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

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Observing reference stars with a known diameter is almost the only way to calibrate optical interferometry data. 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.

Rigorous system analysis

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 a little less than 1000 diameter values (either Uniform Disk or Limb-Darkened Disk) obtained from visible/IR interferometry and lunar occultation only.

Of this database, we:

- remove multiple or strongly variable stars (cepheids, miras, SBs…) to obtain a set of standard stars => 818 measurements
- keep stars with the following complete information:
  - all magnitudes B V J H K and errors (HIP2 & 2MASS);
  - SIMBAD Spectral types with half a sub spectral class precision;
  - Limb-darkened diameter (LD) known or converted from UD (see Neilson et al, 2013) with SNR > 5

=> 460 measurements corresponding to 227 distinct stars

- Spectral types ranging O5 to M7
- Luminosity classes: 175 dwarfs, 205 giants, 65 super giants, 15 unknown

2. Methodology

We pursue the methodology of Bonneau et al 2006, 2011, 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). Until now, it was the logarithm of the diameter that was expressed as a polynomial function of intrinsic colors (Bonneau et al 2006, 2011; Kervella et al 2004; Boyajian 2013).

Drawback: the interstellar extinction and its error must be estimated. This implies 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 (Chelli et al. 2014, submitted). We bypass the extinction computation introducing new quantities called "Absorption Free Colors" (AFC). In this context, the angular diameter D is given by:

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

where:

- F_{ij} is the AFC between i and j photometric bands, expressed by:

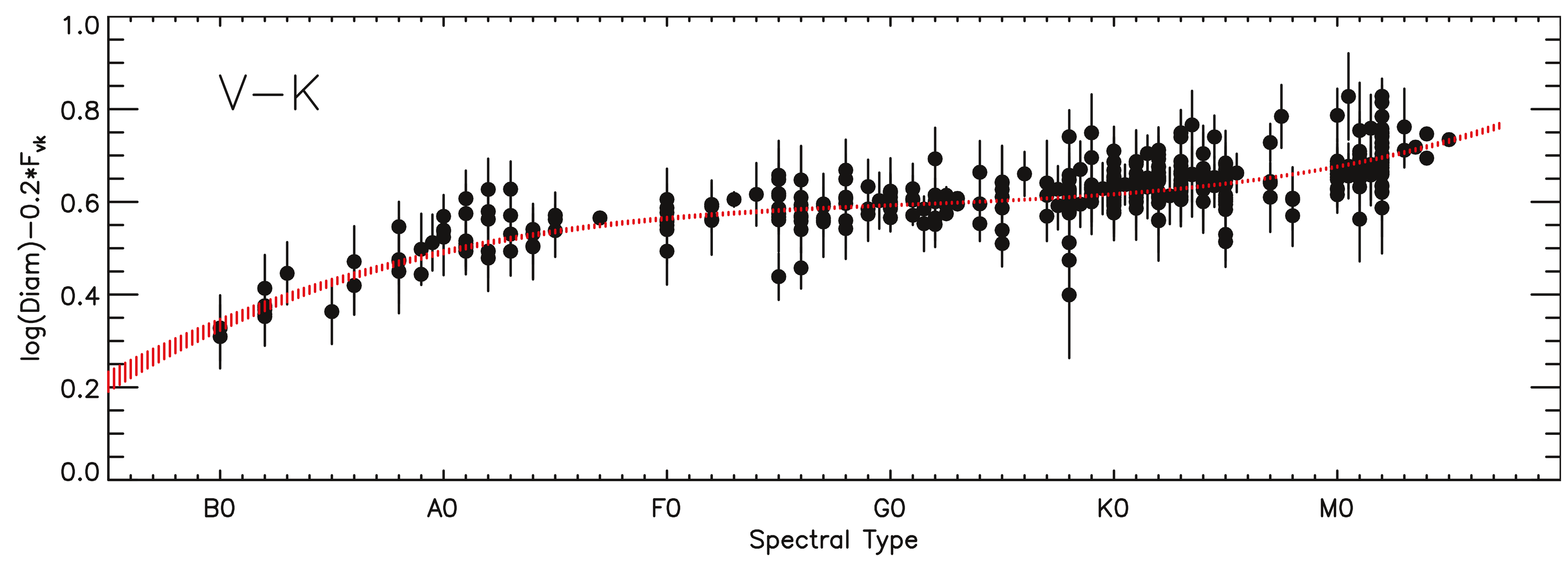
$$F_{ij} = \frac{c_j \times m_i - c_i \times m_j}{c_i - c_j}$$

