Accurate fundamental parameters of Lower Main Sequence stars

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ABSTRACT

For a sample of 104 GK dwarfs with excellent photometry and metallicities, we compare the observed broad-band colours with those computed from the most recent synthetic libraries. We find good agreement between the computed and the observed colours in the optical bands, whereas some discrepancies still remain in the infrared.

We derive our own implementation of the InfaRed Flux Method (IRFM) to recover, from multi-band photometry, accurate effective temperatures, bolometric luminosities and angular diameters of such stars.

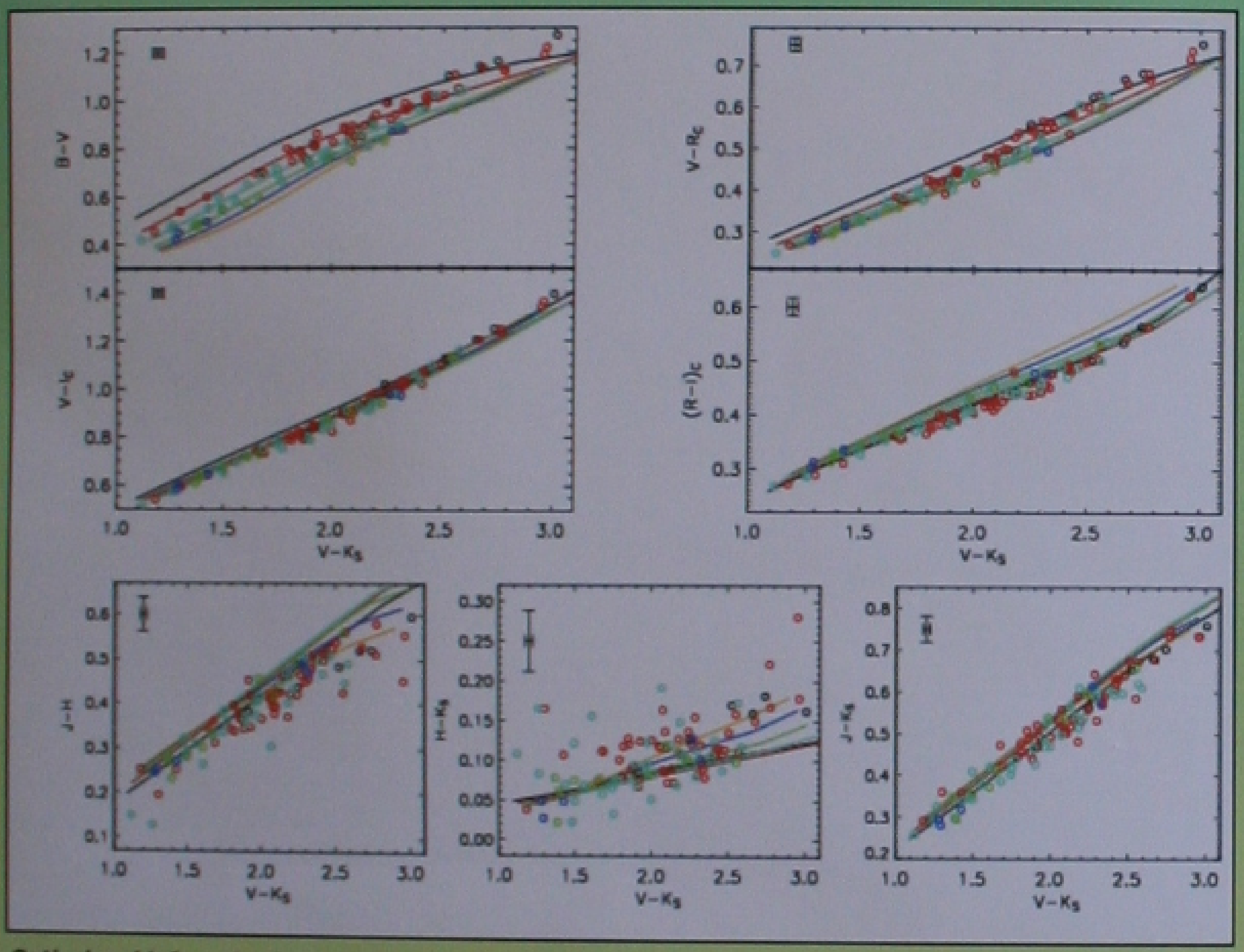
We find very tight relations between photometric indices and the fundamental physical parameters of the stars. In particular, angular diameters show remarkbly small scatter in the relation. Such relation can be used to build a network of small calibrators for future long-baseline interferometric measurements directly from Johnson-Cousins and 2MASS photometry.

