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

Alain Chelli, Laurent Bourgeois, Gilles Duvert, Sylvain Lafrasse, Guillaume Mella, Jean-Baptiste Le Bouquin, Olivier Chesneau

1 UJF-Grenoble I / CNRS-INSU, Institut de Planétologie et d’Astrophysique de Grenoble (IPAG) UMR 5274, Grenoble, F-38041, France
2 Laboratoire Lagrange, UMR 7293, Université de Nice Sophia-Antipolis, CNRS, Observatoire de la Côte d’Azur, Bd. de l’Observatoire, 06304 Nice, France

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.

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 ⇒ 618 measurements
- keep stars with the following complete information:
  - all magnitudes BVJHK 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).

Drafted: 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:

$$\log(D) = 0.2 \times F_j + p_j(n)$$

where:
- F_j is the AFC between i and j photometric bands, expressed by:

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

- m is the magnitude and c the interstellar extinction coefficient
- p(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 \[\log(D) - 0.2 \times F_j\] with 31-degree polynomials, using jointly 4 independent colors and taking into account magnitude & LD errors plus covariances for the 460 selectedmeasurements.

The Figure represents the fitted polynomials 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 fit (log scale) shows the mean diameter estimate vs the measured diameter.