The Penn State/Toruń Centre for Astronomy Search for Planets around Evolved Stars: Planets and Activity

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Abstract

Searches for planets around massive stars are essential for developing general understanding of planet formation and evolution of the planetary systems. The main objective of the PSU-TCfA Search for Planets Around Evolved Stars is detection of planets around G-K subgiants and giants through precision radial velocity (RV) measurements with iodine absorption cell using HET HRS spectrograph. However, the long period radial velocity variations of red giants may also have other than planetary nature (e.g. a non-radial pulsations or rotational modulation in presence of starspots). In this work we present the analysis of radial velocity, rotation velocity, existing photometry, H alpha index and line bisector measurements for a few of stars form PSU-TCfA survey. We also present our approach to determine the basic physical parameters of these stars.

Introduction

High precision stellar radial velocity measurements are extensively used to detect the reflex motion of a star due to planetary companion. Radial velocity method, however is not sensitive only to the motion of a star around the center of mass of star-planet system. Changes in line shapes arising from stellar atmospheric motion (caused by non-radial pulsation or inhomogeneous convection and/or spots combined with rotation) or from light contamination from unseen stellar companion can mimic small radial velocity variations at the spectral resolution 50 000 – 70 000 typically utilized for planet searches. Therefore it is important (especially in case of giant stars) to investigate whether the observed radial velocity curve are caused by a shift of the spectral lines as a whole or by a change in the symmetry of the spectral lines. From the same reasons precise determinations of projected rotational velocities and rotation periods of stars are very important.

Proper interpretation of results obtained from precision RV studies of GK giants also requires detailed knowledge of their physical parameters. Effective temperatures and gravitational accelerations are needed to obtain luminosities and in turn, with additional knowledge of metallicities, an estimate of stellar mass and age through isochrone fitting. Together with estimates of stellar radii and the rotation periods they allow one to address the influence of possible rotation-induced RV variations due to stellar surface inhomogeneities on results.

All other mechanism of GK-giants RV variations have to be ruled out before substellar companion interpretation may be considered. Unfortunately the long period variations, if present, cannot usually be studied using other data than existing (moderate quality) photometry or the data collected within the RV survey. Therefore the detailed activity discussion is usually based on the indicators defined on the same spectra as used for RV. In this paper we illustrate activity analysis and our approach in determination of stellar parameters in the case of a two K-giants: HD 17092 (Niedzielski, et al. 2007) and PSU-TCfA 18, a potential planet hosting star.

Observations

The observational material used in this paper are high quality, high-resolution optical spectra of 27 late-type stars observed within our survey. Observations were made with the Hobby-Eberly Telescope (HET) (Ramsey et al. 1998) equipped with the High Resolution Spectrograph (HRS) (Tull 1998) in the queue scheduled mode (Shetrone et al. 2007). The spectrograph was used in the R=60,000 resolution mode and it was fed with a 2 arcsec fiber. The spectra consisted of 46 Echelle orders recorded on the “blue” CCD chip (407.6 - 592 nm) and 24 orders on the “red” one (602 - 783.8 nm). Typical signal to noise ratio was 200-250 per resolution element. The basic data reduction and measurements were performed using standard IRAF tasks and scripts. IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

Line Bisector Analysis

A basic tool to study the origin of RV variations derived on stellar spectra is the analysis of the shapes of spectral lines via line bisectors (Gray, 1983).

We computed line bisectors for 5 strong, unblended spectral features of a moderate intensity, which were located close to the center of Echelle orders: Cr I 663.003 nm, Ni I 664.638 nm, Ca I 671.77 nm, Fe I 675.02 nm, and Ni I 676.784 nm. All these lines show well defined bisectors.

The changes in the spectral line bisector were quantified using the bisector velocity span (BVS), which is simply the velocity difference between upper and lower point of the line bisector (BVS = v(3) – v(1)) and bisector curvature (BC) which is the difference of the velocity span of the upper half of the bisector and the lower half (BC = (v(3)-v(2)) – (v(2)-v(1))). In choosing the span points, it is important to avoid the wings and cores of the spectral line where the error of the bisector measurements are large (Figure 1). For our span measurements we chose v(1)=0.29, v(2)=0.57, and v(3)=0.79 in the term of the line depth at the line core. Using the bisector measurements of all 5 spectral lines we compute an average velocity span and curvature after subtracting the mean value for each spectral line.

In Figure 3 we present mean bisector velocity span (MBVS) and mean bisector curvature (MBC) for HD 17092 and PSU-TCfA 18 as a function of orbital phase. Uncertainties in the derived values of the MBVS and MBC were estimated as standard deviations of the mean. The bisector span and curvature do not depart significantly from zero in Figure 3. In case HD 17092, because of the proximity of the orbital period to 1 yr, the 0.38 gap in phase coverage will take a long time to fill.

