the computation of the angular diameter is the variance of the calibration residuals (variance of the (O-C)). This variance includes the intrinsic dispersion of the relations, the error on the measured diameters and the error on the photometry. The three relations with the best accuracy are $\psi_V(B-V)$, $\psi_V(V-R)$, and $\psi_V(V-K)$ with an uncertainty of 8%, 10%, and 7%, respectively. We choose these three relations to determine the stellar angular diameter in *SearchCal*. The polynomial fit of these three relations are given in Table 2.

The error in the photometry is propagated in the angular diameter when a surface brightness relation is used. As already mentioned, we impose the restriction that the K magnitude of the calibrators are from observations and that the stars are in the Kharchenko (2001) catalog, where the B and V magnitudes are present. Thus, for the three colors used to determine the angular diameter, only the $(V-R)$ color is determined from our spectral type - color relation, then could have substantial error. In Fig. 4 we show the propagation of the errors in $(V-R)$ on the angular diameter.

In conclusion, our angular diameter determination has an accuracy of $\leq$10% if measured photometric data are used. When the angular diameter is computed with a $(V-R)$ calculated data, the accuracy is $\sim$20%.

For each star, a coherence test of the photometry is done by comparing the computed diameters with the different color indexes, $\theta[BV]$, $\theta[VR]$, $\theta[VK]$. The star is rejected from the list if one value of the angular diameter differs from more than 2σ from the mean value.

In the top of Fig. 3, the enhanced scattering of stars with $(V-K)>4$ (spectral types later than M0) around the polynomial fit mainly reflect an intrinsic dispersion of the photometric data for cool evolved stars. This can be related to stellar variability or to the presence of a circumstellar envelope and a color dependent variation of the computed angular diameter results. Then this type of star cannot be considered as a good calibrator, so it is rejected from the final calibrator list.

4.4. Computation of the squared visibility

The visibility of the calibrator must be computed rigorously to avoid any differential effect with the visibility of the scientific target. For wide spectral band interferometry, a monochromatic visibility can be computed for an effective wavelength taking the spectral-energy distribution of the star into account (calibrator or scientific target) across the filtered spectral bandwidth. For spectrally resolved interferometric measurements (wavelength-resolved fringes), the polychromatic visibility must be computed across the observed spectral bandwidth. In this version of SearchCal, we give only an estimation of the visibility

col. Ind.	Validity domain	a_0	a_1	a_2	a_3	a_4	a_5	Accuracy
B-V	[-0.4; 1.3]	0.33822617	0.76172888	0.16990933	-0.0803159	0.36842746	—-	8%
V-R	[-0.25; 2.8]	0.29974514	0.90469909	-0.0438167	2.32526422	-1.4324917	0.43618476	10%
V-K	[-1.1; 7.0]	0.32561925	0.31467316	0.09401181	-0.0187446	0.00818989	—-	7%

Table 2. Polynomial coefficient of the $\psi_V = \Sigma_k a_k CI^k$ relation for the three color-index retained. This relation is only defined for a given validity domain in color.

for the central wavelength of the photometric band used for the observation. Each star in the list is considered as a uniform disc. The squared visibility V^2_{cal} and its associated error ΔV^2_{cal} are computed as a function of the angular diameter θ(mas) and its error $\Delta\theta$ for the given instrumental configuration (wavelength λ(nm) and maximum baseline B_{max}(m)):

$$V^2_{cal}=|2J_1(x)/x|^2 \quad (11)$$

$$\Delta V^2_{cal}=8J_2(x)|J_1(x)/x|\Delta\theta/\theta \quad (12)$$

with $x = 15.23 B_{max}\theta/\lambda$.

To compute the visibility, the value of the diameter can either be the measured ϕ_{ud} or ϕ_{ld} taken from the catalog CHARM, the computed ϕ_{ld} given in the Catalog of Calibrators for Long Baseline Stellar Interferometry, or the photometric angular diameter $\phi[VK]$. Using θ_{ld} instead of θ_{ud} in Eq.[11] induces a bias in the computed visibility, $\delta V^2 = {V_{cal}}^2(\theta_{ud}) - {V_{cal}}^2(\theta_{ld})$ which must be estimated. With the linear representation of the limb darkening, a good approximation of the ratio θ_{ld}/θ_{ud} as function of the limb darkening coefficient u is given by:

$$\theta_{ld}/\theta_{ud}=[(1-u/3)/(1-7u/15)]^2 \quad (13)$$

with $0.0 \leq u \leq 1.0$ and then $1.0 \leq \theta_{ld}/\theta_{ud} \leq 1.12$. The bias on the visibility is maximum for a full darkened disk ($u = 1.0$) and it is always less then 5% for $x < 1.0$ and $V^2_{cal} > 0.75$ (see Table 3).

