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Do Si stars undergo any rotational braking?[⋆]

P. North

Institut d'Astronomie de l'Université de Lausanne, CH-1290 Chavannes-des-bois, Switzerland

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Abstract. The old question of rotational braking of Ap Si stars is revisited on the empirical side, taking advantage of the recent Hipparcos results. Field stars with various evolutionary states are considered, and it is shown that the loose correlation between their rotational period and their surface gravity is entirely compatible with conservation of angular momentum. No evidence is found for any loss of angular momentum on the Main Sequence, which confirms earlier results based on less reliable estimates of surface gravity.

The importance of reliable, fundamental $T_{\rm eff}$ determinations of Bp and Ap stars is emphasized.

Key words: stars: chemically peculiar – stars: fundamental parameters – stars: individual: HD 124224 – stars: rotation

1. Introduction

It is well known that chemically peculiar stars of the Ap and Am types are rotating more slowly than their normal counterparts (e.g. North 1994). The question then arises, whether slow rotation is acquired during the main sequence life of the star, or before its arrival on the ZAMS, i.e. during the proto-stellar phase. Havnes & Conti (1971) had suggested that magnetic stars undergo magnetic braking during their main sequence lifetime, due to mass accretion from the interstellar medium, while Strittmatter & Norris (1971) proposed the same, but due to mass loss. These theoretical considerations seemed to get support from observational evidence when Wolff (1975, 1981), Stift (1976) and Abt (1979) found some correlation between the radii or ages of Ap stars and their rotational periods obtained from their photometric or spectroscopic variations. On the contrary, Hartoog (1977) concluded that magnetic Ap stars in young clusters do not rotate faster than those in older clusters, and this conclusion was also reached by North (1984a, b, 1985, 1986, 1987), Borra et al. (1985) and Klochkova & Kopylov (1985). The apparent correlation between radius and rotational period has been commented by Hensberge et al. (1991), who conclude that this correlation is real but possibly due to a detection bias depending on the inclination angle, and by Stepien (1994), who concluded on the contrary that this correlation does simply not exist, if spurious rotational periods are duly excluded.

Using the $\log P_{\rm rot}$ vs. $\log g$ diagram for field stars, North (1985, 1986, 1992) showed that for Si stars, there is indeed a trend towards longer periods for low-gravity stars, but which can be entirely explained by conservation of angular momentum as the star evolves with increasing radius within the main sequence.

In this note, we revisit the $\log P_{\rm rot}$ vs. $\log g$ diagram for field stars having both a rotational period in the literature and a reliable surface gravity, the latter being either spectroscopic or obtained from Hipparcos data.

2. The sample

2.1. Spectroscopic surface gravities

The sample has been built from two parts. First was considered the list of silicon stars for which North & Kroll (1989, hereafter NK89) give a spectroscopic estimate of $\log g$ based on the profile of the H_β line. The estimate given in column 5 of their Table 1 was adopted, and corrected for a constant shift

$$\log g(corrected) = \log g(\mathrm{H}_\beta) + 0.14 \qquad (1)$$

which takes into account the systematic error displayed in their Fig. 16, although not exactly according to their Eq. 16 which would imply too large $\log g$ values for some stars. The intersection of this list with all stars having a known rotational period in the literature was then done, using an updated version of the database of Renson et al. (1991) which is a digital version of the catalogue of Renson (1991). Two stars in the list of NK89 which had no known period have been added, since their period has now been determined thanks to the Hipparcos mission (Perryman et al. 1997): they are HD 154856 ($P = 1.9525$ days) and HD 161841 ($P = 3.21048$ days). The original sample of NK89 was biased in favour of low *photometric* gravities, hence also of low *spectroscopic* (and hopefully real) gravities, since there is a loose correlation between them. Most stars of this sample are not very bright ($V \sim 7-8$), nor closeby enough that their parallax is significant, even for Hipparcos.

This sample contains 40 stars.

