Precise Stellar Radial Velocities
ASP Conference Series, Vol. 185, 1999
J. B. Hearnshaw and C. D. Scarfe, eds.

20 Years of CORAVEL Monitoring of Radial-Velocity Standard Stars

S. Udry[1], M. Mayor[1], E. Maurice[2], J. Andersen[3], M. Imbert[2], H. Lindgren[4], J.-C. Mermilliod[5], B. Nordström[3], L. Prévot[2]

[1]*Observatoire de Genève, 51 ch. des Maillettes, CH-1290 Sauverny*

[2]*Observatoire de Marseille, 2 place Le Verrier, F-13248 Marseille*

[3]*Niels Bohr Institute, Juliane Maries Vej 30, DK-2100 Copenhagen OE*

[4]*Lund Observatory, Box 43, S-22100 Lund*

[5]*Institut d'astronomie, Université de Lausanne, CH-1290 Chavannes-des-bois*

Abstract. A preliminary analysis of a sample of more than hundred stars, used as radial-velocity standards and followed with the CORAVEL spectrographs over 1 to 2 decades, is presented. Stars with intrinsic variability or orbital motions are pointed out.

1. Introduction

During more than 20 years a group of 111 stars has been monitored with the two CORAVEL spectrometers as radial-velocity standard stars. The large number of measurements ($N_{tot} \simeq 20\,350$) and their very long time-base (Fig. 1) provide an unequalled sample to check the long term stability of radial-velocity standards. The long term survey permits the rejection of low-amplitude and long-period binaries and of intrinsic variable stars.

One of the aims of the analysis of the CORAVEL standards is to provide a list of constant stars usable as radial-velocity standards, extending the list proposed by the IAU. In most cases, it is however strongly recommended to use the new high-precision standard list defined by combining CORAVEL (very long time base) and ELODIE (high precision) measurements (Udry, Mayor & Queloz 1999).

The subsample of *standard stars* constant in radial velocity has been used to follow and correct the time-dependent drift of the CORAVEL spectrographs.

2. Origin of the sample

The CORAVEL standard stars have been chosen from different lists in order to cover a large range in colour, velocity and magnitude (Table 1): the bright and faint IAU standard stars (Pearce 1955; IAUb, IAUf in Table 1), a suggested extension of northern faint standards (Heard 1968; H in Table 1), a suggested extension of southern faint standards (Evans 1968; E in Table 1), a selected sam-

https://doi.org/10.1017/S0252921100048818 Published online by Cambridge University Press

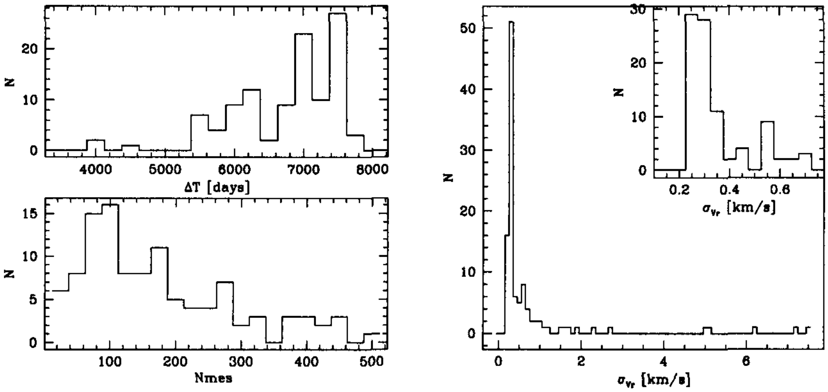

Figure 1. **Left.** Distributions of the number of measurements per star and of the spans in days (ΔT) between their first and last observations. **Right.** Histogram of the radial-velocity dispersion of the measurements. The right-hand tail includes the stars with recognized orbital motion or stars showing intrinsic variations.

ple of stars from the Wilson catalogue (1953) with high (quality a) or moderate (quality b) velocities (Wa and Wb in Table 1).

