A catalog of rotational and radial velocities for evolved stars

V. Southern stars^{★,★★}

J. R. De Medeiros¹, S. Alves¹, S. Udry², J. Andersen^{3,4}, B. Nordström³, and M. Mayor²

¹ Departamento de Física, Universidade Federal do Rio Grande do Norte, Campus Universitário, 59072-970 Natal, RN, Brasil
 e-mail: renan@dfte.ufrn.br

² Observatoire de Genève, Université de Genève, Chemin des Maillettes 51, 1290 Sauverny, Switzerland

³ The Niels Bohr Institute, University of Copenhagen, Juliane Maries Vej 30, 2100 Copenhagen, Denmark

⁴ Nordic Optical Telescope, Apartado 474, 38700 Santa Cruz de La Palma, Spain

Received 19 November 2012 / Accepted 10 December 2013

ABSTRACT

Rotational and radial velocities have been measured for 1589 evolved stars of spectral types F, G, and K and luminosity classes IV, III, II, and Ib, based on observations carried out with the CORAVEL spectrometers. The precision in radial velocity is better than 0.30 km s^{-1} per observation, whereas rotational velocity uncertainties are typically 1.0 km s^{-1} for subgiants and giants and 2.0 km s^{-1} for class II giants and Ib supergiants.

Key words. stars: late-type – stars: fundamental parameters – binaries: spectroscopic – techniques: radial velocities – catalogs – stars: evolution

1. Introduction

Over the past two decades, observations have been carried out at the Geneva Observatory, Switzerland, and the Federal University of Rio Grande do Norte, Brazil, to accurately measure projected rotational velocities ($v \sin i$) of evolved stars, with the aim of studying the evolution of stellar rotation with stellar age.

The technique used is to combine a high-resolution spectrometer with the cross-correlation technique, which yields accurate, high S/N cross-correlation line profiles from relatively low S/N spectra. From these profiles, accurate radial velocities and, once calibrated, projected rotational velocities ($v \sin i$) with an accuracy better than 1 km s^{-1} can be derived, allowing measurements of $v \sin i$ for large samples of relatively faint stars with telescopes of moderate aperture.

Most of the observations presented here were made with the CORAVEL cross-correlation spectrometers (Baranne et al. 1979). In addition, De Medeiros et al. (2006) measured rotational velocities, $v \sin i$, for 100 metal-poor stars with the digital version of the cross-correlation procedure, using spectra obtained with the FEROS (Kaufer & Pasquini 1998) and CORALIE (Baranne et al. 1996) spectrometers.

As part of this programme, De Medeiros & Mayor (1999) measured $v \sin i$ for 1541 stars of luminosity classes IV, III, and II, De Medeiros et al. (2002b) presented $v \sin i$ for 232 Ib supergiant stars, and De Medeiros et al. (2004) also measured $v \sin i$ for 78 double-lined binaries with an evolved component. These high-quality data have inspired several studies,

enabling reliable investigations of stellar rotational characteristics in different regions of the H–R diagram (Carlberg et al. 2011; Cortés et al. 2009; Melo et al. 2001), the relationship between rotation and different stellar properties (Monaco et al. 2011; Raghavan et al. 2010; López-Santiago et al. 2010; Grunhut et al. 2010; Massarotti et al. 2008; De Medeiros et al. 2002a; Cutispoto et al. 2002), constraints on theoretical models (Eggenberger et al. 2010; Brun & Palacios 2009) and in many studies on extra-solar planets (e.g. Watson et al. 2010; Döllinger et al. 2009).

The present work brings complementary results for our observational efforts, with the measurements of projected rotational velocity $v \sin i$ for southern subgiant, giant, bright giant, and Ib supergiant stars of spectral types F, G, and K, listed in the Bright Star Catalog (Hoffleit & Jaschek 1982; Hoffleit et al. 1983). Although the primary aim of this investigation is to study the rotational behaviour of evolved stars, our observational procedure also produced a large set of radial velocity measurements, representing an important tool for answering several questions in stellar astrophysics, including the search for planets around evolved stars.

This paper is arranged as follows. Section 2 presents the definition of the sample, the observational procedure used throughout this survey, and the calibration of rotational velocities, with a discussion of their probable errors. The list of individual $v \sin i$ measurements and mean radial velocities are presented in Sect. 3.

2. The observational programme

The present sample consists of a total of 1702 mainly southern F, G, and K stars of luminosity classes IV, III, II, and Ib listed in the Bright Star Catalog. Most of these stars were observed in different programmes carried out at the Geneva Observatory,

* Based on observations collected at the Haute-Provence Observatory, Saint-Michel, France, and at the European Southern Observatory, La Silla, Chile.

** Table 1 is only available at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via <http://cdsarc.u-strasbg.fr/viz-bin/qcat?J/A+A/561/A126>

Table 2. Double-lined spectroscopic binary systems SB2 with evolved component.

