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Luminosity and related parameters of δ Scuti stars from Hipparcos parallaxes

General properties of luminosity*

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Abstract. The absolute magnitudes of δ Scuti stars derived from parallaxes measured by the Hipparcos astrometric satellite are discussed and compared with the previous estimates based on photometric $uvby\beta$ indices. There are significant differences which are related to photometric effects of metallicity and rotational velocity, but the possible effect of a close companion on the measured apparent magnitude should be also taken into account. The possibility of different groupings of δ Scuti stars based on the absolute magnitudes is briefly discussed. Some high amplitude δ Scuti stars with intermediate or normal metallicity and small and uncertain parallax have apparently a very low luminosity; this could be a systematic effect related to the observational errors.

Key words: stars: distances – stars: fundamental parameters – δ Sct

1. Introduction

The δ Scuti stars are main sequence Pop. I A-, F-type stars pulsating in one or more modes, which can be radial and/or nonradial; the periods are shorter than 0.3 d, and the amplitude is usually well below few tenths of a magnitude (see Breger 1990, and references therein). The utility of the study of these stars is related to the possibility of using the asteroseismological observations to put constraints on the physical parameters and on the models. The identification of the pulsation modes which is necessary for reaching this goal is not a simple task, owing to the observational limitations and the difficult interpretation of the results (e.g. Brown & Gilliland 1994). A better knowledge of other observational parameters such as the luminosity could be helpful in narrowing the possible choice of model parameters.

The new estimates of stellar parallaxes obtained by Hipparcos satellite have allowed a more accurate determination of absolute magnitudes of relatively nearby stars, which include also several pulsating stars. In the present paper we discuss the general characteristics of the new luminosity values in comparison with the previously adopted ones derived from photometric calibrations. We compare moreover the values of δ Scuti stars with those of some field Pop. II SX Phe stars. Several SX Phe stars were found in globular clusters, and their position in the color-magnitude diagram indicates that they are blue stragglers (e.g. Nemec et al. 1995). An important result obtained with the Hipparcos satellite parallaxes is the confirmation that the prototype of the class, the nearby star SX Phe, is a normal Pop. II star following standard evolution (Høg & Petersen 1996), whatever the reason for its being a blue straggler.

Finally we will discuss briefly a possible systematic effect of observational errors on the absolute magnitudes.

2. Absolute magnitudes

Tables 1, 2 and 3 contain the stars which were known to be variable in 1982, when the proposal for their study with Hipparcos data was submitted. The δ Scuti stars with error in absolute magnitude $\epsilon_M \leq 0.6$ mag are listed in Table 1, other faint stars with larger error are listed in Table 2 and the SX Phe stars are listed in Table 3 (see Sect. 4). Table 1 includes the Hipparcos Input Catalogue number (HIC; Turon et al. 1992) in column 1, the visual magnitude in the Johnson system (from The Hipparcos Catalogue, ESA 1997) in column 2, the absolute visual magnitude derived using the Hipparcos satellite parallaxes (column 3) and the respective error (column 4). Similar data are contained in Table 2. 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).

The statistical parameters of astrometric solutions are generally good, apart from the case of faint stars such as HIC 4322 (GP And) and the uncertain solution for HIC 117730 (HT Peg). The error in the parallax estimate is less than 0.001" for 92% of the stars with $\epsilon_M \leq 0.3$ mag, and in some cases (HIC 41483, 42794) it is as low as 0.0004". The star with the best M_V esti-

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* Based on data from Hipparcos astrometry satellite

