Study of the Blazhko type RRc stars in the Stripe 82 region using SDSS and ZTF

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1. Introduction

RR Lyrae :

RR Lyrae stars (RRLs) are low-mass pulsating giant stars that have evolved away from the main sequence, and are on the intersection of the horizontal branch and the classical instability strip of the Hertzsprung–Russell diagram.

Three different types(based on pulsation modes and shape of lightcurves (LCs)):

RRab type pulsates in the fundamental mode and has an asymmetric sawtooth shaped LC;

RRc type pulsates in the first-overtone mode and has more sinusoidal LC than RRab;

RRd type pulsates in both the modes and also has a sinusoidal LC.

Blazhko effect:

In addition to the pulsation, there is a long-term variation observed in all types of RRLs. This is called the Blazhko effect which is a quasi-periodic modulation of amplitude and phase of a LC. Blazhko period (P_B) is longer than the main pulsation period (P), and can be in the range of a few to a hundred days and for some, it is even longer than 1000 days.

Data source:

In the halo region of the Milky Way, an equatorial strip with declination limits of ±1°27, and extending from R.A. ~ 20h to R.A. ~ 4h is known as the Sloan Digital Sky Survey (SDSS) Stripe 82 region. Sesar et al. (2010) (S10) studied RRLs of the area using SDSS's multi-band and multi-epoch observations. This paper used the data of S10 and Zwicky Transient Facility (ZTF).

2. Data and Analysis

For the 104 RRc stars published by S10 in the Stripe82 region, they find that eight of them were RRd type.

SDSS ID	f_0 (d^{-1})	f_1 (d^{-1})	ratio
1078860	1.886082	2.528637	0.746
3478713	2.047186	2.746912	0.745
850835	1.826386	2.449997	0.745
3214909	1.977810	2.655536	0.745
2488976	1.842614	2.468807	0.746
2291937	1.923916	2.577745	0.746
2464128	1.878133	2.514649	0.747
2506078	2.060011	2.769921	0.744

In the study, they used the g-band data. The g filters of SDSS and ZTF are not identical but both can be calibrated to Pan-STARRS magnitude system. ZTF pipeline calibrates ZTF magnitudes to that of Pan-STARRS system (Masci et al. 2019), and Tonry et al. (2012) proved a way to calibrate SDSS magnitudes to that of Pan-STARRS.

$$g_{\mathrm{ps1}} - g_{\mathrm{SDSS}} = -0.012 - 0.139(g - r)_{\mathrm{SDSS}}$$

Period04 package (P04) was used to analyse the combined LCs. They searched for the dominating frequencies from the LCs. These frequencies were then fitted to a LC using the Fourier series:

$$y = A_0 + \sum_k A_k sin(2\pi f_k t + \phi_k)$$

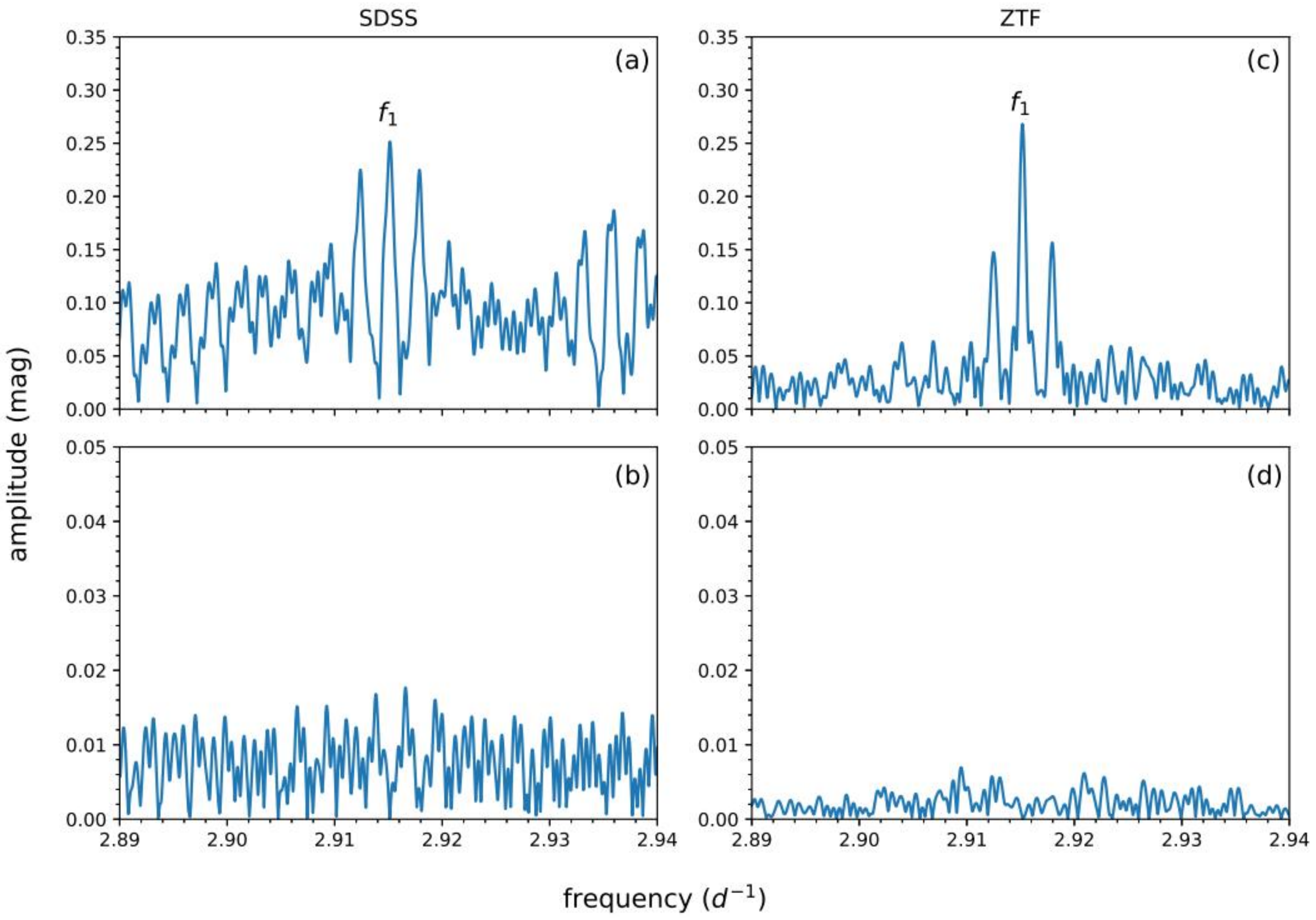
Method:

The first step of the analysis in P04 was to determine the dominating pulsation frequency f_1. Then the main frequency f_1 and its significant number of (generally three) harmonics were subtracted from the LCs to prewhiten them.