Hα Variations

Since our spectra start at 407.6 nm we cannot investigate the variation of the Ca II K emission line (393.4 nm). Also the infrared CaII triplet lines 849.8-854.2 are outside the range of our spectra. Therefore, we use Hα line (656.28 nm) as a chromospheric activity indicator. The EW measurements of the Hα line (Figure 2) can be made in our spectra with a typical precision of a few percent. The measurements give a mean value of 949 ± 7 mÅ in the case of HD 17092 and 1049 ± 20 mÅ in the case of PSUTCfA 18 star. The rms of 7 mÅ corresponds to 0.72% variation and rms of 20 mÅ corresponds to 2% variation in the EW. In Figure 4 we present EW Hα measurements as a function of orbital phase. The correlation coefficients between EW Hα and RV, r = -0.17 (HD 17092) and 0.44 (PSUTCfA 18) show marginal relationship (probably resulting from the non-uniform RV coverage) what supports the planetary hypothesis.

Photometric Variability

The *Hipparcos* star mapper (Tycho) made more than 120 observations of HD 17092 in V_T and B_T and also in H_T for PSUTCfA 18 between JD 2,447,915 and 2,449,039, about 12 yr before beginning of PSU/TCfA survey. We performed a deeper search for any possible periodicities in the Tycho photometry of HD 17092 and PSUTCfA 18 by computing a Lomb-Scargle periodogram of these data. None of the peaks in Figure 4 exceeds the false-positive of 0.5. In particular, no excess fluctuation power is present at the 360 (HD 17092) and 575 (PSUTCfA 18) day periods in the RV data.

The Cross Correlation Function (CCF)

We obtained the cross-correlation function by cross correlating the high S/N blue spectra with a numerical mask (since the mask is a mathematical function it does not add noise to the data). Due to different illumination of the CCD we computed cross correlation between the mask and the centers of the orders where the signal-to-noise ratio is the highest. In Figure 5 we present the spectrum, mask and the CCF for order no 5 of HD 77819 star. In the upper panel the spectrum and the mask used for the determination of the CCF (the wavelength shift between the stellar lines and the mask is due to the non-zero radial velocity of the star) are displayed. The lower panel show the CCF and Gaussian fit computed to determine local minimum of the CCF. After computing the CCFs for every order, they are adjusted to a common reference frame and co-added to get the final normalized CCF for which the FWHM is measured. The dispersion (σ) is related to FWHM as:

$$\mathrm{FWHM} = 2\,(2\ln(2))^{1/2}\,\sigma.$$

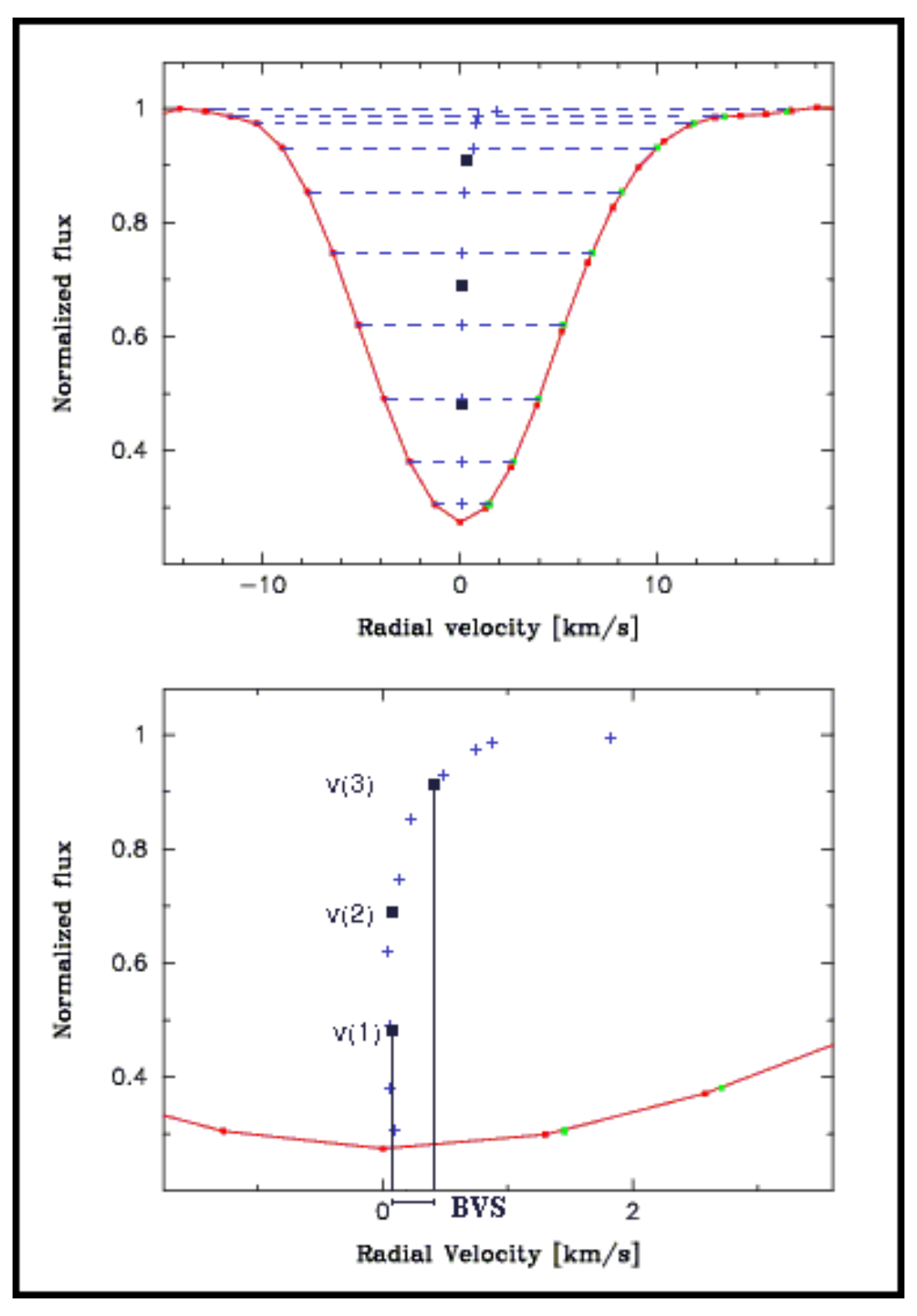

Figure 1. Schematic diagram of a spectral line bisector, illustrating the C shape (upper panel) and construction of the bisector velocity span (BVS) and bisector curvature (BC) from the v(1), v(2) and v(3) points plotted as a black squares (lower panel).

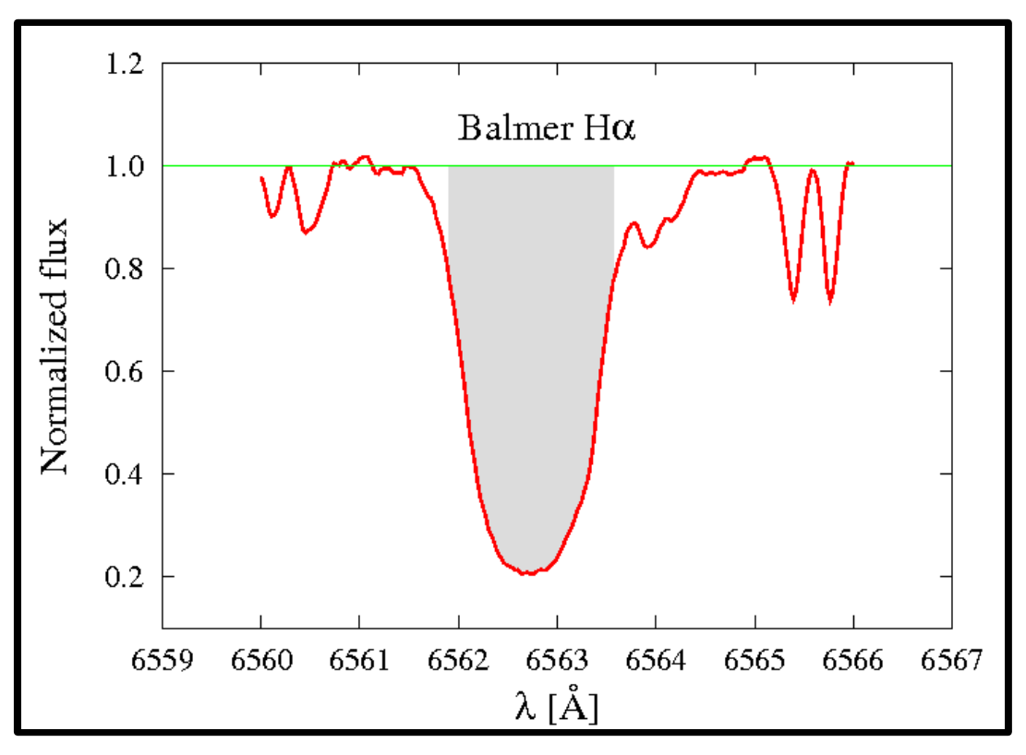

Figure 2. Definition of the Hα “equivalent width”.

