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Pulsating and nonpulsating stars in Hyades observed by Hipparcos satellite*

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Abstract. A study of the stars in the instability strip of Hyades cluster has been performed taking into account the new estimate of the stellar parallaxes. For taking advantage of the improved accuracy of the distances and hence absolute magnitudes it is necessary to separate the photometric effects of close companions, which appear quite common in Hyades. The δ Scuti stars, differently from nonpulsating stars, appear to be located also above the main sequence, and this is due probably to their large rotational velocity. The comparison of the rotational effects on the star position in the color–magnitude diagram with theoretical model predictions tends to confirm the importance of differential rotation. A brief discussion of θ^2 Tau and some remarks on the X–ray emission of other two δ Scuti stars are also reported.

Key words: binaries: general – stars: distances – stars: fundamental parameters – stars: rotation – open clusters and associations: individual: Mel 25

1. Introduction

The lower part of the instability strip in the HR diagram is a region occupied by stars with a variety of characteristics: A – F stars with normal spectral type, Am stars with various degrees of metallicity, nonpulsating stars and stars pulsating in one or in more radial and nonradial modes (e.g. Antonello 1990; Breger 1995). Trying to understand which are the reasons for such different characteristics is not simple owing to the apparent similarity of several physical parameters. It is important to improve the knowledge of these parameters by means of more reliable methods and accurate measurements in order to put more precise constraints on the theories. Hyades is a close cluster containing a representative number of pulsating and nonpulsating stars, and in 1982 we proposed to study this kind of stars using Hipparcos parallax measurements. The purpose of the present paper is to discuss what we have learned with these new data and the problems that have been raised.

2. Stars

The twenty stars selected in 1982 were located in the instability strip, and surveyed for variability by several authors. They are listed in Tables 1 and 2. Table 1: column (1)–(5) Hipparcos Input Catalogue (HIC, Turon et al. 1992) number and other identifications; (6) parallaxes from The Hipparcos Catalogue (ESA 1997a); (7) V_J magnitude from HIC; (8): absolute V magnitude; (9) spectral type from Gray & Garrison (1989a,1989b; for an explanation of the classification scheme, see Gray & Garrison 1987). Table 2: column (2) *b–y* from Hauck and Mermilliod (1980); (3) rotational velocity from the Bright Star Catalogue (Hoffleit & Jaschek 1982, hereinafter BSC); (4) data on wide visual binaries and multiple stars, separation and magnitude difference, from HIC and BSC; (5) data on close astrometric and spectroscopic binaries (periods) taken from BSC and from The Hipparcos Catalogue (ESA 1997a): ?=suspected SB or SB without known period, D=occultation double, O=orbital solution, X=stochastic solution (i.e. probable short period astrometric binary), G=probable very long period astrometric binary (see *The Hipparcos and Tycho Catalogues*, Perryman et al. 1996); (6) peak–to–peak maximum amplitude of observed variability; (7) period; (8) source of variability data.

For a discussion of the general characteristics of catalogued parallaxes and their zero–point and external errors see Arenou et al. (1995), Lindegren (1995) and Perryman et al. (1995). We note that the statistical parameters for our stars indicate generally good astrometric solutions.

The asterisks in Table 2 indicate the stars with specific remarks concerning multiplicity and/or variability discussed in the present section.

HIC 20087 is a spectroscopic binary resolved by speckle (0.08″), with components of spectral type ∼A8 and ∼G0 (Deutsch et al. 1970; McAlister 1977; Gatewood et al. 1992). Torres et al. (1995) made long term spectroscopic observations and using both these and known astrometric data were able to derive the masses of both components and the distance of the

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* Based on data from Hipparcos astrometry satellite

