The Relation between Pulsating Amplitudes of δ Scuti Type Variables and Projected Rotating Velocities

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Abstract

In this study 180 δ Scuti type variables with v sin i values are listed out from different sources. It is found that even for low amplitude non-pulsating δ Scuti type variables, the average v sin i of different groups of variable with different amplitude continuously declines with the amplitude increasing.

I. Introduction

Since 1972, the high amplitude δ Scuti type variables have smaller v sin i values had been recognized (Danziger and Faber 1972). In 1979, Breger showed that the δ Scuti type variables have a larger averaged rotation velocity than non-variables in the same H-R diagram region. In 1985, McNamara showed that all the δ Scuti type variables with amplitude higher than 0.3 have value of v sin i smaller than 40 km/s. Later, Moon and Halplin (1987) and Rodriguez et al. (1994) made statistics research about the amplitudes and v sin i. They found that the amplitude decreases with v sin i increases. Recently Solano and Fernley (1997) made a spectroscopic survey of δ Scuti type variables and published some new results on v sin i. They obtained v sin i for 66 variables, and 41 non-variables. They used 62 variables to make ΔV - v sin i distribution analysis and found out ΔV = 0.1 represents better the border between the high amplitude δ Scuti (HADS) and low amplitude δ Scuti (LADS) variables and all the HADS variables have v sin i smaller than 50 km/s. They also made a non-biased sample of 105 variables and similar spectral type distribution sample of 105 non-variables. As a result of analysing of these samples, they showed that the v sin i distribution for these 2 samples are different and the average v sin i for variables is larger than the non-variables, similar with that of Breger (1979). Jiang and Xia (1987) used the 4th edition of the Bright Star Catalogue (Hoffleit and Jaschek 1982) to do some statistical analysis for spectral type A3 to F5, it was found that the average v sin i for δ Scuti type variables is about 90 km/s, while for the normal non-variables is about120 km/s. This result is in agreement with that the larger the v sin i is, the smaller the light variation is. However it conflicts with the result of Breger and Solano and Fernley. Why the results are different; it needs to be proved, and the problem should be solved. Starting from a complete catalogue of δ Scuti type variables with v sin i in table 1.

II. The v sin i of δ Scuti type variables.

One hundred and eighty δ Scuti type variables with v sin i and amplitude (ΔV) are showed in table 1.

Table 1. The Delta Scuti Stars with v sin i

name	period (d)	vsini (km/s) (1)	(2)	(3)	average	ΔV	b-y / $\log T_{eff}$	sp. Type	Mark
HD 0432	0.1009	85	70	69.1	74.7	0.033	0.216	F2II-IV	
HD 1479	0.0300			135.6	135.6	0.050	0.212	F0	
HD 2628	0.0693	30	18	16.1	21.4	0.050	0.169	A7III	
HD 2724	0.1743	102[d]			102	0.011	3.857	F2III	
HD 3112	0.0493	80	52[g]		66	0.026	3.879	A7IV	
HD 3326	0.0285		98		98	0.003	0.170	A5m..	
CC And	0.1249	20		14.5	17.3	0.**240**	3.869	F3IV/V	
HD 4490	0.1040	185	170		177.5	0.040	0.165	F0Vn	
HD 4818	0.0396			16.1	16.1	0.011	0.166	F2IV	
GP And	0.0787			11.5	11.5	0.**520**	3.876	A3	
HD 6870	0.0650	130			130	0.020	0.170	A2IIwp	
HD 8511	0.0685	185	195	140.5	173.5	0.010	0.137	F0V	
HD 9100	0.1360	125	110	135.6	123.5	0.020	0.090	A4IV	
HD 10845	0.2190	75	85	100.9	87.0	0.020	0.158	A9III	
HD 11285	0.0764			51.8	51.8	0.020	0.182	F0	
HD 11522	0.0903		120		120	0.050	0.162	F0V	
RV Ari	0.0931	18			18	0.**410**	3.870	A	
SS Psc	0.2878	< 18		18	18	**0.390**	0.189	A7/F2	
HD 15165	0.1071	90[e]			90	0.060	3.849	A3	
HD 15550	0.0676	175	170	173.9	173.0	0.010	0.155	A9V	
HD 15634	0.0971		141		141	0.040	0.181	A9V:n	
AB Cas	0.0583	55			55	0.050	0.252	A3V	
HD 17093	0.0355	80	75	68.3	74.4	0.040	0.137	A7III/IV	
HD 19279	0.0692		285:		285:	0.002	0.063	A3Vnn	
HD 20313	0.0666	47			47	0.020	0.175	F2II/III	
V459 Per	0.0375	75			75	0.012	0.212	F0IV	
HD 20919	0.0350	50			50	0.014	0.207	A8V	
HD 21553	0.0295	150			150	0.017	0.167	A6Vn	
HD 23156	0.0236	70		41.6	55.8	0.010	0.150	A7V	
BL Cam	0.0391	30			30	0.**330**	3.901		
HD 23567	0.0320	95		98.6	96.8	0.015	0.229	A9V	
HD 23607	0.0470	6			6	0.010	0.148	A7V	
HD 23643	0.0310	185			185	0.030	0.092	A3V	
HD 23728	0.0994	110	91	102.1	101.0	0.070	0.179	A9IV	
HD 24550	0.0758			132.4	132.4	0.030	0.243	F3II/III	
HD 24809	0.0550	85		129.4	107.2	0.010	0.128	A8V	
HD 24832	0.1559	150	150	126.4	142.1	0.050	0.163	F1V	
HD 26322	0.1272	15		6.8	10.9	0.070	0.226	F2IV/V	
HD 26574	0.0747	115		99.7	107.4	0.030	0.197	F2II/III	
HD 27397	0.0548	100	98	102.1	100.0	0.026	3.869	F0IV	H
HD 27459	0.0365	68	78	81.6	75.9	0.010	3.892	F0V	H

