

# A catalog of rotational and radial velocities for evolved stars.

## IV. Metal-poor stars $\star, \star\star$

J. R. De Medeiros<sup>1</sup>, J. R. P. Silva<sup>2</sup>, J. D. do Nascimento Jr<sup>1</sup>, B. L. Canto Martins<sup>1</sup>,  
L. da Silva<sup>1,3</sup>, C. Melo<sup>4,5</sup>, and M. Burnet<sup>6</sup>

<sup>1</sup> Departamento de Física, Universidade Federal do Rio Grande do Norte, 59072-970 Natal, RN., Brazil  
e-mail: [renan@dfte.ufrn.br](mailto:renan@dfte.ufrn.br)

<sup>2</sup> Universidade Estadual do Rio Grande do Norte, Mossoro, RN, Brasil

<sup>3</sup> Observatório Nacional, RJ., Brazil

<sup>4</sup> European Southern Observatory, La Silla, Chile

<sup>5</sup> Departamento de Astronomía, Universidad de Chile, Casilla 36-D, Santiago, Chile

<sup>6</sup> Observatoire de Genève, Chemin des Maillettes 51, CH-1290 Sauverny, Switzerland

**Abstract.** The present paper describes the first results of an observational program intended to refine and extend the existing  $v \sin i$  measurements of metal-poor stars, with an emphasis on field evolved stars. The survey was carried out with the FEROS and CORALIE spectrometers. For the  $v \sin i$  measurements, obtained from spectral synthesis, we estimate an uncertainty of about  $2.0 \text{ km s}^{-1}$ . Precise rotational velocities  $v \sin i$  are presented for a large sample of 100 metal-poor stars, most of them evolving off the main-sequence. For the large majority of the stars composing the present sample, rotational velocities have been measured for the first time.

**Key words.** Catalogs – Stars: evolution – Stars: fundamental parameters – Stars: Population II – Stars: rotation – Stars: statistics

### 1. Introduction

For the past two decades a large observational effort has been carried out at the Geneva Observatory, Switzerland, and at the Department of Physics at Natal, Brazil, to determine precise rotational velocity for a large stellar sample at different evolutionary stages and populations. The major aim behind such an effort is the understanding of the stellar angular momentum evolution. For population I evolved stars of luminosity classes IV, III, II, and Ib, covering the spectral range F to K, a large set of precise  $v \sin i$  measurements was already published (De Medeiros and Mayor 1999; De Medeiros et al. 2002, 2004). To carry on with these studies, we turn now to the measurement of  $v \sin i$  for field metal-poor stars. Since the pioneering works by Peterson (1983, 1985a,b), there have been an increasing num-

*Send offprint requests to:* J. R. De Medeiros

\* Based on observations collected with the Swiss Euler Telescope, the 1.5-m ESO, the 2.2-m ESO at La Silla Observatory, ESO, Chile (proposals 69.D-0711 and 072.D-0315(A), and with the Brazilian - ESO time (proposal 2002.E-12) operated by the Laboratório Nacional de Astrofísica/MCT, Brazil.

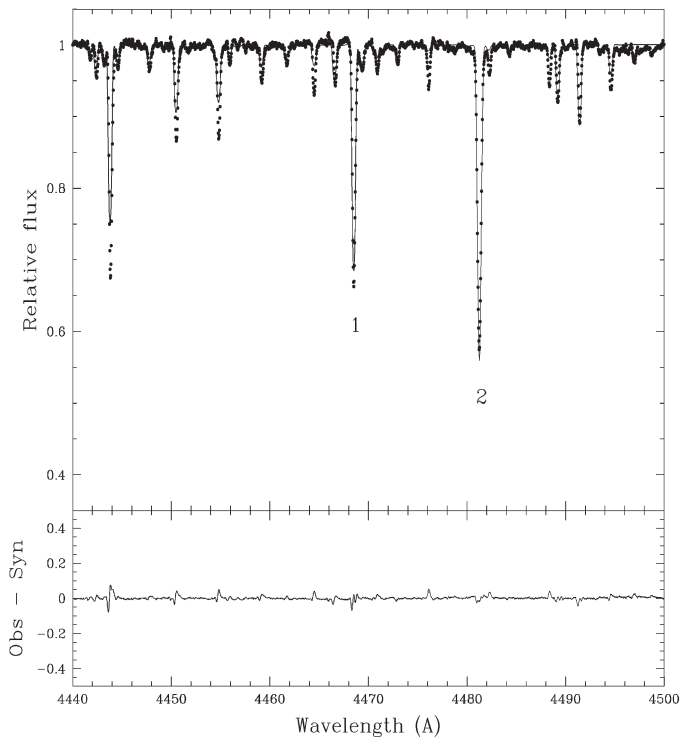
\*\* Table 2 is also available in electronic form at the CDS via anonymous ftp to [cdsarc.u-strasbg.fr](ftp://cdsarc.u-strasbg.fr) (130.79.128.5) or via <http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/XXX/YYY>