Send offprint requests to: P. North

[⋆] Based on data from the ESA Hipparcos satellite

2.2. *Hipparcos surface gravities*

Second, the list of Si, SiCr or Cr stars with a Hipparcos parallax larger than 7 mas was defined and those with a known rotational period were retained. One star had no period in the literature but has a new one from Hipparcos (HD 74067, $P = 3.113$ days). Their mass has been interpolated in theoretical evolutionary tracks (Schaller et al. 1992) from $T_{\rm eff}$ and $M_{\rm bol}$. The effective temperature has been computed using the X and Y parameters of Geneva photometry calibrated by Künzli et al. (1997), and corrected according to the formula $T_{\rm eff} = -230 + 0.941 \times T(X,Y)$ (Hauck & Künzli 1996) which replaces Eq. 1 of Hauck & North (1993) and where $T(X,Y)$ results from the calibration. The bolometric correction was interpolated in Table 6 of Lanz (1984) and corrected by $\delta_{\rm BC}$ plotted in his Fig. 4a. Contrary to the previous sample, this one is not biased regarding the distribution of the surface gravities, at least not *a priori*: it is a volume-limited sample which, although surely affected by a Malmquist-like bias, should be representative of field stars with a more or less uniform distribution of ages. Therefore, it contains a majority of stars which are rather close to the ZAMS in the HR diagram, just because stellar evolution is slower there than near the core-hydrogen exhaustion phase. If there is no *a priori* bias regarding the evolutionary state, one may say, nevertheless, that the $\log g$ distribution is biased towards high values, compared to a uniform distribution (which, then, would be strongly biased towards large ages).

This sample contains 56 stars.

2.2.1. Lutz-Kelker correction

The absolute magnitudes have been corrected for the Lutz-Kelker (1973) correction, but this correction was not applied in its original form which assumes a constant stellar density. Indeed, the distances involved are not negligible compared with the density scale height perpendicular to the galactic disk, so the following generalized formulae were adopted:

$$N(r)dr \propto \quad r^2 \cos b \exp\left(-\frac{r \sin|b|}{\beta(M_V)}\right) dr \tag{2}$$

$$G(Z,\pi_{\rm o},b) = Z^{-4} \times \exp\left(\frac{\sin|b|}{\beta(M_V)\pi_{\rm o}}\left[1-\frac{1}{Z}\right]\right) \times \exp\left(-\frac{(Z-1)^2}{2(\sigma/\pi_{\rm o})^2}\right) \tag{3}$$

$$Z \equiv \frac{\pi}{\pi_{\rm o}} \tag{4}$$

Let us recall that the correction on the absolute magnitude then reads:

$$<\Delta M(\epsilon)>= \frac{5\int_\epsilon^\infty \log Z\, G(Z,\pi_{\rm o},b)dZ}{\int_\epsilon^\infty G(Z,\pi_{\rm o},b)dZ} \tag{5}$$

where $\epsilon = 0.2$, $\beta(M_V)$ is the scale height of the star density above the galactic plane tabulated by Allen (1976), π is the true parallax and $\pi_{\rm o}$ is the observed parallax affected by a gaussian error σ.

2.2.2. Visual absorption

The absolute magnitude also had to be corrected for the visual absorption, even though it remains negligible in most cases. Since Cramer (1982) found that the colour excess $E[U-B]$ defined in the Geneva system was almost the same for Bp, Ap members of clusters as for normal B, A members – and with a smaller dispersion than $E[B-V]$ – this colour excess was used, corrected using Cramer's relation $E[U-B](Bp,Ap) = E[U-B](X,Y) - 0.009$ where $E[U-B](X,Y)$ is the colour excess obtained using the intrinsic colours (of normal stars) of Cramer (1982). A_V is then obtained through $E(B-V) = 1.28E[U-B]$, since $E[U-B] = 0.658E[B-V]$ (Cramer 1994) and $E(B-V) = 0.842E[B-V]$ (Cramer 1984), and $R = A_V/E(B-V) = 3.25 + 0.25(B-V)_{\rm o} + 0.05E(B-V)$ (Olson 1975).

2.2.3. Fundamental parameters from Hipparcos parallaxes

Once the effective temperature and bolometric correction are determined from photometry and the absolute magnitude from Hipparcos parallaxes as described above, it becomes possible to pinpoint the star on a theoretical HR diagram, the luminosity being obtained from

$$\log(L/L_\odot) = -0.4(M_V - 4.72 + B.C.) \tag{6}$$

Then, we assume that Bp stars follow standard, solar-composition evolutionary tracks (since the chemical peculiarities are limited to superficial layers only) and the mass can be interpolated from $T_{\rm eff}$ and $\log(L/L_\odot)$ (using successive 3rd-degree splines in luminosity, $T_{\rm eff}$ and overall metallicity Z, with $Z = 0.018$) whenever there is a one-to-one relation between these quantities. The latter condition is not fulfilled near the core-hydrogen exhaustion phase, when $T_{\rm eff}$ increases, then decreases again, and in this domain we always assumed the star to lie on the lower, continuous branch of the evolutionary track, which also corresponds to the slowest evolution, hence to the higher probability. This assumption, if violated, will lead to a mass overestimate no larger than five percent.