HD	(B – V)	ST
352	1.38	K2III+F
5357	0.38	F4III
5516	0.94	G8IIIb
6397	0.41	F4II-III
7788	0.47	F6IV
8949	1.12	K1III
10308	0.44	F2III
12641	0.88	G5II-III+G5V
13480	0.78	G5III+F5V
16920	0.40	F4IV
17904	0.41	F4IV
18894	0.60	G0IV-V
24546	0.41	F5IV
29104	0.754	G5II-III+A-F
34029	0.80	G5IIIe+G0III
35798	1.11	K1III
38751	1.01	G8III
39040	1.12	K1III
40084	1.23	G5III
41116	0.82	G7III
43358	0.46	F5IV:
46178	1.07	K0III
47415	0.53	F8IV
47703	0.49	F8III
52973	0.79	F7-G3Ib
58972	1.43	K3-IIIFe-0.5
59148	1.11	K2III
59878	1.01	K0II-III+F8V
60318	1.01	K0III
63799	1.12	K1III
64235	0.41	F5IV
68461	0.89	G8III
71622	0.90	G8III
73596	0.401	F5III
75629	0.95	G8III
76143	0.42	F5IV
78418	0.66	G5IV-V
80586	0.93	G8III-IV+F5V
81873	1.04	K0III
82543	0.62	F7IV-V
83808	0.49	F6II+A1-5V
92787	0.33	F5III
98993	1.46	K6III
106677	1.14	K0IIIe+K0IIIe
109312	0.46	F3III-IV
120064	0.49	G5III+A7V:
120672	0.48	F6IV-V
122703	0.45	F5III
123999	0.54	F9IV w
125383	0.92	G8III
129502	0.38	F2III
133340	1.01	G8III
139862	0.94	G7.5IIIaFe-0.5
150682	0.40	F2III
158614	0.72	G9IV-VHdel 1
159870	0.59	G5III+A5V
163506	0.34	F2Ib
164136	0.39	F2II
169268	0.34	F6III-IV
171802	0.37	F5III
172088	0.55	F9IV
172103	0.42	F1IV-V
174881	1.18	K1II-III
178619	0.52	F5IV-V
179094	1.09	K1IV

Table 2. continued.

HD	(B – V)	ST
179950	0.56	G8:III+A8V
185734	0.97	G8III-IV
196753	0.98	K0II-III+A3V
198084	0.54	F8IV-V
200497	0.68	G4III
201051	1.05	K0II-III
201772	0.44	F5IV+F6V
202447	0.53	G0III+A5V
204960	1.04	K1III
205539	0.35	F0IV
205877	0.60	F7III
206901	0.43	F5IV
210334	0.72	G2IV+K0III
218527	0.91	G8III-IV

Table 3. Evolved stars with no CORAVEL dip.

HD	ST
432	F2III-IV
571	F2II
4338	F1IVn
6763	F0III-IV
6953	K7III
11522	F0IIIIn
13305	F4III
20121	F7III+A0V
23010	F5II
34658	F5II
37788	F0IV
56986	F2IV
57852	F0-2IV-V
65925	F5III
72779	G0III
77601	F6II-III
91942	K3-4II
96202	F3IV
104827	F0IV-V
109085	F2III-IV
126251	F4III
127739	F2IV
144183	F2II
164259	F2IV
171237	F3II-III
186357	F1III
187038	K3III
194943	F2IV
200723	F3IV
203784	F6II-III
203842	F5III
207958	F1III
208177	F5IV
219571	F1III

the majority devoted to studying stellar binarity (Duquennoy et al. 1991; De Medeiros & Mayor 1999; De Medeiros et al. 2002b, 2004) or to precise measurements of radial velocity in programmes on Galactic structure (Andersen et al. 1985; Prevot et al. 1985; Maurice et al. 1987; Nordström et al. 2004a).

As in previous papers (De Medeiros & Mayor 1999; De Medeiros et al. 2002b, 2004), the observations reported here were made using the two CORAVEL spectrometers (Baranne et al. 1979) mounted on the 1.54-m Danish telescope at ESO,

La Silla (Chile), and the 1-m Swiss telescope at Haute-Provence Observatory, Saint Michel (France). Radial velocities were derived by direct cross-correlation of the stellar spectra with a binary (0, 1) physical template, constructed from the spectrum of the K2 III star Arcturus and mounted inside the spectrometers. The radial-velocity system applied is that defined by Udry et al. (1999). Typical integration times were 5 min, and data was reduced using standard procedures (Duquennoy 1987; Duquennoy et al. 1991; De Medeiros & Mayor 1999). For a complete discussion of the observational procedure, calibration, and error analysis, readers are referred to Duquennoy (1987), Duquennoy et al. (1991), and De Medeiros & Mayor (1999).

