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SearchCal: a Virtual Observatory tool for Searching Calibrators for 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 observables which can be interpreted in terms of astrophysical parameters. The selection of suitable calibration stars is crucial to obtain the ultimate precision of interferometric instruments like the VLTI. Potential calibrators must have spectro-photometric properties and sky location close to those of the scientific target.

Aims. We have developed a software (*SearchCal*) that builds an evolutive catalog of stars suitable as calibrators within some user-defined angular distance and magnitude around the scientific target. We present the first version of *SearchCal* that is dedicated to the bright object case (V≤10; K≤5).

Methods. Star catalogs available at CDS are consulted via web requests. They provide all the useful information for the selection 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 into account the wavelength and the maximum baseline of the foreseen observation.

Results. *SearchCal* is integrated into ASPRO the interferometric observing preparation software developed by the JMMC, available at the address: http://mariotti.fr.

Key words. Optical Interferometry – Virtual Observatory – Software

1. Introduction

A long baseline optical interferometer gives a measure of 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 to determine the morphology of astronomical sources at high angular resolution. The modulus and the phase of the visibility are respectively derived 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 which 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 into account these effects 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:

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

where $\Delta\mu^2 \simeq \Delta\mu^2{}_{target} \simeq \Delta\mu^2{}_{cal}$ is the uncertainty on the measurement of the visibility amplitudes.

The equation 3 shows that the expected accuracy on the target visibility strongly depends of the accuracy on the calibrator visibility.

A calibrator is a star for which the visibility is known (or can be predicted) with a high accuracy. It should have physical properties (magnitude, spectral-type, colors) and 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 to calibrate the observations either by using reference stars chosen case by case or using specific tools of selection. In 2002, Bordé et al. have 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 200 m baseline. More recently, an observing program (Percheron et al. 2003) has been accomplished to get a list of reference stars with accurate measured angular diameters suitable to calibrate 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 of the accuracy or of the range in sensitivity and angular resolution, the calibration of interferometric data requires the definition of new strategies to search suitable calibrators and the development of selection tools usable by a larger community of astronomers.

In Section 2, we present our method for creating a dynamical list of stars fulfilling the requirements of interferometric calibrators for a bright scientific target($K \leq 5$). The 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 the initial list of possible calibration stars. Section 4 deals with the major steps of the calculations (interstellar absorption, angular diameters, visibility) for each star of the list. Some technical aspects are mentioned in the Section 5. Finally, the current limitations of *SearchCal* and its evolution to the 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) has been 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, Hor K bands) or the mid infrared (N band).

The "*Virtual Observatory*" techniques have been 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 firstly 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 small 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 stars. These parameters are given in the 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 CDS has been 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 of 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 $(B-V)$, $(V-R)$ 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 is 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

3.1. The different scenarii

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

For the definition of the extracted data and the limitation of the number of returns, we have 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.

3.2. Primary request

An on-line interface with 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" depending of the scenario. The primary catalogs have been 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 necessity 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 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 request is a list of star coordinates having magnitude values as specified in the defined calibrator field.

3.3. Secondary request

The second sequence of request 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 and 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 in II/7A, II/225 catalogs and II/246 catalogs. The galactic coordinates are taken from I/196 or II/246 catalogs. The radial velocity and rotational velocity are extracted respectively from the I/196, V/50 or V26B catalogs.

3.4. 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 linked first 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 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:

$$mag[\lambda]_0 = mag[\lambda] - A_\lambda \quad (4)$$

$$R_\lambda = A_\lambda / E(B-V) \quad (5)$$

$$A_\lambda = A_V R_\lambda / R_V \quad (6)$$

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

4.2. Rebuilding missing photometries

If some photometric values are missing, we 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, or range of spectral type, or a limited number of photometric index. To obtain a relation linking all spectral types of all luminosity classes to $BVRIJHJLM$ photometry, we have 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 have 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. The table A.1, A.2 and A.3 list the adopted value of our "spectral type - luminosity class - color" relations respectively for dwarfs, giants and supergiants stars.

In the figure 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 CDS.

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. The 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 *are not* corrected from 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 to estimate our accuracy, since they are closer than OB stars and then less reddened and sufficiently 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 computed complementary photometry has an accuracy of 0.1 mag or better. For visible observations, only the B and V magnitudes are mandatory, then the determination of the missing J, H and K has an accuracy of 0.2 mag.

