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COYOTES III: observational evidence for a lower limit to the rotational velocity of ZAMS G and K dwarfs*

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Abstract. In order to provide additional constraints to current models of angular momentum evolution of solar-type stars, we have conducted a period-determination program in the Alpha Perseus cluster. We have selected a sample of 22 Alpha Persei G and K dwarfs on the basis of their seemingly slow rotation rate ($v\sin i \leq 10$ km.s^{-1}). We searched for periodic modulation induced by stellar spots by performing a photometric CCD monitoring campaign in the V band over a baseline of 14 days. We detected 10 periods ranging from 1.3 to 7.1 days. A period was found for 7 out of the 10 K stars of our sample but for only 3 out of the 12 G and F stars. This bias is due to the existence of a clear relationship between spectral type and the amplitude of modulation by spots. We show that our study is not biased against the detection of very slow rotators and conclude to the existence of a lower limit of about 6 km.s^{-1} for the rotational velocity of Alpha Per G and K dwarfs. A significant fraction of solar-type stars in young clusters thus appear to have equatorial velocities distributed in a very narrow range between about 6 and 10 km.s^{-1} , a result which poses a severe constraint to current models of angular momentum evolution.

Key words: stars: evolution; pre-main sequence; rotation

1. Introduction

Since it was discovered that zero-age main sequence stars (ZAMS) have a velocity distribution peaked at low velocities with a wide high-velocity tail (Van Leeuwen & Alphenaar 1982), it has been emphazised that the physical phenomena ruling the pre-main sequence (PMS) evolution of stellar angular momentum are not as simple as it was once thought. During the pre-main sequence phase, young solar-type stars (T Tauri stars) show a relatively narrow velocity distribution around 20 km.s^{-1} (see Bouvier 1991 for a review). In contrast, Zero-age main-sequence stars belonging to young open cluster, such as Alpha Persei ($\simeq$50 Myr), Pleiades ($\simeq$70 Myr), show an extended velocity distribution (see the review by Stauffer 1991). Indeed, a large fraction of the stars have low rotational velocities ($v\sin i \leq 20$ km.s^{-1}), while a small fraction of them have much higher velocities extending up to 200 km.s^{-1} . Shortly after their arrival on the ZAMS, solar-type stars are then drastically broken down, and at the age of the Hyades (600 Myr) have rotation rates lower than 10 km.s^{-1} .

Models of angular momentum evolution have thus to account for: 1) the narrow distribution of rotation rates among T Tauri stars, 2) the existence of both slow and very rapid rotators on the ZAMS, 3) the observed rapid spin-down on the main sequence.

It is now admitted that accretion disk plays a most important role in the PMS evolution (Bouvier et al. 1993, Edwards et al. 1993). Braking due to the magnetic coupling with circumstellar disk is applied on the star (Königl 1991, Shu et al. 1994, King & Regev 1994), which remains in a rotational balance state. When the disk disappears, the star freely evolves and accelerates, as it contracts on its way to the main sequence. This scenario is supported by the measured rotational periods of T Tauri stars (TTs): the ones still accreting material from a disk (Classical TTs) rotate slower than those which are no more coupled to a disk (Weak-line TTs).

In this scenario, the longer the disk lifetime, the lower the velocity upon the arrival of the star on the ZAMS. Thus, disk lifetimes of about 20 Myr are required to account for velocities as low as 6-7 km.s^{-1} at ZAMS ages, assuming solid-body rota-

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* Based on observations collected at the 1.52m telescope of the Estación de Observación de Calar Alto, and at the Jacobus Kapteyn telescope based on the island of La Palma.

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tion in the stellar interior (Bouvier & Forestini 1995, Cameron et al. 1995). Would equatorial velocities on the ZAMS prove to be lower than 6-7 km.s^{-1}, then even longer disk lifetimes would be implied. These models also depend on parameters such as magnetic field strength and topology and accretion rates, which are poorly known.

It has been emphasized as well that a decoupling between the radiative core and the convective envelope helps the star to keep a low surface rotation rate, as the core acts as a "reservoir" for angular momentum and only the outer envelope slows down. Typical timescales characterizing angular momentum transfer between the core and the envelope have to be short enough to account for very rapid rotators at ZAMS ages, but on the other hand have to be long enough to allow the rapid spin-down of envelopes of ultra-fast rotators on the main-sequence. A core-envelope decoupling process would have a braking effect which may allow for slightly shorter accretion disk lifetimes (Keppens et al. 1995).

In order to test the validity of these models, and better understand the role of disk accretion and core-envelope decoupling in the angular momentum evolution of young stars, an accurate determination of the equatorial velocity distribution of stars located on the ZAMS is required. ZAMS late-type dwarfs belonging to the Pleiades and Alpha Persei clusters have been largely studied by spectroscopic methods, yielding numerous measurements of projected velocities ($v\sin i$) (see e.g. Soderblom et al 1993, Stauffer et al 1985, Stauffer et al. 1989). However, technical limitations most usually set an upper limit on determined velocities of 7-10 km.s^{-1}, while geometric effects set a lower limit due to $\sin i$ factor. Such measurements are therefore usually unable to provide accurate rotational velocity measurements for slow rotators.

In order to derive the true rotation rate of slow rotators in the Alpha Persei cluster, we therefore turned to direct period determination through the detection of light modulation by stellar photospheric spots, and conducted a third COYOTES campaign (Coordinated Observations of Young ObjecTs from Earthbound Sites) from 3 sites (see Table 1). The period determination is a most reliable method which has already been used in the 2 previous COYOTES campaigns on T Tauri stars (Bouvier et al. 1993, 1995), and for members of the young IC4665 cluster (Allain et al. 1996a). Here, we report the observations and analysis of a sample of slowly rotating stars ($v\sin i \leq 10$ km.s^{-1}) in the Alpha Persei cluster.

