DELTA SCUTI STARS IN THE HR DIAGRAM

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ABSTRACT

A sample of 75 δ Scuti stars with parallaxes known to better than 15 per cent is examined. A significant fraction of them ($\sim$ 10 per cent) lie beyond the core-hydrogen exhaustion phase in the HR diagram, compared with the models of Schaller et al. (1992) which have a moderate overshooting distance $d_{\rm over}/H_p = 0.2$. The Period-Luminosity-Colour relation based on these new data shows as much scatter as previous ones, confirming that the scatter is essentially due to the variety of the excited modes, rather than to uncertainties in the absolute magnitude. The mass, interpolated in recent evolutionary tracks (assuming standard evolution), is given for each star, as well as the pulsation constant Q corresponding to the main period. An attempt to determine the pulsation mode using a formula by Fitch (1981) remained inconclusive. The observed parallaxes of SX Phe and AI Vel correspond very well to those predicted on theoretical grounds by Petersen & Christensen-Dalsgaard (1996).

Key words: space astrometry; pulsating stars; δ Scuti stars.

1. INTRODUCTION

δ Scuti stars are the main sequence analogs of Cepheids, and constitute the most numerous class of pulsating variables after the pulsating white dwarfs (Solano & Fernley 1997). Their amplitudes span from hardly detectable to several tenths of a magnitude. Large amplitude seems associated with slow axial rotation, for unevolved stars (close to the ZAMS) – putting aside the special case of Am stars which are slow rotators but do not pulsate – as well as for evolved ones (about to leave the Main Sequence). Large amplitude objects had been designated 'dwarf Cepheids' in the past (Smith 1955), but are physically so intimately related with δ Scuti stars that a special designation is not justified (Breger 1980).

These objects pulsate either in radial or non-radial modes, with a trend for high-amplitude ones to show the fundamental radial mode. Many modes can be found excited in one and the same star, making such objects potentially very interesting for asteroseismological studies.

Period-Luminosity-Colour (PLC) relations published to date show a large scatter (e.g. Breger 1979). They were based essentially on absolute magnitudes derived from photometric calibrations, but the uncertainty of the absolute magnitudes seemed not sufficient to account for the scatter. The latter seems essentially due to the variety of modes excited, and to the fact that the highest photometric amplitude is not necessarily due to the fundamental radial mode in a given star. Breger (1980) showed that the similar period-log g relation becomes much tighter as soon as only radial pulsators are considered.

The identification of modes is a rather delicate matter. It can be done on the basis of multicolour photometry, using phase shifts and amplitude ratios of lightcurves measured in different colours (e.g. Garrido et al. 1990). Spectroscopic observations can also bring strong constraints on the possible modes through line profile variations (e.g. Mathias & Aerts 1996).

The purpose of this poster is to reconsider the PLC relation in the light of the more reliable luminosities obtained from Hipparcos, and to give an estimate of the pulsation constant Q for each star, thus providing constraints on the pulsation mode corresponding to the given period. Our total sample contains 75 δ Scuti stars, 57 of which are presumably single. All have a relative error smaller than 15 per cent on the parallax. The catalogue of Rodriguez et al. (1994) was used to find their properties, especially the period.

2. THE HR DIAGRAM

The absolute magnitudes have been computed from the Hipparcos parallaxes and the apparent V magnitudes of the HIC catalogue, neglecting the interstellar reddening. They have been corrected for duplicity. Their uncertainty was considered to be due only to the parallax error. The effective temperatures have been computed using the simple formula of Hauck & Künzli (1996):

$$\theta_{\rm eff} = 5040/T_{\rm eff} = 0.822(b-y) + 0.544 \qquad (1)$$

which gives practically the same results as the more sophisticated method of Moon & Dworetsky (1985) with the technical improvements of Napiwotsky et al. (1993). The bolometric corrections were taken from Schmidt-Kaler (1982) and interpolated using a 3rd-degree spline interpolation. They cannot be a significant source of error since they are small and do not vary much in this range of temperatures. Knowing the absolute visual magnitude from Hipparcos and the effective temperature from the $uvby\beta$ colours, the bolometric luminosity is obtained from the relation:

$$\log(L/L_\odot) = -0.4(M_V - 4.75 + \mathrm{B.C.}) \qquad (2)$$

The HR diagram of our sample of δ Scuti stars is shown in Figure 1; an uncertainty of 2 per cent (about 150 K) has been assumed on the effective temperature.