Table 1. Hyades stars in the instability strip

HIC	HD	HR		VB	π (mas)	V_J	M_V	Spectral Type
20087	27176	1331	51 Tau	24	18.25±.82	5.65	1.96±.10	kA7hA7mF0 (V$^+$)
20219	27397	1351	57 Tau	30	22.31±.92	5.59	2.33±.09	F0IV
20261	27459	1356	58 Tau	33	21.20±.99	5.26	1.89±.10	F0IV
20400	27628	1368	60 Tau	38	21.87±.96	5.72	2.42±.09	kA3hF2mF2 (III)
20542	27819	1380	64 δ^2 Tau	47	22.36±.88	4.80	1.55±.08	A7IV
20641	27946	1388	67 κ^2 Tau	55	22.65±.84	5.27	2.05±.08	A7V
20711	28024	1392	69 υ Tau	60	21.07±.80	4.28	0.90±.08	A9IV$^-$n
20713	28052	1394	71 Tau	141	20.86±.84	4.50	1.09±.09	F0IV–Vn
20873	28294	1408	76 Tau	68	18.42±1.93	5.90	2.23±.23	F0IV
20894	28319	1412	78 θ^2 Tau	72	21.89±.83	3.40	0.10±.08	A7III
20901	28355	1414	79 Tau	74	20.33±.84	5.01	1.55±.09	kA6hA7mF0 (IIIb)
20995	28485	1422	80 Tau	80	22.93±1.25	5.58	2.38±.12	F0V$^+$n
21029	28527	1427		82	22.54±.77	4.78	1.54±.07	kA5hA5mF0 (IIIb$^-$)
21036	28556	1430	83 Tau	84	21.84±.89	5.40	2.10±.09	F0IV
21273	28910	1444	86 ρ Tau	95	21.39±1.24	4.63	1.28±.13	A9V
21588	29375	1472	89 Tau	103	21.96±1.04	5.79	2.49±.10	F0IV–V
21683	29488	1479	92 σ^2 Tau	108	20.51±.82	4.69	1.25±.09	A5IV–V
22044	30034	1507		111	20.73±.88	5.40	1.98±.09	A9IV$^-$
22565	30780	1547	97 Tau	123	17.27±.82	5.10	1.29±.10	A9V$^+$
23497	32301	1620	102 ι Tau	129	20.01±.91	4.62	1.12±.10	A7IV

system, 54±2.2 pc, which is similar to the Hipparcos satellite value, 54.8±2.5pc. The photometric data reported in Table 1 are those of the system; taking into account a magnitude difference of 2.0 between the two components (Gatewood et al. 1992) and the color of a G0 type star for the secondary (∼0.38), we can estimate directly the magnitude and color of the primary, M_V=2.12 and *b–y*∼0.146. Here and in the following, the color of the companions have been estimated from the *b–y* of Hyades stars with similar spectral type observed by Olsen (1993).

HIC 20641 is a member of a multiple system of six components which includes also HD 27934, a star located just beyond the blue border of the instability strip, and other four stars with magnitude between 9.5 and 12.2.

HIC 20711 is reported in the BSC as a close occultation double (0.02″), with a magnitude difference of 1.9. A main sequence star fainter of 1.9 mag than an A9IV type star is a ∼F8V type star with *b–y*∼0.34; therefore we get M_V ∼1.07 and *b–y*∼0.137 for the primary. As regards the position in the color–magnitude diagram and the high $v_e\sin i$, υ Tau is very similar to the outstanding object 71 Tau (HIC 20713, see below). This suggested to look for other similarities in the UV band and possibly also in X–ray band (Antonello, 1990). Up to now, υ Tau has not been detected in X–ray, at least at the very high level of 71 Tau, nor has shown the same chromospheric features of MgII and other transition–region lines (Pastori et al. 1993). As far as we know, υ Tau has not yet been the target of a pointed observation with X–ray satellites; an anlysis of the sky map reported by Stern et al. (1992, Fig. 1), however, allow us to exclude that it has been detected in the ROSAT all–sky survey, which implies an approximated upper limit of 3 10^{28} erg/s.