From our sample, four stars chosen as standards by R.F. Griffin and also intensively followed with CORAVEL are not included here: HD 3346, HD 54716, HD 113996 and HD 176670. They will be discussed elsewhere.

3. Result summary

The variability analysis of 107 among the 111 stars forming the initial CORAVEL catalogue of standards (including the IAU standards) is presented in Fig. 1 (right) and Table 1. At a precision level of $\sim 0.3\,\mathrm{km\ s^{-1}}$, a large number among these stars (~ 70 stars) are found to be constant (blank in the 'Rem' column of Table 1) over a very long period of time, providing thus a useful, homogeneous sample of standard stars. In particular, they extend the IAU list towards the large velocity values. In the table the radial velocities are given in the "ELODIE" system (Udry et al. 1999), rounding off the values at a $100\,\mathrm{m\ s^{-1}}$ precision level. They supersede the values given in Mayor & Maurice (1985).

The radial-velocity variable stars split in different categories defined by the most probable causes of the observed velocity variations: orbital motion, intrinsic processes or unknown.

For 13 stars of the sample the velocity variations relate to orbital motions. 7 have well determined orbital parameters (SBO or SB2O in Table 1) among which three are new: HD 42397 ($P = 5203.3$d; the SB2 feature was already pointed out by Scarfe 1992), HD 86801 ($P = 9972.1$d, $e = 0.9$) and HD 101266 ($P = 3805.2$d, $m_2 \sin i = 0.076\ \mathrm{M_\odot}$). For the other four binaries, the orbital elements were respectively derived by Mazeh, Latham, & Stefanik (1996) and

https://doi.org/10.1017/S0252921100048818 Published online by Cambridge University Press

Mayor et al. (1997) for HD 29 587 and HD 140 913, by Latham et al. (1989) for HD 114 762, and by McClure (1983) for HD 184 467. The CORAVEL orbits will be given in the main paper describing the CORAVEL standard star sample (Udry et al., in preparation). In addition to those binaries, 6 stars show a very clear drift in radial velocity over a span of more than 6000 days. Two of those are giants and thus could experience intrinsic variations (see below) but the timescale and amplitude of the variations point towards an orbital explanation for the observed drift.

Among the other radial-velocity variables, several red and yellow giants present variations with well defined periodicities. In particular 5 of them (2 new ones) have large radial-velocity variations and/or long periods and were thus considered first as binaries. However, the long-P radial-velocity variations of yellow giants are now associated with intrinsic phenomena (Larson, Yang, & Walker 1999; Walker et al. 1989). The 5 candidates, indicated by SBO–IVAR? in Table 1, are the following: HD 14 969 (P = 1911.6 d, K = 4.56 km s^{-1}, Griffin 1980), HD 35 410 (P = 1491.2 d, K = 1.94 km s^{-1}, new), HD 44 131 (P = 4043.1 d, K = 1.26 km s^{-1}, new), HD 160 952 (P = 181.7 d, K = 2.57 km s^{-1}, Radford & Griffin 1976) and HD 204 934 (P = 143.79 d, K = 6.14 km s^{-1}, Radford & Griffin 1975). A group of 5 additional giant stars of spectral types between K3 and M4 (HD 108 903, HD 115 521, HD 123 782, HD 186 791, HD 223 094) show smaller amplitude variations ($\sigma_{Vr} < 0.6$ km s^{-1}) with well defined time-scales of a few hundred days. Moreover, the variation phases seem to be fairly well conserved over the full time span of our observations i.e. over 10 to 20 cycles of variation. The star HD 3346 (McClure et al. 1985) presents the same characteristics. From our data, a period–amplitude–colour trend can be pointed out for varying giant stars. This trend will be further examined in the future.

Finally, associated with the very high precision of the ELODIE spectrograph, the long time-base of the CORAVEL measurements allows us to propose a list of high-precision radial-velocity standards for solar-type stars (G and K dwarfs). This new high-precision standard sample is given in Udry et al. (1999).