The radius is directly obtained from

$$\log(R/R_\odot) = \frac{1}{2}\log(L/L_\odot) - 2\log(T_{\rm eff}/T_{\rm eff\odot}) \tag{7}$$

and the surface gravity from

$$\log g = \log\left(\frac{M}{M_\odot}\right) + 4\log\left(\frac{T_{\rm eff}}{T_{\rm eff\odot}}\right) - log\left(\frac{L}{L_\odot}\right) + 4.44 \tag{8}$$

The latter equation shows how strongly $\log g$ depends on $T_{\rm eff}$, which remains a crucial quantity. The error on it was generally assumed to be 5 percent. The errors on the other quantities are estimated using the usual, linearized propagation formulae, but caring for the correlations between L, $T_{\rm eff}$ and M.

The results are displayed on Table 1.

Table 1. Fundamental parameters of the Si and He-weak stars derived from the Hipparcos parallaxes. The masses were obtained by interpolation in the evolutionary tracks of Schaller et al. (1992). Note that the errors are multiplied by a factor of 1000 for $T_{\rm eff}$, 100 for Mass, $\log(L/L_{\odot})$ and $\log g$, and 10 for R. The rotational period from the literature (or from Hipparcos photometry in three cases, see text) is given in the last column. "LK" means "Lutz-Kelker correction" and is expressed in magnitudes.