HD 27628	0.0625	30	25	32.0	29.0	0.010	0.196	F2IIIm	H
HD 28024	0.1484	215	225:	205.1	215.0	0.016	0.165	A8Vn	H
HD 28052	0.1625	193	205:	195.7	197.9	0.015	0.150	F0V	H
HD 28319	0.0756	105	80	66.7	83.9	0.035	0.099	A7III	H
HD 28910	0.0670	103	130	126.4	119.8	0.010	0.144	A8V	H
HD 30780	0.0420	151	165	98.6	138.2	0.025	0.122	A7IV/V	H
HD 32045	0.2730	200	195		197.5	0.025	0.165	F0V	
HD 32846	0.1353	70[I]			70	0.073			
HD 33959	0.0881	50	21	28.1	33.0	0.080	0.130	A9IV	
HD 34409	0.1804	165			165	0.050	0.258	F2IV	
HD 37819	0.1893	22.5			22.5	0.080	0.374	F8IIIp	
HD 40372	0.0611	65	71	70.8	68.9	0.010	0.123	A5me	
HD 40535	0.1361	26		18.8	22.4	0.**150**	3.863	F2IV/V	
HD 43378		10	35	60.4	35.1	0.**300**	0.008	A2V	
HD 50018	0.1547	130	150	134.0	138.0	0.014	0.240	F2Ve	
HD 50420	0.1700	25	28	26.3	26.4	0.010	0.221	A9III	
HD 55057	0.1000	150	125	135.6	136.9	0.026	0.184	F0V	
HD 55595			155		155	0.020	0.117	A5IV/V	
Y Cam	0.0665	46			46	0.028		A8V E+D	
HD 62437	0.0953		35		35	0.060	0.123	F0III	
HD 64191	0.1230	20		12.0	16.0	0.**300**	3.880	F2/3III	
HD 65607	0.0400	37			37	0.040	0.289	A3 EA+D	
HD 67390	0.1205	≤20			20	0.**510**	3.873	A7/F2	
HD 67523	0.1409	15	15.3[h]		15.2	0.090	0.260	F6IIp	
HD 69213	0.1157	18			18	0.**670**	3.882	A9IV/V	
AI Hya	0.1400	24			24	0.050	0.240	F2	
HD 69997	0.0755		25		25	0.030	0.188	F3IIIp	
HD 71297	0.0380	25	13		19.0	0.006	0.123	A5III/IV	
HD 71496	0.0960	130	120		125.0	0.025	0.140	F0Vn	
HD 71935	0.0700	122			122	0.010	0.142	A9.5III/IV	
HD 73175	0.0380	180			180	0.020	0.131	F0Vn	P
HD 73345	0.0325	98			98	0.020	0.122	F0V	P
HD 73450	0.0510	138			138	0.020	0.149	A9V	P
HD 73575	0.1023	150			150	0.034	0.153	F0III	P
HD 73576	0.0710	200			200	0.020	0.104	A7Vn	P
HD 73729	0.0740	160			160	0.020	3.872	F2Vn	P
HD 73746	0.1490	110			110	0.020	0.181	F0V	P
HD 73763	0.0388	130			130	0.030	0.130	A9V	P
HD 73798	0.0720	175			175	0.010	0.147	F0Vn	P
HD 73819	0.1717	145			145	0.030	0.091	A6Vn	P
HD 73857	0.1784	10		13.3	11.7	0.**410**	3.851	F2III	
HD 74028	0.0530	160			160	0.020	0.120	A7V	P
HD 74050	0.0580	150			150	0.010	0.115	A7Vn	P
EW Cnc	0.0531	80			80	0.020	0.162		
EX Cnc	0.0589	65			65	0.030	0.155	A7	
HD 75747	0.0770	65			65	0.050	0.134	A7V	
HD 77140	0.0650	59			59	0.015	0.128	Am	
HD 79439	0.1250	155	145		150	0.030	0.113	A5V	
HD 85040	0.0818	25	21.5		23.3	0.040	0.147	A7IVn	
HD 84999	0.1327	115			115	0.050	0.196	F2IV	