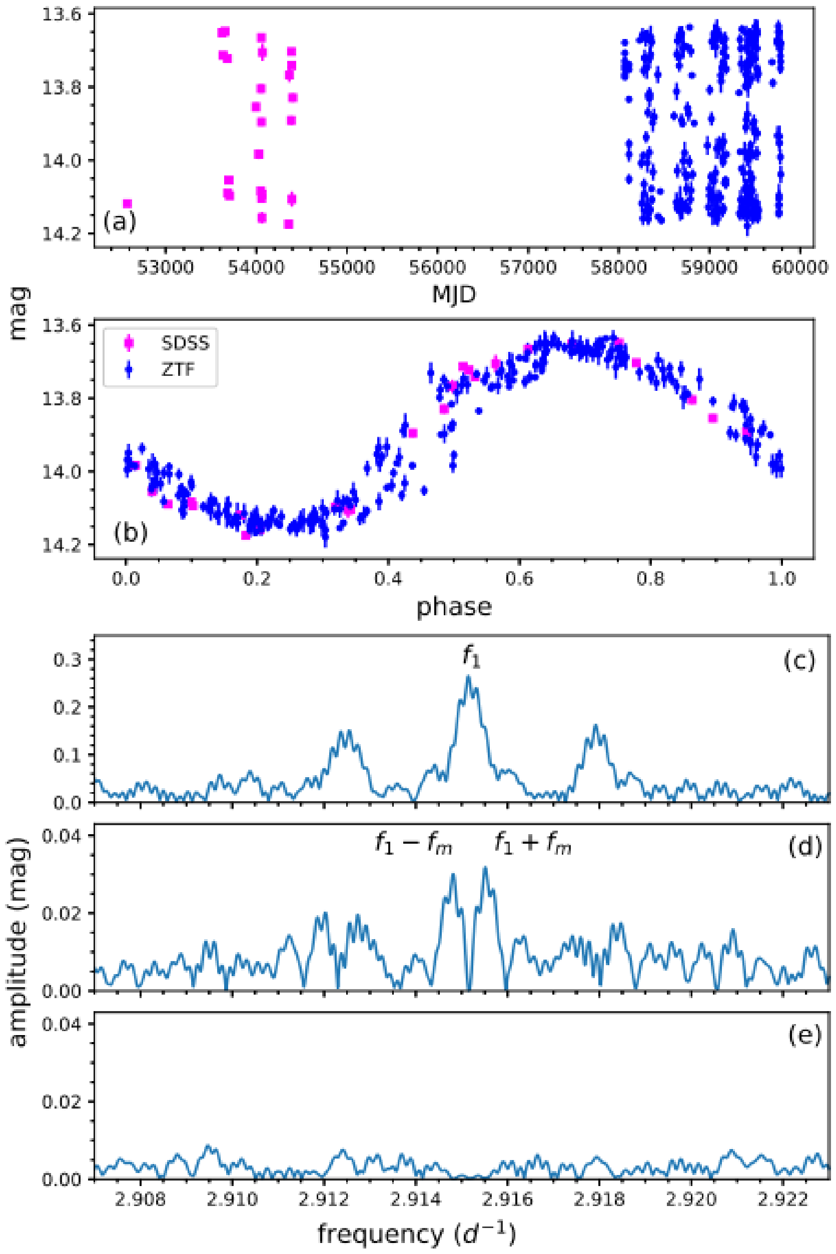
The second step was to search for the other significant frequency peaks in the prewhitened LCs. Each time, prewhitening included all the previously detected peaks subtracted simultaneously, to reduce the error.

Different Blazhko modulations appear as close frequency component(s) in the vicinity of radial mode frequency and its harmonics kf_1 ($k = 1, 2, \ldots$) as $kf_1 - f_m$ and $kf_1 + f_m$. The modulation frequency f_m is called the Blazhko frequency, and its inverse is the Blazhko period P_B. After prewhitening the LCs with kf_1,these Blazhko side peaks emerge in the Fourier spectrum.