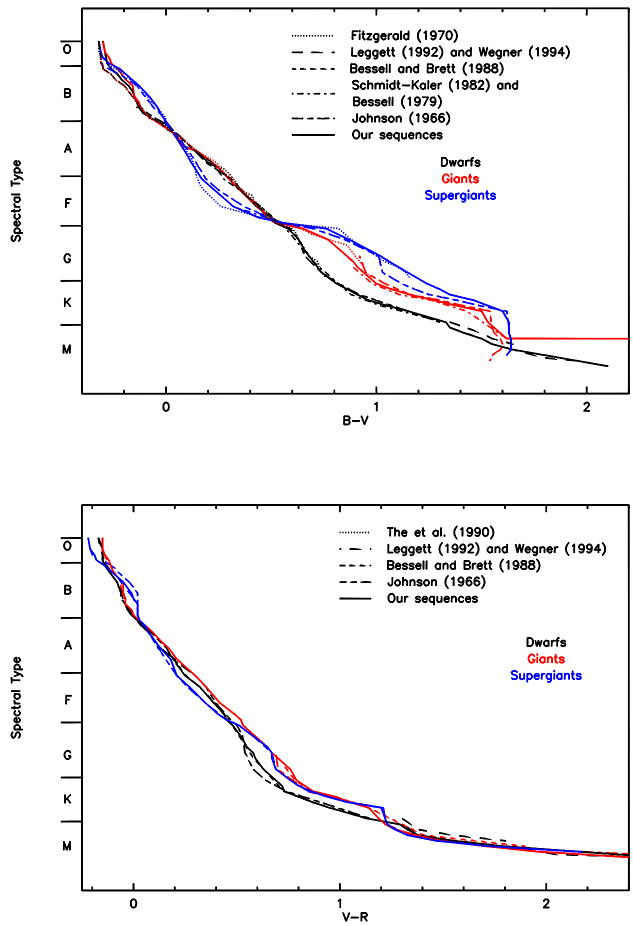

Fig. 1. Example of our "spectral type - luminosity class - color" relations used to compute missed photometry. The relation for dwarfs, giants and supergiants are respectively showed in dark, red and blue. Our sequences are plotted in solid line, when the relation from which they are extracted are in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

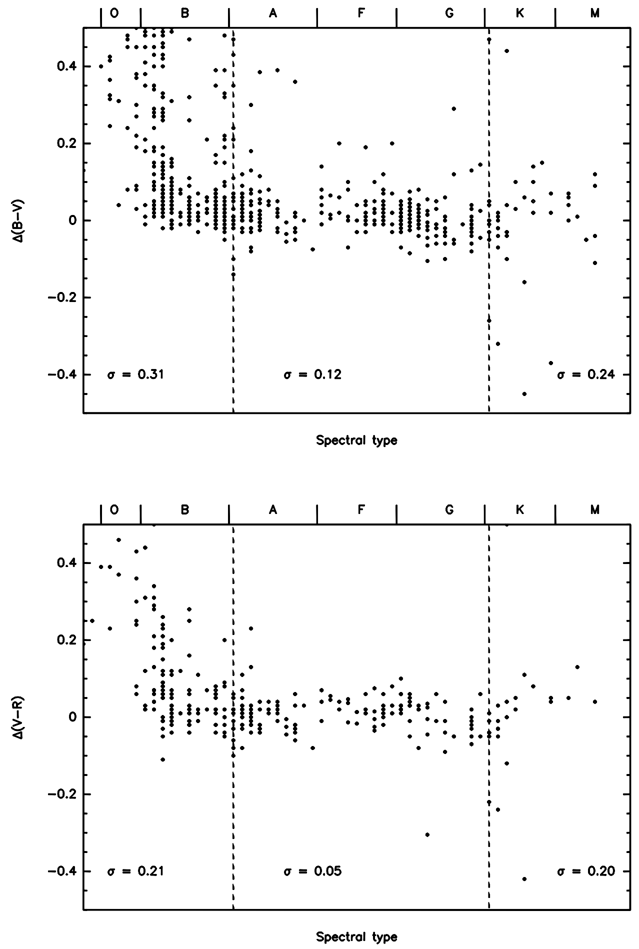

Fig. 2. Difference between measured colors of the stars in the catalog of Ducati (2002) and that computed for the same spectral type and luminosity class. The rms of this O-C are given for three range of spectral type. Only the dwarfs are plotted in this figure, as an example.