Acknowledgments. It is a pleasure to thank the technical support team of the CORAVEL spectrographs and the various CORAVEL observers for their regular and diligent measures of standards. This work has benefited from the continuous support of the *Fonds National Suisse de la Recherche Scientifique*.

References

Evans, D.S. 1968, in Trans. IAU, XIII B, L. Perek, Dordrecht: Reidel, 170

Griffin, R.F. 1980, MNRAS, 190, 711

Heard, J.F. 1968, in Trans. IAU, XIII B, L. Perek, Dordrecht; Reidel, 169

Larson, A.M., Yang, S.L.S., & Walker, G.A.H. 1999, these Proceedings

Latham, D., Mazeh, T., Stefanik, R., Mayor, M., & Burki, G. 1989, Nature 339, 38

Mayor, M., & Maurice, E. 1985, in Stellar Radial Velocities (IAU Coll. 88), A.G.D. Philip & D.W. Latham, Schenectady, L.Davis, 299

Mayor, M., Queloz, D., Udry, S., & Halbwachs, J.-L. 1997, in Astronomical and Biochemical Origins and the Search for Life in the Universe (IAU Coll. 161), C. Cosmovici, S. Bowyer & D. Werthimer, Bologna: Editrice Compositori, 313

Mazeh, T., Latham, D., & Stefanik, R. 1996, ApJ, 466, 415

McClure R.D. 1983, PASP, 95, 201

McClure, R.D., Griffin, R.F., Fletcher, J.M., Harris, H.C., & Mayor, M. 1985, PASP, 97, 740

Pearce, J.A. 1955, in Trans. IAU, IX B, P. Oosterhoff, Cambridge: Camb. Univ. Press, 441

Radford, G.A., & Griffin, R.F. 1975, Observatory, 95, 187

Radford, G.A., & Griffin, R.F. 1976, Observatory, 96, 56

Scarfe, C.D. 1992, Information Bulletin on Variable Stars, 3736

Udry, S., Mayor, M., & Queloz, D. 1999, these Proceedings

Walker, G., Yang, S., Campbell, B., & Irwin, A. 1989, ApJ, 343, L21

Wilson, R.E. 1953, General Catalogue of Stellar Radial Velocities, Washington: Carnegie Institution of Washington

Table 1.: Overview of the CORAVEL radial-velocity standard stars. The first 4 columns give the identification and photometric information. Columns 5 and 6 provide the CORAVEL radial velocity and velocity dispersion (km s^{-1}) in the new "ELODIE" system (Udry et al. 1999). Column 7 provides the source-list of the standards and the last column gives information on the probable cause of variability: *SBO, SB2O, Drift* refer to an orbital motion, *IVAR* indicates a probable intrinsic variability whereas *VAR* is used for variability whose origin is still unclear.

HD/DM	V	Sp	B-V	V_r	σ_{V_r}	list	Rem
26	8.26	G4V	1.05	-215.3	1.2	Wb	Drift
693	4.89	F5V	0.49	15.0	0.3	IAUf	
3712	2.24	K0II-III	1.17	-4.3	0.2	IAUb	
3765	7.36	K2V	0.94	-63.3	0.2	IAUf	
4128	2.04	K0III	1.02	13.1	0.2	IAUb	
4388	7.34	K3III	1.12	-27.5	0.3	H	
6655	8.05	F8V	0.56	19.5	0.3	E	
8779	6.42	K0IV	1.24	-4.2	0.3	IAUf	
9138	4.84	K4III	1.37	34.2	0.2	IAUf	
12029	8.2	K2III	0.40	38.5	0.3	H	
12929	2.01	K2III	1.15	-14.6	0.2	IAUb	
14969	7.07	K3III	1.42	-32.9	2.7	H	SBO-IVAR?
18884	2.54	M2III	1.63	-26.1	0.3	IAUb	
20902	1.79	F5Ib	0.48	-2.0	0.6	IAUb	IVAR
22484	4.29	F9V	0.57	27.9	0.3	IAUf	
22879	6.68	F9V	0.55	120.2	0.3	Wb	