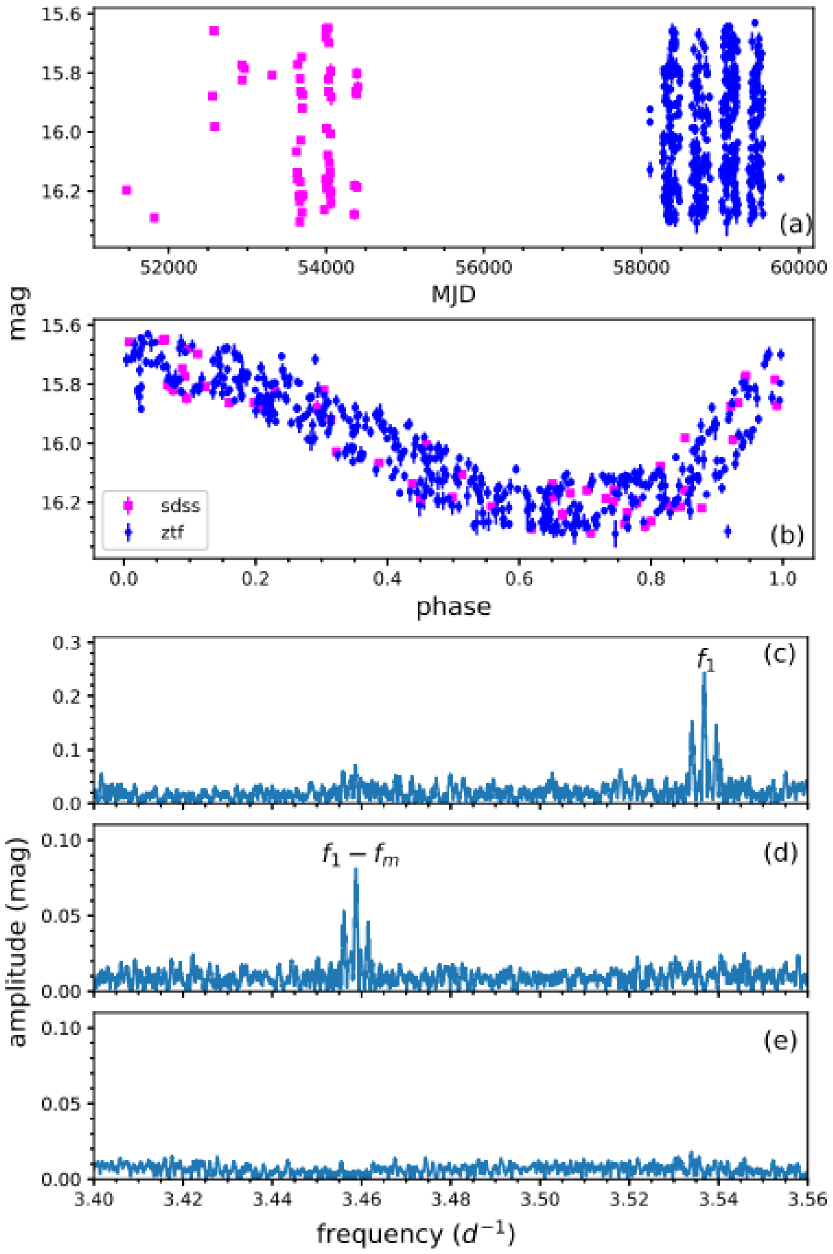
SDSS 3585856

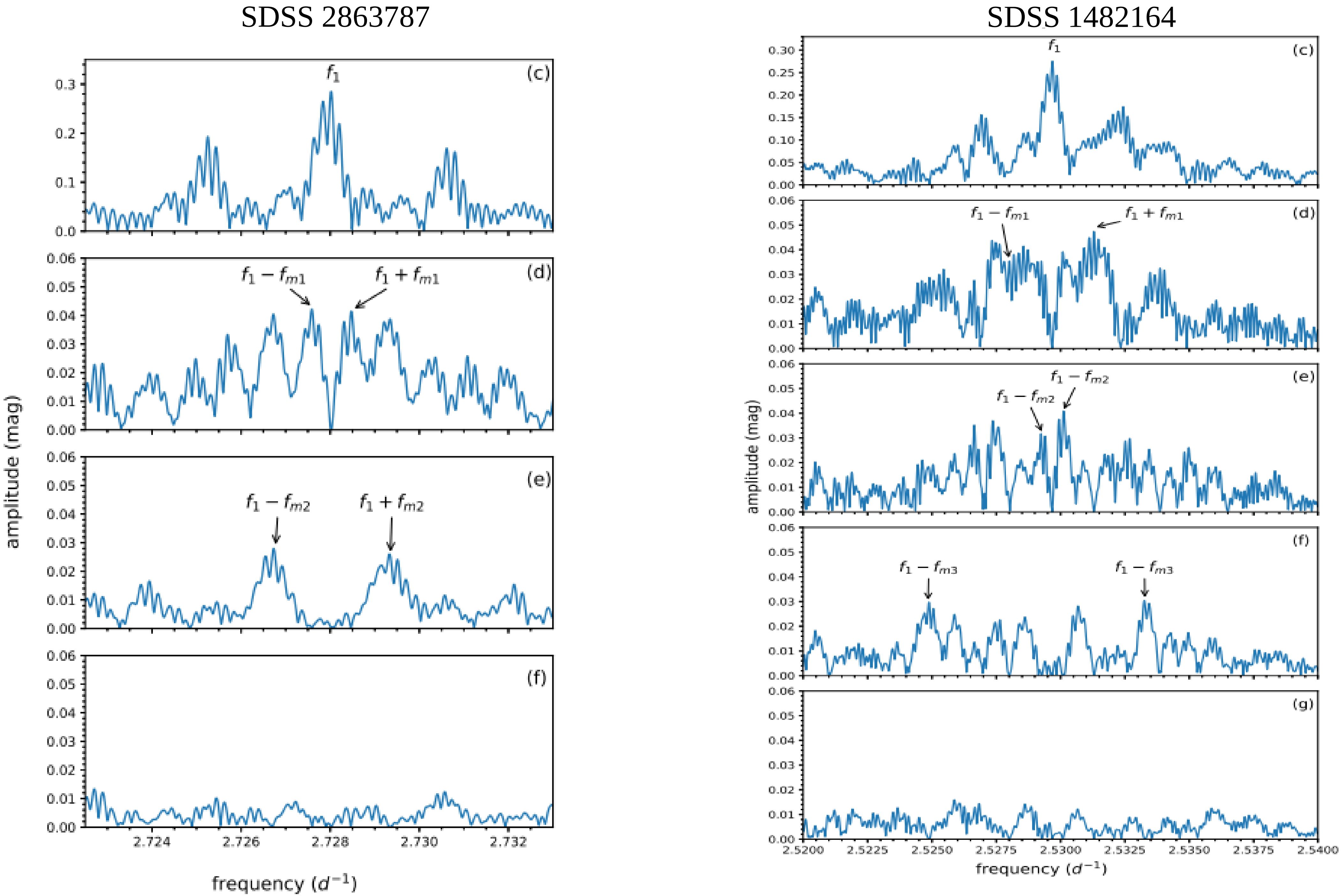


SDSS 3585856



SDSS 747380





SDSS 2863787
SDSS 1482164
amplitude (mag)
frequency (d^{-1})
(c)
(d)
(e)
(f)
(g)
f_1
$f_1 - f_{m1}$
$f_1 + f_{m1}$
$f_1 - f_{m2}$
$f_1 + f_{m2}$
$f_1 - f_{m3}$
2.724
2.726
2.728
2.730
2.732
2.5200
2.5225
2.5250
2.5275
2.5300
2.5325
2.5350
2.5375
2.5400

3. Results and Discussion

SDSS ID	f_1 (d^{-1})	P_B (d)	$\sigma(P_B)$ (d)	A_1 (mag)	ϕ_1 (deg)	f_+ (d^{-1})	A_+ (mag)	ϕ_+ (deg)	f_- (d^{-1})	A_- (mag)	ϕ_- (deg)
747380*	3.536821	12.808	0.001	0.251	0.616	-	-	-	3.458743	0.084	0.706
562035	2.922886	22.889	0.003	0.230	0.500	2.966577	0.070	0.860	2.879197	0.122	0.668
4614863*	3.831802	39.28	0.03	0.249	0.459	3.857263	0.050	0.244	3.806343	0.055	0.103
2659801	3.033801	182	1	0.320	0.836	3.03928	0.016	0.393	3.028298	0.018	0.147
638540	2.972634	192	1	0.245	0.138	2.977831	0.014	0.896	2.967441	0.008	0.634
2609442	3.231722	426	3	0.269	0.427	3.234067	0.013	0.939	-	-	-
3681504	3.076957	428	4	0.279	0.756	3.079215	0.016	0.832	3.074537	0.022	0.701
288008*	2.628844	798	10	0.194	0.734	2.630027	0.113	0.596	2.627511	0.065	0.270
3348773	2.381611	858	15	0.238	0.839	2.382785	0.038	0.174	2.380455	0.037	0.853
1217801	2.939625	1095	32	0.243	0.536	2.940526	0.012	0.226	2.9387	0.015	0.790
959802	2.641075	1219	22	0.247	0.885	2.642081	0.042	0.110	2.640383	0.045	0.746
376465	2.312534	1288	26	0.239	0.961	2.313314	0.016	0.239	2.311762	0.015	0.733
4383295	2.700236	1292	19	0.266	0.489	2.701011	0.050	0.386	2.699463	0.047	0.939
2314306	3.081313	1341	18	0.272	0.509	3.082061	0.106	0.146	3.08057	0.105	0.083
3358190	2.388038	1711	29	0.229	0.303	2.388621	0.052	0.915	2.387453	0.034	0.327
1478867	2.970986	1870	77	0.257	0.748	2.971514	0.028	0.191	2.970444	0.017	0.696
3397977	2.757541	1884	83	0.223	0.019	2.758071	0.028	0.875	2.757009	0.047	0.711