Table 3. x_{max} as a function of the maximum bias δV^2 on the computed visibility

δV^2_{max}	x_{max}
0.05	1.0
0.025	0.65
0.01	0.4

Then, for a requested accuracy ΔV^2 of the computed visibility, the bias δV^2 can be neglected if the angular diameter of the potential calibrator satisfied the condition:

$$\theta(mas) \leq x_{max}(\delta V^2)\lambda(nm)/15.23B(m) \quad (14)$$

Figure 5 shows the values of $\theta(mas)$ as function of the base length B and of the maximum bias δV^2 for the K band ($\lambda = 2.2\mu m$).

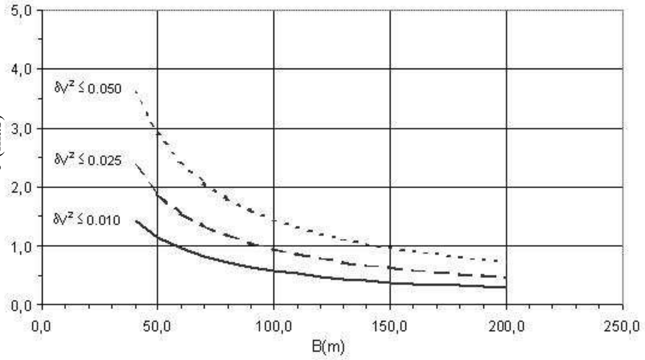


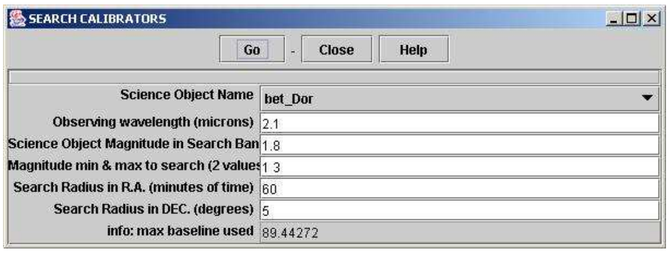
Fig. 5. The maximum value of the angular diameter allowed for a calibrator as a function of the baseline for different values of the expected visibility bias at $\lambda 2.2\mu m$.

5. Technical aspects

SearchCal has been designed as a distributed application that:

- retrieves user requests (either through a GUI interface or via an command line);
- shifts through CDS-based stellar catalogs to retrieve a large number of stellar parameters, according to various scenarii;
- computes the missing photometry, if necessary using the relations mentioned in Sect. 4;
- classifies stars as potential calibrators;
- presents the list to the user through a GUI interface and handles further requests for search refinement and sorting.

SearchCal reads and writes star catalog data in VO-Table format (standardized XML-based format defined for the exchange of tabular data in the context of the Virtual Observatory and return format of the CDS requests). The resulting VO-Tables are parsed to select the possible calibration stars using the "libgdome" XML parser. Its Graphical User Interface (GUI) is a Java applet running on the client side in any web browser. It has been developed using XML to Java Toolkit and is fully integrated in the JMMC's ASPRO Web software, allowing the user to display, sort, filter and save the catalog of calibration stars. The server side application is written in C++ using a flexible and scalable object-oriented methodology. The design allows easily the application to be updated to follow the improvements in scientific knowledge (in, e.g., the scenarii), as well as changes in the web queries and evolutions in data formats.