HD	$\rm M_V$	Mass [$\rm M_{\odot}$]	$\log T_{\rm eff}$	$\log(L/L_{\odot})$	$\log g$	R [$\rm R_{\odot}$]	d [pc]	$\sigma(\pi)/\pi$	LK [mag]	$\rm P_{rot}$ [days]
4778	1.18	2.24± 9	3.972± 14	1.51± 7	4.12± 9	2.2± 2	93	0.07	-0.046	2.5616
9484	1.00	2.34± 12	3.987± 22	1.59± 9	4.12± 13	2.2± 3	128	0.09	-0.070	0.7 ?
9531	0.35	2.85± 15	4.039± 20	1.96±10	4.19± 13	2.7± 4	126	0.10	-0.103	0.67
9996	0.68	2.47± 15	3.987± 23	1.72±12	4.01± 14	2.6± 4	149	0.12	-0.143	8395 (23 y)?
10221	-0.28	3.12± 12	4.030± 20	2.19± 9	3.95± 11	3.6± 5	141	0.08	-0.069	3.18
11502	-0.15	2.87± 8	3.989± 18	2.05± 6	3.76± 9	3.7± 4	63	0.05	-0.026	1.60920
12767	-0.60	3.65± 18	4.111± 20	2.39± 9	4.14± 12	3.2± 4	114	0.09	-0.059	1.9
14392	0.26	3.07± 14	4.078± 20	2.04± 8	4.29± 11	2.4± 3	112	0.08	-0.056	4.189
18296	-0.54	3.32± 15	4.036± 20	2.31±11	3.89± 12	4.1± 6	125	0.11	-0.109	2.8842
19832	0.25	3.16± 17	4.095± 20	2.04±10	4.36± 12	2.3± 3	119	0.10	-0.096	0.7278972
24155	0.18	3.39± 20	4.132± 20	2.11±12	4.48± 13	2.1± 3	145	0.12	-0.138	2.535
25267	-0.30	3.35± 15	4.080± 20	2.26± 7	4.11± 11	3.1± 4	103	0.07	-0.041	1.210
27309	0.34	3.06± 12	4.079± 13	2.02± 8	4.32± 9	2.4± 3	99	0.07	-0.052	1.569
29305	-0.39	3.33± 10	4.064± 14	2.29± 5	4.02± 7	3.5± 3	54	0.03	-0.006	2.94
32549	-0.98	3.29± 17	3.985± 23	2.37±12	3.47± 14	5.5±10	131	0.12	-0.144	4.64
32650	0.05	3.08± 13	4.059± 20	2.10± 7	4.15± 11	2.9± 4	117	0.06	-0.037	2.73332
34452	-0.42	3.95± 21	4.160± 20	2.42±10	4.34± 12	2.6± 4	144	0.10	-0.097	2.4660
40312	-1.05	3.38± 8	3.997± 13	2.42± 6	3.49± 7	5.5± 5	54	0.04	-0.018	3.6190
49976	1.13	2.21± 11	3.955± 23	1.51± 8	4.04± 13	2.3± 3	104	0.08	-0.067	2.976
54118	0.35	2.73± 9	4.022± 17	1.89± 5	4.03± 9	2.7± 3	87	0.04	-0.015	3.28
56455	0.02	3.25± 14	4.096± 20	2.13± 7	4.29± 11	2.5± 3	133	0.07	-0.045	1.93
72968	1.06	2.25± 9	3.960± 14	1.55± 7	4.04± 9	2.4± 3	84	0.07	-0.047	11.305
74067	0.45	2.57± 7	3.988± 13	1.82± 6	3.93± 7	2.9± 3	87	0.05	-0.024	3.11299
74521	-0.02	3.01± 16	4.033± 20	2.11±10	4.04± 13	3.3± 5	131	0.11	-0.103	7.0501
89822	0.76	2.57± 9	4.025± 16	1.72± 6	4.18± 9	2.2± 2	93	0.05	-0.020	7.5586
90044	0.71	2.51± 12	4.002± 22	1.73± 8	4.07± 12	2.4± 3	110	0.08	-0.054	4.379
92664	-0.37	3.86± 17	4.154± 20	2.38± 8	4.35± 11	2.5± 3	146	0.07	-0.053	1.673
103192	-0.55	3.36± 15	4.044± 20	2.33±10	3.90± 12	4.0± 6	117	0.10	-0.091	2.34
112381	1.40	2.26± 12	3.999± 24	1.45± 9	4.29± 13	1.8± 3	105	0.09	-0.076	2.8
112413	0.24	3.00± 9	4.060± 14	2.04± 5	4.21± 8	2.6± 2	34	0.04	-0.011	5.46939
114365	0.83	2.80± 13	4.069± 20	1.81± 8	4.45± 11	1.9± 3	108	0.08	-0.055	1.27
115735	0.48	2.55± 7	3.990± 13	1.80± 6	3.96± 7	2.8± 3	85	0.05	-0.024	0.77 ?
116458	-0.17	2.95± 11	4.012± 22	2.09± 8	3.81± 11	3.5± 5	146	0.08	-0.063	147.9
119419	1.09	2.62± 13	4.048± 20	1.69± 9	4.45± 12	1.9± 3	116	0.08	-0.071	2.6006
124224	0.42	3.03± 17	4.084± 13	1.97± 8	4.37± 9	2.2± 2	82	0.07	-0.046	0.52068
125248	1.19	2.24± 9	3.972± 14	1.51± 8	4.12± 9	2.2± 3	93	0.08	-0.063	9.2954
125823	-1.27	5.69± 30	4.248± 20	3.07±10	4.20± 12	3.7± 5	134	0.10	-0.089	8.817744
126515	1.03	2.29± 17	3.970± 24	1.57±15	4.06± 16	2.3± 5	155	0.15	-0.200	129.95
129174	-0.39	3.49± 14	4.094± 14	2.33± 9	3.98± 9	3.2± 4	100	0.09	-0.067	2.24 ?
133652	0.68	3.05± 14	4.113± 12	1.89± 9	4.57± 9	1.8± 2	99	0.09	-0.082	2.304
133880	0.09	3.17± 18	4.079± 20	2.12±11	4.22± 13	2.7± 4	134	0.11	-0.116	0.877485
140728	0.48	2.58± 7	3.998± 13	1.81± 6	3.99± 7	2.7± 2	98	0.05	-0.020	1.29557
142301	-0.57	4.41± 36	4.193± 20	2.59±18	4.35± 17	2.7± 6	161	0.17	-0.311	1.459
142884	0.53	3.45± 22	4.160± 20	2.03±13	4.67± 14	1.7± 3	133	0.13	-0.176	0.803
149822	0.61	2.58± 14	4.010± 22	1.78±10	4.07± 13	2.5± 4	140	0.11	-0.101	1.459
152308	0.68	2.43± 12	3.976± 22	1.71±11	3.97± 13	2.7± 4	146	0.11	-0.111	1.10 (or 0.92)?
166469	0.49	2.62± 15	4.012± 22	1.81±10	4.04± 13	2.6± 4	140	0.10	-0.112	2.9
170000	0.21	2.99± 10	4.058± 14	2.03± 6	4.21± 8	2.7± 2	89	0.04	-0.017	1.71649
170397	1.07	2.35± 9	3.993± 13	1.57± 8	4.16± 9	2.1± 2	89	0.07	-0.055	2.1912
175362	-0.52	5.17± 31	4.249± 20	2.78±12	4.45± 14	2.6± 4	140	0.12	-0.152	3.67375
183806	-0.22	2.89± 14	3.976± 22	2.07±11	3.68± 13	4.1± 7	142	0.16	-0.126	2.9
187474	0.27	2.70± 11	4.004± 22	1.90± 9	3.94± 12	2.9± 4	108	0.09	-0.075	2345
199728	0.43	3.00± 20	4.078± 20	1.97±13	4.35± 14	2.3± 4	143	0.14	-0.177	2.2
203006	0.99	2.36± 8	3.989± 13	1.60± 6	4.12± 8	2.2± 2	58	0.05	-0.024	2.122
221006	0.27	3.38± 14	4.135± 20	2.08± 7	4.51± 11	2.0± 2	118	0.06	-0.033	2.3
223640	0.08	3.21± 15	4.089± 13	2.12±10	4.27± 10	2.5± 3	103	0.10	-0.090	3.735239