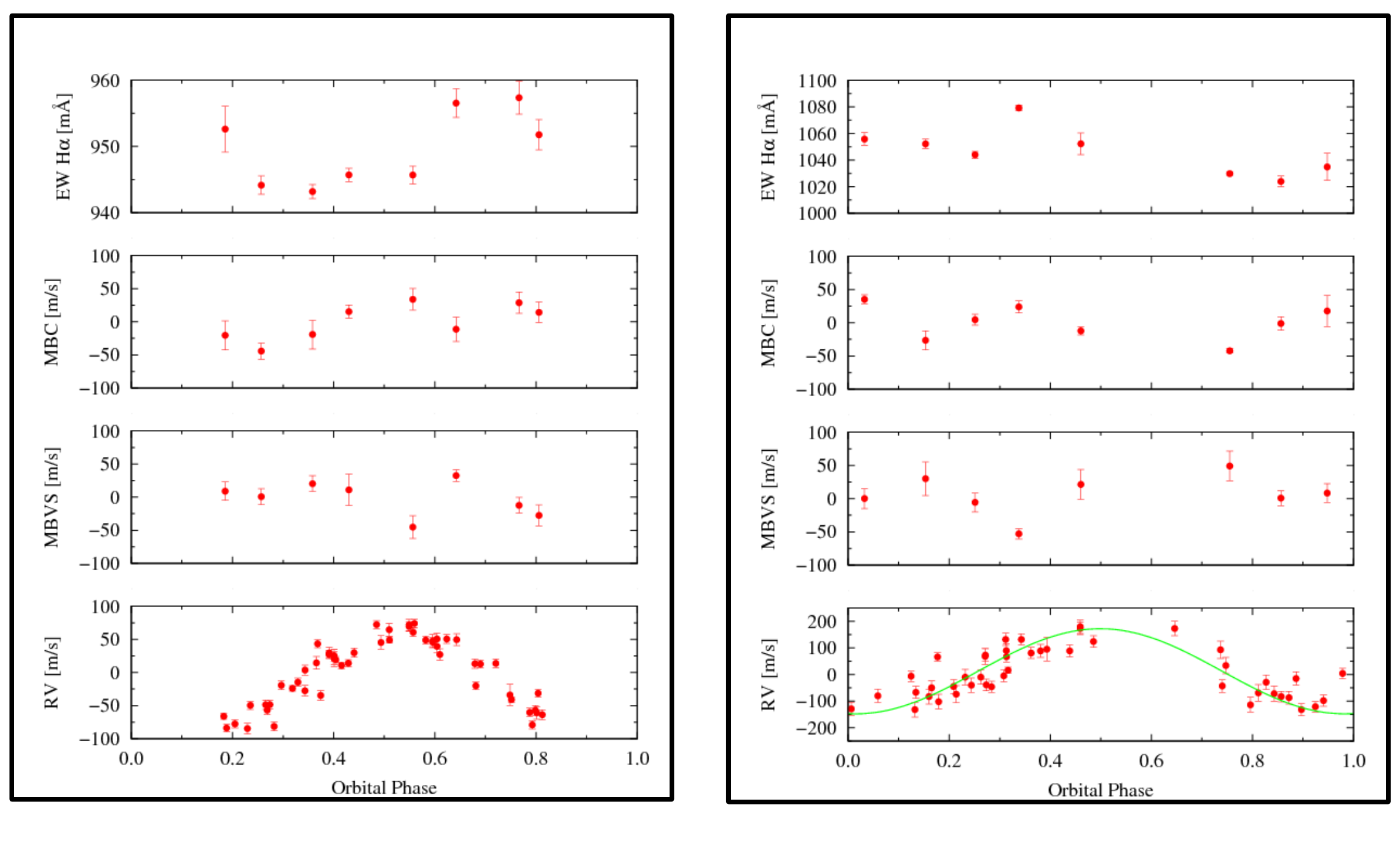

Figure 3. Mean bisector velocity span (MBVS), mean bisector curvature (MBC) and equivalent width of the Hα line (EW Hα) for HD 17092 (left) and PSU-TCfA 18 (right), binned as a function of orbital phase at the 0.1 interval, and compared to the measured radial velocities of the stars.