HD 88824	0.1253	163			163	0.050	0.155	A7V
HD 89343	0.1555	150	160		155.0	0.050	0.153	A7Vn
HD 93044	0.0833	100			100	0.080	3.881	A7III
HD 94033	0.0595	≤40[j]			40	0.**800**	3.883	
HD 101158	0.0775	132[a]			132	0.033	3.881	
HD 102647	0.0500	120	115		117.5	0.025	0.044	A3V
HD 104513	0.0400	70	78		74.0	0.020	0.174	A7m
HD 106384	0.0786	46.3[b]	21[f]		33.7	0.021	3.875	A5m
HD 107131	0.0551	175	180		177.5	0.025	0.100	A6IV/V
HD 107513	0.0300	50			50	0.005	0.173	A3
HD 107904	0.1103	73	115		94.0	0.025	0.226	F3III/IV
HD 108506	0.0500	175	180		177.5	0.010	0.279	F2III
HD 108662		19	10		14.5	0.**170**	-0.051	A0p E+D
HD 108945	0.0210	60	65		62.5	0.050	0.024	A3p
HD 109585	0.0820	80	91		85.5	0.020	0.211	F0V
HD 110377	0.0500	175	160	180.0	171.7	0.020	0.120	A7/8Vn
HD 110411	0.0220	175	140		157.5	0.020	0.040	
HD 110951	0.0719	65	28		46.5	0.020	0.189	F0IIIm
HD 115308	0.1192	51	75		63.0	0.040	0.198	F1IV
HD 115604	0.1217	15	15		15.0	0.050	0.180	F3III
HD 117661	0.0430	65	51		58.0	0.012	0.108	A7IV/V
HD 124675	0.0762	140	115		127.5	0.080	3.911	A8IV
HD 124953	0.0400	125	85		105.0	0.030	0.162	A8III
HD 125161	0.0265	137[k]	130		133.5	0.007	3.903	A9V
HD 127762	0.2903	145	115		130.0	0.050	0.116	A7III
HD 127929	0.0878	40	63		51.5	0.070	0.266	F0III
HD 127986	0.1500	5			5	0.020	0.343	F5
EH Lib	0.0884	16		13.3	14.7	0.**504**	3.886	F0
HD 137422	0.1430	160	165		162.5	0.050	0.121	A3
YZ Boo	0.1041	16		18.8	17.4	0.**390**	3.874	A6/F1
HD 138917	0.1340	70	73		71.5	0.044	0.152	F0IV
HD 138918	0.1557	70			70	0.040	0.152	F0IV
HD 140436	0.0300	100	100		100.0	0.060		A0IV
HD 142500	0.2544	225	210:		217.5	0.020	0.101	A7Vn
HD 143466	0.0763	135	150		142.5	0.010	0.178	F0IV
HD 146361	1.1398	13			13	0.**234**	0.383	F8V ?
DY Her	0.1486	20			20	0.**510**	3.860	A9III
HD 152830	0.1151	20		15.6	17.8	0.040	0.208	F3Vs
HD 152896?				50.2	50.2	0.**144**	0.219	A5
HD 155514	0.0884	175	160	191.1	175.4	0.020	0.125	A8V
HD 156697	0.1874	160	185	188.9	178.0	0.020	0.254	F1IV/Vn
HD 159223	0.2900			130.9	130.9	0.040	0.114	A7V
HD 160589	0.1152	16			16	0.**700**	3.863	A9V
HD 160613	0.0530	135	95		115.0	0.010	0.047	A2V
V567 Oph	0.1495	≤18[j]			18	0.**330**	3.873	
HD 165373	0.0720	80	81		80.5	0.035	0.202	F0IV/V
HD 171369	0.0906		81		81	0.040	0.167	F0IV/V
HD 172167	0.1900	15	15		15.0	0.050	0.004	A0V
HD 172748	0.1938	35		30.1	32.6	0.**290**	0.213	F2IIIp