Alpha Per [3h 18m, +48°,26m (1950)] is a $\simeq$50 Myr old cluster, which implies that G and K members are on or close to the ZAMS. A membership analysis has been conducted by Prosser (1992) based upon photometric, spectroscopic, radial velocities and proper motion criteria , and $v\sin i$ measurements were provided as well. Period determinations have been obtained so far mostly for rapid rotators (O'Dell and Cameron 1993, Prosser et al. 1993a, 1993b, Martín et al. 1996, Bouvier 1996), and on a few slow rotators as well (Stauffer et al. 1985 for AP70, Prosser et al. 1995 for AP212 and AP201).

Table 1. Table of observations.

Date (1993)	JD 2449000+	Observatory
oct 29–nov 13	290–305	Haute-Provence
nov 22–30	317–322	La Palma
dec 1–9	323 – 331	Calar Alto

In Sect. 2 we describe observations and data analysis. In Sect. 3 we present the result of the period determination. And in Sect. 4 we analyze and discuss the results.

2. Observations and data analysis

Observations at Observatoire de Haute-Provence in early November 1993 were unfortunately totally compromised by bad weather.

The observing run at the Observatorio del Roque de los Muchachos on La Palma island was partially hampered by high humidity. We lost the three first nights (November 22–24), and were able to observe under clear skies during the six subsequent nights. Occasionally, there were tenuous cirrus clouds but they did not severely affect the differential photometry. We used the 1m Jacobus Kapteyn telescope (JKT) with a CCD camera mounted on the Cassegrain focus. The detector was the EEV7 chip (1150x1050 pixels), which covered 5.94 x 5.42 arcmin^2. The exposure times for the αPer stars ranged from 20 to 90 seconds, depending on the apparent magnitude, seeing conditions and moon background.

From the 1 to 9 December 1990, CCD photometric observations (band V, Johnson) were carried out at the 1.5m telescope at the Estación de Observación de Calar Alto (Spain). We used a Thompson CCD (THX 31156), 1024x1024 pixels, with a 19 μm pixel size (5.5 x 5.5 arcmin^2 field). Integration times varied between 30 and 300 seconds, in order to get 2/3 of the saturation value at the maximum intensity pixel for the brightest ZAMS or comparison star in the field. The first night was cloudy, while conditions during the end of the run varied from (little) clouds to photometric.

The reduction of CCD images was performed with the IRAF/CCDPROC package for bias subtraction and flat-field correction. Aperture photometry, with annulus sky background determination, was applied using the APPHOT package for uncrowded fields, and DAOPHOT for crowded fields. A complete description of the differential photometry reduction procedure, and object's light curve determination is given in Allain et al.(1996a).

3. Search for periods and results

The search for periods was conducted using two independent methods: the periodogram analysis (Scargle 1982, Horne & Baliunas 1986), and the string-length method (Dworestky 1983). As a complement we also used the CLEAN algorithm: to the raw periodogram is applied a deconvolution algorithm handling alias-

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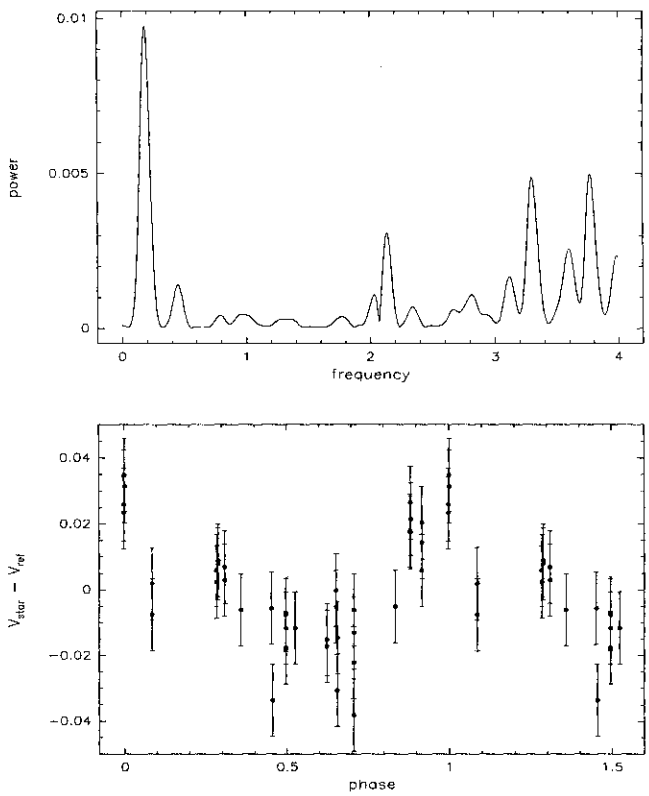

Fig. 1. *Top*: AP41 CLEANed periodogram. Frequency (in day^{-1}) is defined as 1/Period, and power is in arbitrary unit. *Bottom*: AP41 light curve folded in phase with P= 5.5d.