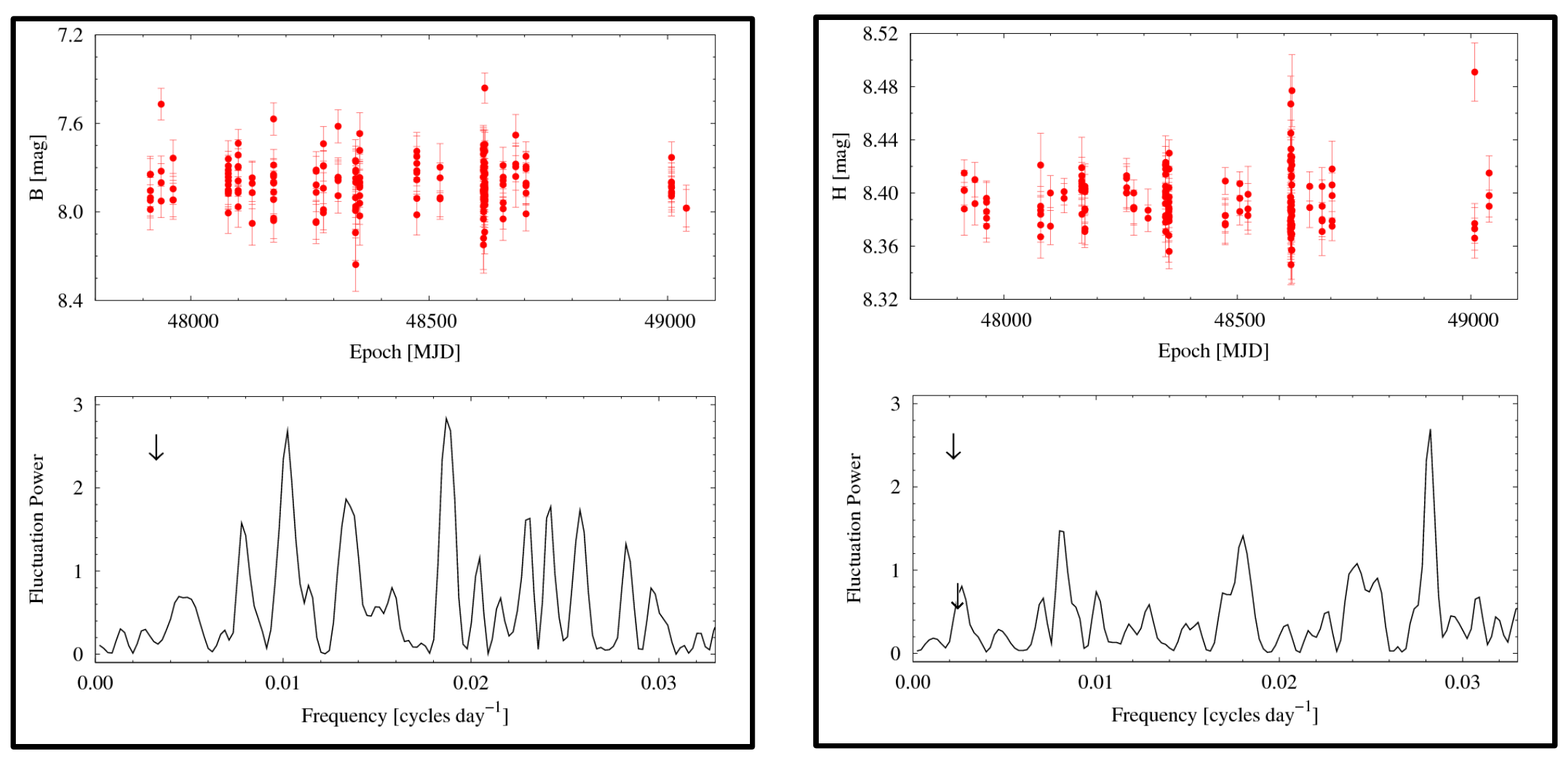

Figure 4. *Hipparcos* photometric measurements of HD 17092 (left) and PSUTCfA 18 (right) and theirs periodograms. The vertical arrows marks the frequencies corresponding to the 360 (HD 17092) and 575 (PSUTCfA 18) day periods of the observed radial velocities variations.

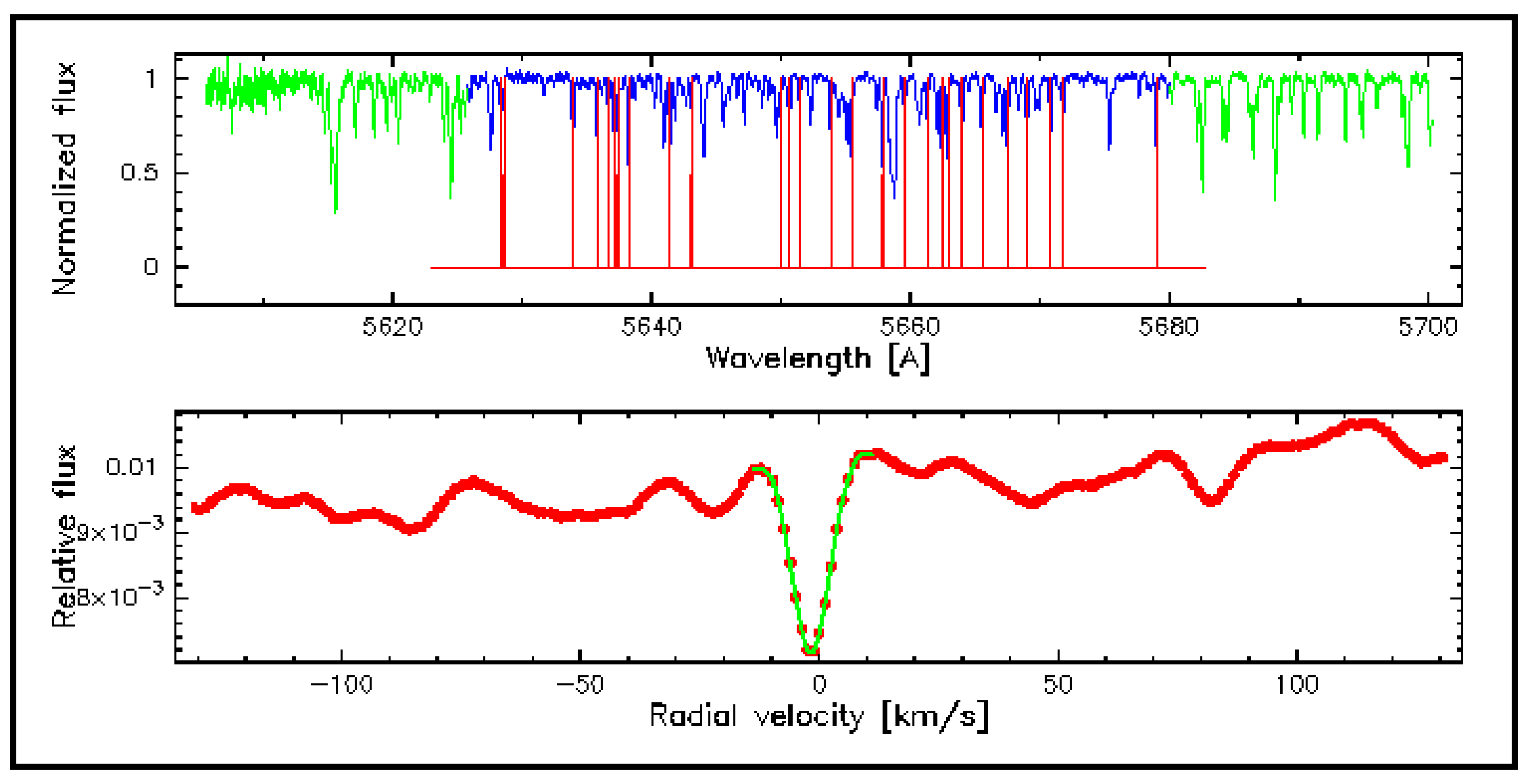

Figure 5. One order of HET/HRS spectrum of HD 77819 and its cross-correlation function.