4.3. Determination of the angular diameter

The goal being to calculate the value of the visibility for each possible calibrator, it is 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 from 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 they are determined only for particular luminosity class or only for few photometric index.

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

The angular diameter θ and 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:

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

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 have been determined for all the index of $BVRIJHK$ system using a polynomial fit done for each color index (CI).

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

To determine our relations we have compiled 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 $BVRIJHK$ photometry (from Ducati 2002 and Gezari et al. 1999 catalogs) for a large sample of stars of spectral type O to M and for all the luminosity class. We plan to regularly add in our compilation new and more accurate measurements, and refresh our relation in *SearchCal*. Such relations are also very useful for other studies and they will be described in details in a forthcoming paper.

In the top of the figure 3 we plot one example of the relation for the $(V-K)$ color. The angular diameters could then be computed by using Eq. 9 and Eq. 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 figure 3.

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

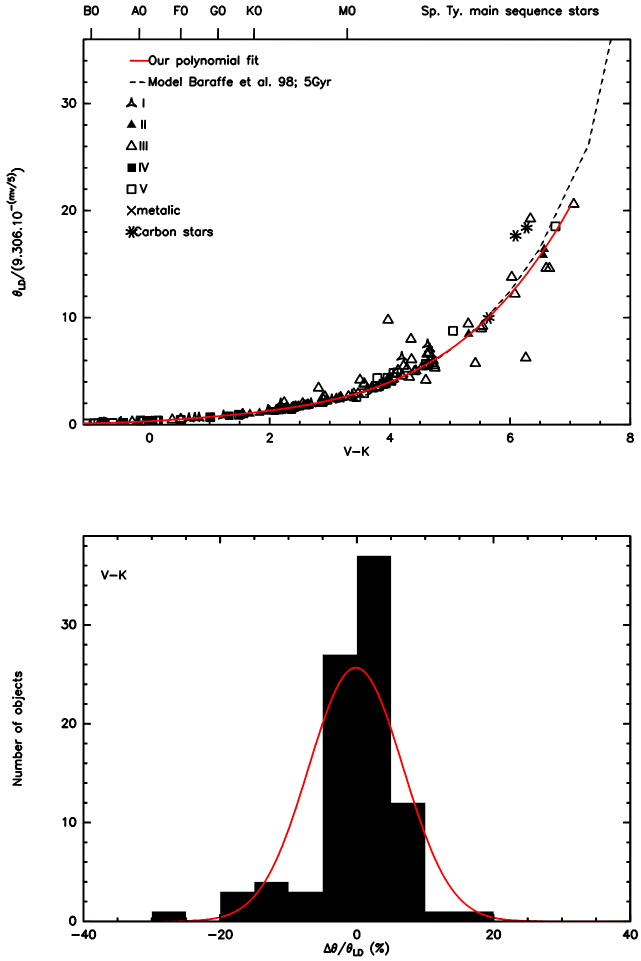

Fig. 3. top: ψ_V as a function of $(V-K)$ colors. The red line is our polynomial fit. bottom: Distribution of the angular diameters (O-C) from the ψ_V versus $(V-K)$ colors relation. The red curve is a gaussian function fitting the distribution of the (O-C). $\Delta\theta$ is the difference between angular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

intrinsic dispersion of the relations, the error of the measured diameters and of the photometry. The three relations with the best accuracy are the $\psi_V(B-V)$, $\psi_V(V-R)$ and $\psi_V(V-K)$ ones with respectively an uncertainty of 8%, 10% and 7%. 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 that the K magnitude of the calibrators are from observation and that the stars are in the Kharchenko (2001) catalog, where the B and V magnitudes are present. So, for the three colors used to determine the angular diameter, only the $(V-R)$ one is determined from our spectral type - color relation, and then could have substantial error. In the figure 4 we show the propagation of the errors in $(V-R)$ on the angular diameter.