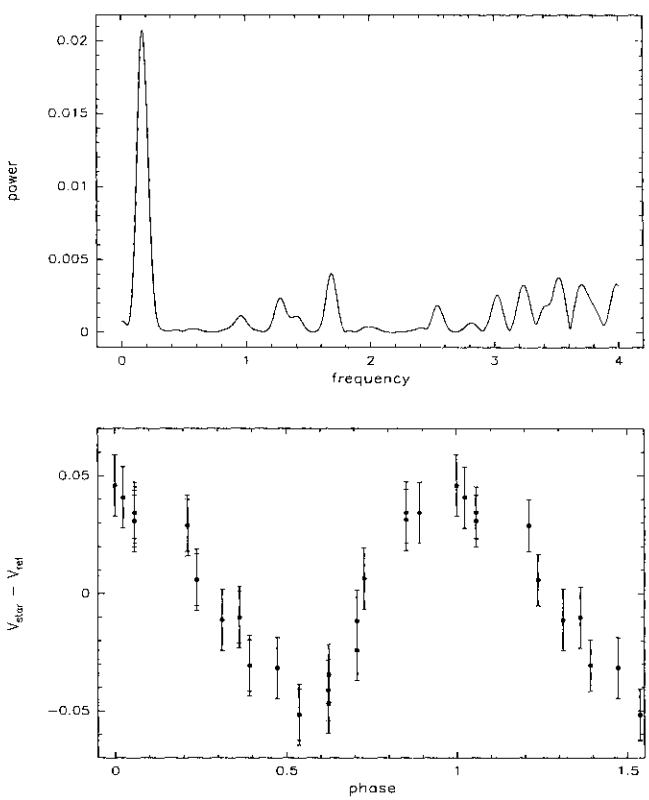

Fig. 2. Same as Fig.1 for AP70 and P=6.4d

AP 98: The raw periodogram shows 2 periods with probability levels higher than 99.9%: 0.85d and 6.1d. The string-length method finds periods of 5.7 and 6d. And finally, CLEAN algorithm retains a 6.2d period. Fig. 4 shows the light curve folded in phase with a period of 6.1 ± 0.1d. The amplitude of variations is 0.06mag, corresponding to a stellar spot's area of 5%. The radius is $0.9 R_{\odot}$, leading to $V_{eq} = 7 \pm 1$ km.s^{-1} .

AP 101: The three methods find a most likely period of 3.2d (see Fig. 5 for the CLEANed periodogram). Our observational run covers 4 complete periods, allowing us to determine a 3.20 ± 0.05d period. Using a stellar radius of 0.7 $R_{\odot}$, we find an equatorial velocity of 11 ± 1 km.s^{-1} . The amplitude is the largest one among our sample: 0.2mag, so the spot covers 17% of the stellar disk.

AP 114: For this star we only got 22 measurements, and we used one reference star, the only non-variable object among 4 reference stars. The raw periodogram find two periods with probability level of 99.9%: 1.3 and 4.4d, and the string-length and CLEAN method both find a 1.3d period. (See Fig. 6) The overall observations cover 9 periods, which allows us to derive an accurate period for this star of 1.30 ± 0.01. This period corresponds to $V_{eq} = 31 \pm 4$ km.s^{-1} , using a radius of 0.8 $R_{\odot}$. And the amplitude is 0.15mag, leading to a stellar spot's area of 13%.

AP 156: The complete light curve of AP156 shows a luminosity discontinuity between the data of the runs of La Palma and Calar Alto. The difference between the mean values of the two set of data is almost 0.03mag. This effect, seen as well on the following stars: AP38, AP90, AP104, AP173, is probably instrumental though we could not identified its cause. As this effect is hard to correct for, we have chosen to derive the two light curves separately– using the same reference stars – leading to two zero-mean light curves. We then merged the curves to do the period analysis.

The light curve of AP 156 shows some evidence of slow variations with low amplitude. Scargle's periodogram gives periods of 4.4d and 1.3d. The string-length method finds 1.3d, 11.8d and 4.6d. And after CLEAN application a 4.4d period remains. (See Fig.7) So the period is 4.5 ± 0.1d, with an amplitude of 0.04mag. The spot then covers 4% of the disk. And with a radius of 0.9 $R_{\odot}$, we find an equatorial velocity of 10 ± 1 km.s^{-1} .

AP 169: The light curve of AP 169 shows some variations with an amplitude of 0.06-0.07mag. Scargle's periodogram finds two possible periods of 5.1 and 0.83 day with a high probability level. The string-length method finds 5.0d or 1.2d, and the CLEAN algorithm finds a 0.8d period. A 0.8d period would lead to $V_{eq} = 50$ km.s^{-1} and an inclination angle $\leq 10^{o}$ (using $v \sin i$ = 10 km.s^{-1}). It is very doubful that modulation by spots could be detected for a star seen at such a low inclination. For this reason, and also because it yields a smoother phased light curve, we believe the 5.1d period to be the correct one. Fig. 8 shows the CLEANed spectrum and folded light curve with a period of

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Table 2. Stellar properties and photometric periods and amplitudes. Except AP201, all stars have $v\sin i \leq 10$ km.s^{-1} . Spectral types for AP169, 173, 201 and 212 were found in Prosser 1992. For other stars it was calculated from (B-V)$_0$ as explained in the text.

AP	V	(B-V)$_0$	Sp.T.	R/$R_\odot$	period *day*	V_{eq} *km.s^{-1}*	amplitude *mag*	rms *mag*	notes
14	11.93	0.68	G4	0.95				0.03	
33	12.92	0.88	K0	0.85				0.01	
38	11.61	0.65	G3	1.0				0.02	
41	12.03	0.71	G5	0.95	5.5 ± 0.1	9 ± 1	0.04	0.02	
65	13.00	0.91	K0	0.85				0.025	
70	12.83	0.88	K0	0.85	6.4 ± 0.1	7 ± 1	0.09	0.03	
72	12.78	0.87	K0	0.85	6.3 ± 0.1	7 ± 1	0.09	0.03	
89	12.31	0.74	G6	0.9				0.015	
90	11.17	0.55	F9	1.0				0.025	
97	12.08	0.75	G6-G7	0.9				0.02	
98	12.80	0.86	G9	0.9	6.2 ± 0.1	7 ± 1	0.06	0.025	
101	13.89	1.24	K6	0.7	3.2 ± 0.1	11 ± 1	0.2	0.075	
104	12.06	0.66	G3-G4	1.0				0.01	
110	12.27	0.81	G8	0.9				0.02	
114	13.40	1.06	K2	0.8	1.30 ± 0.01	31 ± 4	0.15	0.055	
121	11.89	0.70	G5	0.95				0.02	
156	11.89	0.73	G6	0.9	4.5 ± 0.1	10 ± 1	0.04	0.02	SB1?
169	13.28	1.07	K7.0	0.8	5.1: ± 0.2	8 ± 1	0.07	0.02	
173	12.26	0.88	K3.2	0.85				0.008	SB2
201	13.08	1.04	K5.2	0.8	3.75 ± 0.05	11 ± 1	0.07	0.03	vsini = 12 km.s^{-1}
212	13.24	0.87	K4.1	0.85	7.1 ± 0.2	6 ± 1	0.07	0.025	
213	11.55	0.74	G6	0.9				0.01	SB2