Table 1. HET/HRS projected rotational velocities for several stars from our survey and their comparison with previous work: (a) Fischer & Valenti (2005), (b) Da Silva et al. (2006).

Name	Spectral type	(B-V)	σ_{obs}	V sin(i) HET/HRS	V sin(i) other
HD 17092	K0	1,000	3,437	0,98	-
HD 38529	G4 V	0,773	3,551	2,94	$3,90^a$
HD 118203	K0	0,810	3,896	4,44	$4,70^b$
HD 10697	G5 IV	0,860	3,288	2,17	$2,48^a$
HD 88133	G5 IV	0,860	3,167	1,38	$2,17^a$
HD 75732	G8 V	0,869	3,136	1,07	$2,46^a$
HD 95296	K0	1,000	3,484	1,46	-
HD 77819	G5	0,860	3,845	4,37	-
BD+57 144	G4 V	0,940	3,720	3,64	-

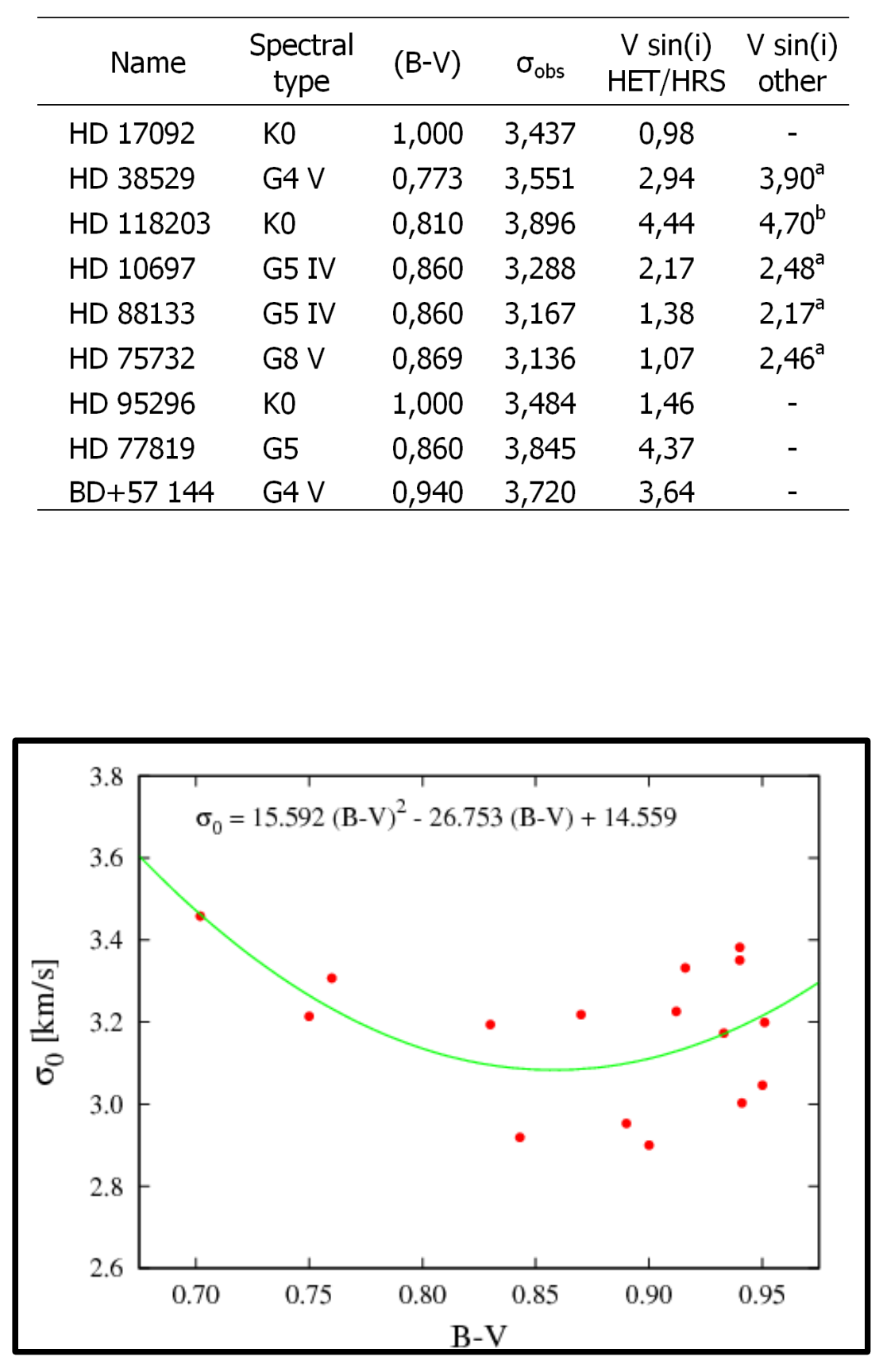

Figure 6. Intrinsic width of the cross-correlation function (σ_0) as a function of (B-V) for the calibrators.