HIC 20713 is reported as SB, but according to Abt and Levy (1974) there is no evidence of radial velocity variability. Peterson et al. (1981) have resolved the binary system with lunar occultations, indicating a magnitude difference of 3.6 and a secondary of G4V type (*b–y*∼0.42), therefore the primary should have M_V=1.13 and *b–y*∼0.141. We note that Δm_v=3.6 for a F0IV star implies a ∼G9V star (*b–y*∼0.46), but the resulting color of the primary is not very different. This is a famous star, since it is one of the two brightest X–ray source in Hyades (e.g. Micela et al. 1988; Stern et al. 1992, 1994). The origin of the X–ray emission, unusually strong for a star with this spectral type, is yet enigmatic. Since the other F–M type stars in Hyades have lower X–ray emission than 71 Tau, Stern et al. hypothesized a triple system with a faint M dwarf, where both the G4 and the M type star could be the sources; on the other hand, Antonello (1990) suggested a possible correlation with the pulsation and the high $v_e\sin i$ of the F-type star itself. The case of υ Tau is a counter–example which tends to rule out the second hypothesis. An exhaustive discussion of these and other related stars is reported by Pasinetti & Pastori (1996). The MgII doublet of 71 Tau exhibits variations probably correlated with the pulsation and with the presence of chromospheric emission (Pastori et al. 1993). Chromospheric emission is also indicated by CII line (Walter et al. 1988) and L_α (Landsman & Simon 1993). A IUE spectrum taken in 1980 showed a narrow absorption core in MgIIk line (Zolcinski et al. 1982) which was not observed in the series of IUE spectra taken at a later date (Pastori et al. 1993); finally, only small variations of UV flux, which does not show specific anomalies, have been observed by Monier & Kreidl (1994) and related to the pulsation.

HIC 20894. The variability of θ^2 Tau, a well studied member of Hyades cluster, was detected both by Millis (1967) and by Horan (1979), and confirmed by Duerbeck (1978). Antonello & Mantegazza (1982, 1983) found this star to be multiperiodic

Table 2. Hyades stars in the instability strip (continued)

HIC	b–y	$v_e \sin i$	$\Delta s('')$, Δm_v	binaries	ΔV	P (d)	ref.	
20087	.175	97	166, 5.0	11.245 yr, O	–	–	1	*
20219	.170	109	34, 7.9	?	.026	.0548, .0489	1,2,3	
20261	.126	65		?	.01	.0365, .0674	4,3	
20400	.196	25	79, 7.5; 107, 7.0	2.144 d	$\lesssim 0.01$	.06	1,2,5	
20542	.081	59	137, 8.5		–	–	2	
20641	.149	153	*		–	–	2,6	*
20711	.165	196	14, 8.2	D	.02	.148	1,2,6	*
20713	.150	192	137, 6.6	D	.02	.182, .131	1,2,7	*
20873	.206	102		X	–	–	1,8	
20894	.099	78	337, 0.4	140.728 d	.035	*	*	*
20901	.114	104			–	–	2	
20995	.197	134	*		–	–	1,2,8	*
21029	.088	71	250, 1.7	D?	–	–	1,2	*
21036	.154	95	112, 5.8		–	–	1,2,4,8	
21273	.144	117		?, O	.01	.07	1,2	*
21588	.191	115	142, 5.9	G	–	–	2,4,8	
21683	.088	117	437, 0.4	?	–	–	2	
22044	.149	86	79, 6.0; 12, 7.2		–	–	2, 4(var?)	
22565	.122	141	175, 5.3		.025	.04	1	
23497	.080	126		D?	–	–	2	*

Ref.: 1. Millis (1967), 2. Horan (1979), 3. Fu Jian-ning et al. (1996), 4. Breger (1970), 5. Poretti (private communication), 6. Bossi et al. (1983), 7. Krisciunas et al. (1995b), 8. Krisciunas et al. (1995a).

with several closely spaced frequencies, indicating the presence of a complex set of simultaneously excited nonradial pulsations. For solving this complexity, coordinated multisite photometric campaigns were performed by Breger et al. (1987, 1989). Four pulsation periods (0.075588, 0.07418, 0.073027 and 0.069844 d) were confirmed by the second campaign, and a fifth mode of 0.068425 d was added (see also Kovacs & Paparo 1989); moreover the amplitudes and periods were found constant over four years. The recently published results of the MUSICOS campaign (Kennelly et al. 1996) on radial velocity and line profile variations have complicated the scenario, confirming three known modes but finding two new ones. θ^2 Tau is a known spectroscopic binary resolved by lunar occultations (e.g. Peterson et al. 1981), and with the corresponding visual orbit measured interferometrically (Pan et al. 1992; a=0.0186$''$±0.0002$''$). The spectrum of the secondary member has been also detected, and the re-analysis of the system has given an estimate of the physical parameters and distance of the star: Peterson et al. (1993) report 42.4±1.5 pc, Tomkin et al. (1995) report 44.1±2.2, to be compared with the Hipparcos satellite value of 45.7±1.8 pc. The wealth of information allowed a first detailed comparison with evolutionary models (Krolikowska 1992). From the period, the new parallax and the semi–major axis a of the interferometric orbit we can derive the sum of the masses of the two components, 4.13 ±0.23$\mathcal{M}_\odot$. The mass of each star will depend on the spectroscopic orbit solution; adopting that derived by Tomkin et al. (1995), we get 2.33±0.21 and 1.80±0.31$\mathcal{M}_\odot$, respectively. Taking into account the magnitude difference and spectra reported in the literature, the primary should have M_V=0.44 and b–y∼0.102, and the secondary M_V=1.54 and b–y∼0.090. The analysis of (O-C) values (orbital light–time effect; Breger et al. 1989) and of the line profile variations (Kennelly et al., 1996) suggests that only the primary is pulsating.