ing effects due to observational sampling (Roberts et al.1986). The way period, amplitude of variations and spot's sizes are derived is fully described in Allain et al. (1996a). The amplitude of variability ΔV is derived by fitting a sine curve to the light curve. The spot's model described in Bouvier et al. (1993) is used to determine the spots sizes from ΔV:

$$G_{eq} = 1 - 10^{-\frac{\Delta V}{2.5}}$$

where G_{eq} is the lower limit to the true surface (relative to the disk surface) coverage by spots. A distance modulus $(m-M)_0$ = 6.1 (Stauffer et al. 1985) and a reddening E(B-V)=0.11 (Stauffer et al. 1989), were used to determine stellar radii from (B-V)$_0$ (Prosser 1992) and the table (B-V)$_0$ vs. spectral type, bolometric correction and effective temperature (Allen 1976, p.197). The radius is then given by:

$$\frac{R_\star}{R_\odot} = 10^{-\frac{1}{5}(M_{bol}-42.36+10 log T_{eff})}$$

The stellar parameters and results of period determinations are listed in Table 2.

We present below the results for the stars for which we could detect a period with a probability level of 99.9% or more. We were able to detect periodicity for 10 stars of the sample, with periods ranging from 1.3 to 7.1d, corresponding to equatorial velocities from 31 to 6 km.s^{-1} .

AP 41: The raw periodogram show several periods with probability levels higher than 99.9%. However, after CLEAN application, only one remains around 5.5d (see Fig. 1). The light curve folded in phase with a period of 5.5d is also shown. The fit of a sine curve on the data gives an amplitude of 0.04 mag, corresponding to a spot covering 4% of the stellar disk. With a radius of 0.95 $R_\odot$ we deduce an equatorialvelocity of 9 ± 1 km.s^{-1} .

AP 70: Stauffer et al. (1985) reported a period of 5.15d and an amplitude of 0.05 mag for this star.

In spite of the small number of observational points (only 20), the curve shows a nice modulation. The three methods applied find a period of 6.4 ± 0.2 day (Fig. 2). The uncertainty is due to the fact that the observations cover a little less than two periods. The amplitude of variations is 0.1 mag, corresponding to a spot covering 8% of the disk. With a 0.85 $R_\odot$ radius, we derive an equatorial velocity of 7 ± 1 km.s^{-1} .

The two periods of 5.15 and 6.4d may imply a differential rotation on the star's surface of at least 20%. This result would need further investigation, as different determinations of periods can have different causes: a change in the spot's configuration during the observations or a spot's shift on the star's surface.

AP 72: The light curve of AP 72 shows clear variations. The raw periodogram and the string-length method both find a 6.3d period. After the CLEAN application, aliasing periods of 1.1 and 0.9d disappear (Fig. 3). The observations cover almost 2 rotational periods, and we then derive a period of 6.3 ± 0.1d, leading to V_{eq} = 7 ± 1 km.s^{-1} . The amplitude of variations and the spot area are the same as AP70: 0.1mag and 8%.

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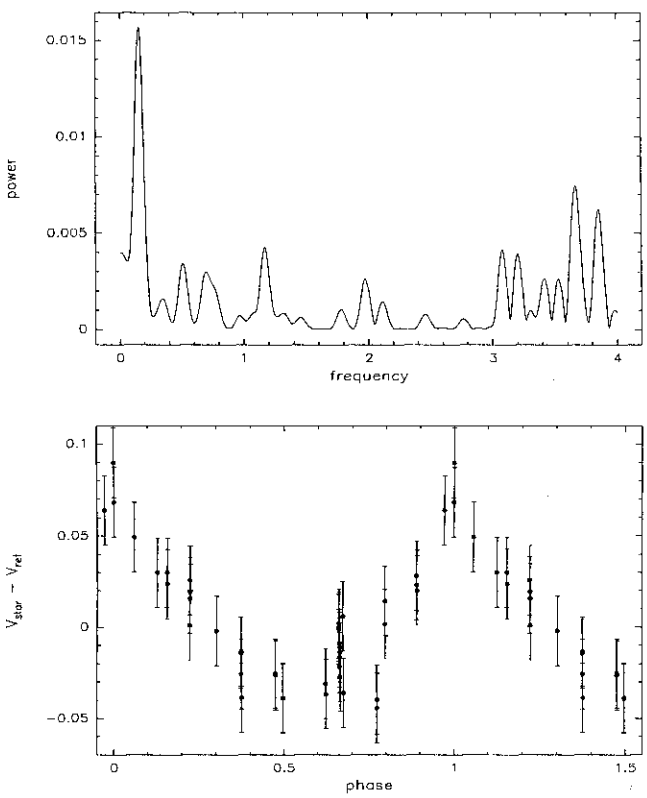