Our smaller angular diameters are more in line with the limb-darkening correction predicted by the latest 3D models and also with asteroseismology.

1) To recover accurate bolometric fluxes and effective temperatures of our stars, we have obtained accurate and homogeneous Johnson-Cousins $BV(RI)_C$ and 2MASS JHK_S photometry.

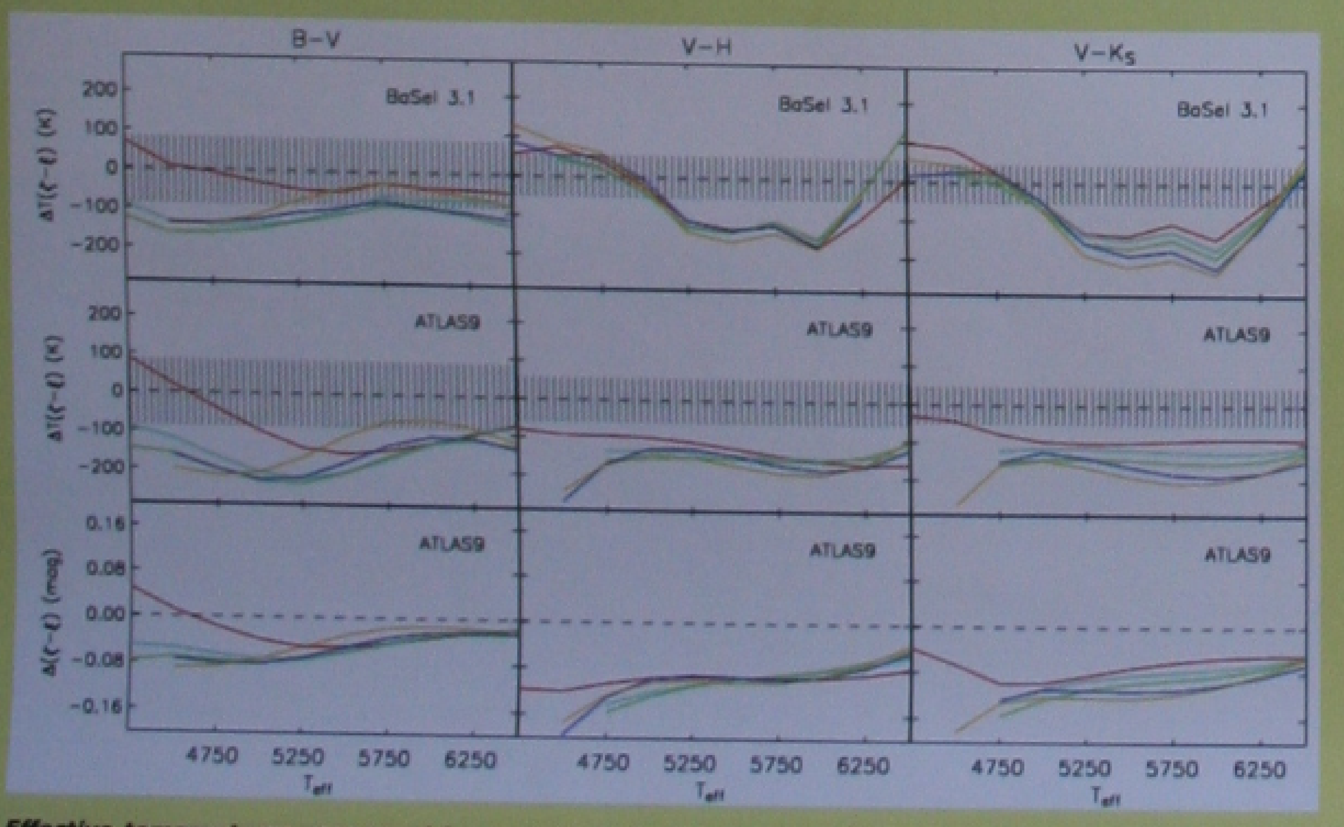
We have also gathered spectroscopic metallicities [Fe/H] from the recent literature and for most of the stars alpha-elements are also available. This permits to recover the total heavy-elements mass fraction [M/H] and it makes the comparison with theoretical models more straightforward.