3031571	2.731217	1949	42	0.306	0.753	2.731697	0.040	0.967	2.730667	0.041	0.144
3308790	2.662176	1985	38	0.225	0.041	2.66268	0.078	0.132	2.661672	0.066	0.427
765345	3.811996	2011	87	0.153	0.930	3.812496	0.015	0.392	3.811501	0.022	0.659
1091627	3.201902	2119	41	0.250	0.220	3.202372	0.051	0.614	3.201428	0.053	0.624
1986301	3.242536	2150	35	0.298	0.716	3.242995	0.082	0.175	3.242065	0.093	0.567
2213142	3.313901	2514	112	0.248	0.505	3.314263	0.028	0.268	3.313459	0.024	0.081
429508	2.85003	2906	148	0.245	0.523	2.850376	0.059	0.151	2.849688	0.034	0.113
3585856	2.915149	3088	126	0.244	0.039	2.915485	0.031	0.203	2.914836	0.031	0.008
4455741	2.752802	962	8	0.215	0.724	-	-	-	2.751762	0.041	0.590
		2412	39			2.753207	0.099	0.011	2.752377	0.071	0.026
2396176*	2.762629	1027	4	0.179	0.632	-	-	-	2.761655	0.128	0.486
		431	3			2.765078	0.048	0.306	2.760429	0.062	0.643
2639854	3.353221	1534	23	0.138	0.314	3.353902	0.062	0.944	3.352596	0.071	0.856
		910	13			3.354286	0.035	0.926	3.352084	0.048	0.648
2445511	2.536248	1182	18	0.259	0.438	2.537088	0.095	0.152	2.535396	0.059	0.980
		712	13			2.537599	0.046	0.642	2.534785	0.060	0.226
2175525	2.514798	1158	11	0.220	0.676	2.515677	0.062	0.832	2.513949	0.083	0.286
		706	12			2.516243	0.030	0.722	2.513409	0.037	0.796
4455741*	2.752802	2412	39	0.215	0.724	2.753207	0.099	0.011	2.752377	0.071	0.026
		962	8			-	-	-	2.751762	0.041	0.590
1747387	2.872223	1722	13	0.140	0.519	2.872804	0.069	0.328	-	-	-
		1124	22			2.873118	0.039	0.257	2.871339	0.020	0.952
2863787	2.728025	2291	71	0.289	0.571	2.728464	0.036	0.119	2.72759	0.044	0.287
		750	14			2.729367	0.022	0.658	2.726701	0.026	0.988
1482164	2.529674	610	9	0.276	0.472	2.531294	0.031	0.649	2.528014	0.031	0.864
		2426	46			2.530091	0.119	0.274	2.529266	0.077	0.688
		244	1			2.53327	0.045	0.075	2.524887	0.038	0.995