Fig. 3. Same as Fig.1 for AP72 and P=6.3d

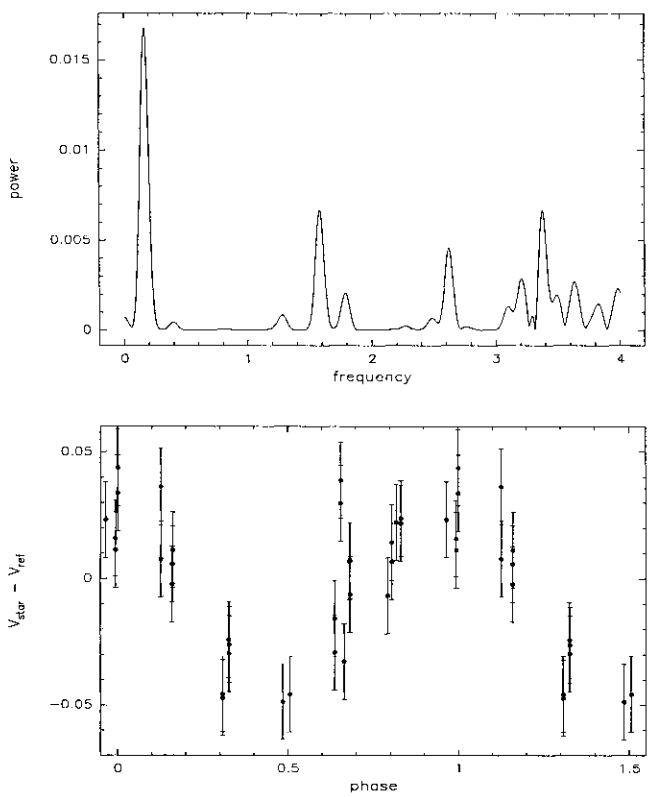

Fig. 4. Same as Fig.1 for AP98 and P=6.1d

5.1d. A period of 5.1 ± 0.2d leads to an equatorial velocity of 8 ± 1km.s^{-1} . The amplitude is 0.06mag, corresponding to a stellar spot of 5%.

AP 201: This star is one of the two stars in our sample previously observed by Prosser et al. (1995), from November 1993 to January 1994. They found a 3.75d period, with an amplitude of 0.08 mag. From our data, 3 periods in the raw periodogram appear to have high probability level: 3.75d, 1.34d and 0.77d. The string-length and CLEAN method both select a 3.7d: see Fig.9. We therefore confirm Prosser's determination with P=3.75 ± 0.05d. With a radius of 0.8 $R_{\odot}$, the equatorial velocity is 11 ± 1 km.s^{-1} . The amplitude of variations is 0.07mag, leading to a stellar spot of 6%.

AP 212: Prosser et al. (1995) observed AP 212 on November 1993. They report an uncertain period of 6.2d, with an amplitude of 0.07mag.

From our data, two probable periods are found in the raw periodogram: 7.1 and 1.2d. The string-length method find the same periods, and after CLEAN application only the period of 7.1d remains. Fig. 10 shows the CLEANed periodogram and the phased light curve of AP 212. The 7.1 ± 0.2d period leads to $V_{eq} = 6 \pm 1$ km.s^{-1} . The amplitude is 0.07mag, corresponding to a spot's area of 6%. We thus cannot confirm the 6.2d period suspected by Prosser. However, a 7.1d period, as found here, does not fit Prosser's data. Surface differential rotation could be an explanation for these discrepant results.

4. Discussion

We detected 10 periods out of our 22-star sample. Periods range from 1.3 to 7.1 day, leading to equatorial velocities from 31 to 6 km.s^{-1} . Amplitudes of modulation vary within a factor of 5 from 0.04 to 0.2 mag in the V band, indicating – with the assumptions described in Sect. 3 – the presence of dark starspots covering from 4% up to 17% of the stellar disk. Most notably, stars with detected periods are mostly K-type dwarfs (see Table 2). Indeed, we derived a period for 7 out of 10 K stars, but for only 3 out of 11 G stars. The remaining star is of spectral-type F9. We discuss this spectral type bias in the detection of periods below.

Of the 12 stars that do not exhibit periodicities, some do show non-negligable photometric variations. These stars are given in the following list together with a crude estimate of their characteristic time-scale of variation (corresponding to the highest peak in the periodogram): AP14 (1.34d), AP38 (2.4d), AP65 (4.8d), AP89 (a few hours), AP97 (4.6d), AP110 (a few hours) and AP173 (4.3d). An estimation of their variability, through the root-mean square of the luminosity curve dispersion, is also given in Table 2. Several factors may account for the non-detection of periodic variations in these stars. First, AP173 is listed by Prosser (1992) as being a spectroscopic binary: the intrinsic variations of the two components may be superimposed. Second, the existence of two or more spots on the star's surface, or a change in the spot's configuration during the observing time could also lead to erratic variations. The other stars

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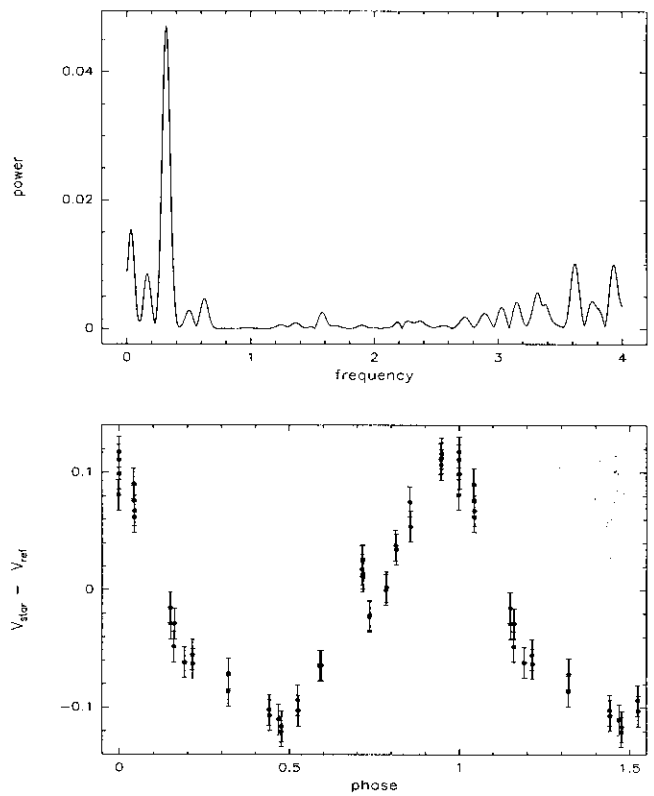