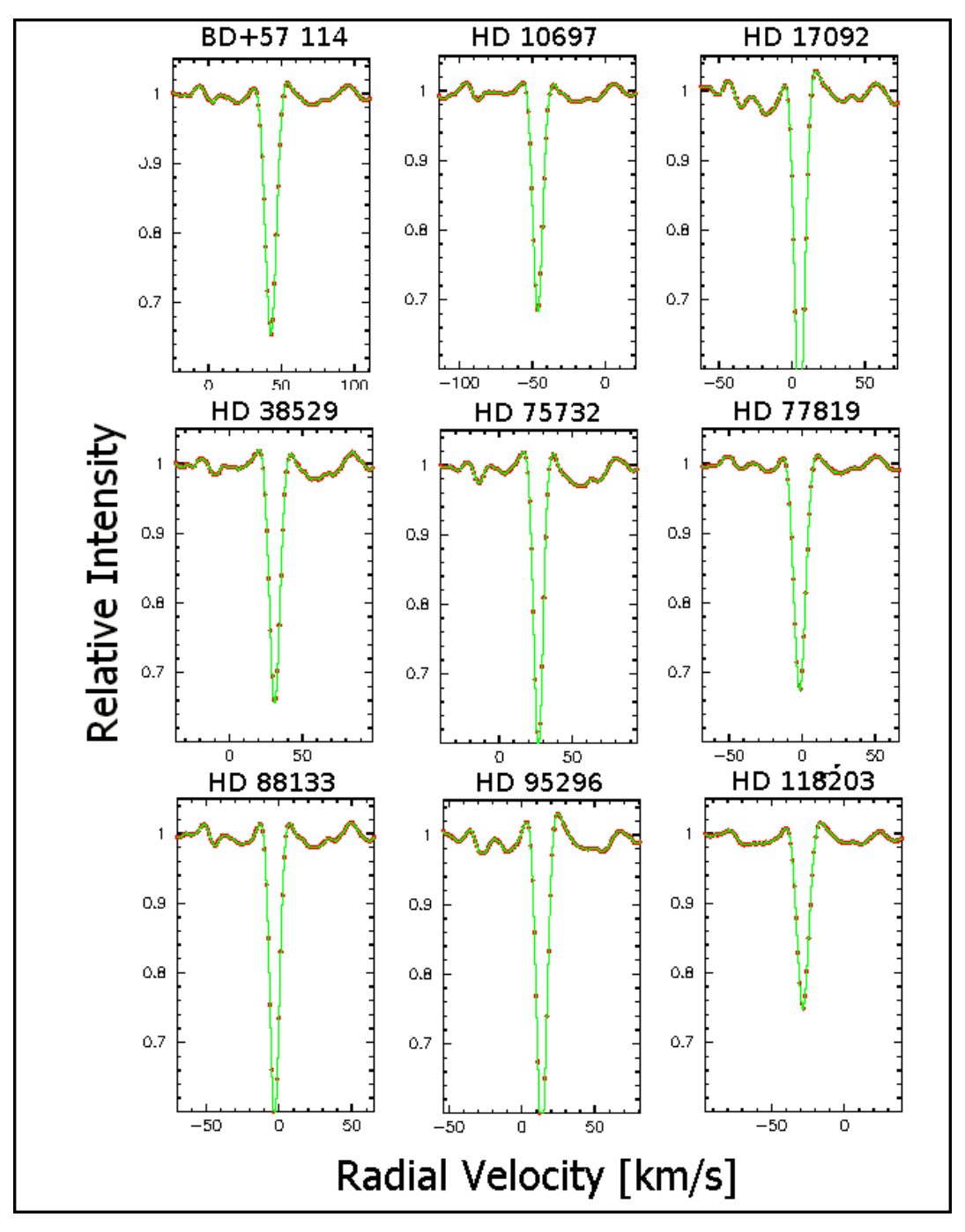

Figure 7. CCF relative intensity versus radial velocity for stars listed in Table 1.

V sin(i) Measurements

To measure V sin(i) we built σ_0 - V sin(i) calibration for HET/HRS. To determine the σ_0 vs. (B-V) relation we used 16 slow rotators with accurate projected rotational velocities measured in various papers, preferably from by Gray (1989), Fekel (1997) and de Medeiros & Mayor (1999). For every of these stars we determined σ_0 using formula from Benz & Mayor (1984) $V\sin(i) = A\sqrt{(\sigma_{obs}^2 - \sigma_o^2)}$ and assuming the constant A = 1.9 following Queloz et al. (1998). We carried out a least-squared fit to the data by the analytical function $\sigma_0 = a_2(B-V)^2 + a_1(B-V) + a_0$ which yields the following calibration: $\sigma_0 = 15.592(B-V)^2 - 26.753(B-V) + 14.559$ (Figure 6).

In Table 1 we present projected rotational velocity for several stars from PSU/TCfA Search for Planets Around Evolved Stars (the typical error of our measurements is about 1.0 km/s). For some of them Vsin(i) are available also from the literature (Fischer & Valenti 2005 and Da Silva et al. 2006). It is clear, that our measurements are in good agreement with previous determinations.