HD/DM	V	Sp	B-V	V_r	σ_{V_r}	list	Rem
23169	8.5	G2V	0.60	14.2	0.3	H	
23614	4.43	M1III	1.60	45.2	0.5	Wa	IVAR
24331	8.61	K2V	0.91	23.9	0.2	E	
25025	2.97	M1IIIb	1.59	61.1	0.5	Wa	IVAR
25532	8.20	F6IV-V	0.66	-111.5	0.4	Wb	VAR
26162	5.51	K2III	1.08	24.8	0.3	IAUf	
29139	0.87	K5III	1.54	54.2	0.2	IAUb	
29587	7.29	G2V	0.63	112.4	0.5	IAUf	SBO
32963	7.60	G5IV	0.66	-62.4	0.3	H	
35410	5.07	K0III	0.96	20.7	0.7	IAUf	New SBO-IVAR?
36079	2.81	G5II	0.81	-14.2	0.3	IAUb	
36673	2.58	F0Ib	0.21	25.2	1.0	IAUb	IVAR
37160	4.09	G8III-IV	0.95	99.0	0.3	Wa	
39194	8.09	K0V	0.76	13.9	0.3	E	
39364	3.76	G8III-IV	0.98	100.2	0.3	Wa	
42397	7.7	G0IV	0.90	38.3	9.0	H	New SB2O
44131	4.91	M1III	1.61	48.7	0.9	IAUf	New SBO-IVAR?
-43:2527	8.61	K1III	1.15	19.7	0.9	E	VAR
48381	8.49	K5	1.05	40.5	0.2	E	
50778	4.08	K4III	1.42	96.2	0.4	Wa	
51250	5.00	B9.5V	1.18	18.1	0.3	IAUf	
54810	4.91	K0III	1.02	77.5	0.3	Wa	
62509	1.16	K0III	0.99	3.2	0.3	IAUb	
65583	6.97	G8V	0.72	14.7	0.3	IAUf	
65934	7.70	G8III	0.93	35.8	0.3	H	
66141	4.39	K2III	1.25	71.6	0.3	IAUf	
75935	8.46	G8V	0.77	-18.1	0.3	H	
76932	5.80	F7-F8IV-V	0.52	119.2	0.5	Wb	VAR
80170	5.31	K2III	1.17	0.5	0.2	IAUf	
81797	1.99	K3III	1.44	-4.7	0.3	IAUb	
83443	8.23	K0V	0.81	28.7	0.3	E	
83516	8.63	K0III	0.97	43.5	0.2	E	
84441	2.97	G0II	0.81	4.5	0.4	IAUb	
86801	8.78	G0V	0.58	-11.4	1.9	H	New SBO
89449	4.78	F6IV	0.45	6.3	0.5	IAUf	VAR
90861	6.88	K2III	1.11	37.1	0.3	H	
92588	6.25	K1IV	0.88	42.5	0.3	IAUf	
101266	9.30	G5IV	0.66	23.0	0.8	E	New SBO
102494	7.48	G9IV	0.87	-22.1	0.3	H	
102870	3.59	F8V	0.52	4.3	0.3	IAUb	
103095	6.42	G8V	0.75	-98.3	0.3	IAUf	
107328	4.97	K1III	1.17	36.4	0.3	IAUf	
108903	1.59	M4III	1.60	21.0	0.4	IAUb	IVAR
109379	2.65	G5II	0.89	-7.6	0.3	IAUb	
111417	8.30	K3IV	1.40	-19.1	0.2	E	
112299	8.39	F8V	0.58	3.9	0.3	H	
114762	7.30	F9V	0.53	49.4	0.5	IAUf	SBO