Here, we just recall a few salient points. In all cases, the radial velocity uncertainty is derived from an instrumental error added in quadrature to photon and scintillation noise, which are estimated using the computed parameters of the cross-correlation profiles (Baranne et al. 1979). Different studies of large data samples (Duquennoy et al. 1991; Udry et al. 1997; De Medeiros & Mayor 1999) show that the typical uncertainty for CORAVEL radial velocity is about 0.3 km s^{-1} for slowly rotating stars, generally with $v \sin i < 20 \text{ km s}^{-1}$. For faster rotators, the uncertainty is somewhat greater.

Rotational velocities ($v \sin i$) were obtained through an appropriate calibration of the widths of cross-correlation profiles, as described by De Medeiros & Mayor (1999). The original $v \sin i$ calibration by Benz & Mayor (1984) is also valid for subgiant and giant stars of luminosity classes IV and III, but for class II and Ib bright giants and supergiants, the increase in macroturbulence with spectral type required a new calibration of the width of the cross-correlation profile into $v \sin i$ as measured from a Fourier transform of line profiles from Gray & Toner (1986, 1987). Whereas Benz & Mayor (1984) obtained for the parameter associated with the CORAVEL cross-correlation profiles σ_0 the value of 6.88 km s^{-1} for stars of luminosity classes V to III, the new calibration shows that for the luminosity classes II and Ib the value of σ_0 is 7.158 km s^{-1} and 7.978 km s^{-1} , respectively.

The computed $v \sin i$ has a typical uncertainty of around 1.0 km s^{-1} for subgiant and giant stars with $v \sin i \ll 30 \text{ km s}^{-1}$, whereas for bright giants and Ib supergiants, we conservatively assume an uncertainty of 2.0 km s^{-1} , since it is impossible to define precise limits between rotation and macroturbulence. For faster rotators, those with $v \sin i$ higher than 30 km s^{-1} , De Medeiros & Mayor (1999) estimate an uncertainty of about 10%, regardless of luminosity class.

3. Contents

The main results of this catalogue are listed in Table 1, which presents CORAVEL rotational and mean radial velocities for 1589 evolved FGK stars of luminosity classes IV, III, II, and Ib, ordered by HD number, for single stars and single-lined spectroscopic binaries. Columns are as follows:

1. HD number;
2. spectral type;
3. $(B - V)$ color index;
- 4–5. mean radial velocity RV and its uncertainty ϵ , on N number of CORAVEL observations. In this case, the uncertainty is given by $\max(\epsilon_1 / \sqrt{N}, \sigma / \sqrt{N})$, where ϵ_1 is the typical error for one single radial velocity measurement;
6. radial velocity dispersion (rms) σ ;
7. E/T , the ratio of observed to expected rms dispersion for observations, when $N \geq 2$;

8. $P(\chi^2)$, the probability that the radial velocity of the star is constant;
9. N , number of observations for each star;
10. time span ΔT of observations;
- 11–12. rotational velocity $V \sin i$ and its uncertainty ϵ_{rot} ;
13. remarks. The remarks SBO and SB indicate, respectively, single-lined spectroscopic binaries for which orbital parameters are available in the literature, and stars displaying single-lined spectroscopic binary behaviour. Nevertheless, for a few stars classified as SB, the RV variability may reflect another cause, e.g. pulsation.

A number of the programme stars, identified in Table 1, were already included in the papers by Andersen et al. (1985), Prevot et al. (1985), and Maurice et al. (1987), with radial velocities referred to in the 1985 standard system of Udry et al. (1999), while the velocities listed here are referred to in the revised zero-point of Udry et al. (1999). The colour-dependent differences from the earlier velocities are small, about 0.11 , 0.31 , and 0.45 km s^{-1} for F-, G-, and K-type stars, respectively, but can be noticed in precise work.

Table 2 lists 79 SB2 and SB3 binary systems also observed by CORAVEL, many of which were detected here for the first time, while Table 3 presents the evolved F-type stars for which no correlation dip was obtained with CORAVEL. These are undoubtedly fast rotators.

The individual radial velocity measurements for single and SBO stars, as well as for SB not included in follow-up programmes, are available at the Centre de Données Astronomiques de Strasbourg (CDS).

Acknowledgements. We gratefully acknowledge the support of the CORAVEL observers in this survey, particularly Gilbert Burki, Bernard Pernier, Pierre North, Jean-Claude Mermilliod and Gerard Jasiewicz. We also thank Emile Ischi and Bernard Tartarat for technical maintenance of the CORAVELs and B. L. Canto Martins, I. C. Leão and J. D. do Nascimento for assistance in preparing tables and data controls. S. Alves acknowledges a graduate fellowship and a PNPd fellowship from the CAPES Brazilian agency. This study used the SIMBAD database, operated at the CDS in Strasbourg, France, and it was supported by continuous grants from the Swiss National Science Foundation. Research activities of the Observational Stellar Board of the Federal University of Rio Grande do Norte are supported by the Brazilian agencies CNPq, FAPERN, and the INCT INEspaço. The observations at the Danish 1.54 m telescope from ESO, La Silla, Chile, was supported by grants from ESO and Danish observing time, and financially by the Danish Natural Science Research Council through the Danish Board for Astronomical Research.