2) The sophisticated physics implemented in the latest spectral synthesis codes (ATLAS9 and MARCS) leads to a remarkable good agreement between synthetic and observed colours, though small offsets still remain in the infrared.



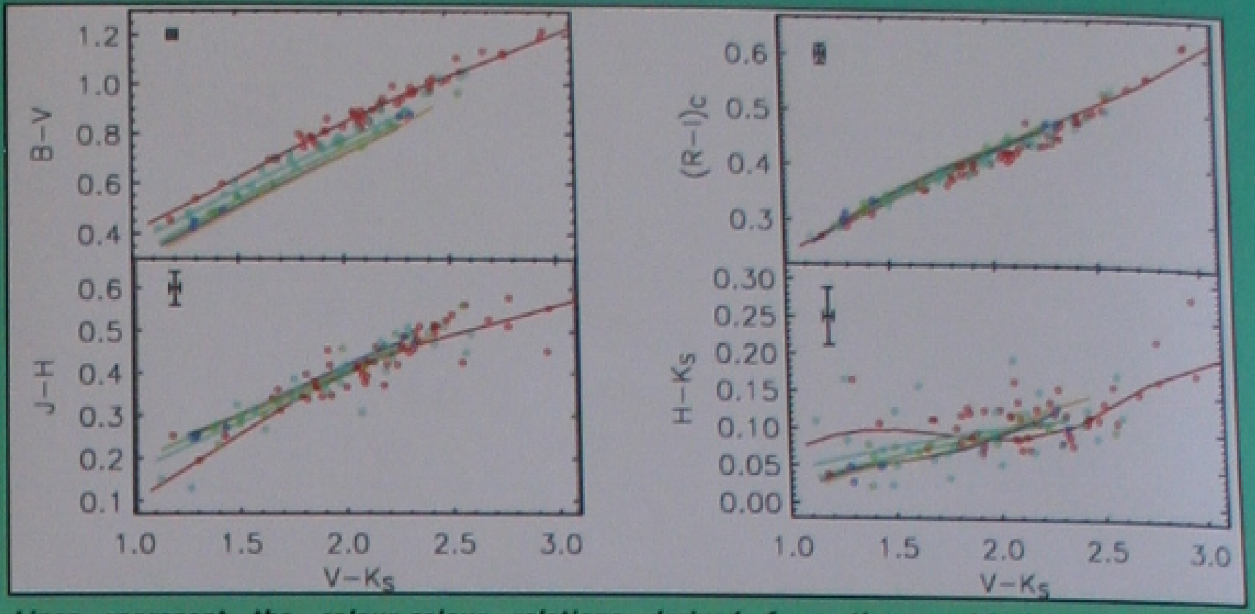
Optical and infrared colours computed from the ATLAS9 model (Castelli & Kurucz, 2003) are compared to the empirical colours for G and K dwarfs. Synthetic colours are shown for [M/H] equal to +0.5 (black line), +0.0 (red line), -0.5 (cyan line), -1.0 (green line), -1.5 (blue line), -2.0 (yellow line). Points correspond to the observed colours for the sample stars in similar [M/H] ranges.

