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Small Telescopes Can Also Do Great Galactic Science

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ABSTRACT
Asiago Red Clump Survey (ARCS) was an observational project carried out in between 2008-2010 with 1.22 m Asiago Galileo Telescope of University of Padova. The aim of ARCS survey was to provide accurate radial velocities, atmospheric parameters, distances and space velocities for a well selected sample of Red Clump (RC) stars, distributed along the celestial equator. A catalog of 245 RC stars, 60 of them re-observed at a second epoch, used for investigation of the structure and kinematics of Galactic disk in the Solar Neighborhood. Here we present validation of ARCS survey in the framework of *Gaia* DR2 to encourage and increase Galactic studies with ground-based 1 m class telescopes.

1. Introduction

The displayed properties of RC stars make them a primary tool to investigate Galactic structure and kinematics: (i) their absolute magnitude shows minimal dispersion at optical and infrared wavelengths; (ii) they are intrinsically bright and observable throughout most of the Galaxy; (iii) in magnitude limited surveys they count for a fairly large fraction of observed targets; (iv) their spectral types make them ideal stars to measure accurate radial velocities and atmospheric chemical abundances.

For our survey project, we selected 500 RC stars according to the following selection criteria: (i) a star of spectral type between G8 III and K2 III as classified by the Michigan Project (Houk & Swift, 1999); with (ii) a high accuracy in the spectral type (quality index ≤ 2); and (iii) a blank spectroscopic duplicity index; (iv) uniformly distributed in right ascension within ±6° of celestial equator; (v) at Galactic latitude $|b| \geq 25°$. In addition we selected our target stars with (vi) valid entries both in the *Hipparcos* (ESA, 1997) and Tycho-2 catalogs; (vii) have non-negative *Hipparcos* parallaxes; (viii) avoid any other *Hipparcos* and *Tycho-2* stars closer than

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10 arcsec on the sky; (ix) within the magnitude range $7.8 \leq V_{Tycho2} \leq 9.5$; (x) have an absolute magnitude (from *Hipparcos* parallax) incompatible with either luminosity class V or I; (xi) not presented previous radial velocity surveys in the literature.

2. Observations and Data Reduction

The spectra were obtained from 2008 to 2010 with the 1.22 m Asiago Galileo telescope and B&C spectrograph of University of Padova. The 1200 ln/mm grating provided a scale of 0.61 Å/pix in between 4750-5950 Å wavelength range. The final instrumental set-up yielded R=5500 and 600s exposure time provided a $S/N > 200$ on the final extracted spectra at the faint end of the magnitude distribution of observed program stars.

The data reduction was carried out in IRAF following standard bias correction from over-scan regions, dark and flat-field corrections, sky-background subtraction, scattered light removal, wavelength calibration (from Fe-Ar comparison lamp frames exposed immediately before and after the science exposure with the telescope tracking the stars) and heliocentric correction.

3. Radial Velocities and Atmospheric Parameters

The radial velocities (RV) for program stars were obtained via cross-correlation against a set of RC stars that were also IAU RV standard stars. At least three of such IAU standard stars were observed each night together with the target stars. The RV of the latter was obtained as the mean of the cross-correlation results against all standards observed that night. The cross-correlation was performed in IRAF with the task *FXCOR*. To test the accuracies of derived RV'ies, we used a sample of 15 bright IAU RV standard stars. We derived RV by cross-correlation against all other standards observed the same night. The median dispersion of these measurements was 1.36 km/s, while the mean uncertainty of the tabulated RV'ies were 0.27 km/s. The overall accuracy of our RV determination was 1.3 km/s.

Atmospheric parameters ($T_{\rm eff}$, log g, [M/H]) were derived via χ^2 fitting to the synthetic spectral library of Munari et al. (2005), the same library as used in the analysis of RAVE spectra, which is based on the atmospheric models of Castelli & Kurucz (2003). To test the accuracy of the χ^2 fitting, based solely on observability at the telescope, we selected 47 RC stars from Hekker & Melendez (2007), 34 RC stars from Takeda et al. (2008), six RC stars from Soubiran & Girard (2005) and observed them interspersed with the program stars. The results of the comparison is given in Figure 1.