HD 176723	0.1353	265			265	0.040	0.215	F2III/IV
HD 177392	0.1096	150		135.6	142.8	0.034	0.206	F2III
HD 177482	0.0970	145			145	0.030	0.172	F0III
HD 181333	0.1497	55	48	50.8	51.3	0.040	0.164	F0III
HD 181577	0.0500	80	83	81.6	81.5	0.020	0.129	F0III/IV
HD 186357	0.0880	95	98	103.3	98.8	0.020	0.222	F1III
HD 187764	0.1000	115	85		100.0	0.080	0.185	F0III
XX Cyg	0.1349	18			18	0.**850**	3.870	A7
HD 191747	0.1215	45			45	0.016	0.045	A3III
HD 192518	0.1881	190	205:	205.1	200.0	0.016	0.118	A7IVn
HD 192640	0.0310	25	35		30.0	0.030	0.101	A2V
HD 195961	0.1141	45			45	0.030	0.254	Fm…
HD 197461	0.1568	35	28	29.4	30.8	0.070	0.190	F0IV
CD-247599	0.0262	52[c]			52	0.015	3.920	
HD 199124	0.0990	200	145	132.4	159.2	0.020	0.176	A9Vn
HD 199908	0.0789	60		57.9	59.0	0.050	0.179	F1IV
HD 199757	0.0672	18			18	0.**350**	0.127	A3/F1IV
HD 200356				41.9	41.9	0.010	0.240	
HD 200925	0.2673			31.2	31.2	0.**310**	3.846	F2III
HD 201707	0.0970	150		134.0	142.0	0.070	0.179	F0III
HD 202444	0.0277	90	98		94.0	0.020	0.256	F0IV
HD 204188	0.0440	70	31	36.9	46.0	0.010	0.142	A8m
HD 206379	0.1470	≤40[j]			40	0.**560**	3.873	
DE Lac	0.2537	20		20	31.5	0.**350**	3.846	F5/8
HD 211336	0.0412	105	80	97.4	94.1	0.014	0.169	F0IV
HD 213534	0.0560	32	48	46.2	42.1	0.015	0.118	A5m
CY Aqr	0.0610	18			18	0.**710**	3.888	F4
HD 214698	0.0500	85			85	0.011	0.014	A2V
HD 215874	0.0870		98	99.7	98.9	0.020	0.166	A9III/IV
HD 218549	0.0730	16		23.6	19.8	0.**540**	3.887	F5
HD 220061	0.0543	150	135		142.5	0.010	0.104	A5V
HD 220392	0.2140	165			165	0.050	0.147	F0IV
HD 223065	0.0550	18[j]			18	0.**550**	3.887	
HD 223338	0.1978	20	5[j]		12.5	0.**520**	3.862	F2
HD 223781	0.0600	156	165		160.5	0.010	0.100	A4Vn
V1162 Ori	0.0787			46.4	46.4	0.**100**	3.877	A9
V1in47Tuc	0.0633	180			90	0.**177**	0.270	*
V2in47Tuc	0.1020	54			27	0.**135**	0.340	*
V3in47Tuc	0.0557	53			26.5	0.091	0.260	*
V14in47Tuc	0.0468	112			56	0.040	0.260	*

In the table 1 the first column is the name of the stars in HD number. The second column is the main period. The 3rd column is the old data get from Garcia (Garcia et al. 1995) or other sources with some superscripts as follows:

* for Gilliland et al. 1998. It is v not v sin i, so when use as v sin i, must multiple with 0.5. The amplitude is in U band, not in V band, so it can't use them for statistic;

a for Mantegazza 1997;

b for Breger et al. 1995;

c for Handler et al. 1997;

d for Bossi et al. 1998;
e for Andriovsky et al. 1995;
f for Mantegazza et al. 1994;
g for Hoffleit 1982;
h for Mathias et al. 1997;
i for Mantegazza and Poretti 1996;
j for McNamara 1985;
k for Rodriguez et al. 1994.