Blazhko side peaks were found for 34 of the 96 stars of S10.

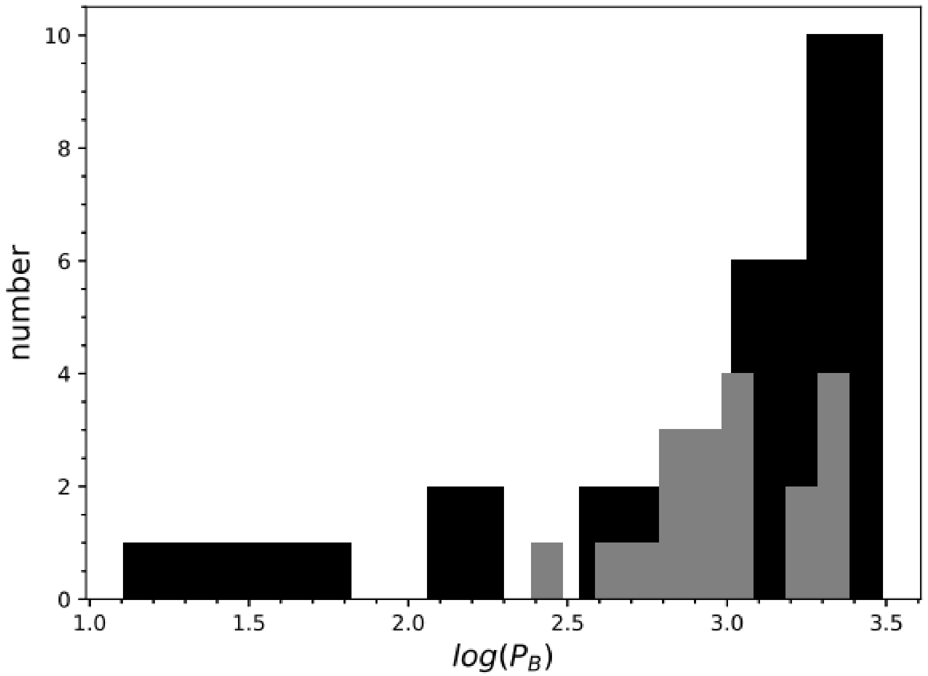
The period P of BRRc stars were found to be in the range of 0.261 to 0.432 d.