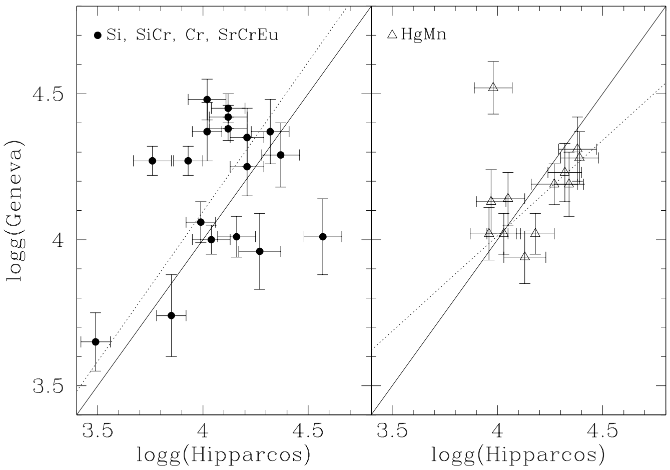

Fig. 1. Comparison between photometric and Hipparcos $\log g$ values for Si (left, full dots) and HgMn (right, open triangles) stars closer than 100 pc. The continuous line is the one-to-one relationship, while the dotted line is a least-squares fit which takes into account similar errors on both axes. The discrepant point on the right panel is HD 129174, a visual double excluded from the fit.

2.3. *Comparison between different sources of* $\log g$

A comparison between photometric and spectroscopic $\log g$ values was already shown by NK89. Fig. 1 shows how photometric and Hipparcos values compare, for Si and HgMn stars lying closer than 100 pc to the Sun. The diagrams look exactly the same as in the comparison of photometric vs. spectroscopic values, i.e. the Si stars are strongly scattered ($\sigma_{\rm res} = 0.273$ dex) while the HgMn stars follow the one-to-one relation much more closely ($\sigma_{\rm res} = 0.080$ dex), with the exception of HD 129174, a visual double which was excluded from the fit. The nice behaviour of the HgMn stars in this diagram inspires confidence in the value of Hipparcos gravities.

The comparison between spectroscopic and Hipparcos gravities for Si stars is shown in Fig. 2, where all stars of the list of NK89 having Hipparcos parallaxes with $\sigma(\pi)/\pi \leq 0.14$ are plotted (please note that some of them do not appear in Table 1 because they have $\pi < 7$ mas). Unfortunately, only six objects fulfil this criterion; among them, four are on the equality line within the errors (at least within 2σ), while two are clearly below. The two outsiders are HD 147010 and HD 199728. Interestingly, these stars have the largest photometric amplitude, as shown in Table 2 where the peak-to-peak amplitude in Strömgren's u band (or Geneva $[U]$ band) is given with its source. This suggests that photometry overestimates $T_{\rm eff}$ in cases of extreme peculiarities[1], and is quite coherent with the fact that, in Table 1, some stars have $\log g$ values (determined from Hipparcos luminosities) around 4.5, which is about 0.2 dex more than the theoretical ZAMS value. This is probably due to an overestimate of their effective temperature. It seems that those Ap stars having a more or less fundamental $T_{\rm eff}$ value have on average less extreme peculiarities than those having a good rotational period (hence a large photometric amplitude) and considered here, so that the photometric calibration tends to overestimate $T_{\rm eff}$ for some of the latter. Nevertheless, no systematic correction will be made on $\log g$ in this sample, because the bias strongly depends on the individual stars.