ber of observational studies on the rotational velocity of population II stars ( Peterson et al. 1995; Cohen and McCarthy 1997; Behr et al. 2000a,b; Carney et al. 2003; Recio-Blanco et al. 2002, 2004), dedicated mostly to field stars. Nevertheless, in spite of these solid observational efforts, the data presently available in the literature are not yet large enough in quantity for a statistically robust analysis of the rotational behavior of metal-poor stars in different evolutionary stages.

The present work brings the first results of an observational effort dedicated to the study of the rotational velocity of metal-poor stars, with an emphasis on field evolved stars. The paper is structured as follow: in Sect. 2 the main characteristics of the sample and the observational procedure are described. The data reduction, spectral synthesis, and the projected rotational velocity  $v \sin i$  measurements are presented in Sect. 3.

### 2. The observational program

For this observing program we have built a preliminary list of 150 metal-poor stars, listed by Bond (1980) and Schuster and Nissen (1988), with Hipparcos parallaxes and Stromgren photometric indices available in the literature. Observations were collected with the FEROS spectrometer mounted on the ESO 1.50-m telescope, and with the CORALIE spectrometer mounted on the Euler Swiss 1.2-m telescope (Queloz et al. 2000), both at La Silla (Chile). Some spectra were obtained in the ESO-LNA Brazil agreement. The FEROS provides a full wavelength coverage of 3500–9200 Angstroms over 39 spec-



**Fig. 1.** Comparison between the observed and synthetic spectra for HD 16456 around the 4468 Å region. The solid line and points represent the synthetic and observed spectra, respectively. (1) and (2) represent the lines Ti II at 4468.50 Å and Mg II at 4481.20 Å, respectively.

tral orders at a resolving power  $R=48,000$  (Kaufer and Pasquini 1998), whereas the CORALIE wavelength coverage is 3875–6820 Angstroms on 68 orders at a resolving power  $R=50,000$ . Both spectrometers are equipped with a double fiber system, one for the object and the second for recording the sky or a simultaneous wavelength calibration. The exposure times were defined to produce spectra with a S/N better than 80 at the spectral region previously chosen to diagnose the rotation effects on the spectra, namely lines at the range 4440–4500 Angstroms.

### 3. The rotational velocity $v \sin i$ computation

For the determination of the projected rotational velocity  $v \sin i$ , we applied the procedure by fitting the observed spectrum with a synthetic one. An essential step in this analysis is the definition of suitable spectral lines to measure the  $v \sin i$ . The lines that are the best candidates for use in the determination of rotation are presented in the Fig. 1. For the present spectral analysis we have used the lines listed in Table 1.

For the present analysis we used a version of the spectrum synthesis code MOOG (Snedden 1973), using the profiles of a few strong lines on the Mg II 4481 Å region for synthesis. For the MOOG analysis we adopted the grid of LTE model atmospheres computed by Kurucz & Bell (1995). Required models were interpolated on the grid. For each star we have selected the synthetic spectrum for use as a template that best matches