For five stars, P values published in S10 were incorrect because their data were suffering the one day alias problem. Using the extended LCs, the correct periods were determined, which can be confirmed via folding the LCs. These stars are marked with an asterisk in Table.

Their 34 stars showing the Blazhko effect represent a 35.42% incidence rate. It is higher than any previously documented rates.

46% of all BRRc stars with single or multiple P_B, show very long period Blazhko effect (P_B > 1000 d).

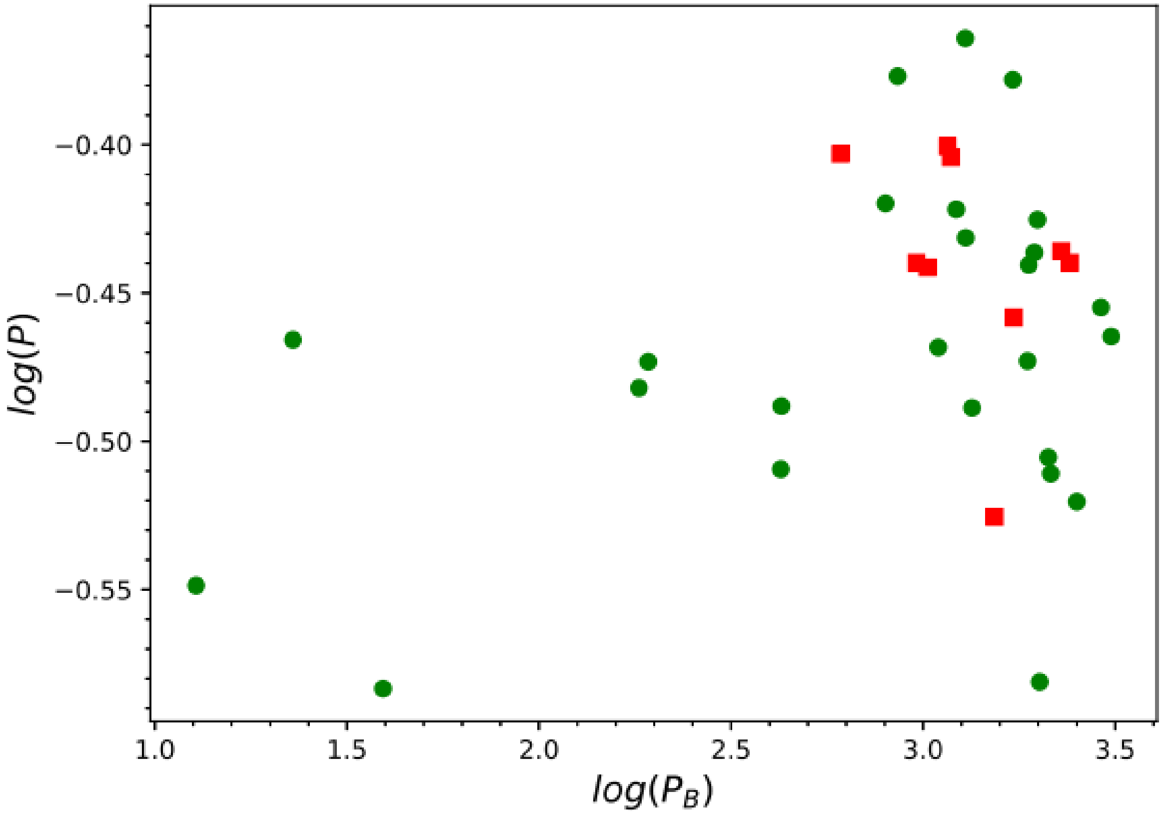
The P_B is in the range of 12.808 and 3088 d. The latter value (although with a large error) is the longest Blazhko period ever detected for an RRc star.



They plotted P against P_B to check the presence of any correlation.

Szczygiel & Fabrycky (2007) detected a bimodal distribution for the modulation period of the RRc stars in the ASAS Survey. The two maxima of the distribution are around ~ 10 and ~ 1500 days, and there is a gap between the two groups (between ~20 and ~300 d) where there are hardly any stars. There may be two different physical origins behind the variations in the two groups. If it is true and the stars with 'classical' Blazhko effect are only in the group of 10 days, and the long period group is something else.