Fig. 5. Same as Fig.1 for AP101 and P=3.2d

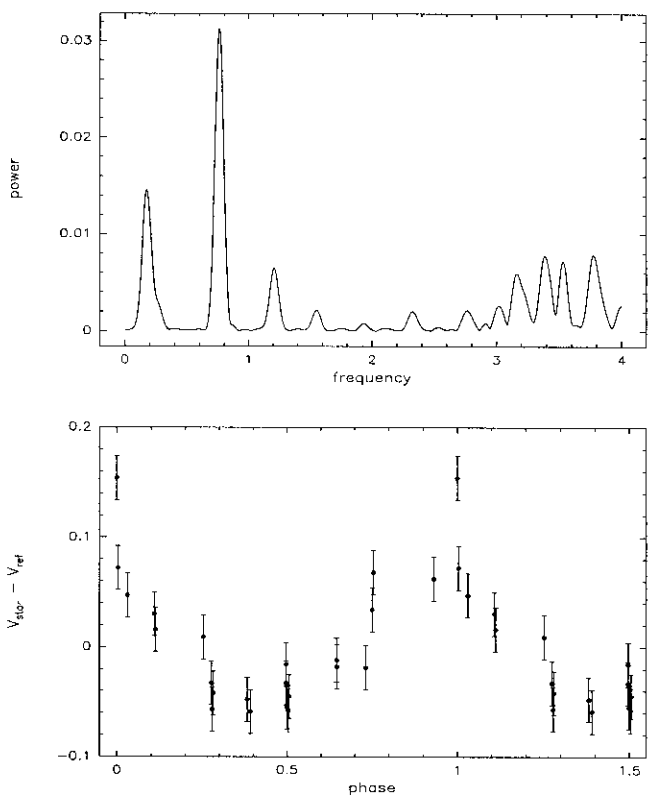

Fig. 6. Same as Fig.1 for AP114 and P=1.3d

show only low-level variations for which we are unable to derive any time-scale: AP33, AP90, AP104, AP121, AP213. Either the photometric variations are intrinsically small so that we cannnot distinguish them from noise, or significant variations only occur on a time-scale longer than our baseline. In the first case, the non-detection of a period would result from small spot sizes and/or high inclination. In the second case, non-detection would result from the rotational period being significantly longer than our two-week monitoring.

We must therefore adress the issue of detection bias in our study. It may be that stars with low-level variations, i.e. those for which we are unable to derive a period, are precisely the extremely slow rotators we are searching for. This could be the case for instance if the spot size scales with rotation thus leading to insignificant amplitude of variation for the slowest rotators. We show below that this is *not* the case in our sample and that our study is not affected by such a bias.

The effect of rotation upon the amplitude of variations induced by spot's modulation has been investigated by Dorren et al. (1994). They compared light modulation for a sample of solar-type stars (i.e spectral types between G0 V and G5 V) on the main sequence at different ages. As convective zone depth is essentially constant on the MS, a difference in the amplitude is an effect of decreasing rotation with age only. They find that the amplitude of modulation decreases from 0.08 to 0.009 mag as the rotational period increases from 1.5d to 14d. Such is not the case, however, in ZAMS dwarfs. In the Alpha Per cluster, for instance, previous period determinations now provide quite a large database of rotational periods and corresponding V band amplitudes (O'Dell et al. 1995). For periods varying from a few hours to typically one day, amplitudes range between 0.02 and 0.25mag. And from the present work, we find that amplitudes for slow rotators, with periods longer than one day, vary in a similar range between 0.04 to 0.2mag.

It thus appears that, in young solar-type stars with spectral type G and K, the modulation amplitude, i.e., the spot size, does not *primarily* depend upon rotation. Instead, there seems to be a much more pronounced relationship between the modulation amplitude and spectral type. This is already apparent in O'Dell et al.'s Fig. 3: for B-V between 0.5 and 1, there is a clear increase of the magnitude with color. We find the same trend in our slow rotators sample as shown in Fig. 11 where the amplitude of variation is plotted as a function of $(B\text{-}V)_0$. And it is interesting to observe that the increase is more rapid for the Alpha Per's rapid rotators as plotted by O'Dell et al. than for slow rotators.