Science Object Name	bet_Dor
Observing wavelength (microns)	2.1
Science Object Magnitude in Search Ban	1.8
Magnitude min & max to search (2 values	1 3
Search Radius in R.A. (minutes of time)	60
Search Radius in DEC. (degrees)	5
info: max baseline used	89.44272

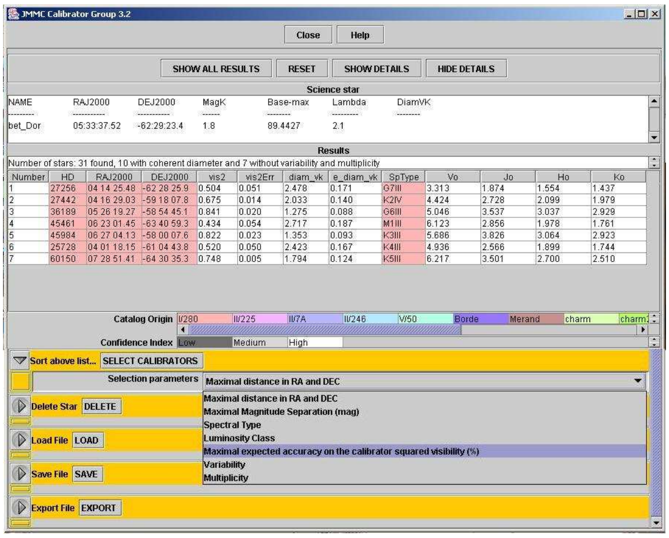
Fig. 6. Input panel of SearchCal

The input panel of *searchCal* is presented in Fig. 7. As already described, the parameters of the request are: the observing wavelength, the range of magnitude of calibrators in the observing photometric band, and the field (maximum distance of calibrators in right ascension and declination). The output panel is presented in Fig. 8. In the "result" window, a summary of the output of the request is given as three numbers: the number of stars returned from CDS request as potential calibrators, the initial number of potential calibrators selected after the coherence test of the photometry, and finally the proposed calibrators without variability or multiplicity indications in the Hipparcos catalog. The final list of calibrators is displayed in the central window. The origin of each parameter is encoded by a color code corresponding to the name of the relevant catalog. For the computed parameters (missing magnitude, angular diameter, visibility), the color code indicates the confidence level based on the quality of the photometric data. The detailed description of the tables, as well as the function of the different buttons, are given in the *SearchCal* Help available as a PDF file in the ASPRO web site.

Finally, from the final list of potential calibrators, one can refine the selection of the calibrators by changing, *a posteriori*, the parameters of the request: field around the scientific target, object - calibrator magnitude difference, spectral type and luminosity class, accuracy on the calibrator visibility, indication of variability, or multiplicity.

6. Conclusion

We have described the principles of our calibrator's selection tool dedicated for optical interferometric observations. Based on an online CDS request and a dedicated computing program, we built a powerful piece of software that is already open to the astronomical community. Our application (*SearchCal*) and the concurrent one (*GetCalWeb*) are the only software able to find suitable calibration stars in the vicinity of bright scientific targets and that are based on a dynamical approach using a Web-based interface. However, differences of strategy and method can be noted between these two softwares. In the current version of *SearchCal*, we impose the knowledge of the magnitudes V and K, whereas in *GetCalWeb*, the magnitude K is deduced from magnitude V and the spectral type. The angular diameters are calculated in *SearchCal* by a surface brightness method whereas in *GetCalWeb*, they are calculated as black bodies of the selected spectral type and of magnitude V.



NAME	RAJ2000	DEJ2000	MagK	Base-max	Lambda	DiamVK
bet_Dor	05:33:37.52	-62:29:23.4	1.8	89.4427	2.1	

Number of stars: 31 found, 10 with coherent diameter and 7 without variability and multiplicity

Number	HD	RAJ2000	DEJ2000	vis2	vis2Err	diam_vk	e_diam_vk	SpType	Vo	Jo	Ho	Ko
1	27256	04 14 25.48	-62 28 25.9	0.504	0.051	2.478	0.171	G7III	3.313	1.874	1.554	1.437
2	27442	04 16 29.03	-59 18 07.8	0.675	0.014	2.033	0.140	K2IV	4.424	2.728	2.099	1.979
3	36189	05 26 19.27	-58 54 45.1	0.841	0.020	1.275	0.088	G6III	5.046	3.537	3.037	2.929
4	45461	06 23 01.45	-63 40 59.3	0.434	0.054	2.717	0.187	M1III	6.123	2.856	1.978	1.761
5	45984	06 27 04.13	-58 00 07.6	0.822	0.023	1.353	0.093	K3III	5.686	3.826	3.064	2.923
6	25728	04 01 18.15	-61 04 43.8	0.520	0.050	2.423	0.167	K4III	4.936	2.566	1.899	1.744
7	60150	07 28 51.41	-64 30 35.3	0.748	0.005	1.794	0.124	K5III	6.217	3.501	2.700	2.510