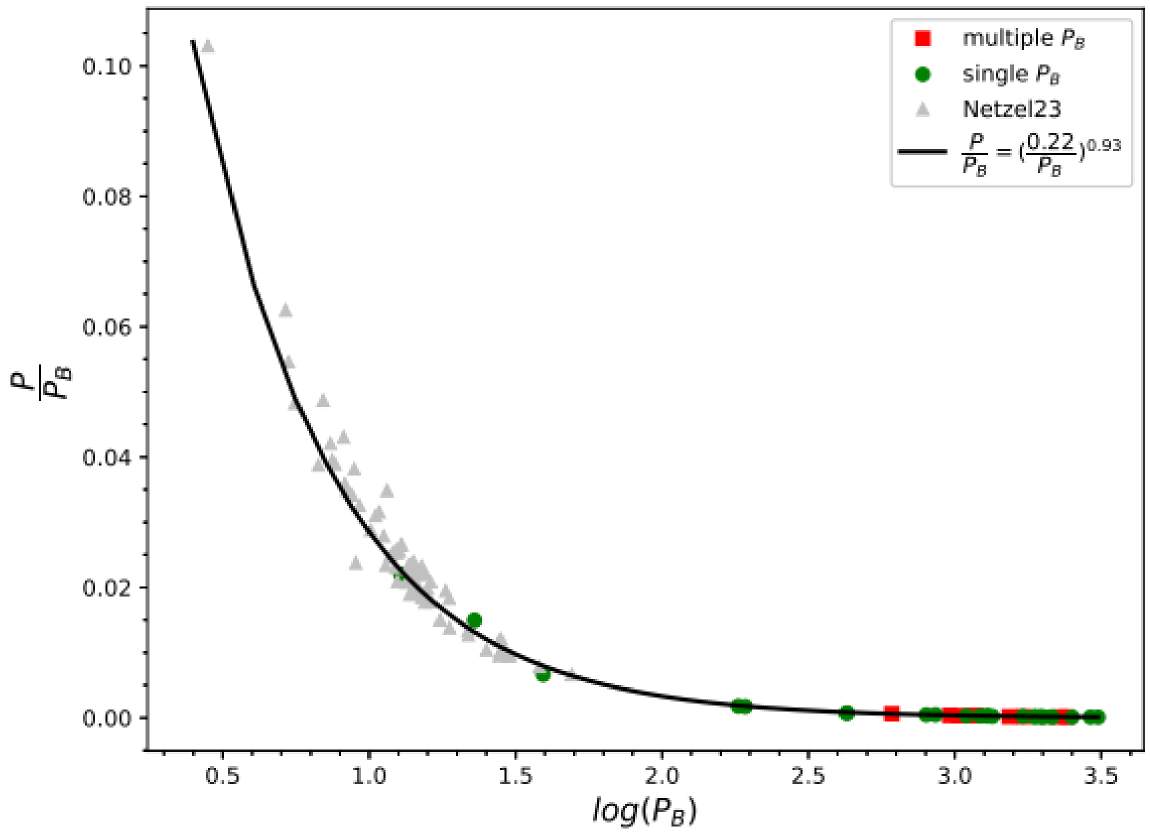
This paper's data series are mainly the long periods, so they have mostly obtained the long-period part of the bimodal distribution.



empirical equation:

$$\frac{P}{P_B} = \left(\frac{k}{P_B}\right)^{\epsilon}$$

k = 0.22 ± 0.024 d, and ϵ = 0.93 ± 0.002



4. Summary

- Using the S10 and ZTF, They found 96 RRc stars. And 34 of them display Blazhko effect. The incidence rate of 35.42% is higher than any previously published values.
- The shortest Blazhko period (P_B) found is 12.808±0.001 d for SDSS 747380, while the longest is 3100±126 d for SDSS 3585856. And it is the longest P_B ever detected. The vast majority (85%) of detected P_B are above 200 days. The 8 BRRc stars show two Blazhko modulations, and one, SDSS 1482164, shows three modulations.
- Period ratio P to P_B shows a steep decreasing trend with increasing P due to a large number of long P_B, which indicates that P is inversely proportional to P_B.

Thank you!