Table 1. δ Scuti stars with $\epsilon_M \leq 0.6$

HIC	V_J	M_V	ϵ_M	HIC	V_J	M_V	ϵ_M	HIC	V_J	M_V	ϵ_M	HIC	V_J	M_V	ϵ_M
746	2.28	1.17	0.02	2355	5.20	1.43	0.11	2629	6.11	0.22	0.17	3685	6.11	0.96	0.20
3903	6.49	1.56	0.17	3949	5.24	0.82	0.10	3965	6.38	2.26	0.10	5661	5.95	1.62	0.11
6539	6.21	2.07	0.11	6552	8.07	1.88	0.26	6888	6.59	1.88	0.15	6981	6.01	0.69	0.19
8271	6.55	-0.13	0.41	8619	6.70	-0.06	0.44	11644	6.50	1.36	0.21	11678	6.14	1.94	0.12
12832	5.17	2.26	0.08	17846	5.95	1.75	0.14	18265	7.44	1.72	0.35	18455	6.18	1.05	0.20
18547	6.54	2.60	0.11	19513	5.39	1.51	0.12	19587	4.04	1.11	0.09	20219	5.58	2.32	0.09
20261	5.26	1.89	0.10	20400	5.72	2.42	0.10	20711	4.28	0.90	0.08	20713	4.48	1.08	0.09
20894	3.40	0.10	0.08	21273	4.65	1.30	0.13	22565	5.08	1.27	0.10	23596	6.32	1.27	0.15
24504	5.01	0.43	0.21	28271	5.89	0.72	0.23	28321	6.15	1.22	0.18	33041	6.10	0.04	0.28
33269	6.16	-0.97	0.43	33616	8.39	1.09	0.39	34724	5.44	0.92	0.13	37705	6.46	0.84	0.27
38473	9.31	3.93	0.45	39757	2.83	1.41	0.03	40330	6.56	1.56	0.12	40766	6.31	1.14	0.19
41483	5.08	1.10	0.06	41574	6.05	1.45	0.26	42319	8.24	2.06	0.45	42485	6.65	0.59	0.34
42594	7.73	1.40	0.40	42705	7.90	2.32	0.30	42794	6.05	1.10	0.10	44093	5.17	1.02	0.09
45493	4.80	2.00	0.06	48218	6.10	0.11	0.32	48319	3.78	1.04	0.05	51075	6.67	1.19	0.27
53530	5.90	0.96	0.12	55641	6.93	1.44	0.22	58684	5.22	2.57	0.06	59676	6.56	1.96	0.14
60066	6.44	2.03	0.12	60467	6.03	0.98	0.15	60813	6.23	1.42	0.17	61071	5.47	0.57	0.17
61496	6.20	1.77	0.13	61937	6.22	2.04	0.12	62267	5.22	0.85	0.13	64769	6.69	1.26	0.22
64844	4.72	0.00	0.13	65715	8.72	2.35	0.47	69483	4.53	1.14	0.09	71168	6.39	2.07	0.13
75736	6.49	2.45	0.07	76276	3.80	-0.24	0.11	78180	4.96	2.31	0.04	82798	6.35	1.87	0.13
83410	7.41	1.04	0.40	84054	6.20	1.49	0.14	84704	6.51	0.79	0.23	85840	6.84	2.44	0.11
86650	7.85	0.81	0.54	91726	4.70	0.91	0.10	93603	6.61	1.16	0.20	94982	5.53	0.39	0.16
95168	3.92	1.06	0.06	96967	7.68	1.66	0.35	96988	6.54	1.98	0.12	97326	6.34	0.31	0.18
97674	6.04	2.15	0.09	99738	5.19	0.18	0.13	101773	4.86	0.98	0.08	102281	4.43	0.45	0.09
103261	6.55	2.05	0.17	103471	7.26	1.24	0.18	104382	5.45	0.86	0.09	104634	6.47	0.82	0.27
105860	6.08	2.76	0.08	109857	4.18	2.13	0.03	111191	6.33	0.85	0.20	112355	6.55	1.55	0.12
112615	6.19	0.87	0.21	115250	4.58	1.03	0.08	117730	5.30	1.49	0.16				

Table 2. Faint δ Scuti stars with $\epsilon_M > 0.6$

HIC		V_J	M_V	ϵ_M	HIC		V_J	M_V	ϵ_M
3432	CC And	9.36	1.25	1.22	4322	GP And	10.86	5.68	1.00
6301	SS Psc	10.94	3.84	1.17	6942	XX Scl	8.91	1.77	0.72
15726	KN Per	11.57	5.64	1.16	39042	UX Mon	8.42	-0.01	1.29
39960	SZ Lyn	9.44	1.18	1.32	47181	AE UMa	11.31	4.49	1.26
73315	EH Lib	9.85	3.98	0.64	75373	YZ Boo	10.63	2.65	1.31
80903	DY Her	10.52	4.59	0.64					

mate is β Cas (HIC 746), with ϵ_M=0.020 mag (parallax error = 0.0005”).