HIC 20995 is an excellent comparison star according to Krisciunas et al. (1995a). The secondary member of the double star (P=189.5 yr) is of G2V type (BSC), and the magnitude difference is 2.5 (HIC); the primary should have M_V ∼2.48 and b–y∼0.179. We note however that the magnitude difference would imply a secondary of G6V type, and a primary with b–y∼0.175. Hipparcos satellite has given a reliable solution with ΔH_p = 2.52 ± 0.03 mag and Δs=1.654$''$±0.009$''$.

HIC 21029. Lunar occultation observations indicated the possible duplicity with Δm_v ∼3, however there was no confirmation (see Evans & Edwards 1981).

HIC 21273 is a spectroscopic binary, but the period usually reported in the literature (488 d) has not been confirmed (Abt and Levy, 1974). Hipparcos satellite has provided the astrometric orbit of the system.

HIC 23497, according to BSC, should be an occultation double (0.1$''$) with Δm_v ∼0.0; however this would imply a too low M_V for the primary.

3. Discussion

3.1. Membership

One could suspect that our sample is not homogeneous because some stars could be nonmembers. For example, Schwan (1991), in his accurate work using proper motions, has not included HIC 20873 (HD 28294). The location of the stars is shown in Fig. 1; in this figure all the units are parsecs and the scale is the same.

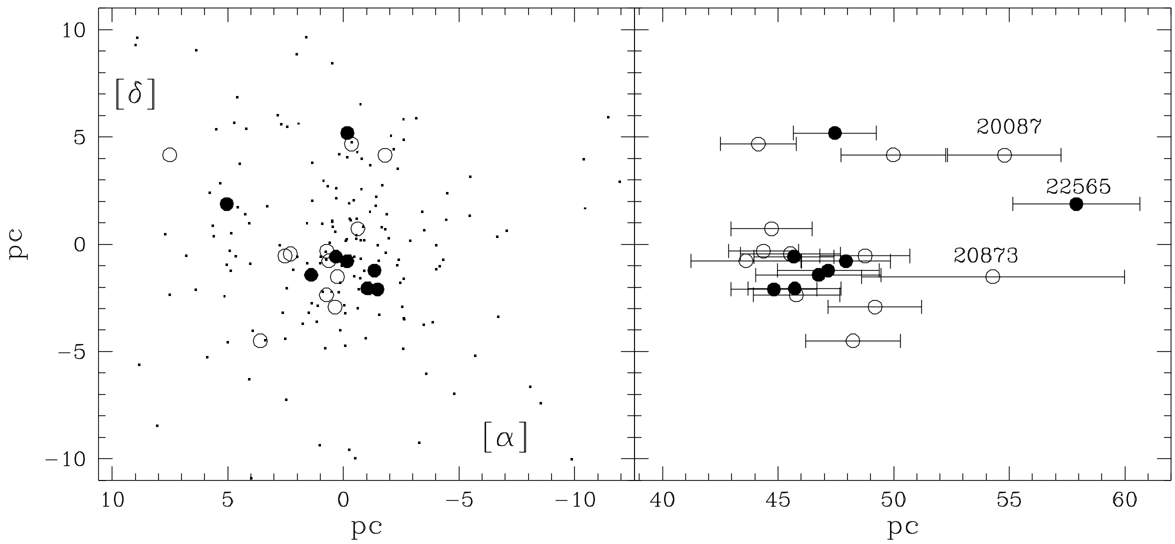

Fig. 1. Spatial location of the variable (*filled circles*) and nonvariable (*open circles*) stars in our sample; all the coordinates are parsecs with the same scale. The front view (*left panel*) shows the central part of the cluster, and the *dots* are the other Hyades members; the origin of coordinates is approximatively the apparent center of the cluster. The *right panel* shows the side view, where the abscissae are the distances from the observer