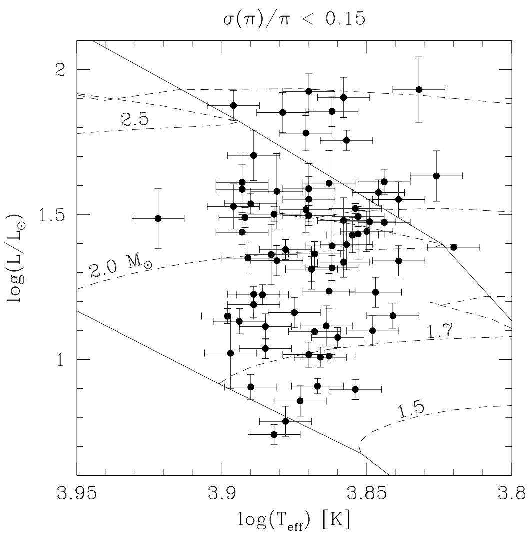

Figure 1. HR diagram for the whole sample of 75 δ Scuti stars. The continuous lines are the ZAMS and the upper limit of the Main Sequence (TAMS), while the dotted lines are the evolutionary tracks of Schaller et al. (1992) for the indicated masses and metallicity Z = 0.020.

It is quite visible on this figure that many δ Scuti stars are evolved and have even gone beyond the end of the core-hydrogen exhaustion phase, if they have undergone a standard evolution.

3. THE PLC RELATION REVISITED

The periods have been taken from Rodriguez et al. (1994); only one period is considered for each star. Figure 2 shows the classical PLC relation thus obtained, which does not differ much from that of Breger (1979) as far as the scatter is concerned (the abscissa has been taken from Breger (1979): we have not redetermined the colour effect). However, the slope of the relation is slightly smaller here than in Breger (1979): assuming negligible errors in P, we obtain $M_V \propto (-3.33 \pm 0.37) \log P$ instead of $M_V \propto -3.05 \log P$, while $M_V \propto (-5.61 \pm 0.62) \log P$ if errors on M_V are neglected.

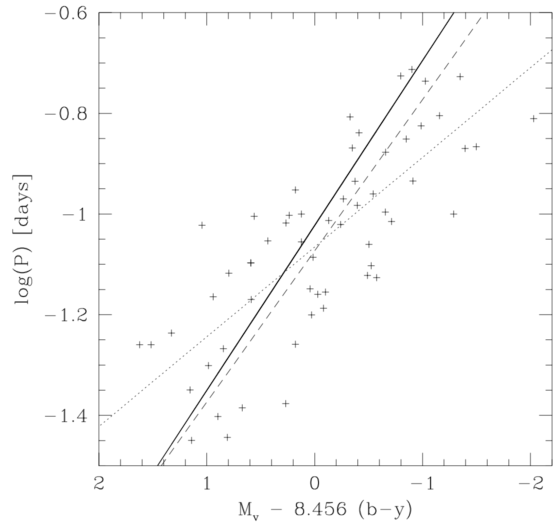

Figure 2. PLC relation for our sample of 57 single δ Scuti stars. The continuous line is the relation by Breger (1979), the dotted line is the fit obtained assuming no error on M_V and the broken line is obtained assuming no error on log P, which gives M_V = –3.33 log P + 8.46 (b-y) – 3.57.

4. MASS, DENSITY AND PULSATION CONSTANT

4.1. Mass Determination

The masses have been interpolated in the grids of models of Schaller et al. (1992) (Z = 0.020 and 0.001), Schaerer et al. (1993a) (Z = 0.008), Charbonnel et al. (1993) ($Z = 0.004$) and Schaerer et al. (1993b) (Z = 0.040) using successive 3rd-degree splines in luminosity, $T_{\rm eff}$ and metallicity Z. The metallicity was derived from Geneva photometry using the calibration of Künzli et al. (1997). Using only $Z = 0.020$ grids would not have been quite satisfactory, because some of our objects are clearly metal-deficient. On the other hand, some are metal-rich and have a δ Del or marginal Am classification, which raises a problem: if the radiative diffusion mechanism is responsible for their large metallicity, then the latter is confined to the superficial (atmospheric) layers only and is not, therefore, representative of the internal metal-content. Then, nobody can tell what is the pertinent Z of such stars; we circumvented the problem by imposing an upper limit of +0.2 to $[M/H]$ since the probability of finding more metal-rich stars in the vicinity of the Sun is small.

Another problem is the ambiguity zone around the end of the core-hydrogen exhaustion phase, where there is no one-to-one relation between the position in the HR diagram and the mass. This is a relatively rapid phase, but since many δ Scuti stars are evolved, several of them have an ill-defined mass. For the sake of a smooth interpolation, the turning back of the evolutionary tracks has been ignored, so that $T_{\rm eff}$ decreases monotonically with time and L undergoes a sudden increase at the end of the main sequence, just before the star reaches the Hertzsprung gap. Therefore, there is a narrow band where the mass may be overestimated for some stars by about 5 per cent.