Owing to the high accuracy of M_V, it is essential to take into account the possible photometric effects both in M_V and colour of a close companion; this issue has been discussed in detail for a sample of δ Scuti stars in Hyades cluster by Antonello & Pasinetti (1997). For example, a companion fainter by 4 mag than the main star changes the observed luminosity by about 0.027 mag.

3. Color-magnitude diagram for δ Scuti stars

One of the aims of our proposal of 1982 was to verify the presence of different groupings of δ Scuti stars according to their luminosity (Antonello et al., 1982), as suggested several years ago by Leung (1970), Elliott (1974) and Dvorak and Zieba (1975). This possibility was usually rejected in the past since the growing number of known variables with photometrically derived absolute magnitudes excluded any groupings. In order to check this point, we have taken into account the nearby stars with $\epsilon_M \leq 0.2$ mag, while the $uvby\beta$ photometric indices of Hauck & Mermilliod (1990) have been adopted for plotting the diagrams shown in Fig. 1. We have taken into account the effect of a close companion when the magnitude difference was known (Hoffleit & Jaschek, 1982); therefore the following M_V values, 1.16, 0.44, 1.07 and 1.13, were adopted for HIC 95168 (ρ^1 Sgr), 20894 (θ^2 Tau), 20711 (69 Tau) and 20713 (71 Tau), respectively.

It is interesting to note that the stars within 50 pc could be probably separated in two groups, one close to the main sequence and the other at about one magnitude above it. The separation does not seem related to differences in rotational velocity $v\sin i$ or metallicity index δm_1. However, it tends to disappear when we include progressively more distant stars. It would be interesting to make a comparison with the other nonvariable

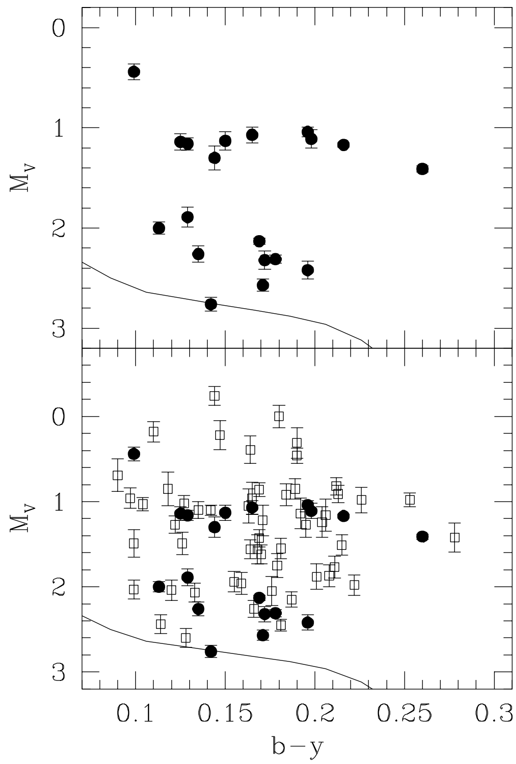

Fig. 1. Color-magnitude diagram of δ Scuti stars. Upper panel: stars with distance less than 50 pc; lower panel: all the stars with $\epsilon_M < 0.2$ mag. The continuous line is the zero age main sequence

nearby A-F stars. This check has been made recently for a subsample of Hyades stars by Antonello & Pasinetti (1997), and in this case, contrarily to what stated above, the rotational velocity is the most plausible explanation for the separation.

The accurate Hipparcos satellite parallaxes allow to make a check of the usually adopted absolute magnitudes of δ Scuti stars derived from photometric calibrations of $uvby\beta$ system. We have used the data of Hauck & Mermilliod (1990) and the calibration code of Moon & Dworetsky (1985) based on the photometric calibrations of Crawford (1975, 1979). The absolute visual magnitudes M_{Ph} were derived and they are compared with the Hipparcos values M_V in Fig. 2. Only the stars with $\epsilon_M < 0.3$ mag are taken into account. There are clearly large differences even for nearby stars. The possible explanations could be in part the effects of undetected companions on M_V, and metallicity and rotational velocity effects on M_{Ph}. In order to check the latter effects, the differences $\Delta M = M_{Ph} - M_V$ have been plotted against δm_1 and $v\sin i$ in Fig. 3. The trends show qualitatively the combined effects of these two parameters on M_{Ph}. Therefore, it is quite evident that a calibration of M_{Ph} in terms of $uvby\beta$ photometry should include also δm_1 and $v\sin i$, as proposed for example by Guthrie (1987).