In the left panel (front view) the distances are measured from the approximate centre of the cluster, in the right ascension and declination directions. In the right panel (side view), the origin of abscissae is the observer position and we have plotted of course only the stars of our sample, with the corresponding errorbar. According to the new parallaxes, HIC 20873 is located in the bulk of the cluster, and there should not be reason for excluding it; on the other hand, we note that HIC 22565 and 20087, usually accepted members, are farther than the other stars.

3.2. Color–magnitude diagram

Thanks due to the accurate new parallaxes, it would be possible to construct a color–magnitude diagram where each point has a typical error less than 0.1 in M_V, while with ground–based observations (photometric calibrations) the error is generally not less than 0.3. However, as it is probably clear from the detailed descriptions in the previous section, we are faced with the uncertainty related with the presence of a close companion. In order to exploit the accuracy of M_V it is necessary to detect the companions which have a magnitude difference $\lesssim 2.5 - 3$. About half our sample is composed of reliably detected spectroscopic or occultation binaries. Since only HIC 20087 has been detected as a binary by speckle observations of Mason et al. (1993), while HIC 20995 was not observed and for the other eighteen stars there were negative results, it would be important to improve the interferometric techniques using large telescopes for increasing the possible detections. For example, HIC 20873, 21029 and 23497 can be considered suspected astrometric close binaries.

The 'rough' color–magnitude diagram and the 'corrected' one are reported in Fig. 2, where we have adopted ground based colors and V_J magnitudes. The corrected diagram has been constructed taking into account the analysis of the effects of companions reported in Sect. 3. The main deviations are given by five δ Scuti stars: HIC 20894 is an evolved star, 20711 and 20713 have the largest $v_e \sin i$, 21273 is a binary and there is probably a photometric effect due to the companion, 22565 has a large $v_e \sin i$ (however HIC 20641 has similar $v_e \sin i$ but 'normal' luminosity). Another possible deviation is that of HIC 20873, the coolest star in our sample, whose large uncertainty in the parallax estimated by Hipparcos satellite could be related to a close companion.

It is known that stellar rotation systematically displaces stars in any photometric diagram in a direction and by an amount which depends on the equatorial velocity and inclination presented by the stars, but any comparison between model and observations is complicated owing to the parameters involved (Collins & Smith 1985; hereinafter CS). The two stars of our sample with the largest velocity are located at ~0.8 mag above the apparent main sequence; the estimate is probably reliable because the photometric companion has been taken into account. According to the results obtained by CS, a large deviation such as this one cannot be explained by rigid rotation, but it could be explained by differential rotation. Following CS, for a more detailed comparison with their model results, we have tried to correlate $v_e \sin i$ with the distance of stars from the Zero–Age, Zero–Rotation Main Sequence (ZAZRMS), δM_T, for a given color, and for this purpose we used the homogeneous photometric data V_T and B_T taken from The Tycho Catalogue (ESA 1997b). In order to express the ZAZRMS as a function of $B_T - V_T$, the following transformations between Tycho and Johnson systems were derived