HD/DM	V	Sp	B-V	V_r	σ_{V_r}	list	Rem
115521	4.78	M2III	1.64	-28.6	2.3	IAUf	IVAR
120223	8.97	G8IV	0.97	-25.1	0.5	E	Drift
122693	8.11	F8V	0.59	-5.5	0.3	H	
123782	5.26	M2III	1.64	-13.9	0.6	IAUf	IVAR
124897	-0.05	K2III	1.24	-5.3	0.3	IAUb	
126053	6.25	G1V	0.64	-19.3	0.3	IAUf	
132737	7.64	K0III	1.01	-23.9	0.2	H	
136202	5.04	F8III-IV	0.54	54.3	0.3	IAUf	
140913	8.06	G0V	0.61	-20.0	1.1	H	SBO
144579	6.66	G8V	0.73	-59.5	0.3	IAUf	
145001	5.00	G8III	0.93	-10.3	0.3	IAUf	
146051	2.73	M1III	1.58	-19.6	0.3	IAUb	
149803	8.58	F7V	0.48	-7.5	0.7	H	VAR
150798	1.91	K2II-III	1.45	-3.0	0.3	IAUb	
154417	6.00	F9V	0.58	-16.8	0.3	IAUf	
156014	2.78	M5II	1.16	-32.0	1.2	IAUb	IVAR
157457	5.19	K1III	1.05	17.8	0.3	IAUf	
160952	7.81	G8III	0.95	26.4	1.7	H	SBO-IVAR?
161096	2.76	K2III	1.17	-12.5	0.3	IAUb	
168454	2.72	K3III	1.38	-20.4	0.3	IAUb	
171232	7.44	G8III	0.88	-37.3	0.8	H	Drift
171391	5.12	G8III	0.93	7.4	0.2	IAUf	
176047	8.10	K0III	0.96	-42.5	0.2	E	
182572	5.17	G8IV	0.76	-100.4	0.3	IAUf	
184467	6.60	K1V	0.86	11.2	9.9	IAUf	SB2O
184499	6.62	G0V	0.59	-166.1	0.5	Wb	VAR? SB?
186791	2.72	K3II	1.51	-2.8	0.6	IAUb	IVAR
187691	5.12	F8V	0.56	-0.0	0.3	IAUf	
193231	8.39	G5V...	0.73	-31.8	1.5	E	Drift
194071	7.9	G8III	0.60	-9.4	0.3	H	
194598	8.33	F7V-VI	0.50	-246.5	0.9	Wb	VAR
196983	9.08	K2III	1.18	-9.1	0.3	E	
203638	5.38	K0III	1.18	22.1	0.2	IAUf	
204867	2.90	G0Ib	0.83	6.3	0.3	IAUb	
204934	8.20	K1III	1.10	-4.8	4.9	H	SBO-IVAR?
206778	2.38	K2Ib	1.52	3.4	0.6	IAUb	IVAR
212943	4.78	K0III	1.04	54.2	0.2	IAUf	
213014	7.45	G9III	0.89	-39.9	0.2	IAUf	
213947	6.88	K2	1.48	16.5	0.3	H	
219509	8.71	K5	1.05	67.5	0.5	E	Drift
222368	4.13	F7V	0.51	5.6	0.3	IAUb	
223094	6.97	K5III	1.63	20.2	0.4	H	IVAR
223311	6.09	K4III	1.45	-20.2	0.3	IAUf	
223647	5.10	G7III	0.93	15.4	0.6	IAUf	Drift

Discussion

Walker: With all the considerable efforts now being devoted to radial-velocity standards it is really important to monitor, simultaneously, chromospheric activity. Otherwise the question of intrinsic versus binary variability will keep coming up.

Udry: We are planning to do so with ELODIE.

Isaak: Adding to Gordon Walker's comment on monitoring chromospheric activity, one should monitor the velocity frequently in order comfortably to satisfy the Nyquist criterion for the activity-induced velocity modulation we discovered on the sun in 1982.