4. Comparison with SX Phe stars

The confirmed or suspected SX Phe stars (Frolov & Irkaev 1984; Nemec & Mateo 1990) with measured parallax are listed in

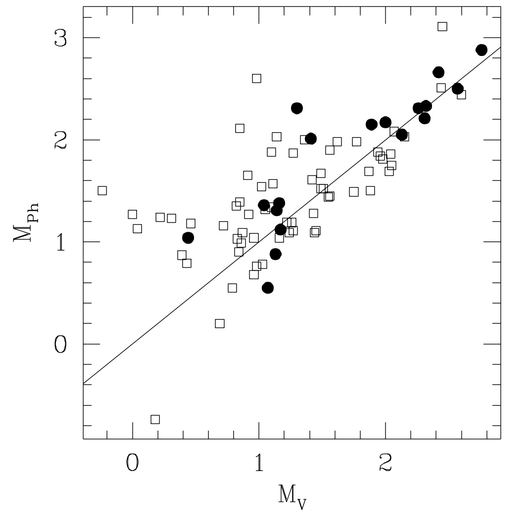

Fig. 2. Comparison between absolute magnitudes of δ Scuti stars derived from photometric indices and those from Hipparcos satellite parallaxes (see text). Symbols as in Fig. 1. The continuous line marks identity

Table 3. Confirmed and suspected SX Phe stars

HIC		V_J	M_V	ϵ_M	P	$[Fe/H]$
5321	BS Tuc	7.48	2.54	.13	.060	-0.8
11390	VW Ari	6.69	1.35	.23	.160	-0.5
56327	SU Crt	8.64	1.62	.70	.055	-0.4
107231	RS Gru	8.28	1.51	.52	.149	-0.3
117254	SX Phe	7.33	2.88	.13	.055	-1.7

Table 3: columns (1)-(2) Hipparcos Input Catalogue and star name; (3) V_J magnitude; (4) absolute M_V magnitude; (5) error in M_V; (6) period; (7) $[Fe/H]$ values. The Hipparcos parallaxes of other SX Phe stars such as CY Aqr and DY Peg are too much uncertain.

BS Tuc has a low amplitude and it has not been much observed for studying its variability; taking into account the one-night observations of Rodriguez et al. (1993), we can say it should be multiperiodic with at least probably two relatively close frequencies. VW Ari is an anomalous visual binary whose primary is pulsating and has low metal abundances, and the secondary has normal chemical composition (e.g. Andrievsky et al. 1995); it was intensively observed by Liu et al. (1996) who found eight periods from 0.16077 to 0.0738 d. SU Crt has low amplitude and probably is multiperiodic. RS Gru has high amplitude and is monoperiodic, probably pulsating in the fundamental mode. SX Phe is a well known double-mode pulsator with high amplitude.

According to Nemec & Mateo (1990), SX Phe has halo kinematics and low metal abundances, BS Tuc and SU Crt have old disk kinematics and intermediate metal abundances, but VW Ari and RS Gru should not be considered Pop. II stars.

The five stars are plotted in the $P-L$ diagram shown in Fig. 4 (*filled circles*) along with the other δ Scuti stars (*crosses*).