From Fig. 11, there is a clear trend of increasing maximum amplitude with $(B\text{-}V)_0$, but no clear relationship between the amplitude of modulation and rotation. Dispersion in the relation may have several causes related to the star's inclination, spot's temperature and location on the star. A similar relationship was reported for low-mass pre-main sequence stars by Bouvier et al.(1995) who studied a sample of 23 G and K PMS stars with rotational periods between 1.2d and 9.3d, and V band amplitudes of modulation between 0.03 and 0.37 mag. They find that

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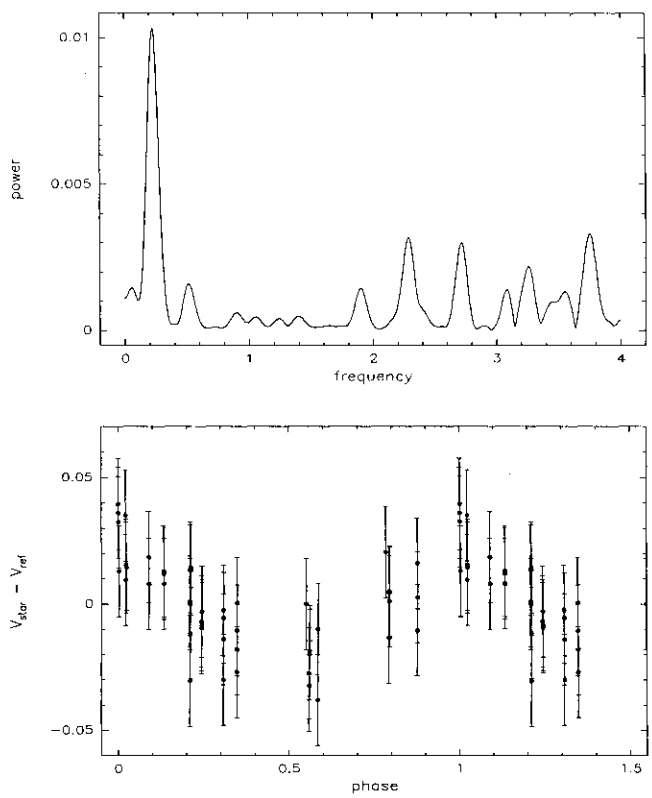

Fig. 7. Same as Fig.1 for AP156 and P=4.5d

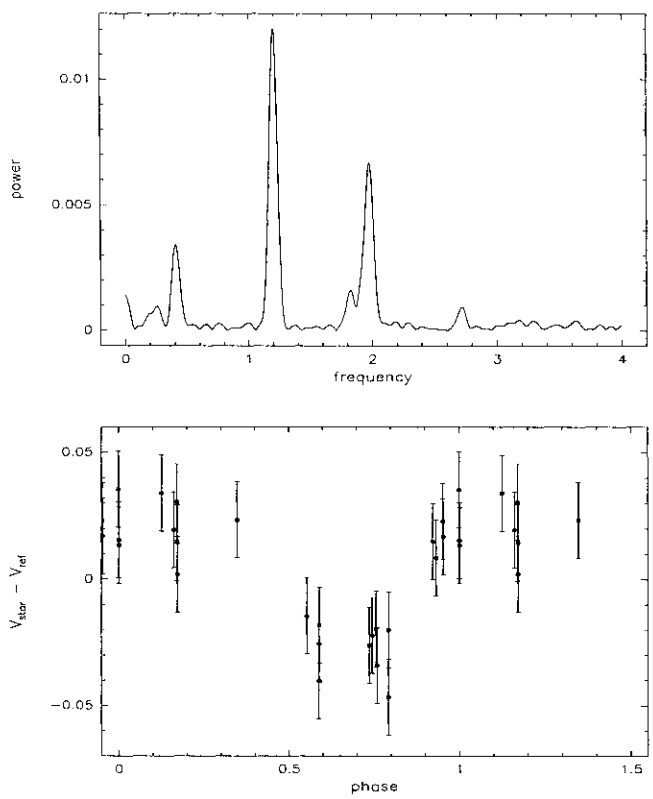

Fig. 8. Same as Fig.1 for Ap169 and P=5.1d

the maximum amplitude of modulation sharply increases towards later spectral types. In addition, comparing the modulation amplitudes of PMS stars with those of ZAMS dwarfs, they concluded that as the convective zone retreats during pre-main sequence evolution, the spot size decreases (see also Simon et al. 1985). All these results concur to indicate that the depth of the convective zone, which is related to spectral type on the ZAMS, has a primary effect on the amplitude of modulation by spots.

We therefore conclude that our study is not biased against the detection of very slow rotators: the reason why we detect periods for most K stars but for only a few G stars is simply because the latter have smaller stellar spots as a result of their less extended convective zone. In other words, the non detection of periods among G stars does not imply that they are slower rotators than K stars. Indeed, that G and K dwarfs in the Alpha Persei cluster have similar rotational distributions is supported by the results of $v\sin i$ surveys (Prosser 1992, Fig.17).

Then, the lack of periods longer than 7 days for stars in our sample leads us to the conclusion that very few solar-type stars indeed have an equatorial velocity less than 6 km.s^{-1} by the age of the Alpha Per cluster. This sets a lower limit of about 6 km.s^{-1} to the previously unknown velocity distribution of slowly rotating G and K dwarfs in this young cluster. The determination of such a lower limit to the rotation of solar-type stars as they reach the ZAMS provides a strong constraint for the models of angular momentum evolution. It shows that even though these stars have been strongly braked during their PMS evolution, their velocity on the ZAMS is still significantly higher than that measured for older dwarfs such as the Sun. The slowest rotation rate on the ZAMS is directly related to the maximum lifetime of circumstellar disks around PMS stars. Depending on the assumptions of the model regarding core-envelope decoupling, a lower limit of 6 km.s^{-1} at the ZAMS, suggests a maximum disk lifetime of at least 10 to 20 Myr around contracting stars (Bouvier & Forestini 1995, Keppens et al. 1995).