4.2. Density, Surface Gravity and Pulsation Constant

The mean density, surface gravity and pulsation constant of the stars have been computed according to the formulae:

$$\log(\frac{\overline{\rho}}{\overline{\rho}_\odot}) = \log(\frac{M}{M_\odot}) - -1.5\log(\frac{L}{L_\odot}) +6\log T_{\rm eff} - 22.57 \quad (3)$$

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

$$\log Q = \log P + 0.5\log(\frac{\overline{\rho}}{\overline{\rho}_\odot}) \quad (5)$$

These quantities are listed in Table 1. It is encouraging to see that Q is around 0.033 for several stars, in agreement with the fundamental radial mode. We tried to determine the pulsation mode using Equation 7 of Fitch (1981) but the result was not convincing, probably because the internal structure models used by this author were not realistic enough.

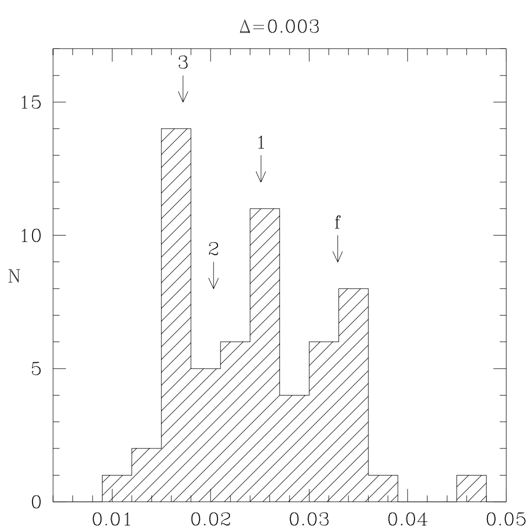

Figure 3. Distribution of the Q values obtained here for the 57 single δ Scuti stars. Notice the three peaks corresponding to the fundamental, 1st overtone and 3rd overtone of the radial mode respectively.

Figure 3 shows the histogram of the pulsation constants for the stars of Table 1. Interestingly, three peaks are visible which correspond quite well with radial pulsations in the fundamental mode, the first and the third overtones respectively, as indicated by the arrows (whose Q values were taken from Breger 1979, Table 11). The second overtone may be present too but cannot be distinguished. This result shows that although many stars pulsate in the fundamental radial mode, they do not constitute more than one third or so of the whole sample; many others pulsate in some overtone.

5. CONCLUSION

The Hipparcos data are extremely helpful to define good quality physical parameters of δ Scuti stars, which will certainly prove useful for coming asteroseismological studies. As an illustration, Petersen & Christensen-Dalsgaard (1996) predicted, from the period ratio in SX Phe (HD 223065), $\pi = 0.012 \pm 0.002$ arcsec for this star, while Hipparcos gives $\pi = 0.01291 \pm 0.00078$ arcsec. Similarly, their prediction for AI Vel (HD 69213) was $\pi = 0.009$ arcsec, Hipparcos giving $\pi = 0.00999 \pm 0.00050$ arcsec. This is a very nice success for Petersen & Christensen-Dalsgaard (1996), and one may expect that conversely, good parallaxes will make mode identification easier.

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Table 1. Physical parameters of the δ Sct stars measured with Hipparcos with a relative error on the parallax smaller than 15 per cent. An 'a' in the last column indicates that the mass may be overestimated by 5 per cent (at most) because the star lies in the ambiguity zone in the HR diagram. The uncertainties are given in units of the last digit of the corresponding quantity (e.g. log g = 3.61±4 means log g = 3.61±0.04). δ Scuti itself is HD 172748; SX Phe is HD 223065, while AI Vel is HD 69213.