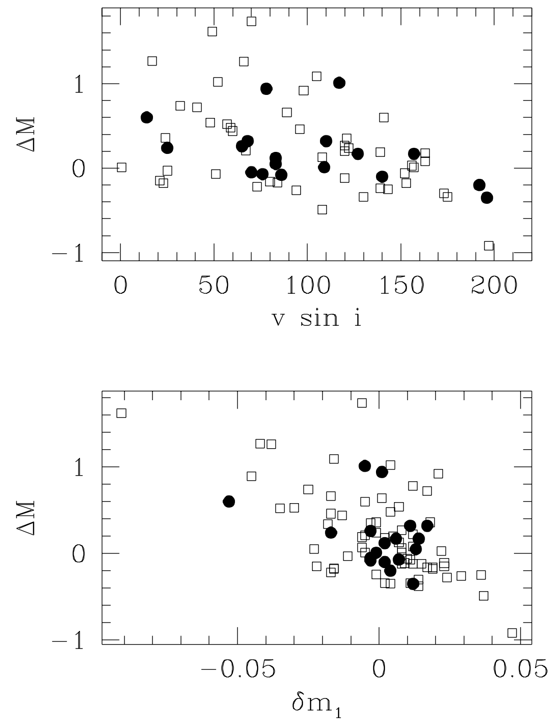

Fig. 3. Magnitude difference $\Delta M = M_{Ph} - M_V$ vs. metallicity index δm_1 (lower panel) and rotational velocity $v \sin i$ (upper panel). Symbols as in Fig. 1

The included δ Scuti stars have $\epsilon_M < 0.72$. The large scatter in Fig. 4 is not related to the parallax error only (70% of the sample have $\epsilon_M < 0.21$), and it is significant. The two straight lines are the $P - L$ relations valid for fundamental mode SX Phe stars with $[Fe/H]$ =-2 and -1, respectively, reported by Nemec et al. (1995). Finally, three faint δ Scuti stars with uncertain parallax, AD CMi, EH Lib and DY Her, are plotted with the respective errorbars and are discussed in the next section.

5. Luminosity and periods

Several factors can affect the $P-L$ relation of δ Scuti stars. For a star with a given luminosity, a different pulsation mode will correspond to a different period; for example, in a first approximation, the log P of first, second and third radial overtone mode differ by -0.11, -0.21 and -0.28, respectively, from that of the fundamental mode. Since the main pulsation mode of several δ Scuti stars could be a nonradial mode and it is not yet possible to identify it correctly, a significant general $P - L$ relation for all of these variables cannot be presently obtained. Høg & Petersen (1996) have obtained a relation for a small sample of high amplitude δ Scuti stars with well identified pulsation modes.

In the case of SX Phe stars, the adopted period for RS Gru and SX Phe corresponds to the fundamental mode, while there is no indication of the mode of BS Tuc and SU Crt. According to Liu et al. (1996), VW Ari main period could correspond to a nonradial mode with l = 1, p_1; if true, its hypothetical fundamental mode would have $P \sim .189$ d or log $P \sim -.723$,

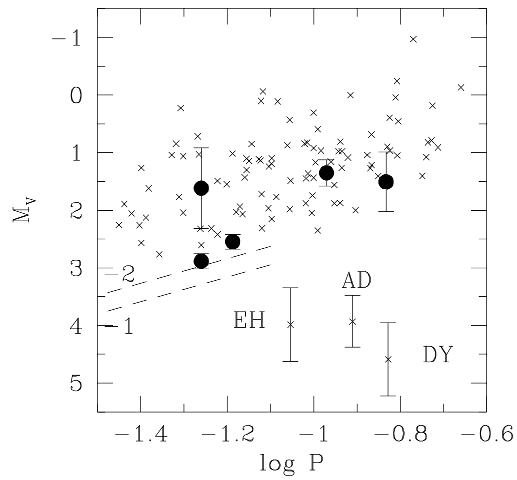

Fig. 4. Period-luminosity diagram of δ Scuti (*crosses*) and SX Phe stars (*filled circles*). The dashed lines are the $P - L$ relations for SX Phe stars. The locations of EH Lib, AD Cmi and DY Her are marked (see text)

placing the star close to the extension of the $P-L$ relation for SX Phe fundamental mode pulsating stars in globular clusters. As a general remark, we can see that the SX Phe stars with accurate parallax lie near the lower border of the envelope formed by all the δ Scuti stars (SU Crt and RS Gru have a large uncertainty).

The spread of observed, even if rather uncertain, $[Fe/H]$ values do not seem to support a $P - L$ relation for $[Fe/H]$=-1 *below* that for $[Fe/H]$=-2 as proposed by Nemec et al. (1995). An intriguing result in this context, however, is the position in the $P - L$ diagram of some high amplitude δ Scuti stars such as EH Lib, AD CMi and DY Her, since they have $[Fe/H] > -1$ and are located *below* the $P - L$ relation of SX Phe stars. Høg & Petersen (1996) pointed out the case of AD CMi without offering a possible explanation. Since these three stars, apart possibly from AD CMi (Antonello et al. 1986), are not different from other high amplitude δ Scuti stars with 'normal' M_V, it is difficult to find a physical explanation for their apparent low luminosity. The reddening is small, not larger than A_V = 0.2 mag, and there are no remarks concerning the quality of the parallax determination.