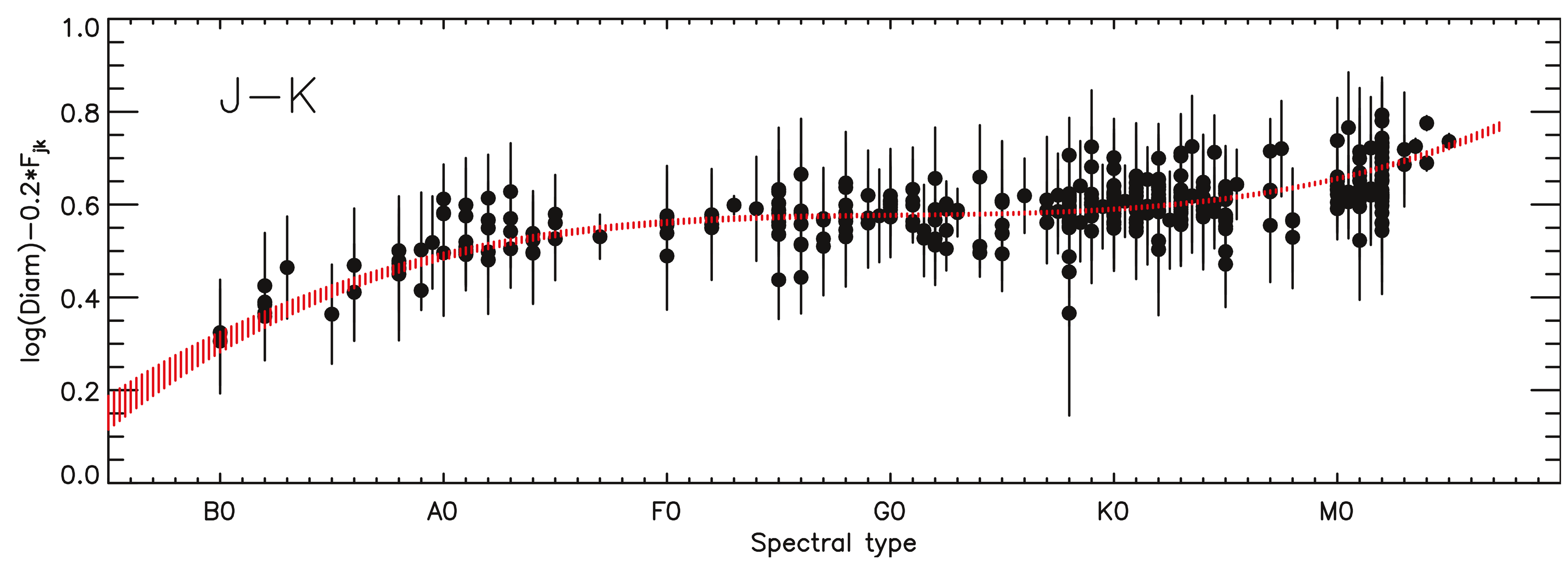
- m_i is the magnitude and c_i the interstellar extinction coefficient
- $p_{ij}(n)$ is a polynomial function of the spectral type n (expressed as numbers) which also allows to bypass the knowledge of intrinsic colors

3. Fitting polynomial relations

From the 5 magnitudes B V J H K, 10 colors may be built but only 4 are statistically independent. We perform a rigorous least-square fit of the quantity lg(D) – 0.2 x Fij with 3[rd] degree polynoms, using jointly 4 independent colors and taking into account magnitude & LD errors plus covariances for the 460 selected measurements.