HD	b-y	[M/H]	P [d]	M_V	M [$M_\odot$]	$\log T_{\rm eff}$	$\log(\frac{L}{L_\odot})$	Z	$\log(\frac{\bar\rho}{\rho_\odot})$	$\log g$	Q [d]	
432	0.216	0.00	0.1009	1.17	2.065± 42	3.844	1.473± 9	0.018	-1.402± 56	3.61± 4	0.020± 1	a
2628	0.169	-0.14	0.0693	1.43	1.963± 54	3.868	1.364± 43	0.013	-1.117± 79	3.79± 5	0.019± 2	
4490	0.165	0.00	0.1040	0.96	2.178± 85	3.870	1.553± 78	0.018	-1.342±116	3.66± 7	0.022± 3	a
4818	0.166	0.20	0.0396	2.30	1.757± 48	3.870	1.017± 43	0.029	-0.634± 79	4.10± 5	0.019± 2	
4849	0.168	0.20	0.0551	1.56	1.975± 71	3.869	1.312± 69	0.029	-1.033±106	3.85± 7	0.017± 2	
4919	0.216	0.20	0.1836	0.82	2.231± 61	3.844	1.613± 43	0.029	-1.578± 79	3.50± 5	0.030± 3	
8511	0.137	-0.13	0.0685	2.07	1.732± 47	3.885	1.114± 43	0.013	-0.695± 79	4.05± 5	0.031± 3	
15165	0.191	-0.62	0.1071	1.35	1.651± 70	3.857	1.396± 87	0.004	-1.308±126	3.64± 8	0.024± 3	
15550	0.155	-0.03	0.0676	1.94	1.804± 54	3.875	1.162± 52	0.017	-0.807± 88	3.99± 6	0.027± 3	
15634	0.181	0.12	0.0971	1.36	2.018± 86	3.862	1.392± 87	0.024	-1.183±126	3.75± 8	0.025± 4	
17093	0.137	-0.21	0.0355	2.26	1.548± 39	3.885	1.038± 35	0.011	-0.629± 71	4.08± 5	0.017± 1	
23728	0.179	-0.25	0.0994	1.75	1.761± 58	3.863	1.236± 61	0.010	-1.002± 97	3.85± 6	0.031± 3	
24809	0.128	-0.10	0.055	2.60	1.605± 44	3.890	0.905± 43	0.014	-0.384± 79	4.25± 5	0.035± 3	
24832	0.163	0.03	0.156	1.05	2.150± 84	3.871	1.517± 78	0.019	-1.288±116	3.69± 7	0.035± 5	a
26322	0.226	0.04	0.1450	1.51	1.955± 59	3.839	1.340± 52	0.020	-1.255± 88	3.70± 6	0.034± 3	a
26574	0.198	0.13	0.0747	1.11	2.160± 54	3.853	1.493± 35	0.024	-1.358± 71	3.64± 5	0.016± 1	a
27397	0.172	0.11	0.054	2.32	1.713± 43	3.866	1.008± 35	0.023	-0.651± 71	4.08± 5	0.026± 2	
27459	0.129	0.13	0.036	1.89	1.891± 52	3.889	1.189± 43	0.024	-0.741± 79	4.04± 5	0.015± 1	
30780	0.122	-0.02	0.042	1.27	2.063± 56	3.893	1.439± 43	0.017	-1.056± 79	3.84± 5	0.012± 1	
32045	0.165	-0.21	0.135	0.03	2.400± 79	3.870	1.925± 61	0.011	-1.858± 97	3.33± 6	0.016± 2	
32846	0.195	-0.48	0.1352	1.27	1.758± 58	3.855	1.429± 61	0.006	-1.342± 97	3.63± 6	0.029± 3	
50018	0.240	0.09	0.1547	0.04	2.538±133	3.832	1.931±113	0.022	-2.069±158	3.19±10	0.014± 3	
62437	0.123	-0.04	0.0953	0.84	2.260±111	3.893	1.611±104	0.016	-1.277±147	3.70± 9	0.022± 4	a
67523	0.266	0.20	0.1409	1.41	2.061± 42	3.820	1.387± 9	0.029	-1.419± 56	3.60± 4	0.028± 2	
69213	0.168	-0.20	0.1116	1.56	1.868± 51	3.869	1.312± 43	0.011	-1.057± 79	3.82± 5	0.033± 3	
69997	0.188	0.20	0.0755	1.14	2.151± 84	3.858	1.480± 78	0.029	-1.310±116	3.68± 7	0.017± 2	a
71496	0.140	0.08	0.096	1.45	2.008± 99	3.883	1.362±104	0.022	-1.011±147	3.86± 9	0.030± 5	
71935	0.142	0.05	0.07	1.10	2.140± 49	3.882	1.501± 26	0.020	-1.199± 65	3.75± 4	0.018± 1	
74050	0.115	0.08	0.058	2.32	1.756± 98	3.897	1.022±122	0.022	-0.476±169	4.20±11	0.034± 7	