**Table 1.** List of the spectral lines used (when possible) for the  $v \sin i$  measurement.

Wavelength (Å)	Element
4466.55	Fe I
4468.50	Ti II
4481.20	Mg II
4488.33	Ti II
4489.18	Fe II
4491.40	Fe II

the derived temperature, gravity, metallicity, and broadening mechanisms (macroturbulence, instrumental, and  $v \sin i$ ). The metallicity was determined making use of the calibrations obtained by Schuster & Nissen (1989) and Bond (1980), using the Strömgren photometry. The error on the metallicity was estimated taking into account the uncertainty of about 0.04dex from the photometry and associated uncertainties, combined with the uncertainty of 0.16dex from the calibration itself, leading to a total error of about 0.17dex. In fact this estimation is true for single stars, since for binary systems the uncertainty on photometry may increase as a consequence of light contribution of the components. In this context, readers should be cautious of the metallicity listed for binary stars. For the effective temperature  $T_{\text{eff}}$ , they were estimated from the calibrations of Alonso et al. (1996, 1999). The error in this parameter was derived from the error due to these calibrations and also the error due to the photometry, resulting in a total error of 111K for our stars. For the large majority of the stars, the gravity was measured from a relation between  $T_{\text{eff}}$ , visual magnitude, parallax, bolometric correction BC (measured from a calibration of Alonso et al. 1995), and mass (obtained from the evolutionary tracks of Girardi et al. 1996 and Girardi 2000). The maximum error measured for the gravity, 0.15dex, is a sum of the individual errors due to those parameters. For a few stars the gravity was taken from the literature, namely HD 136316 and HD 204543 (François 1996); HD 51754, HD 111980, HD 132475, HD 140283, HD 158809, and HD 179626 (Fulbright 2000); BD  $-9^\circ$  5831, BD  $+8^\circ$  2856, and BD  $+10^\circ$  2495 (Carney et al. 2003); HD 99383 and HD 199289 (Nissen et al. 1997); HD 51929 and HD 200654 (Aker et al. 1994); HD 215257 (Edvardsson et al. 1993); HD 274939 (Gratton 1994); HD 83220 (Nissen and Schuster 1997); and HD 111777 (Jonsell et al. 2005). The total error on the projected rotational velocity value has been estimated by computing the quadratic sum of errors induced by errors on individual parameters ( $T_{\text{eff}}$ ,  $\log g$ , and  $[\text{Fe}/\text{H}]$ ). Considering our errors on fundamental parameters,  $v \sin i$  has an accuracy of about  $2.6 \text{ km s}^{-1}$ .

An external comparison with  $v \sin i$  measurements of stars in common with Carney et al. (2003), Behr (2003), and Peterson (1983) confirms the good accuracy of our  $v \sin i$  data. The rms of rotational velocity differences, from data listed in Tables 3, 4, and 5 for comparative purposes, is  $1.4 \text{ km s}^{-1}$ , indicating that the present  $v \sin i$  measurements are as accu-

**Table 2.** Rotational velocities for metal-poor stars. The remarks *f* and *c* refer to  $v \sin i$  data from FEROS and CORALIE observations, respectively, *V* to variable stars and *SB* for known spectroscopic binary stars.