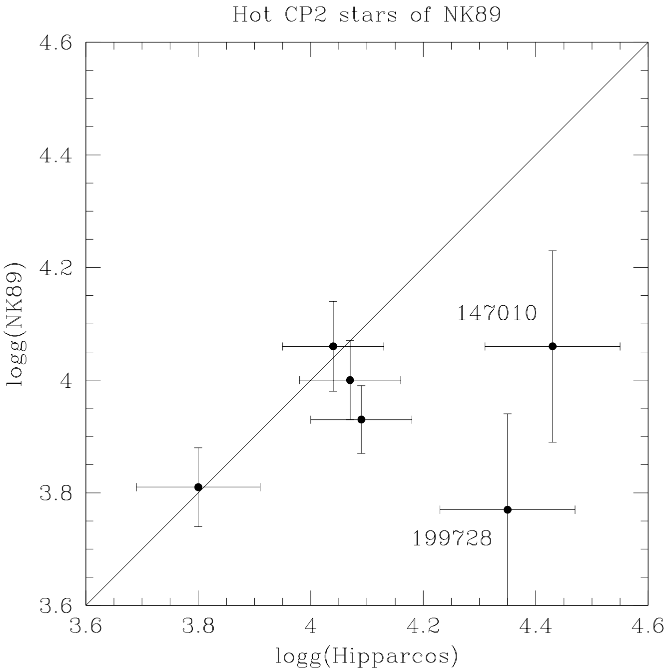

Fig. 2. Comparison between spectroscopic and Hipparcos $\log g$ values for Si stars with $\sigma(\pi)/\pi \leq 0.14$. The continuous line is the one-to-one relationship.

Table 2. Peak-to-peak amplitudes of the 6 stars having both a spectroscopic and a Hipparcos $\log g$ value.

HD	u or $[U]$ total ampl.	Source
49976	0.055	Catalano & Leone (1994)
90044	0.060	Manfroid & Renson (1994)
94660	0.035	Hensberge (1993)
147010	0.080	North (1984c)
164258	0.016	Catalano & Leone (1994)
199728	0.127	Renson (1978)

2.4. *Hipparcos radii versus* $v \sin i$

In order to test the validity of the radii obtained using Hipparcos parallaxes, a comparison between the observed projected rotational velocities and equatorial velocities obtained from the formula of the oblique rotator model

$$V_{eq}[\mathrm{km\,s^{-1}}] = 50.6 \times R[\mathrm{R}_\odot]/P[\mathrm{days}] \tag{9}$$

is shown on Fig. 3. The sources of $v \sin i$ are Abt & Morrell (1995), Levato et al. (1996), Renson (1991) and Uesugi & Fukuda (1981). Most stars fall below the equality line, as ex-

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[1] Interestingly, Abt & Morrell (1995) classify HD 199728 as F0:Vp while it is surely hotter than 10000 K, even though photometry tends to overestimate its effective temperature.

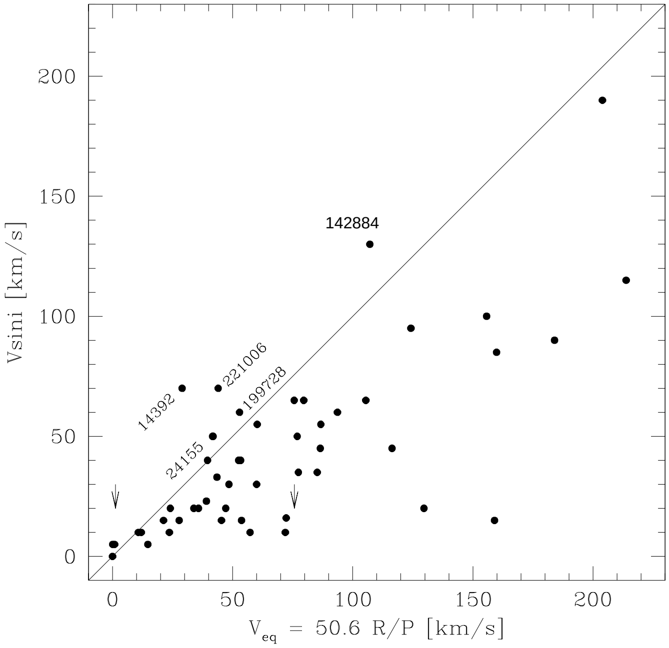

Fig. 3. Comparison between the observed $v \sin i$ and the equatorial velocity computed from the period and from the Hipparcos radius. The continuous line is the one-to-one relationship. Stars lying above this line are labelled by their HD number. Arrows indicate cases where only an upper limit to $v \sin i$ is known.