3) Nonetheless, when colour-temperature relations (Ramírez & Meléndez, 2005) are applied to synthetic colours, the temperatures of the underlying models are recovered with a typical offset of 100 K. This is also true when semi-empirical synthetic libraries (BaSel 2.1 and 3.1) are adopted in generating synthetic colours.



Effective temperatures recovered by means of the Ramírez & Meléndez (2005) empirical calibration are compared with the effective temperature of the corresponding BaSel 3.1 and ATLAS9 models used to generate synthetic photometry. The dashed area is the standard deviation of the empirical calibration in the corresponding colours. The third row shows the shift in colours required to set the ATLAS9 models on the empirical relations. Line colours for different [M/H] same as above except that metallicities of +0.5 have been excluded since the Ramírez & Meléndez (2005) empirical relations do not hold in that range.

4) The required shifts in colours seem too large to blame model atmospheres only, especially in light of the good agreement shown in the colour-colour diagrams. At the same time, also colour-temperature relations show room for improvement.



Lines represent the colour-colour relations derived from the empirical colour-effective temperature calibrations of Ramírez & Meléndez (2005). Points correspond to our sample of stars. Colours and metallicities ranges for lines and points are same as in the previous Figures.

5) We have implemented the InfraRed Flux Method (Blackwell et al. 1977, 1979, 1980; Alonso et al. 1995, 1996) to recover effective temperatures, bolometric luminosities and angular diameters. We bootstrap the method by requiring the convergence in effective temperature.

i) From multi-band photometry

ii) From infrared photometry

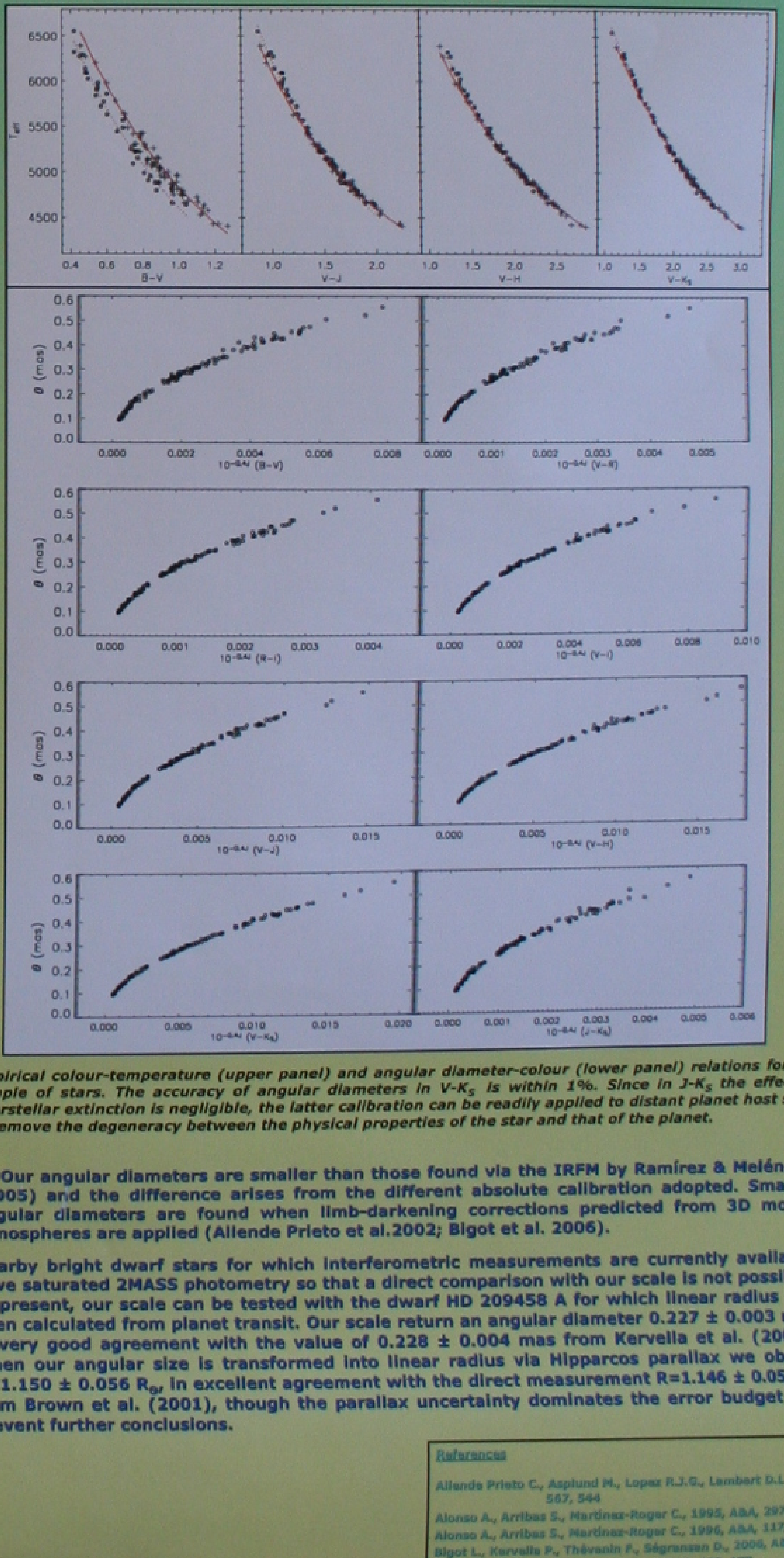
$$\frac{\mathcal{F}_{Bol}(\mathrm{earth})}{\mathcal{F}_{\lambda_{IR}}(\mathrm{earth})} = \frac{\sigma T^4_{eff}}{\mathcal{F}_{\lambda_{IR}}(\mathrm{model})}$$