Selection parameters: Maximal distance in RA and DEC

- Maximal distance in RA and DEC
- Maximal Magnitude Separation (mag)
- Spectral Type
- Luminosity Class
- Maximal expected accuracy on the calibrator squared visibility (%)
- Variability
- Multiplicity

Fig. 7. Output panel of SearchCal

In *SearchCal*, the limiting magnitude attainable for the selected calibrators is imposed by the magnitude of the fainter stars for which the maximum number of astrometric and spectro-photometric parameters are available in the catalogs used for this selection, i.e. typically V magnitude ≤ 10 or K magnitude ≤ 5. In practice, these limits agree with the sensitivity of the interferometers currently in operation in the visible or the near infrared. With the gain in sensitivity expected with the instruments AMBER and PRIMA on the VLTI, it will be necessary to find fainter calibrators. We have already started the development of an extended version of *SearchCal* for K magnitude > 5.

The use of UCD and VOtable, as well as the splitting of our API in three modules ("Access to CDS", "Computation", "Display"), will allow us to easily continue the development in the framework of the Virtual Observatory concept. Development of a CDS web service and display in the environment of a VO portal are foreseen in near future.

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Appendix A: Spectral type - luminosity class - color relations

Sp Ty	B-V	V-I	V-R	I-J	J-H	J-K	K-L	L-M
O5	-.30	-.42	-.17	-.31	-.08	-.14	.01	-.10
O7	-.29	-.42	-.15	-.30	-.08	-.13	.02	-.09
O8	-.28	-.41	-.15	-.28	-.09	-.14	.03	-.07
O9	-.28	-.39	-.15	-.22	-.11	-.17	.03	-.09
B0	-.26	-.37	-.14	-.21	-.11	-.17	.02	-.08
B1	-.23	-.33	-.12	-.18	-.09	-.13	-.01	-.05
B2	-.21	-.29	-.10	-.19	-.03	-.10	.00	-.05
B3	-.18	-.24	-.08	-.15	-.05	-.09	.00	-.05
B4	-.16	-.20	-.07	-.14	-.04	-.09	.01	-.04
B5	-.15	-.19	-.05	-.15	-.05	-.08	.01	-.02
B6	-.14	-.18	-.04	-.13	-.03	-.07	.03	-.03
B7	-.13	-.16	-.04	-.12	-.03	-.06	.03	-.02
B8	-.11	-.11	-.03	-.12	-.01	-.03	.03	-.02
B9	-.07	-.08	-.01	-.07	.00	-.01	.03	-.01
A0	-.02	-.01	.02	-.06	-.01	-.01	.03	.00
A1	.01	.03	.04	-.02	.00	.00	.03	.00
A2	.05	.07	.07	.02	.01	.01	.04	.01
A4	.08	.24	.11	.03	.04	.05	.05	.02
A5	.15	.33	.13	.03	.06	.08	.05	.03
A7	.20	.30	.20	.07	.08	.10	.06	.03
A8	.25	.34	.21	.09	.11	.12	.06	.03
F0	.30	.42	.25	.13	.12	.15	.06	.03
F2	.35	.51	.32	.14	.15	.19	.06	.03
F5	.44	.68	.39	.14	.22	.26	.07	.02
F7	.48	.79	.44	.16	.27	.33	.07	.02
F8	.52	.81	.45	.19	.28	.34	.07	.02
G0	.58	.84	.48	.21	.29	.35	.08	.01
G2	.63	.87	.52	.24	.31	.36	.08	.01
G4	.66	.91	.55	.24	.32	.38	.08	.01
G5	.68	.94	.58	.23	.34	.40	.08	.00
G6	.70	.97	.59	.24	.36	.43	.08	.00
G8	.74	1.06	.63	.25	.39	.48	.09	.00
K0	.81	1.14	.69	.30	.44	.53	.09	-.01
K1	.86	1.20	.72	.31	.46	.57	.10	-.01
K2	.91	1.26	.73	.34	.49	.59	.10	-.02
K3	.96	1.38	.80	.37	.53	.62	.11	-.03
K4	1.05	1.48	.87	.40	.57	.67	.12	-.04
K5	1.15	1.58	.95	.43	.60	.71	.13	-.01
K7	1.33	1.86	1.14	.43	.64	.78	.14	.06
M0	1.35	2.10	1.29	.45	.73	.92	.21	.10
M1	1.42	2.31	1.33	.52	.72	.93	.24	.13
M2	1.50	2.53	1.38	.60	.71	.93	.28	.17
M3	1.55	2.93	1.55	.75	.66	.92	.31	.20
M4	1.65	3.42	1.80	.83	.65	.94	.40	.30
M5	1.80	4.03	2.17	.95	.62	.95	.43	.35
M6	1.95	4.65	2.55	1.06	.60	.96	.46	.40
M7	2.10	5.68	3.38	1.17	.63	1.04	.53	.50
M8	—-	—-	—-	—-	.74	1.24	.68	—-