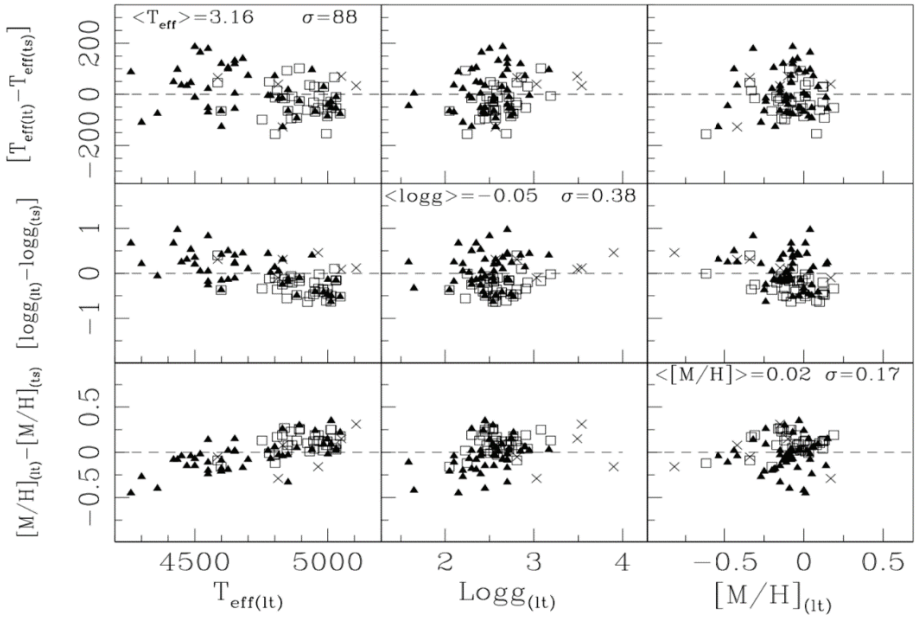

Figure 1. Differences with literature for the atmospheric parameters derived from χ^2 fitting for 87 RC stars. Empty squares are stars from Takeda et al. (2008), filled triangles Hekker & Melendez (2007) and the crosses from Soubiran & Girard (2005).

4. Validation of ARCS in *Gaia* DR2 Framework

Gaia is ESA's cornerstone mission lunched in 2013 to chart a three-dimensional map of our Galaxy. *Gaia* DR2 (Gaia Collaboration, 2018) was published in April 2018 consisting of astrometry, photometry, radial velocities and information on astrophysical parameters and variability for all sources brighter than 21 magnitude. The mean radial velocities for around 7 million sources are presented in *Gaia* DR2. Soubiran et al. (2018) presented the accuracy of mean radial velocities for a common 4290 stars in *Gaia* DR2 against radial velocities derived from five high-resolution spectrographs. The mean dispersion on RV was found 165m/s, with an offset of ~500 m/s for the reddest stars with G_{BP}-$G_{RP} \geq 1.8$, corresponding to M stars in the sample.

As the validation of ARCS data, we compared the radial velocities and effective temperatures given in *Gaia* DR2 for 246 common RC stars (Figure 2).