iii) From model atmosphere

Since as much as 80% of the bolometric flux is directly observed through our multi-bands photometry the dependence on the adopted synthetic spectra to estimate the missing flux is small.

However the adopted absolute calibration sets the zero-point of the recovered effective temperature, bolometric luminosity and angular diameter scales.

6) The recovered scales show a high internal accuracy. Depending on the adopted photometric indices, the accuracy sets to 1% level, though the adopted absolute calibration can introduce a systematic uncertainty of comparable magnitude.



Empirical colour-temperature (upper panel) and angular diameter-colour (lower panel) relations for our sample of stars. The accuracy of angular diameters in $V-K_S$ is within 1%. Since in $J-K_S$ the effect of interstellar extinction is negligible, the latter calibration can be readily applied to distant planet host stars to remove the degeneracy between the physical properties of the star and that of the planet.

7) Our angular diameters are smaller than those found via the IRFM by Ramírez & Meléndez (2005) and the difference arises from the different absolute calibration adopted. Smaller angular diameters are found when limb-darkening corrections predicted from 3D model atmospheres are applied (Allende Prieto et al.2002; Bigot et al. 2006).

Nearby bright dwarf stars for which interferometric measurements are currently available have saturated 2MASS photometry so that a direct comparison with our scale is not possible. At present, our scale can be tested with the dwarf HD 209458 A for which linear radius has been calculated from planet transit. Our scale return an angular diameter 0.227 ± 0.003 mas in very good agreement with the value of 0.228 ± 0.004 mas from Kervella et al. (2004). When our angular size is transformed into linear radius via Hipparcos parallax we obtain $R=1.150 \pm 0.056\ R_\odot$, in excellent agreement with the direct measurement $R=1.146 \pm 0.050\ R_\odot$ from Brown et al. (2001), though the parallax uncertainty dominates the error budget and prevent further conclusions.

CONCLUSIONS

We have recovered fundamental stellar parameters in a semi-empirical way, avoiding at all the use of previously known relations. Together with the high quality of the observational data, this approach returns extremely tight relations and makes clearer the evaluation of possible biases and/or errors in the results. The zero-points of our scales depend exclusively on the adopted absolute calibration that we tie on Vega. Accurate interferometric measurements for a set of nearby solar-like stars would permit to set the absolute calibration via solar analogs directly. Besides, the shape of the visibility function in the second lobe would directly probes limb-darkening corrections.

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