The Figure represents the fitted polynoms for V-K & J-K colors:





Fit outputs:

- 16 polynomial coefficients (4 per colors) together with a 16 x 16 covariance matrix

Reduced chi2 ~ 1.0

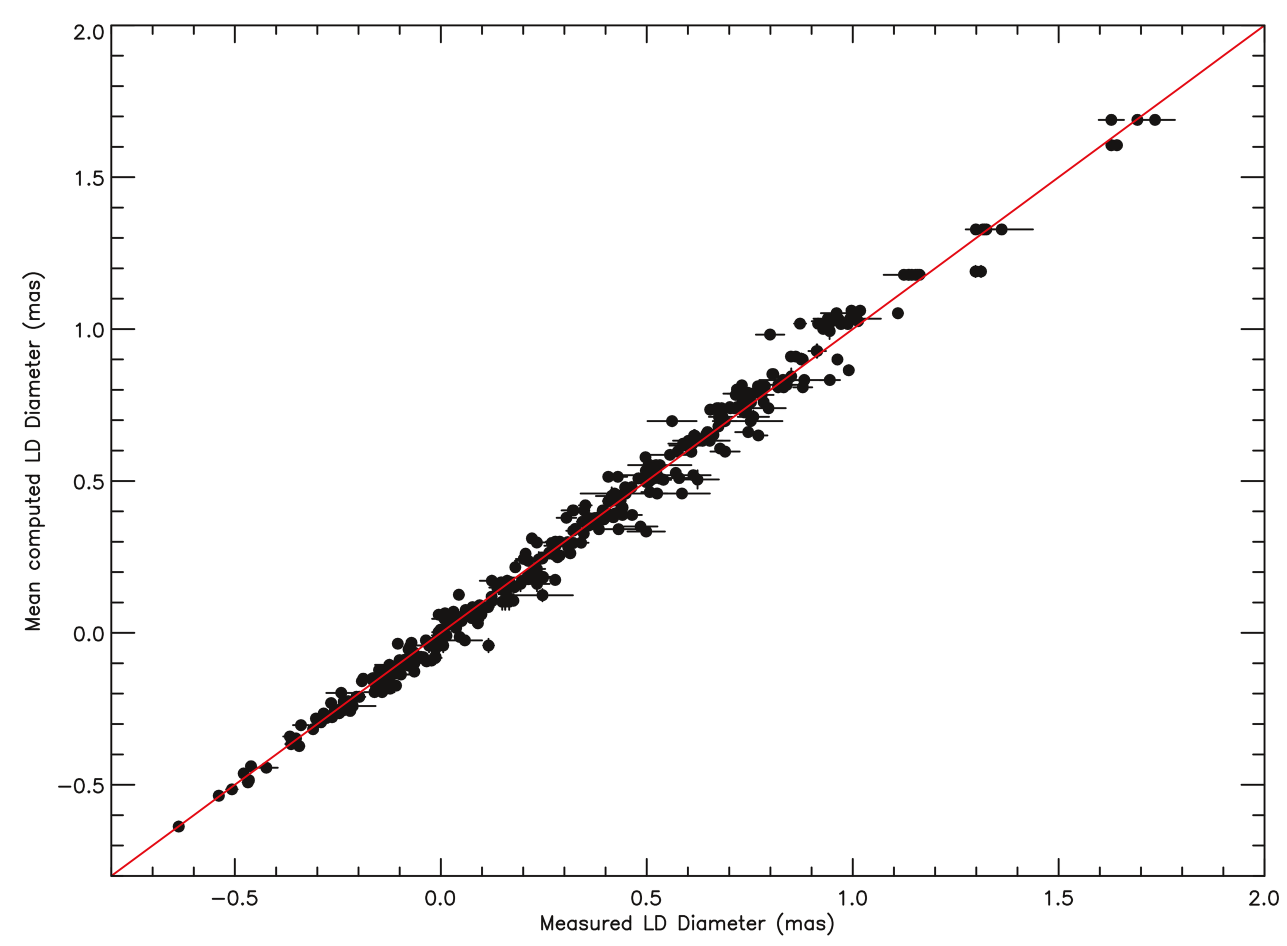
4. Computing mean diameters

For each database star, 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 5 sigma from the measured diameter. Final selection:

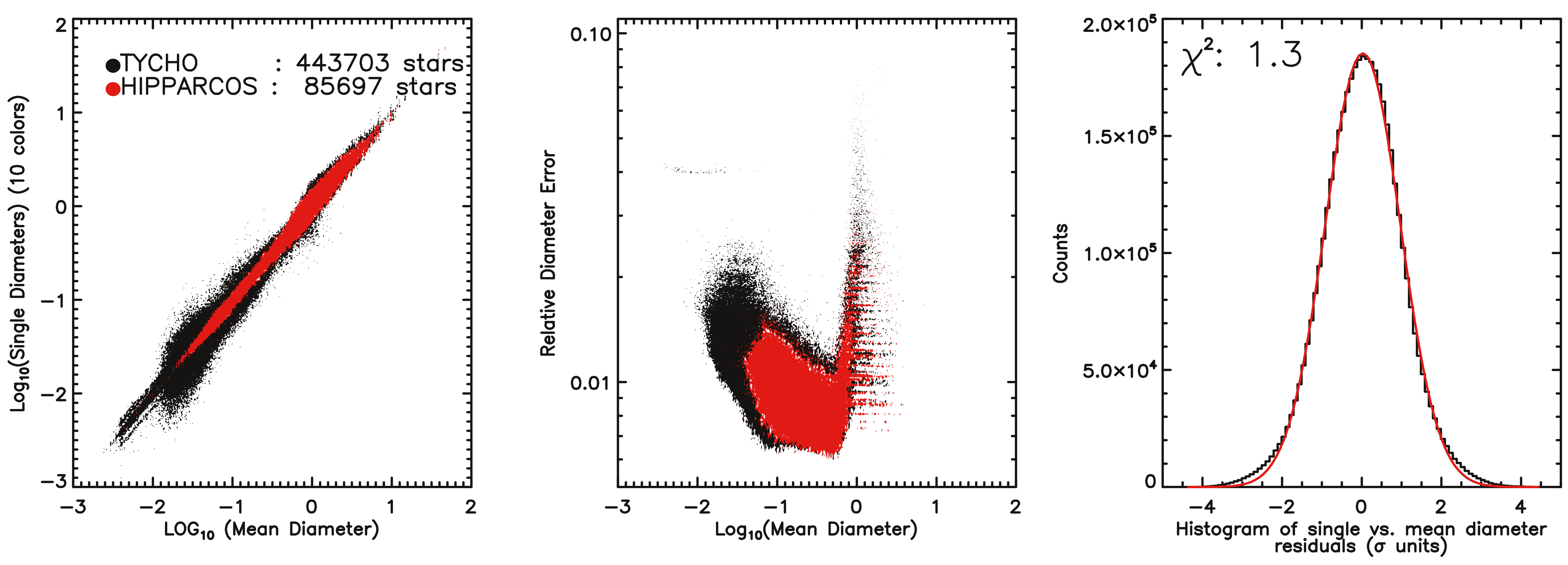
- 410 measurements corresponding to 204 distinct stars
- Reduced chi2 (measured vs mean computed diameter) ~ 1.3

The figure (log scale) shows the mean diameter estimate vs the measured diameter:



The angular diameter of stars

We used the SearchCal software to gather the pertinent information (magnitudes) from various catalogs (HIP2, ASCC, 2MASS …) and SIMBAD (spectral type). We end with a catalog of 477 000 stars which is a subset of Tycho and Hipparcos catalogs having a known spectral type.



We applied the new algorithm, ending with the results:

- Number of selected stars: **443 703**
- Angular diameter: 2.5 µas to 50 mas
- **Mean diameter relative error: 1%**
- Mean diameter chi2: 1.3

The figure shows:

- Left: individual diameters (in 10 colors) vs mean computed diameter.
- Center: diameter relative error vs mean diameter.
- Right: Residuals for all single diameters (individual vs mean computed diameter)

Acknowledgments & References: This research has made use of the **SIMBAD** database and **VizieR** catalogue access tool, **CDS**, Strasbourg, France.
TOPCAT [2005ASPC..347...29T] **& STILTS** [2006ASPC..351..666T], **Boyajian et al [2012ApJ...746..101B], Bonneau et al [2006A&A...456..789B], [2011A&A...535A..53B], Neilson et al [(2013A&A...556A..86N],[2013A&A...554A..98N].**