References

- Andersen, J., Nordstrom, B., Ardeberg, A., et al. 1985, A&AS, 59, 15
 Baranne, A., Mayor, M., & Poncet, J. L. 1979, Vist. Astron., 23, 279
 Baranne, A., Queloz, D., Mayor, M., et al. 1996, A&AS, 119, 373
 Benz, W., & Mayor, M. 1984, A&A, 138, 183
 Brun, A. S., & Palacios, A. 2009, ApJ, 702, 1078
 Carlberg, J. K., Majewski, S. R., Patterson, R. J., et al. 2011, ApJ, 732, 39
 Cortés, C., Silva, J. R. P., Recio-Blanco, A., et al. 2009, ApJ, 704, 750
 Cutispoto, G., Pastori, L., Pasquini, L., et al. 2002, A&A, 384, 491
 De Medeiros, J. R., & Mayor, M. 1999, A&AS, 139, 433
 De Medeiros, J. R., Da Silva, J. R. P., & Maia, M. R. G. 2002a, ApJ, 578, 943
 De Medeiros, J. R., Udry, S., Burki, G., & Mayor, M. 2002b, A&A, 395, 97
 De Medeiros, J. R., Udry, S., & Mayor, M. 2004, A&A, 427, 313
 De Medeiros, J. R., Silva, J. R. P., Do Nascimento, J. D., Jr., et al. 2006, A&A, 458, 895
 Döllinger, M. P., Hatzes, A. P., Pasquini, L., Guenther, E. W., & Hartmann, M. 2009, A&A, 505, 1311
 Duquennoy, A. 1987, A&A, 178, 114
 Duquennoy, A., Mayor, M., & Halbwachs, J.-L. 1991, A&AS, 88, 281
 Eggenberger, P., Miglio, A., Montalbán, J., et al. 2010, A&A, 509, A72
 Gray, D. F., & Toner, C. G. 1986, ApJ, 310, 277
 Gray, D. F., & Toner, C. G. 1987, ApJ, 322, 360

- Grunhut, J. H., Wade, G. A., Hanes, D. A., & Alecian, E. 2010, *MNRAS*, 408, 2290
- Hoffleit, D., & Jaschek, C. 1982, *The Bright Star Catalogue* (New Haven, USA: Yale University Observatory)
- Hoffleit, D., Saladyga, M., & Wlasuk, P. 1983, *A Supplement to the Bright Star Catalogue* (New Haven, USA: Yale University Observatory)
- Kaufer, A., & Pasquini, L. 1998, *Proc. SPIE*, 3355, 844
- López-Santiago, J., Montes, D., Gálvez-Ortiz, M. C., et al. 2010, *A&A*, 514, A97
- Massarotti, A., Latham, D. W., Stefanik, R. P., & Fogel, J. 2008, *AJ*, 135, 209
- Maurice, E., Andersen, J., Ardeberg, A., et al. 1987, *A&AS*, 67, 423
- Mayor, M., & Maurice, E. 1985, in *Stellar Radial Velocities*, eds. A. G. D. Philip, & D. W. Latham (Schenectady: L. Davis Press), *Proc. IAU Colloq.*, 88, 299
- Melo, C. H. F., Pasquini, L., & De Medeiros, J. R. 2001, *A&A*, 375, 851
- Monaco, L., Villanova, S., Moni Bidin, C., et al. 2011, *A&A*, 529, A90
- Nordström, B., Mayor, M., Andersen, J., et al. 2004a, *A&A*, 418, 989
- Nordström, B., Mayor, M., Andersen, J., et al. 2004b, *VizieR Online Data Catalog*, V/117
- Prevot, L., Andersen, J., Ardeberg, A., et al. 1985, *A&AS*, 62, 23
- Raghavan, D., McAlister, H. A., Henry, T. J., et al. 2010, *ApJS*, 190, 1
- Udry, S., Mayor, M., Andersen, J., et al. 1997, *Proc. of the ESA Symp., Hipparcos – Venice '97*, ESA SP, 402, 693
- Udry, S., Mayor, M., & Queloz, D. 1999, in *Precise Stellar Radial Velocities*, *IAU Colloq.*, 170, ASP Conf. Ser., 185, 367
- Watson, C. A., Littlefair, S. P., Collier Cameron, A., Dhillon, V. S., & Simpson, E. K. 2010, *MNRAS*, 408, 1606