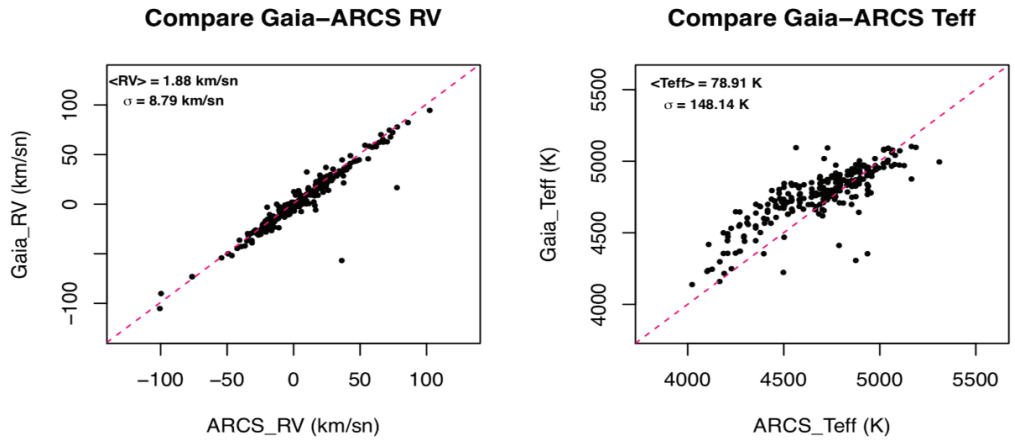

Figure 2. The comparison between the radial velocities and effective temperatures of 246 RC stars from ARCS and *Gaia* DR2.

5. Conclusions

We have presented the validation of ARCS project (Saguner et al., 2011) in the framework of *Gaia* DR2. The mean differences for $\langle RV \rangle$ = 1.88 km/s with a standard deviation σ = 8.79 km/s. There are two stars (HD 23876 and HD 123410) which has a difference greater than the mean differences for rest of the sample. The reason of that will be investigated. But if we took out those stars from the sample, the mean difference for $\langle RV \rangle$ = 1.25 kms^{-1} with a standard deviation σ = 5.29 kms^{-1}. For the effective temperatures the mean difference $\langle T_{eff} \rangle$ = 78.91 K with a standard deviation of σ = 148.14 K, which are very high compare to the overall accuracy on effective temperatures of ARCS (σ = 88 K). This difference can be due to difference methods used to derive effective temperatures for two surveys.

ARCS was performed in between 2008-2010 and since there have been several RV surveys published in the literature. One such survey is Radial Velocity Experiment (RAVE) which is currently at DR5 (Kunder et al., 2017). We also search RAVE DR5 to compare the parameters with ARCS, unfortunately we found only 10 stars in common within the RAVE framework. The differences between the radial velocities and effective temperatures are given in Figure 3. Statistically 10 sample is very low, although the mean difference for $\langle RV \rangle$ = 1.98 km/s with a standard deviation σ = 7.02 km/s and for $\langle T_{eff} \rangle$ = 77.98 K with a standard deviation of σ = 93.75 K can be found. For a survey performed with a 1 meter class telescope at a medium-resolution, the comparison of ARCS results with two the-state-of-the-art survey is very promising, confirming that with a big amount of telescope time to perform a survey, ground-based small telescopes can also be used for follow-up and complement big ground-based or space telescope survey projects for Galactic studies.

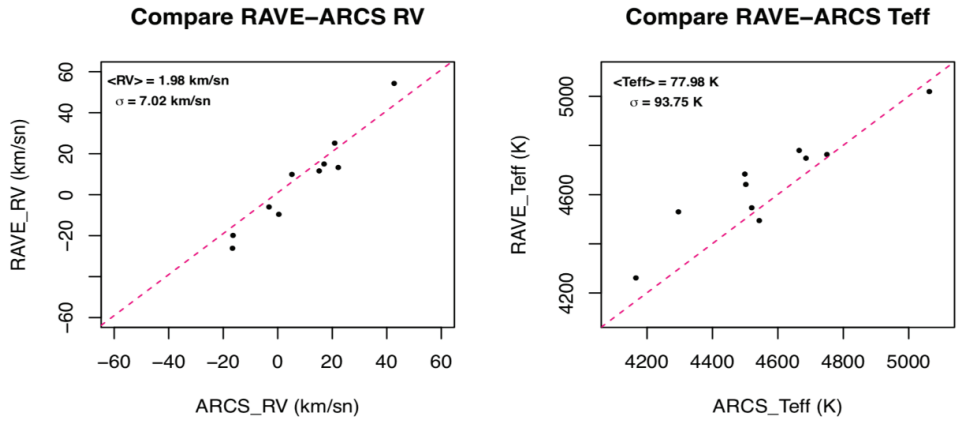

Figure 3. Comparison of radial velocities and effective temperatures for 10 common RC stars in ARCS and RAVE DR5.

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