pected from $\sin i \leq 1$; therefore, the test appears rather successful, statistically speaking. However, seven of them are above, at least two of which simply because of the uncertainty on the $v \sin i$ determination (HD 126515 and HD 187474, with $V_{\mathrm{eq}} \sim 0$). HD 199728 is only slightly above, but this may well be due to an underestimate of its radius linked with an overestimate of its effective temperature (see Subsect. 2.3 and Fig. 2 above). This is also the case of HD 24155, HD 142884 and HD 221006 (which have $\log g = 4.48$, 4.67 and 4.51 respectively, suggesting an overestimated radius), although the radius of the latter star would need to be strongly underestimated. The star HD 14392 (and possibly HD 221006 too) lies so high above the equality line that its rotational period may be questioned. Indeed, Pyper & Adelman (1985) proposed a period of 1.3102 days (following Winzer 1974), instead of 4.189 days proposed later by e.g. Adelman & Knox (1994). The photometric curves of HD 14392 are so scattered that the shorter period may be the right one after all; magnetic and spectroscopic observations should be done to settle the matter. The rotational period of HD 221006 has been found to lie around 2.31 days by Renson (1978) and this was confirmed by Manfroid & Mathys (1985) and by Leone et al. (1995). There seems to be no reason to question this value; therefore, we are left with two possibilities: either $v \sin i = 69$ km s^{-1} (Uesugi & Fukuda 1970) is overestimated, or the radius is underestimated by more than 30 percent. This appears doubtful, since $T_{\mathrm{eff}} = 13275$ K has been estimated in a quasi-fundamental way (with the IR Flux Method) by Mégessier (1988) and is only 370 K lower than our photometric estimate: such a difference does not imply an increase of R by more than 3 percent.

Finally, HD 142884 has a reliable period and its radius must be underestimated by about 20 percent, as suggested by its very large $\log g$ (4.67). An independent estimate of its T_{eff} would be extremely welcome.

3. The $\log P_{\mathrm{rot}}$ vs. $\log g$ diagram

Fig. 4 shows the distribution of stars according to their rotational period and surface gravity. There is of course an intrinsic scatter, but on average the width of the period distribution is relatively narrow and there are clearly longer periods among the more evolved stars. Stars with both a small $\log g$ and a very short period are lacking. There are two stars falling below the lower envelope in a significant way: HD 115599 and HD 150035. HD 115599 was measured photometrically by Moffat (1977) only once a night near culmination, so that the published period might very well be an alias of the real one. The photometric measurements of HD 150035 made by Borra et al. (1985) do not seem very precise, judging from the low S/N lightcurve they published. The period of this star appears to remain highly uncertain.

It is interesting to consider the case of CU Vir or HD 124224, because in the literature a very small $\log g$ is sometimes quoted: for instance, Hiesberger et al. (1995) quote values as small as 3.45 to 3.60 (obtained from spectrophotometric scans), but also 4.2 and 3.71. The latter two values come from the same $uvby\beta$ photometric indices but through two different calibrations. The Hipparcos data, together with $T_{\mathrm{eff}} = 12130$ K obtained from Geneva photometry, point to $\log g = 4.37 \pm 0.09$, i.e. the star is very close to the ZAMS. If a higher effective temperature is adopted, like $T_{\mathrm{eff}} = 13000$ K, the result becomes worse, with $\log g = 4.50 \pm 0.08$ (the error on $\log g$ was computed assuming an error of only 400 K on T_{eff}). The conclusion that CU Vir is unevolved seems unescapable and is coherent with the fact that no Bp or Ap star has a rotational period significantly shorter than 0.5 days (the record is held by HD 60431, with $P_{\mathrm{rot}} = 0.47552$ days, see North et al. 1988). This may bear some importance in view of the fact that CU Vir is the only Ap star for which a period change has been unambiguously identified (Pyper et al. 1998). Any explanation for this intriguing discovery will have to take into account the unevolved state of the star.

The full and broken lines drawn in Fig. 4 are kinds of evolutionary tracks: assuming an initial period of 0.5 days (respectively 4.0 days), they show how a star rotating as a rigid body will evolve, if no loss of angular momentum occurs. These lines essentially reflect how the moment of inertia changes with evolution for stars having 2.5 and 5 M$_{\odot}$. They depend in a negligible way on the mass and are entirely compatible with the observations. They were established starting from the conservation of angular momentum:

$$I\omega = I_0\omega_0 \tag{10}$$

where ω is the star's angular velocity, I the moment of inertia and the subscript 0 indicates initial value (i.e. on the ZAMS). For the period, one has

$$P = \frac{2\pi}{\omega} \Rightarrow P = P_0 \frac{I}{I_0} \Rightarrow \log P = \log P_0 + \log \frac{I}{I_0} \qquad (11)$$

How the moment of inertia changes with evolution is provided by the models of Schaller et al. (1992), through a code kindly provided by Dr. Georges Meynet.

The two steep, straight dotted lines illustrate the extreme case of conservation of angular momentum in concentric shells which would rotate rigidly but glide one over the other without any viscosity, i.e. without the least radial exchange of angular momentum. In such a case, the moment of inertia of each shell of mass δm and radius r reads

$$I = \frac{2}{3} \delta m \, r^2 \qquad (12)$$

and in particular, the outermost shell having $r = R$ and being the only one observed, one gets

$$P = P_0 \left(\frac{R}{R_0} \right)^2 = P_0 \frac{g_0}{g} \qquad (13)$$

$$\log P = \log P_0 + \log g_0 - \log g \qquad (14)$$

Surely this case is an ideal and not very realistic one, but it is shown for illustrative purpose.