The 4th column is the v sin i from Abt and Morrell (1995) or other sources with some superscripts; the 5th column is the v sin i from Solano and Fernley (1997); the 6th column is the averaged value of v sin i; the 7th column is the main amplitude of each variable; the 8th column is the (b - y) or log T_{eff} value of each variable. Some stars still do not have a reliable period. The amplitude is not easy to get so accurate, especially for low amplitude multi-periodic variables. For mark, H means the member of Hyades, in total is 8 with average of v sin i is 119.7 km/s; P means the member of Praesepe, in total is 12 with average of v sin i is 149.7 km/s. Another 4 stars in the last four lines are members of 47 Tuc with average of v is 99.8 km/s or v sin i is 49.9 km/s which transfers v to v sin i by multiplying v with 0.5 factor.

III. Some statistics of table 1

From table 1 the average v sin i of 180 stars is 87.8 km/s, the value is similar but a little smaller than that the value was gotten by Jiang and Xia (1987). Among them there are 33 stars with ΔV larger than 0.1 (HADS). The other 147 stars with Δ V smaller than 0.1 (LADS) will have average of 102 km/s. This is a little higher than the 96.7 km/s which was gotten by Solano and Fernley only use 51 LADS. Inside these 147 LADS, 72 or just 50% have v sin i ≥ 100 km/s. If we use all the 180 δ Scuti stars, 147 LADS variables make an histogram of the v sin i distribution with ΔV ranges as in table 2, their averaged v sin i will decrease from 112.6 km/s to 81.1 km/s as the ΔV increase from smaller than 0.02 to 0.091. The fastest v sin i is 285km/s of HD 19279 with very low amplitude of 0.002. The lowest v sin i is 5 km/s of HD 127986 with amplitude of 0.02. The second one is 6 km/s for HD 23607 with amplitude of 0.01. They may be pole on pulsators. So our results do not support the idea that high rotation may increase the probability of δ Scuti pulsation. The way of choosing the 2 samples with same spectral distribution may be biased the results. As we can see from table 3, the spectral type distribution of δ Scuti variables is different from the result in the figure 6 of the paper of Solano and Fernley. The reason is that we use much larger samples with N = 134 and N = 216 on compared with their small samples of N = 48. In the paper of Antonello and Pasinetti Fracassini (1998), the spectral distribution (from the figure 2) is not the same for non-variables and variables detected inside the Hyades cluster. In the paper of Aerts et al. (1998), the distribution for detected variables (from the figure 2) is not homogeneous but the distribution of non-variables is quite homogeneous. Another important thing is that many non-variables may be very low amplitude variables which we can not detected their light variation due to not have enough high S/N in our observation. So we should use all the stars inside the instability strip and compare all the normal non-variables and variables to get the real relation between the light variation amplitude and average v sin i (ignoring the influence of different sin i).

In table 1 there are 3 small groups of variables in clusters; 12 variables in open cluster Praesepe (with mark P) have the largest average v sin i of 149.7 km/s, much higher than the averaged value of field LADS; 8 variables in open cluster Hyades (with mark H) have an average v sin i of 119.7 km/s, also larger than the averaged value of field LADS. The other 4 variables inside globular cluster 47 Tuc (with mark *) have much lower average v sin i less than 99.8 km/s or close to 50 km/s. Their averaged amplitude is much higher than that of Praesepe and Hyades. Normally as star evolving its rotation will be slow down. So Praesepe should be younger than Hyades, which is really true. We also know that open clusters of population I are much younger than globular clusters of population II, our statistic is really to show that the averaged rotating velocity of the member stars of younger group of stars is larger than that of older group of stars. Due to the pulsation amplitude is limited by fast rotating velocity, it is very easy to understand why there is no any HADS be found out in open cluster till now.