Object	$v \sin i$ (km s <sup>-1</sup> )	$T_{\text{eff}}$ (K)	log <i>g</i>	[Fe/H]	Remarks
HD 97	4.2	4953	3.1	-1.4	f
HD 5426	5.2	5114	2.8	-2.1	f
HD 6268	7.5	4800	0.8	-2.5	f
HD 13780	10.0	7930	3.1	-1.5	f
HD 16456	15.0	7700	2.8	-1.5	V,f
HD 19445	10.0	5911	4.3	-1.6	V,f
HD 21581	5.0	4825	2.0	-1.7	f
HD 22879	4.7	5808	4.2	-0.9	f
HD 23798	6.2	4566	0.8	-2.1	f
HD 24289	6.3	5700	3.5	-2.2	f
HD 25704	4.8	5830	4.1	-1.1	f
HD 26297	5.0	4500	1.2	-1.7	f
HD 27928	4.0	5206	2.9	-2.0	f
HD 29574	5.5	4310	0.6	-1.9	V,f
HD 31943	6.0	7690	3.2	-1.0	f
HD 34328	5.5	5928	4.3	-1.7	f
HD 36702	5.6	4485	0.8	-2.0	f
HD 44007	5.0	4850	2.0	-1.7	f
HD 45282	3.0	5477	3.3	-1.4	f
HD 46341	4.0	5683	4.2	-0.8	f
HD 51754	3.5	5830	4.3	-0.5	c
HD 51929	3.0	5886	3.5	-0.5	c
HD 56274	5.0	5700	4.3	-0.6	f
HD 63077	5.0	5715	4.1	-1.0	f
HD 63598	4.5	5852	4.1	-0.7	f
HD 74721	1.0	8900	3.3	-1.4	f
HD 76932	5.0	5880	4.0	-1.0	f
HD 78913	10.0	8515	3.2	-1.5	f
HD 83212	6.0	4439	1.4	-1.4	f
HD 83220	8.0	6546	4.2	-0.7	c
HD 84903	6.0	4700	3.3	-1.4	c
HD 84937	5.2	6409	3.9	-2.2	f
HD 85773	7.0	4450	1.1	-2.0	f
HD 86986	13.0	7950	3.2	-1.8	f
HD 93529	8.0	4840	2.4	-1.2	f
HD 97916	10.2	6016	4.0	-1.1	f
HD 99383	4.0	6143	4.2	-1.5	SB,c
HD 101063	5.0	5163	3.4	-1.1	f
HD 103036	8.0	4375	0.8	-1.7	f
HD 103545	5.7	4725	1.7	-2.1	f
HD 104893	6.0	4500	1.1	-2.2	f
HD 106304	5.0	9747	3.5	-1.5	f
HD 110184	4.0	4366	0.5	-2.4	f
HD 111721	5.0	4825	2.2	-1.5	f
HD 111777	5.0	5693	4.4	-0.7	c
HD 111980	4.0	6032	3.7	-0.7	c
HD 113083	4.5	5762	4.0	-0.9	f
HD 117880	16.5	7880	3.3	-1.6	f
HD 118055	5.0	4088	0.8	-1.8	c
HD 121261	5.0	4210	1.0	-1.5	f
HD 122563	5.0	4697	1.3	-2.6	V,f
HD 122956	8.0	4575	1.1	-1.8	f
HD 126238	5.0	4979	2.5	-1.7	f
HD 128279	5.0	5275	2.8	-2.0	f
HD 130095	7.0	9000	3.3	-1.8	f
HD 132475	5.0	5920	3.6	-1.1	V,c
HD 134169	5.2	5861	3.9	-0.8	f

**Table2:** Cont.

Object	$v \sin i$ (km s <sup>-1</sup> )	$T_{\text{eff}}$ (K)	log <i>g</i>	[Fe/H]	Remarks
HD 136316	4.0	4998	1.1	-1.4	c
HD 140283	5.0	5928	3.4	-2.0	V,c
HD 145417	5.0	4953	4.5	-1.2	f
HD 145598	5.0	5525	4.4	-0.6	f
HD 148704	6.2	5096	4.0	-0.5	SB,f
HD 148816	5.7	5882	4.0	-0.7	f
HD 149414	5.0	5437	4.4	-1.0	f
HD 149996	5.0	5700	3.9	-0.6	f
HD 158809	5.0	5450	3.8	-0.5	c
HD 159482	5.0	5987	4.3	-1.0	f
HD 160617	6.2	6209	3.8	-1.7	f
HD 161770	5.8	5547	3.9	-2.0	f
HD 163799	5.2	5859	3.9	-0.9	f
HD 163810	6.0	5523	4.1	-1.1	f
HD 165195	5.0	4100	0.8	-1.9	V,c
HD 171496	7.0	4700	1.6	-0.9	f
HD 175179	4.4	5830	3.9	-0.7	f
HD 179626	4.0	6106	3.7	-0.8	c
HD 184266	8.5	5500	2.5	-1.5	f
HD 184711	8.2	4500	0.6	-2.2	V,f
HD 189558	5.2	5602	3.7	-1.1	f
HD 192031	5.0	5324	4.4	-0.8	f
HD 199288	5.0	5655	4.2	-0.6	f
HD 199289	4.0	5984	4.3	-0.8	c
HD 200654	4.0	5477	3.6	-2.4	c
HD 200973	4.8	6453	3.9	-0.5	f
HD 201099	5.3	5912	4.0	-0.5	f
HD 204543	4.0	5365	1.2	-2.0	c
HD 206739	5.3	4930	1.7	-1.6	c
HD 212038	4.4	5076	4.5	-0.5	f
HD 215257	3.0	5978	4.4	-0.7	c
HD 219617	6.2	5825	4.3	-1.5	f
HD 222434	5.4	4477	1.1	-1.7	f
HD 274939	3.0	5282	3.0	-1.2	c
BD -1° 1792	4.6	4850	2.7	-1.2	f
BD -1° 2582	10.0	5130	2.4	-2.3	f
BD -9° 5831	3.0	5327	1.4	-2.0	c
BD -10° 548	4.0	5706	3.0	-1.5	f
BD +3° 740	1.5	6075	3.8	-2.8	f
BD +6° 648	6.0	4500	1.1	-2.1	f
BD +8° 2856	7.0	4480	1.1	-2.3	c
BD +10° 2495	3.0	5027	1.4	-2.0	c
CD -24° 1782	8.0	5300	2.8	-2.8	f