All the stars we have studied had upper limits of 7 to 10 km.s^{-1} set on their projected velocity. From the rotational period, we derive equatorial velocities in the range between 6 and 11 km.s^{-1} for all but one (rapidly rotating) star. This suggests that most of the stars with $v\sin i$ upper limits of 7 to 10 km.s^{-1} , which represents a very significant fraction of all G and K dwarfs in young clusters, have true velocities in the range from 6 to 11 km.s^{-1} . The same conclusion has been reached for the Pleiades cluster by Allain et al. (1996b) from a different approach. By measuring accurate $v\sin i$ for a complete sample of G and K slow rotators, then inverting the $v\sin i$ distribution to get the distribution of true equatorial velocities, they were able to show that 50% of the G and K dwarfs in the Pleiades have equatorial velocities between 5 and 10 km.s^{-1} , and only 10% have V_{eq} lower than 5 km.s^{-1} .

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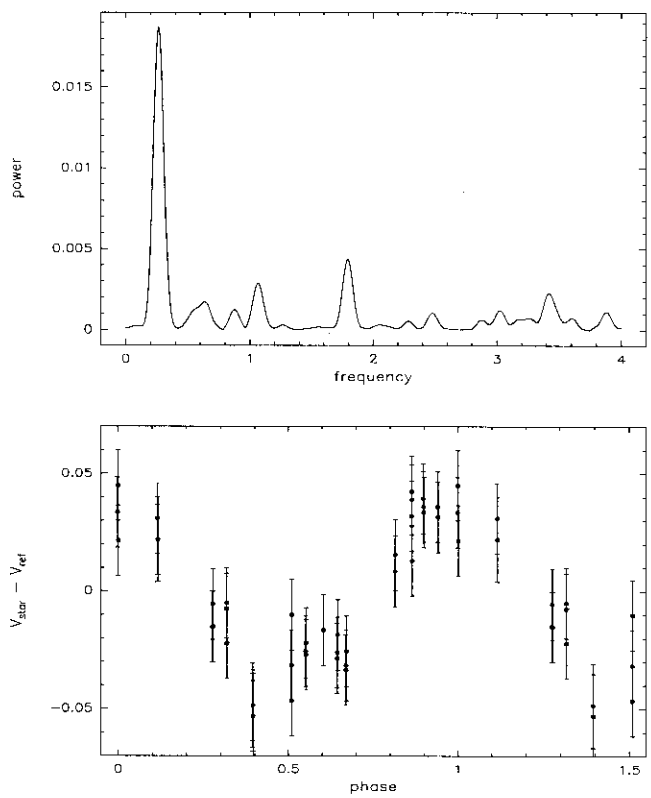

Fig. 9. Same as Fig. 1 for AP201 and P=3.75d.

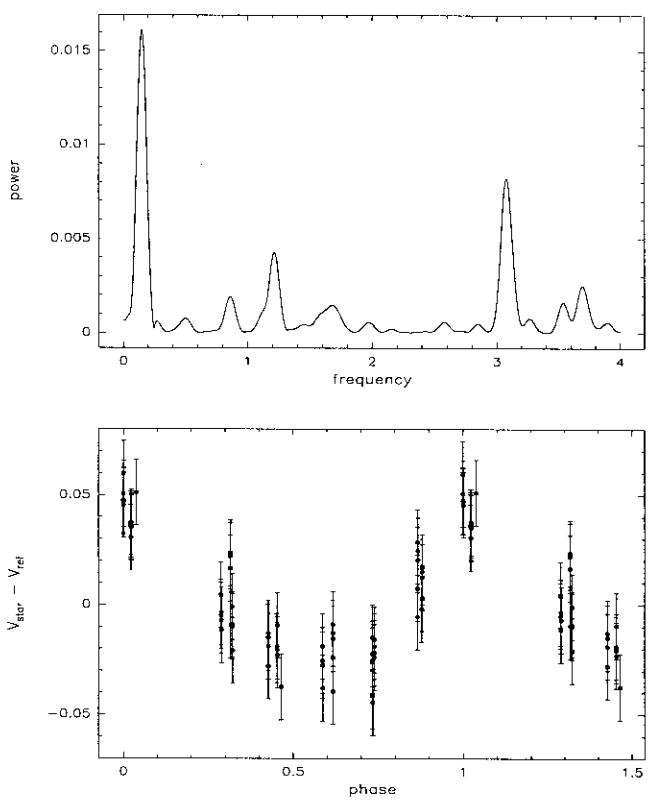

Fig. 10. Same as Fig. 1 for AP212 and P=7.1d.

5. Conclusion

By measuring the periods of slowly rotating G and K stars of the Alpha Persei cluster, we reach the conclusion that there exists a *lower* limit to the equatorial velocity of solar-type stars as they reach the ZAMS. Based on our limited sample, we find this limit to be about 6 km.s^{-1} . Thus, a large fraction of solar-type stars in young clusters, Alpha Persei studied here and the Pleiades (see Allain et al. 1996b), appear to have equatorial velocities spanning a very narrow range from about 6 and 10 km.s^{-1} . This provides a strong and precise constraint against which the validity of current models of angular momentum evolution can be readily tested.

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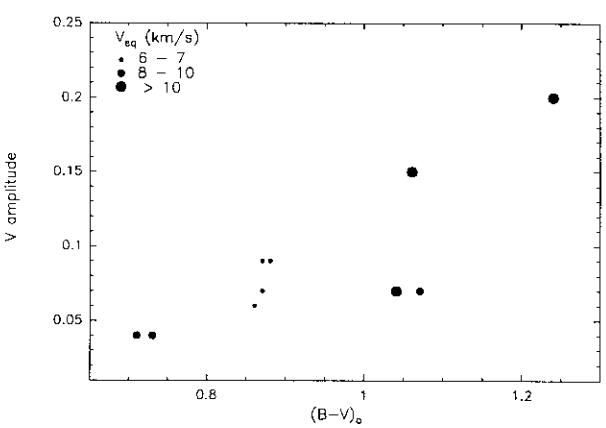

Fig. 11. Amplitude vs. $(B-V)_0$ for slow rotators in the Alpha Per cluster

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