Do Si stars undergo any rotational braking during their life on the Main Sequence? Because of the decreasing number of stars with decreasing $\log g$, the statistics remains a bit small, and doubling the number of stars in the range $\log g < 3.8$ would be very useful. Nevertheless, the data are entirely compatible with nothing more than conservation of angular momentum for a rigidly rotating star. They may be marginally consistent with the dotted lines whose slope is 1 (conservation of angular momentum for independent spherical shells): if these lines are interpreted as betraying some *loss* of angular momentum through some braking mechanism yet to be understood, then this loss cannot increase the period by more than about

$$\log P = \log P_0 + 0.325 (\log g_0 - \log g) \qquad (15)$$

meaning a relative increase of no more than 82 percent during the whole Main Sequence lifetime. This is only a fraction of the increase due to angular momentum conservation alone (for a rigid sphere).

The whole reasoning has been applied to a mix of stars with various masses (between 2.2 and 5.7 $M_\odot$), but if any magnetic breaking exists, its efficiency might well be a sensitive function of mass. Then, one would need a larger sample, allowing $\log P$ vs $\log g$ diagrams to be built separately for stars in narrow mass ranges. The sample as a whole would not need to be enlarged in an unrealistic way: it is especially the evolved stars which are crucial for the test, so increasing their number from 13 (for $\log g < 3.8$) to about 50 or 70 would probably be enough to answer the question on firmer grounds. Spectroscopic observations would be needed to estimate $\log g$ (and hopefully $T_{\rm eff}$!) and photometric ones to determine the periods.

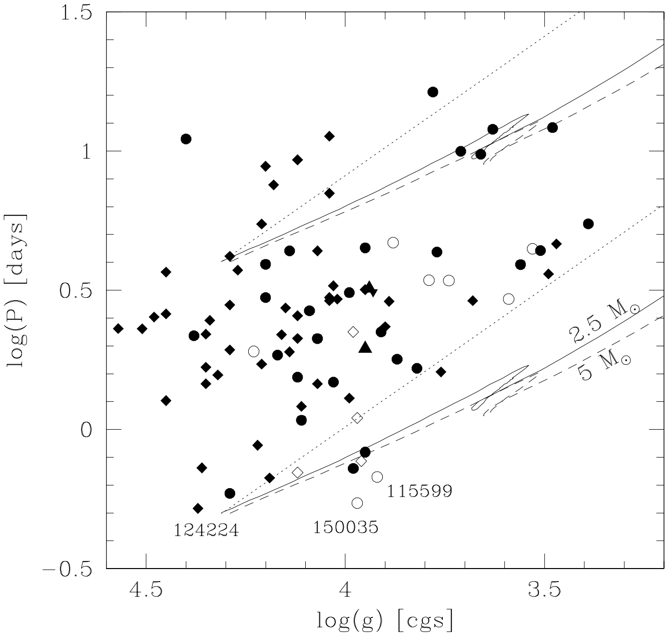

Fig. 4. Rotational period versus surface gravity. Full symbols represent stars with a reliable period, open symbols are for possibly ambiguous periods. Round dots (and triangles) represent stars with a spectroscopic value of $\log g$, while diamonds are for stars with $\log g$ determined from Hipparcos data. The three triangles are for stars with a rotational period newly determined from Hipparcos photometry (the upside-down triangle has $\log g$ determined from Hipparcos, the others from spectroscopy). The continuous and broken lines represent the evolution of the period predicted from that of the moment of inertia, under the assumption of rigid-body rotation and for initial periods of 0.5 and 4 days. The dotted lines show the ideal case of conservation of angular momentum in independent spherical shells.

4. Conclusion

New surface gravities of magnetic Bp and Ap stars obtained from the Hipparcos parallaxes, as well as homogeneous spectroscopic gravities, have been used to reconsider how the rotational period of such stars varies with age. The result is entirely consistent with previous works suggesting that field Si stars do not undergo any significant magnetic braking during their life on the Main Sequence; it is also more firmly based than earlier studies made on field Ap stars. Therefore, the slow rotation of these objects must be a property acquired *before* they arrive on the ZAMS. How this occurs has just been explored by Stepien (1998) but further investigations remain worthwhile.

On the other hand, this study has shown that $\log g$ values obtained from Hipparcos luminosities may be overestimated by up to 0.2 dex for some extreme Ap stars, probably through an overestimate of their $T_{\rm eff}$. This shows how badly fundamental determinations of $T_{\rm eff}$ are needed for these stars.

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