Table A.1. Adopted colors for the dwarfs, in Johnson system.

Sp Ty	B-V	V-I	V-R	I-J	J-H	J-K	K-L	L-M
O5	-.30	-.37	-.15	-.31	-.12	-.19	.01	-.05
O7	-.29	-.36	-.15	-.30	-.11	-.18	.02	-.06
O8	-.27	-.34	-.14	-.28	-.11	-.17	.01	-.07
O9	-.26	-.31	-.12	-.28	-.10	-.17	.02	-.02
B0	-.23	-.27	-.11	-.24	-.09	-.17	-.02	-.01
B1	-.21	-.25	-.10	-.20	-.09	-.18	-.01	-.01
B2	-.19	-.24	-.08	-.15	-.08	-.17	-.02	-.02
B3	-.16	-.18	-.05	-.17	-.05	-.11	-.01	-.02
B5	-.15	-.18	-.05	-.14	-.03	-.09	.01	-.02
B6	-.13	-.15	-.04	-.13	-.02	-.06	.01	-.02
B7	-.12	-.15	-.04	-.10	-.01	-.04	.03	-.02
B8	-.10	-.10	-.01	-.09	.00	-.01	.03	-.01
B9	-.07	-.05	.00	-.03	.00	-.01	.03	.00
A0	-.03	.00	.03	-.01	.02	.01	.03	.00
A1	.01	.05	.06	.01	.04	.03	.03	.00
A2	.05	.12	.09	.02	.06	.05	.03	.00
A4	.08	.22	.14	.04	.10	.11	.04	.00
A5	.15	.27	.17	.06	.12	.13	.04	.00
A7	.22	.39	.21	.10	.15	.17	.04	.00
A8	.25	.44	.24	.11	.17	.20	.04	.00
F0	.30	.54	.30	.14	.21	.24	.05	.00
F2	.35	.66	.35	.17	.25	.28	.05	.00
F5	.43	.81	.42	.22	.31	.36	.05	.00
F7	.50	.93	.49	.24	.34	.40	.06	.00
F8	.54	.98	.52	.26	.35	.43	.06	.00
G0	.65	1.03	.53	.28	.36	.45	.07	.00
G2	.77	1.10	.59	.32	.40	.49	.07	.00
G4	.83	1.16	.65	.34	.46	.55	.08	-.01
G5	.86	1.18	.67	.36	.47	.56	.08	-.01
G6	.89	1.21	.70	.37	.49	.58	.09	-.02
G7	.91	1.21	.73	.36	.49	.58	.09	-.02
G8	.94	1.22	.76	.37	.49	.58	.09	-.01
K0	1.00	1.29	.79	.40	.52	.62	.10	-.03
K1	1.07	1.39	.83	.44	.57	.68	.11	-.04
K2	1.16	1.51	.87	.46	.62	.73	.12	-.05
K3	1.27	1.75	.98	.44	.66	.82	.13	-.06
K4	1.38	1.93	1.05	.46	.72	.88	.14	-.07
K5	1.50	2.03	1.14	.64	.77	.95	.15	-.08
K7	1.53	2.14	1.19	.64	.81	.97	.15	-.09
M0	1.56	2.20	1.22	.65	.82	1.01	.15	-.09
M1	1.59	2.35	1.27	.68	.84	1.05	.16	-.10
M2	1.62	2.54	1.37	.70	.85	1.08	.18	-.12
M3	—-	2.80	1.49	.73	.88	1.13	.20	-.13
M4	—-	3.20	1.71	.86	.91	1.17	.21	-.14
M5	—-	3.64	1.97	—-	—-	1.23	—-	—-
M6	—-	4.28	2.41	—-	—-	1.26	—-	—-
M7	—-	5.03	2.97	—-	—-	1.27	—-	—-
M8	—-	5.90	3.61	—-	—-	—-	—-	—-