77140	0.128	0.20	0.065	1.02	2.201± 55	3.890	1.537± 35	0.029	-1.195± 71	3.76± 5	0.016± 1	
79439	0.113	-0.16	0.095	2.00	1.788± 41	3.898	1.150± 26	0.012	-0.655± 65	4.09± 4	0.045± 3	
84999	0.196	-0.14	0.1327	1.04	2.031± 43	3.854	1.521± 17	0.013	-1.421± 59	3.59± 4	0.026± 2	a
90386	0.072	-0.28	0.0799	1.19	2.006± 99	3.922	1.486±104	0.009	-0.967±147	3.89± 9	0.026± 4	
99002	0.151	0.11	0.1	1.44	2.009± 85	3.878	1.363± 87	0.023	-1.048±126	3.84± 8	0.030± 4	
104513	0.171	0.04	0.0447	2.57	1.617± 37	3.867	0.908± 26	0.020	-0.523± 65	4.16± 4	0.024± 2	
107904	0.226	0.12	0.1163	0.98	2.168± 71	3.839	1.552± 61	0.024	-1.528± 97	3.53± 6	0.020± 2	
109585	0.211	-0.18	0.082	1.77	1.813± 54	3.847	1.232± 52	0.012	-1.081± 88	3.80± 6	0.024± 2	a
110377	0.120	-0.59	0.05	2.04	1.555± 43	3.894	1.132± 43	0.005	-0.711± 79	4.03± 5	0.022± 2	
115308	0.198	-0.26	0.1162	1.26	1.917± 81	3.853	1.433± 87	0.010	-1.320±126	3.65± 8	0.025± 4	
115604	0.180	0.20	0.1217	0.20	2.437± 73	3.862	1.856± 52	0.029	-1.794± 88	3.37± 6	0.015± 2	
124675	0.125	-0.32	0.071	1.14	1.993± 50	3.892	1.490± 35	0.009	-1.157± 71	3.77± 5	0.019± 2	a
143466	0.178	0.10	0.0763	2.31	1.708± 36	3.863	1.012± 17	0.023	-0.677± 59	4.06± 4	0.035± 2	
155514	0.126	-0.08	0.0884	1.49	1.935± 58	3.891	1.350± 52	0.015	-0.963± 88	3.89± 6	0.029± 3	
156697	0.254	-0.49	0.1874	0.79	1.958± 83	3.826	1.633± 87	0.006	-1.776±126	3.35± 8	0.024± 4	
172748	0.213	0.20	0.1938	0.91	2.254± 62	3.846	1.576± 43	0.029	-1.510± 79	3.55± 5	0.034± 3	
177392	0.206	0.09	0.1096	1.16	2.124± 83	3.849	1.475± 78	0.022	-1.362±116	3.64± 7	0.023± 3	a
181333	0.164	-0.02	0.1497	0.39	2.334± 77	3.871	1.781± 61	0.017	-1.651± 97	3.46± 6	0.022± 2	
186357	0.222	0.20	0.088	1.98	1.807± 49	3.841	1.151± 43	0.029	-0.994± 79	3.86± 5	0.028± 3	
186786	0.184	0.02	0.08	2.15	1.720± 43	3.860	1.076± 35	0.019	-0.788± 71	3.99± 5	0.032± 3	
187764	0.188	-0.22	0.10	0.31	2.248± 81	3.858	1.812± 69	0.011	-1.789±106	3.36± 7	0.013± 2	
192518	0.118	-1.17	0.1881	0.18	2.023± 61	3.896	1.876± 52	0.001	-1.707± 88	3.40± 6	0.026± 3	
197461	0.190	-0.17	0.1568	0.45	2.198± 55	3.857	1.756± 35	0.012	-1.721± 71	3.40± 5	0.022± 2	
199124	0.176	-0.18	0.099	2.05	1.676± 60	3.864	1.116± 69	0.012	-0.835±106	3.96± 7	0.038± 5	
199908	0.204	0.20	0.0789	1.24	2.116± 76	3.850	1.442± 69	0.029	-1.309±106	3.67± 7	0.017± 2	a
201707	0.179	0.08	0.0966	0.82	2.271±119	3.863	1.608±113	0.022	-1.450±158	3.59±10	0.018± 3	a
206553	0.180	0.10	0.063	1.55	1.947± 53	3.862	1.316± 43	0.023	-1.082± 79	3.81± 5	0.018± 2	
211336	0.169	0.04	0.0412	2.10	1.751± 36	3.868	1.096± 9	0.020	-0.765± 56	4.01± 4	0.017± 1	
215874	0.166	0.01	0.087	0.87	2.216± 94	3.870	1.589± 87	0.018	-1.391±126	3.63± 8	0.018± 3	a
223065	0.151	-1.41	0.0550	2.88	1.208± 36	3.878	0.787± 52	0.001	-0.405± 88	4.20± 6	0.034± 3	