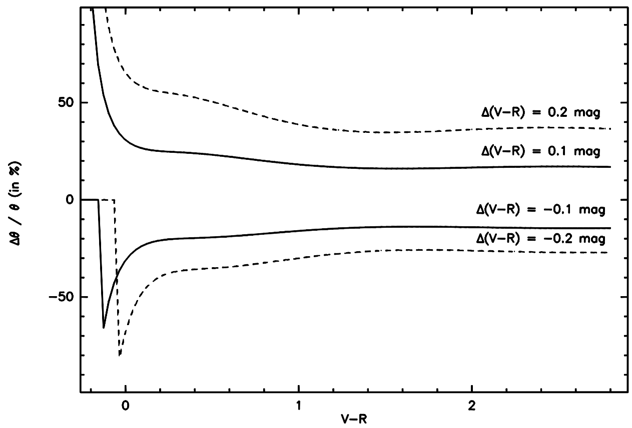

Fig. 4. Error in the determination of the angular diameter when the ψ_V versus $(V-R)$ relation is used and that $(V-R)$ magnitude have errors of -0.2; -0.1; 0.1 and 0.2 magnitude.

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 comparison of the computed diameters with the different color index, $\theta[BV]$, $\theta[VR]$, $\theta[VK]$. The star is rejected from the list if one value of the angular diameter differs from more than 2σ from the mean value. Indeed a color dependent variation of the computed diameter can be related to the stellar variability or to the presence of an circumstellar envelope, and then the star cannot be considered as a good calibrator.

4.4. Computation of the squared visibility

Each star of the list is considered as an 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 $x=15.23B_{max}\theta/\lambda$.

To compute the visibility, the value of the diameter can be either 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 the equation [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:

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

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 colors index retained. This relation are only defined for a given validity domain in color.

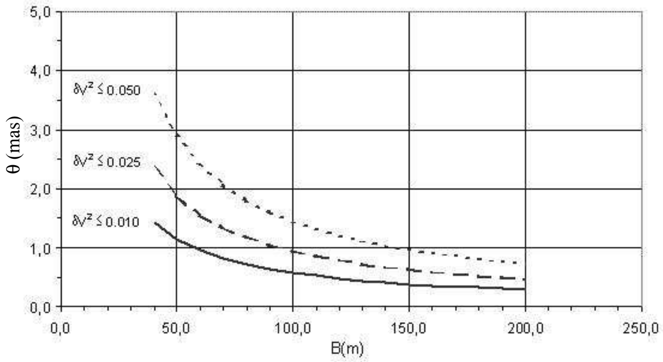

Fig. 5. The maximum value of the angular diameter allowed for a calibrator as function of the baseline for different values of the expected visibility bias at $\lambda 2.2 \mu m$.

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

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;
– compute the missing photometry if necessary using the relations mentioned in section 4;
– classifies stars as potential calibrators;
– present the list to the user through a GUI interface, and handle 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).

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 to update easily the application to follow the improvements of scientific knowledge (in, e.g., the scenarii) as well as changes in the web queries and data format evolutions.

The input panel of *searchCal* is presented on 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 on 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 indication 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 gives an indication of 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

