A robust approach to estimate stellar angular diameters from photometry and spectral type

A. Chelli[a], L. Bourgès[a], G. Duvert[a], S. Lafrasse[a], G. Mella[a], J-B. Le Bouquin[a], O. Chesneau[b]

[a]UJF-Grenoble 1 / CNRS-INSU, Institut de Planétologie et d'Astrophysique de Grenoble (IPAG) UMR 5274, Grenoble, F-38041, France

[b]Laboratoire Lagrange, UMR7293, Université de Nice Sophia-Antipolis, CNRS, Observatoire de la Côte d'Azur, Nice, France

ABSTRACT

Observing reference stars with a known diameter is almost the only possibility to calibrate optical interferometry observations. The JMMC Calibrator Workgroup develops methods to ascertain the angular diameter of stars since 2000 and provides this expertise in the SearchCal software and associated databases. We provide on a regularly basis the JSDC, a catalogue of such stars, and an open access to our server that dynamically finds calibrators near science objects by querying CDS hosted catalogs.

Here we propose a novel approach in the estimation of angular stellar diameters based on observational quantities only. It bypasses the knowledge of the visual extinction and intrinsic colors, thanks to the use of absorption free pseudo-colors (AFC) and the spectral type number on the x-axis. This new methodology allows to compute the angular diameter of 443 703 stars with a relative precision of about 1%. This calibrator set will become after filtering the next JSDC release.

Keywords: Stars: standard, Interferometry, Fundamental catalog; Photometry: visible, infrared; Parallaxes: trigonometric; Stars: diameters, visual extinction

1. INTRODUCTION

We present here recent theoretical improvements obtained on the method used since 2000 by the Jean-Marie Mariotti Centre for Expertise in Interferometry* in its `SearchCal` software [? ?] to estimate stellar angular diameters. Being able to estimate precisely the diameter of stars in the vicinity of a science target, everywhere in the sky, is of utmost importance to calibrate interferometric observations, at least in the visible and infrared ranges. We published a catalog of $\sim$ 40000 such stars in [?], where uncertainties of the diameters were conservatively fixed at a maximum of 10% of the diameter. We have since then followed all the error propagations rigorously in our SearchCal code, finally giving way to new concepts that minimize all possible sources of uncertainty and biases, while keeping the same overall methodology as in [?].

2. METHODOLOGY

We pursue the methodology of [? ?], in that we have no a priori model of a star (e.g., as opposed to SED fitting) and we only use low-order polynomials to describe relations between measured quantities (apparent diameters, magnitudes). Our base data is only observational: measured diameters of stars, and their associated photometries. [? ?] have shown that one can derive a polynomial function between the quantities

$$\psi V = \frac{\theta}{9.306\,10^{-m_v/5}}$$

(a compound measurement of the star apparent diameter and its apparent magnitude in any band, here V), and colors indexes between this band and all the others.

Further author information: send correspondence to jmmc-user-support@ujf-grenoble.fr

*Please visit http://www.jmmc.fr

2.1 Measured diameters database

We use a new compilation of measured stellar diameters, complete up to the most recent publications, provided by one of us (G. Duvert). The database regroups the $\sim$ 1000 apparent diameter values ever published since the first experiments by Michelson. We retained in the database the measurements obtained from visible/IR interferometry and lunar occultation only. In the publications where reported diameters are measured in several optical/IR bands, we retained the measurement with the best accuracy and favored the measurement at the longest wavelength to minimize the effect of limb-darkening correction, either applied by the author, or by us. We retrieved all the ancillary information such as photometries, parallaxes, spectral types, etc, at once by using our `GetStar` service, a specially crafted version of our `SearchCal` server[†] that fetches all relevant information in $\sim$ 20 different CDS-based catalogs (VizieR, Simbad for object and spectral types). This insures that there is no difference in origin, thus no added bias, between the database we use to derive our polynomials (see below) and those that will be used in the reverse process, on any object known by Simbad at CDS.

In the course of history the limb-darkened published values have used various limb-darkening coefficients, inserting some kind of bias in the LD values. As said, we already have minimized this bias by selecting as much as possible measurements at the longest wavelength available. We further use the published UD measurement, or retrieve the original, unpublished UD measurement from the LD value and the limb-darkening coefficient used by the authors, and convert uniformly these UD values in LD angular diameters using the recent 3D correction factors by [**?**],[**?**]

2.2 Database Filtering

Starting from the above mentioned database, we have removed all the known multiple or strongly variable stars (cepheids, miras, SBs. . .) to obtain a set of standard stars. This gave us 818 measurements and we kept stars with the following complete information: BVJHK magnitudes and errors (HIP2 and 2MASS); SIMBAD Spectral types within half a subclass precision; LD diameters and their errors. We then kept all measurements with a SNR above 5 for LDDs, giving 460 measurements corresponding to 227 distinct stars.