Using this calibration we obtained for HD 17092 Vsin(i) ≤ 1 km/s. From this value and the adopted stellar radius, we have obtained an estimate of the rotation period of HD 17092, P_{rot} = 551 days. Given the error estimates of Alonso et al. (2000), the rotation period of HD 17092 may range from 409 to 692 days, which makes it significantly longer than the observed 360 day period of radial velocity variation. For PSU-TCfA 18 star Vsin(i) = (3 ± 1) km/s. Adopting the radius for this star we estimated its rotational period to be 220 – 950 days. The large uncertainty in the rotation period is caused by uncertainties related to determination of the radius and Vsin(i).

Stellar Parameters

The atmospheric parameters of the program stars were obtained with the spectroscopic method (Takeda et al. 2005a, b), which is based on analysis of FeI and FeII lines and relies on conditions resulting from assumption of LTE. Typically, over 200 FeI and about 25 FeII lines were measured for every star.

We tested a reliability of our determinations with the Takeda et al. (2005a) code TGVIT by applying it to 8 stars for which the parameters have been published by Butler et al. (2006). A comparison of the results shows that T_{eff} agree within 49 K, and that the same is true for log g within 0.11 dex and [Fe/H] to within 0.11 dex, respectively.

Stellar masses were derived by comparing the position of stars in the HR diagram with the theoretical evolutionary tracks of Girardi et al. (2000) and Salasnich et al. (2000) for a given metallicity. For stars for which the parallax determinations are precise enough, the metallicity may introduce a significant uncertainty in mass because of choice of an evolutionary track. We assume that for an average red giant with a known parallax, the mass may be estimated within 0.3 $M_\odot$. We also note that for stars in the red giant clump, which are in the fast evolution phase with mass-loss, the derived masses are probably the upper limits.

Stellar radii were determined using the calibration given in Alonso et al. (2000). Stellar ages are usually estimated with the aid of the theoretical stellar isochrones.

For HD 17092, the basic physical parameters are T_{eff} = 4649 K, log g = 3.00, V_t = 1.27 km/s, [Fe/H] = 0.22, M = 2.3 M_o, R = 10.9 R_o. For PSUTCfA 18 star, the basic physical parameters are T_{eff} = 4246 K, log g = 2.43, V_t = 1.52 km/s, [Fe/H] = 0.11, M = 5.5 M_o, R = 27.4 R_o. Intrinsic uncertainties of our determinations are σT_{eff} = 29 K, σlog g = 0.09, σV_t = 0.13 km/s and σ[Fe/H] = 0.06.

Future Prospects

We plan to improve our bisector analysis by measuring BVS and BC from cross-correlation function (CCF) constructed from the spectra used for radial velocity determination but cleaned from the I_2 lines. Iodine cell provides most accurate wavelength calibration, removing uncertainties due to for example variations of pressure and light or slit illumination. For this reason we plan to use only the part of blue spectra where the strong Iodine lines appear (500 – 610 nm).

We also plan to extend our Vsin(i) measurements by measuring σ from the CCF constructed from exactly the same spectra as used for radial velocity determination but cleaned from the I_2 lines. Since ~1000 G-K giants are observed within our survey we plan to obtain σ_0 not only by use of calibrators with precise V sin(i) measurements, but also by fitting the lower envelope of the distribution of sigma vs. B-V, where, in principle, is the expected location of non-rotating stars (Santos et al. 2002).

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References

Alonso, A., Salaris, M., Arribas, S., Martinez-Roger, C. & Asensio Ramos, A. 2000, A&A, 355, 1060
Benz, W., & Mayor, M. 1984, A&A, 138, 183
Butler, R.P., Wright, J. T., Marcy, G. W.,et al., 2006, ApJ, 646, 505
Da Silva, R, et al. 2006, A7A, 446, 717
Fekel, F.C. 1997, PASP, 109, 514
Fischer, D. A., & Valenti, J. 2005, ApJ, 622, 1102
Girardi, L., Bressan, A., Bertelli, G., Chiosi, C. 2000, A&AS, 141,371
Gray, D. F. 1983, PASP, 95, 252
Gray, D.F. 1989, ApJ, 347, 1021
de Medeiros, J.R., & Mayor, M. 1999, A&AS, 139, 433
Niedzielski, et al., ApJ, 669, 1354
Queloz, et al. 1998, A&A, 335, 183
Ramsey, L.W., et al. 1998, Proc. SPIE, 3352, 34
Salasnich, B., Girardi, L., Weiss, A., Chiosi, C. 2000, A&A, 361, 1023
Santos, N. C., et al. 2002, A&A, 392, 215
Shetrone, M., Cornell, M., Fowler, J., et al.. 2007, PASP, 119, 556
Takeda, Y., Ohkubo, M., Sato, B., Kambe, E., Sadakane, K. 2005, PASJ, 57, 27
Takeda, Y., Sato, B., Kambe, E., Izumiura, H, Masuda, S. & Ando, H., 2005, PASJ, 57, 109
Tull, R.G., 1998, Proc. SPIE, 3355, 387