rate as the values obtained by these authors. In fact, this excellent agreement between our  $v \sin i$  data and those from the referred authors is more meaningful if we consider that different approaches have been applied in the  $v \sin i$  determinations. For Carney et al. (2003) and Berh (2003), synthetic spectral analysis was applied by adjusting rotational broadening of absorption lines to a synthetic template, whereas Peterson (1983) made use of spectral synthesis and Fourier Transform techniques.

**Table 3.** Rotational velocities  $v \sin i_{Our}$  estimated in the present work and by Carney et al. (2003)  $v \sin i_{Carney}$ .

Object	$v \sin i_{Our}$ ( $\text{km s}^{-1}$ )	$v \sin i_{Carney}$ ( $\text{km s}^{-1}$ )
HD 97	4.2	4.0
HD 5426	5.2	6.3
HD 21581	5.0	5.7
HD 23798	6.2	5.0
HD 27928	4.0	1.7
HD 36702	5.6	6.5
HD 45282	3.0	5.0
HD 83212	6.0	7.3
HD 93529	8.0	5.0
HD 103545	5.7	3.0
HD 111721	5.0	7.4
HD 118055	5.0	6.3
HD 121261	5.0	7.1
HD 122956	8.0	11.7
HD 171496	7.0	5.1
HD 184266	8.5	5.0
HD 206739	5.3	7.3
HD 222434	5.4	6.9
BD $-1^\circ$ 2582	10.0	8.0
BD $-9^\circ$ 5831	3.0	5.1
BD $+8^\circ$ 2856	7.0	8.9
BD $+10^\circ$ 2495	3.0	3.8

**Table 4.** Rotational velocities  $v \sin i_{Our}$  estimated in the present work and by Behr (2003)  $v \sin i_{Behr}$ .

Object	$v \sin i_{Our}$ ( $\text{km s}^{-1}$ )	$v \sin i_{Behr}$ ( $\text{km s}^{-1}$ )
HD 97	4.2	4.0
HD 74721	1.0	2.6
HD 86986	13.0	9.2
HD 117880	16.5	14.5
HD 161770	5.8	2.6
HD 184266	8.5	9.3
BD $+3^\circ$ 740	1.5	6.0
BD $+10^\circ$ 2495	3.0	2.6

**Table 5.** Rotational velocities  $v \sin i_{Our}$  estimated in the present work and by Peterson (1983)  $v \sin i_{Peterson}$ .

Object	$v \sin i_{Our}$ ( $\text{km s}^{-1}$ )	$v \sin i_{Peterson}$ ( $\text{km s}^{-1}$ )
HD 19445	10.0	10.0
HD 74721	1.0	6.0
HD 84937	5.2	6.0
HD 86986	13.0	9.0
HD 117880	16.5	12.0
HD 130095	7.0	6.0

## 4. Contents

The present study brings projected rotational velocity  $v \sin i$  for 100 metal-poor stars, most of which were evolving off the main sequence. The main results of this part of the program concerning the rotational velocity for metal-poor stars are listed in Table 2, where stars appear in order of increasing HD number, except for those stars presenting only a BD number in the literature. The columns mean:

1. HD number
2. The measured rotational velocity  $v \sin i$
3. Effective temperature
4. Gravity
5. Metallicity
6. Remarks

For the stars with a flag  $f$  or  $c$  in the Remarks column, the rotational velocity  $v \sin i$  was determined from observations carried out with the FEROS and CORALIE spectrometers, respectively.  $V$  in the Remarks column stands for variable stars and  $SB$  for known spectroscopic binary stars.

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