Table A.2. Adopted colors for the giants, in Johnson system.

Sp Ty	B-V	V-I	V-R	I-J	J-H	J-K	K-L	L-M
O5	-.32	-.46	-.22	-.25	-.15	-.18	-.03	-.01
O7	-.31	-.46	-.21	-.23	-.14	-.17	-.03	-.01
O8	-.30	-.44	-.19	-.24	-.13	-.15	-.03	-.01
O9	-.27	-.39	-.18	-.21	-.13	-.14	-.03	-.01
B0	-.22	-.31	-.14	-.17	-.11	-.12	-.01	-.01
B1	-.19	-.26	-.11	-.15	-.11	-.11	-.01	-.01
B2	-.16	-.22	-.08	-.12	-.10	-.10	.00	.00
B3	-.13	-.17	-.05	-.10	-.09	-.08	.00	.00
B5	-.08	-.09	-.01	-.06	-.06	-.06	.02	.00
B6	-.06	-.06	.00	-.03	-.06	-.06	.03	.00
B7	-.04	-.02	.02	-.02	-.04	-.02	.02	.00
B8	-.03	-.01	.02	-.02	-.05	-.02	.02	.00
B9	-.01	.02	.02	.01	-.04	-.02	.02	.00
A0	.00	.09	.03	-.01	—-	.04	.05	—-
A1	.02	.11	.06	-.01	—-	.10	.05	—-
A2	.04	.14	.07	-.02	—-	.12	.05	—-
A4	.09	.25	.13	-.03	—-	.14	.05	—-
A6	.12	.35	.18	.01	—-	.16	.05	—-
F0	.17	.41	.21	.04	—-	.19	.05	—-
F2	.23	.48	.27	.06	—-	.21	.05	—-
F5	.32	.59	.35	.08	—-	.26	.05	—-
F7	.44	.65	.41	.10	—-	.32	.06	—-
F8	.56	.72	.45	.13	—-	.36	.06	—-
G0	.76	.85	.51	.19	—-	.40	.07	—-
G2	.87	.99	.58	.22	—-	.47	.08	—-
G4	.97	1.07	.65	.28	—-	.50	.08	—-
G5	1.02	1.11	.67	.32	—-	.53	.09	—-
G6	1.06	1.12	.67	.32	—-	.53	.10	—-
G8	1.15	1.15	.69	.30	—-	.54	.11	—-
K0	1.24	1.24	.76	.34	—-	.58	.12	—-
K1	1.30	1.32	.80	.35	—-	.62	.13	—-
K2	1.35	1.40	.86	.37	—-	.66	.14	—-
K3	1.46	1.58	.94	.42	—-	.72	.14	—-
K4	1.53	1.77	1.04	.48	—-	.76	.15	—-
K5	1.60	2.10	1.21	.61	—-	.99	.15	—-
K7	1.63	2.14	1.22	.63	—-	.99	.16	—-
M0	1.63	2.17	1.23	.65	—-	.97	.17	—-
M1	1.63	2.27	1.27	.63	—-	1.02	.17	—-
M2	1.64	2.44	1.33	.64	—-	1.03	.18	—-
M3	1.64	2.79	1.47	.72	—-	1.07	.19	—-
M4	1.64	3.39	1.73	.86	—-	1.02	.20	—-
M5	1.62	4.14	2.17	.89	—-	1.02	.25	—-

Table A.3. Adopted colors for the supergiants, in Johnson system.