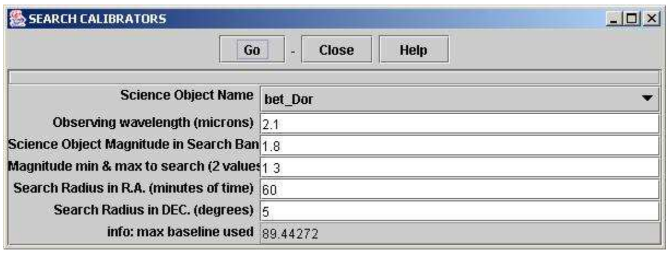

Fig. 6. Input panel of SearchCal

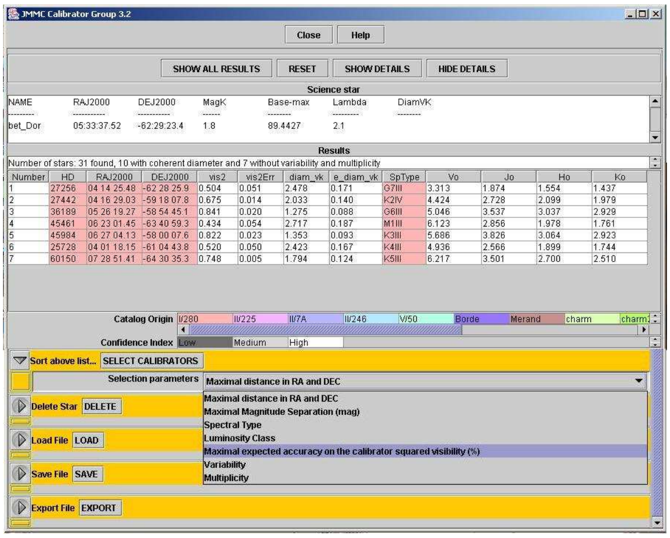

Fig. 7. Output panel of SearchCal

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 on a dedicated computing program, we have build a powerful software already open to the astronomical community. Our application (*SearchCal*) and the concurrent one (*GetCal*) are the only softwares to find suitable calibration stars in the vicinity of bright scientific targets that are based on a dynamical approach and 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 *GetCal*, the magnitude K is deduced from the magnitude V and the spectral type. The angular diameters are calculated in *SearchCal* by a surface brightness method whereas in *GetCal*, they are calculated as black bodies of the selected spectral type and of magnitude V.

In *SearchCal* the limiting magnitude reachable 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 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 a near future.

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References

Andersen J., 1991, A&AR 3, 91.
Barnes T.G., Evans D.S., 1976, MNRAS, 174, 489
Barnes T.G., Evans D.S., Moffet T.J., 1978, MNRAS 183, 285
Bessel, M.S., 1979, PASP 91, 589
Bessel, M.S., PASP 95, 480, 1983
Bessel, M.S. and Brett, J.M., PASP 100, 1134, 1988
Boden, A.F., Observing with the VLTI, Eds. G. Perrin and F. Malbet, 2003, EAS 6, 151
Bordé, P., Coudé du Foresto, V., Chagnon, G. and Perrin, G., 2002, A&A 393,183
Chen, B., Vergely, J.-L., Valette, B. and Carrano, G., A&A 336, 137, 1998
Cohen, M., Walker,R.G., Carter, B., Hammersley, P., Kidger, M. and Noguchi, K., 1999, AJ 117, 1864
Delfosse, W. and Bonneau, D., SF2A-2004: Semaine de l'Astrophysique Francaise, meeting held in Paris, France, June 14 - 18, 2004, in press
Di Benedetto G.P., 1998, A&A 229, 858
Ducati J. R.,VizieR On-line Data Catalog: II/237.
Duvert, G., Berio, P., Malbet, F., Proc. SPIE 4844, 60, 2002
Duchene, G., Berger, J-P., Duvert, G., Zins, G. and Mella, G., Proc. SPIE 5491, 611, 2004
Fitzgerald M.P., 1970, A&A 4, 234
Fitzpatrick, E.L., PASP 111, 63, 1999
Fouqué P., Gieren W.P., 1997, A&A 320, 799.
Genova, F., Egret, D., Bienaymé, et al., A&A 143, 1, 2000
Gezari D.Y., Pitts P.S., Schmitz M., 1999, Catalog of Infrared Observation, Edition 5
Glass I.S., 1975, MNRAS 171, 19
Johnson, H.L., ARA&A 4, 193,1966
Kervella P., Thevenin F., Di folco E., Ségransan D., 2004 A&A 426, 297
Legett, S.K., ApJSS 82, 351, 1992
Morel, M., Magnenat, P., 1978, A&A 34, 477
Mozurkewich D.,Armstrong J.T., Hindsley R.B., Quirrenbach A., Hummel C.A., Hutter D.J., Johnston K.J., Hajian A.R., Elias N.M. II, Buscher D.F., Simon R.S., 2003, AJ 126, 2502

Mérand A., Bordé P. and Coudé du Foresto, V., A&A 433, 1155
Oschenbein, F., Bauer, P. and Marcout, J., A&AS 143, 23, 2000
Percheron, I., Richichi, A. and Wittkowski, M.,2003, Interferometry for optical Astronomy II, ed. W. A. Traub, SPIE 4838, 1424
Richichi, A., Percheron, I. and Khistiforova, M., A&A 431, 773, 2005
Schmidt-Kaler, T., Landolt-Bornstein, New series, group 6 vol 2, Astronomy and astrophysics (Berlin: Spronger-Verlag), p1, 1982
Ségransan D., Kervella P., Forveille T., Queloz D., 2003, A&A 397, L5
Thé, P.S., Thomas, D., Christensen, C.G. and westerlund, B.E., PASP 102, 565, 1990
Van Belle G.T., 1999, PASP 111, 1515
Wegner, W., MNRAS 270, 229, 1994

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.