Our Spectral Types range from O5 to M7 in three luminosity classes: 175 dwarfs, 205 giants, 65 super giants, 15 unknown.

2.3 New Methodology

In all previous polynomial color estimates, [**?**],[**?**],[**?**], the interstellar extinction and its error must be estimated (the polynomials are valid for deredenned stars). This is without harm for bright, close stars, but becomes a problem for faint, and this possibly very remote stars, a problem studied in [**?**], enabling the "faint" mode of SearchCal.

All these approaches need, or would benefit greatly from, a precise knowledge of the luminosity class and of the absolute colors of stars, i.e., "external" assumptions. To overcome this problem, we propose a new approach based on observational quantities only [**?**]. We bypass formally the extinction computation introducing new quantities called "Absorption-free colors" (AFC). In this context, the *logarithm* of the angular diameter D is given by:

$$\lg D = 0.2 \times F_{ij} + p_{ij}(n)$$

where:

- F_{ij} is the absorption-free color (AFC) between i and j photometric bands, expressed by:

$$F_{ij} = \frac{C_j \times m_i - C_i \times m_j}{C_i - C_j}$$

- m_i is the magnitude in the band i and C_i the interstellar extinction coefficient in the same band.
- $p_{ij}(n)$ is a polynomial function of the spectral type n (expressed as numbers) which also allows to bypass the knowledge of intrinsic colors

[†] http://jmmc.fr/ betaswmgr/getstar

3. FITTING POLYNOMIAL RELATIONS

From the 5 magnitudes B, V, J, H and K we can build 10 colors, of which only 4 are statistically independent. We perform a rigorous least-square fit of the quantity $\lg(D) - 0.2 \times F_{ij}$ with a third degree polynom, using jointly the four independent colors and taking into account magnitude and LD errors plus covariances for the 460 selected measurements.

Figure **??** represents the fitted polynoms for V-K and J-K colors.

Figure 1. fit of a third degree polynomial function between 460 measurements of $\lg(D) - 0.2 \times F_{ij}$ and a simple index of increasing Spectral Types (without differentiation between Luminosity Classes), for two colors.

We will publish the fit outputs, consisting in 16 polynomial coefficients (4 per color) together with a 16×16 covariance matrix. The reduced χ^2 of our fit on the database is ~ 1.0.

4. COMPUTING MEAN DIAMETERS

For each database measurement, we estimate 4 individual diameters (1 per color) that are combined through their covariance matrix to produce the best mean diameter and its error.

We iteratively exclude from the fit all measurements where any individual diameter stands at a distance larger than 5σ from the measured diameter. We finally obtain 410 measurements corresponding to 204 distinct stars, with a reduced χ^2 (measured vs. mean computed diameter) of ~ 1.3, a value particularly good in view of the inherently discrepant nature of the observable used, that comes from a number of different sources.

Figure **??** shows the mean diameter estimate vs. the measured diameter.

Figure 2. Mean diameter estimate obtained by this method vs. the measured diameter with their error bars. Log scale is used for both axis.

5. APPLICATION TO HIP2 AND TYCHO-2 CATALOGS

We show here the application of this apparent diameter estimation on two catalogs, Hip2 (the revised version of the Hipparcos Catalog) and the more numerous Tycho-2 catalog.

As for the observational database stars, we used the GetStar software to gather the pertinent information (photometries and spectral types), in a uniform way starting uniquely from the position of the stars in these catalogs. We end with a catalog of 477000 stars which is a subset of Tycho and Hipparcos catalogs having a known spectral type, photometry and errors.

We applied the new algorithm to estimate 443703 angular diameters, ranging from 2.5 μas to 50 mas with mean diameter relative errors of 1%.

Figure **??** shows 3 panels. In the left panel, we plot the individual diameters (in 10 colors) vs. the mean computed diameter. Owing to the different limiting magnitudes and associated errors, we see a more important scatter of estimated *individual* diameters for the (fainter) Tycho stars. This is shown differently in the center panel, where we plot the diameter relative error vs. mean diameter, but conveys the same information and illustrates that important relative diameter errors concern brightest stars where 2MASS IR magnitude errors are very large (typically 0.2 mag). Finally, in the right panel, we show the histogram of residuals for all single diameters (individual vs. mean computed diameter) and the associated distribution, well represented by a gaussian of HWHM of 1 with a $\chi^2 \simeq 1.3$.

Figure 3. Application of our diameter estimates to Hip2 (red) and Tycho (black) catalogs. See text for explanations.