Table 2 The averaged v sin i with amplitude ranges

ΔV	≤ 0.020	0.021 / 0.040	0.041 / 0.091	≥ 0.092	total
N	71	42	34	33	180
v sin i km/s	112.9	100.5	81.1	24.6	87.8

Table 3 The spectral type distribution of delta

Spectral type	A0	A1	A2	A3	A4	A5	A6	A7	A8	A9	F0	F1	F2	F3	F4	F5	F6	F7	F8	F9	total
N in table 1		3	4	10	3	7	3	23	9	14	33	5	16	7	2	1	2		2		144
N of Garcia et al. 1995	11	1	6	12	3	17	9	25	14	27	42	10	23	5	1	4	5		1		217

IV. The relation between amplitude and v sin i

As we can see from the statistic above, if we use all the average v sin i and plot them with the corresponding pulsating amplitude ΔV (figure 1), we can clearly see that the ΔV decline with v sin i increasing. We also agree with the suggestion of Solano and Fernley to use this value as the separation point for HADS and LADS. All these HADS have v sin i smaller than 50 km/s. How to get reasonable explanation about this distribution? We try to explain it as follows:

From a relation between luminosity L, the radius R, and effective temperature T_{eff}

$$L = 4\pi\sigma R^2 T_{eff}^4 \qquad (1)$$

$$dm = - 2.174\ dR/R - 4.348\ dT_{eff} / T_{eff} \qquad (2)$$

It means that the light variation is caused by the variations of radius and effective temperature of the variable. So the amplitude must be also determined by the combination results of these 2 parameters.
From observation we have the following:

$$\log T_{eff} = 3.869 - 0.175\ (B_0 - V_0)$$
$$dT_{eff} / T_{eff} = - 0.403\ d(B_0 - V_0) \qquad (3)$$

Combing (2) and (3), we get

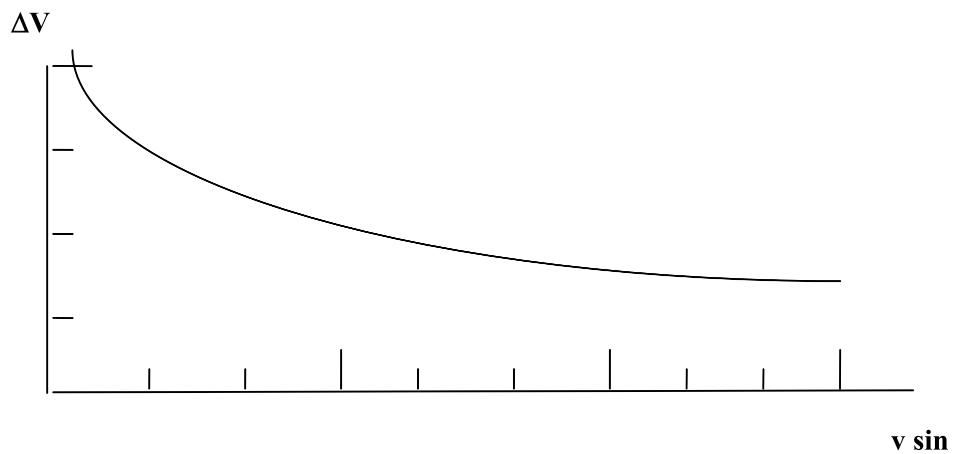

Figure 1. The distribution of v sin i with amplitude ΔV

$$dm = - 2.174\ dR/R + 1.752\ d(B_0 - V_0) \qquad (4)$$

From the angular momentum conservation we know that $dR/R = - dv/v$, so we have

$$dm = 2.174\ dv/v + 1.752\ d(B_0 - V_0) \qquad (5)$$

Within one period, from the light minimum to light maximum, the total light variation range is the amplitude Δm, so it is proportional to the ratio of the amplitude variation of rotation velocity Δv/v and the effective temperature or the variation of colour index. We can measure the v sin i, but when star is pulsating, its sin i does not change, so dv/v is the same as d(v sin i)/(v sin i). That is to say the ΔV related to v sin i should be a logarithmic function adding some logarithm function of effective temperature or some linear function of colours index.

V. Conclusion

After we compiled all the δ Scuti stars with v sin i, we get the statistical results on the v sin i with amplitude, prove that in general and in average the lower v sin i, the higher light variation amplitude and all the variables with light variation amplitude higher than 0.1 in V have v sin i smaller than 50 km/s. The average v sin i for 180 variables is 87.8km/s and for those 147 low amplitude variables is 102 km/s. All of them are smaller than the average value of all the non-variables inside the instability strip taken from the 4th edition of the Bright star catalogue compiled by Hoffleit and Jaschek (1982). The way of selecting non-variable with the same spectral type distribution is perhaps incorrect. The only reliable comparison is to use all the normal non-variables (or strict to say the combination of real non-variables and many undetected very low amplitude variables) inside the instability strip and all the δ Scuti variables inside the same region. The main reason is that the detected variability for different spectral type is different.

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