We suspect the low luminosity values are an observational effect related to the observational errors as discussed by Lutz and Kelker (1973). Some simulations have been performed. Firstly, for simplicity, we have assumed a large sample of stars with the same M_V, uniformly distributed around the Sun, and with the same uncertainty σ in the parallax π. We have simply verified what shown analytically by Lutz & Kelker, that is, for a given distance (or given π_0), the *measured* parallaxes π are *not* normally distributed around π_0, implying a certain probability of finding stars erroneously close to us and thus with erroneous small luminosities (large 'observed' M_V); roughly speaking, the probability increases for increasing σ/π_0 ratio. Then we have assumed a relation between the uncertainty σ in the parallax and the apparent magnitude of the stars, similar to that

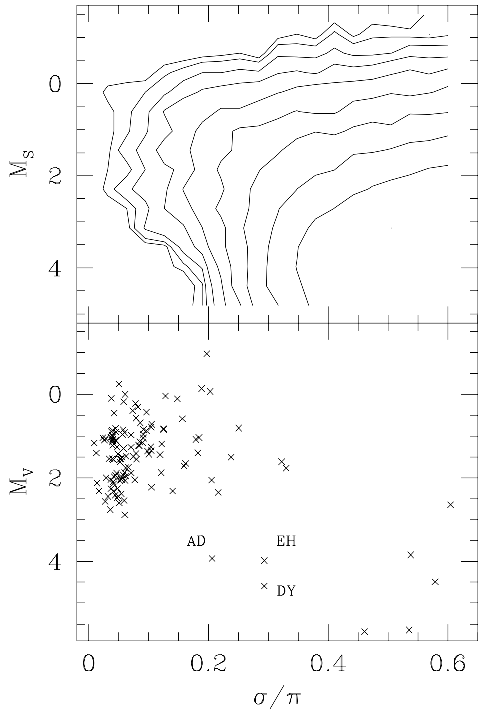

Fig. 5. Comparison of simulated and really observed M_V values against σ/π. Upper panel: results of a simulation assuming intrinsic M_V randomly distributed between 0 and 3 mag; the continuous curves are isograms of star density (see text). Lower panel: stars in the lower part of the instability strip observed with Hipparcos

suggested by the stars in Table 1 and 2; σ varies from about 0.0007" to 0.002". Moreover we have assumed M_V randomly distributed between 0 and 3 mag (the range suggested by nearby δ Scuti stars). The 'observed' M_S values of simulated stars have been plotted against σ/π in Fig. 5 (upper panel) and compared with a similar plot for the available real stars in the instability strip (lower panel). For clarity instead of plotting the individual simulated stars, which would have generated a black cloud, we have drawn 'level curves', or isograms of star density in the $(M_S, \sigma/\pi)$ plane. Star density increases by a factor two per level curve from left to right. For a fixed σ/π ratio the diagram can be read as the probability of finding stars with $0 < M_V < 3$ at a certain observed M_S. We can see that for low values of the σ/π ratio the probability is uniform in the correct range of absolute magnitudes, but for $\sigma/\pi > 0.15$ the probability of deriving too much high M_S values increases very steeply with this ratio. This can offer a possible explanation for the deviating real stars shown in the lower panel.

6. Conclusion

A comparison of absolute magnitudes of δ Scuti stars derived from parallaxes measured by the Hipparcos astrometric satellite with those previously estimated on the basis of photometric $uvby\beta$ indices shows that there are significant differences due to the photometric effects of metallicity and rotational velocity.

The absolute magnitudes of few bright SX Phe stars support the period-luminosity relation obtained with ground based observations of globular clusters, while it does not seem to confirm the empirical dependence of this relation on the metallicity; in this context it is important to confirm the nature of the nearby star BS Tuc.

The very low absolute magnitudes of some high amplitude δ Scuti stars with intermediate or normal metallicity and uncertain parallaxes could be explained by the systematic effects related to observational errors.

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