$$(B_T - V_T)(\pm 0.006) = 0.949(B - V)_J + 0.042, \quad (1)$$

$$V_T(\pm 0.012) = V_J, \quad (2)$$

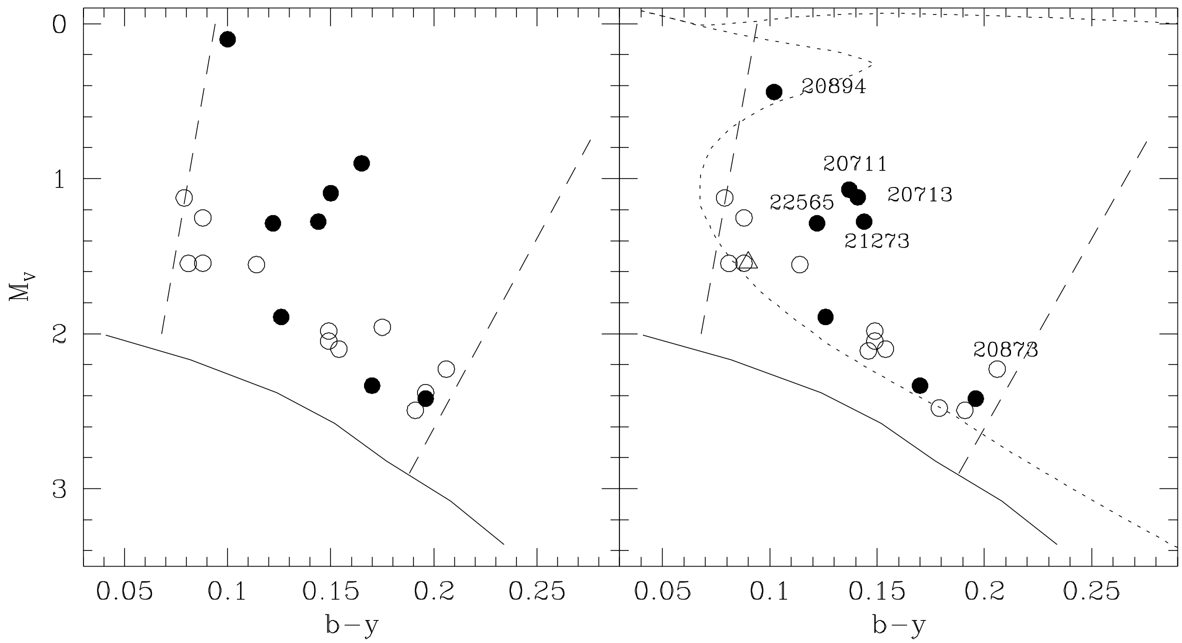

Fig. 2. Left panel: 'rough' color–magnitude diagram of the stars in our sample; *open circles*: nonvariable stars, *filled circles*: pulsating stars; the dashed lines mark the borders of the instability strip, and the continuous line is the Zero–Age, Zero–Rotation Main Sequence (Collins & Smith, 1985). Right panel: diagram constructed taking into account the photometric effect of known close companions; *triangle*: the companion of HIC 20894 (θ^2 Tau); *dotted line*: isochrone of 625 Myr (Perryman et al. 1997)

with correlation coefficient r = 0.993 and 0.9998, respectively, using the magnitude and colors of nineteen stars in our sample; HIC 20995 was excluded because there is not the Johnson photometry of the resolved system as in the Tycho catalogue. Moreover, in order to allow for the cases with known close companions, also the following transformation between b–y and $B_T - V_T$ with r = 0.992 was derived,

$$(B_T - V_T)(\pm 0.007) = 1.330(b - y) + 0.082. \quad (3)$$

The results are shown in Fig. 3; the evolved star θ^2 Tau is not included. There is a group of stars with $\delta M_T \sim$0.6 – 0.8 and a rough trend of δM_T to increase with $v_e \sin i$. Two stars, HIC 20400 and 21273, have been marked since they could have δM_T larger by $\sim 0.2-0.3$ mag than other stars with analogous $v_e \sin i$. HIC 21273 is a spectroscopic (and astrometric) binary, and a G-type companion could be responsible for this photometric effect. Also HIC 20400 is a spectroscopic binary; moreover it is a classical Am star and it should be a *slow* rotator. Taking into account these indications, the two stars could be placed to the left of the dashed line in Fig. 3. The models suggest that, in general, we should not expect a clear correlation between δM_T and $v_e \sin i$; in particular a large δM_T does not imply necessarily a large $v_e \sin i$, but it implies a large v_e. However there are ensemble properties discussed by CS which relate statistically the photometric parameters (magnitude and colors) to v_e. The group of stars with $\delta M_T \sim$0.6 – 0.8 in Fig. 3 would correspond, in CS' notation, to models with a ratio $\delta M_V/[\delta M_V(max) - \delta M_V(min)]$ close to zero. If we take into account this zero–point, the observed maximum and minimum values of δM_T and the star colors, we note very interesting similarities, not only at a qualitative level, between our Fig. 3 and Fig. 5 (I, p=0.5) of CS. Essentially similar results would have been obtained with a plausible main sequence, such as the isochrone shown in Fig. 2 (Perryman et al. 1997), instead of the old ZAZRMS adopted by us. As a cautionary note we remark, however, that the few stars in our sample do not allow firm conclusions.

3.3. Variable and nonvariable stars

When dealing with δ Scuti stars, the comparison with nonvariable stars is hampered by the uncertainty on the detection limit of variability and the possibility that so-called nonvariable stars are pulsating below it. For example, the limit of the survey performed by Millis is estimated $\Delta V \sim$0.015, which could be easily overcome with longer time series or more accurate observations. In fact, in well observed δ Scuti stars some detected pulsational modes have total amplitude as low as few millimag (e.g. θ^2 Tau). The low number of stars in the present sample do not allow a statistical study of the dependence of the pulsational amplitude on the position in the color–magnitude diagram and rotational velocity; this will be treated in another work on a large sample of δ Scuti stars. Even in that case it should be important to detect possible companions, since the true amplitude of the pulsator differs by a factor (1 + L_2/L_1) from the observed amplitude, where L_2/L_1 is the luminosity ratio of the two stars. In the present case we just note that pulsating and nonpulsating stars are found indifferently at any value of $b - y$. As already noted long time ago by Breger (1975), in Hyades the average $v_e \sin i$ of pulsating stars is higher than that of nonpulsating stars;

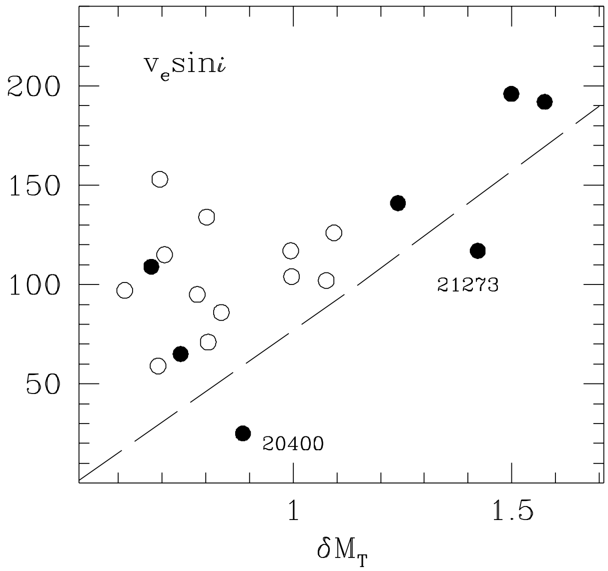

Fig. 3. Rotational velocity against the magnitude difference between stars and ZAZRMS for the same $B_T - V_T$. Symbols as in previous figures (dashed line: see text)

however, it is not yet clear what is the role played by the rotation on the pulsation stability characteristics (for a discussion of this point and the relation with diffusion phenomena, see e.g. Antonello 1990).

For the well observed θ^2 Tau we can derive a better estimate of the pulsation constants Q. Taking into account $\mathcal{M}$=2.33±0.21$\mathcal{M}_\odot$, T_e=8200±100 K and M_{bol}=0.46±0.09, (small bolometric correction taken from Flower, 1996), the Q range is 0.0158 – 0.0193 d for the set of seven detected modes, and for the dominant mode with P=0.075587 d we get Q=0.0171 ± 0.0015 d. The difference with respect to the published values is due to the lower mass (or lower gravity, $\log g$ = 3.701 ± 0.058) than that previously adopted.

Finally, we recall the negative result concerning the X–ray emission of υ Tau. This star is very similar in many respects to 71 Tau: it is a pulsating star, a very fast rotator, probably a binary star, and has similar magnitude and color; however it does not show the same strong X–ray emission. This result lead us to conclude that the strong emission of 71 Tau probably is not related to the fast rotation coupled with the pulsation of the star.

4. Conclusion

The improved estimate of M_V of Hyades stars of our sample has shown that it is essential to allow for the possible close companions owing to their photometric effect. In fact, any comparison with models and theories at the accuracy level which is now available requires the solution of this problem. For example, we have shown that, bearing this effect in mind, the stars in our sample seem to support the differentially rotating models against those rigidly rotating. As regards pulsating and nonpulsating stars, the present study indicates only that, differently from nonvariable stars, the δ Scuti stars are located both on the main sequence *and* above it, and the high luminosity appears to be related to the high rotational velocity. Probably a statistical study of a larger sample could give further indications about possible luminosity difference between pulsating and nonpulsating stars.

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