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51 new γ Doradus stars from the ZTF survey

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Abstract: *51 new* γ *Doradus variables are presented, which were found in the Zwicky Transient Facility Catalog of Periodic Variable Stars. This study confirms that high-amplitude multiperiodic γ Doradus variables with peak-to-peak amplitudes of 0.1 mag (V) and more are not rare objects.*

Introduction

The γ Doradus stars (designation GDOR according to the GCVS) are a relatively recently discovered class of pulsating main-sequence variables that are situated between spectral types A7 and F7 [1, 2] (effective temperature between about 6100 and 7500 K, see e.g. [3]). The GDOR stars are characterized by high-order, low-degree, non-radial gravity mode pulsation.

Although the GCVS and most older studies assumed a maximum peak-to-peak amplitude of 0.1 mag (Johnson *V*) for this type of variable, a recent study [4] has shown that significantly larger amplitudes can be achieved. The unusually high amplitudes of the so-called high-amplitude γ Doradus stars can be explained by the superposition of several base frequencies in interaction with their combination and overtone frequencies. Although the maximum amplitude of the primary frequencies was not found to exceed a peak-to-peak amplitude of 0.1 mag, total light-variability amplitudes of over 0.3 mag (*V*) have been reported [4]. To validate these findings, a search for further high-amplitude GDOR stars was conducted in the Zwicky Transient Facility (ZTF) survey.

Observations and data analysis

The ZTF is a sky survey that had first light at Palomar Observatory in 2017 and monitors the northern and parts of the southern sky down to a magnitude of $r \sim 20.6$ mag. The ZTF uses a camera with a 47 square-degree field of view that is mounted on a 48-inch Schmidt telescope and produces high-quality data in two bands (*g* and *r*) that are made publicly available [5, 6, 7].

To discover new GDOR stars, periodic variables extracted from Data Release 2 of the ZTF survey ("Zwicky Transient Facility Catalog of Periodic Variable Stars") [8] were examined in detail. In that work, 781,602 periodic variables down to the limiting magnitude of r ~ 20.6 mag were identified and subdivided into 11 main types (low- and high-amplitude δ Scuti, RRab and RRc, Cepheid, EW, EA, RS CVn stars etc.) using an automated classification method. Compared with previously published catalogs, 79.5 % of the entries are new discoveries[1].

[1] http://variables.cn:88/ztf/

Since GDOR stars are a rather uncommon type of variable stars as compared with other variability classes and a corresponding variability type does not exist in [8], it can be assumed that these objects were assigned to other categories, especially to the RS CVn stars, which also exhibit complex light curves and similar main periods without, however, showing multiperiodicity.

GDOR stars show higher surface temperatures than the slightly cooler and more solar-like RS CVn variables, which was exploited for the preselection of GDOR candidates. When available, temperatures from Starhorse [9] or Gaia DR2 [10] were used, and only those objects with temperatures between 5900 and 7600 K were kept as candidates and considered more closely. The light curves of all candidates were inspected visually and promising candidates were analysed with PERIOD04 [11]. Objects which turned out to be multiperiodic with at least two independent frequencies and which were not registered as GDOR stars in the International Variable Star Index of the AAVSO [12] were included in the final sample.

Results

In total, 51 new GDOR variables were identified, which are presented in Table 1. The analysis of the ZTF data with PERIOD04 indicated that, due to the characteristics and the available number of data points of the ZTF data as downloaded from the NASA/IPAC Infrared Science Archive, generally only two dominant frequencies were found to be significant. Together with the amplitudes and phases as calculated with PERIOD04, these frequencies are listed in Table 2. The maximum amplitude of the individual frequencies does not exceed 0.1 mag (semi-amplitude of 0.05 mag), which agrees with the results described in [4].

The corresponding Fourier spectra of the period analysis in the frequency realm between 0 and 2 cycles per day (c/d) are presented in Figure 1. The light curves folded on the main period (see Table 1) are shown in Figure 2. There is a scattering of brighter data points in the folded light curves around phase 0, which is due to beating effects and indicates the typical multiperiodic behaviour of γ Doradus stars. Therefore, the determination of the peak-to-peak amplitudes of multiperiodic stars is somewhat more complicated as for monoperiodic objects, since besides the scatter due to the measurement uncertainties, the folded light curves are also "broadened" by multiperiodicity. Nevertheless, it was shown in [4] that the peak-to-peak amplitudes estimated in this way from ground-based survey data agrees very well with the peak-to-peak amplitudes determined from high-precision satellite data.

Summary

51 new γ Doradus stars are presented, which were found in the ZTF survey. The majority of the objects (N = 40) exhibits a peak-to-peak amplitude of at least 0.1 mag (r) and can therefore be regarded as high-amplitude γ Doradus stars. Since the pulsation amplitudes in early-type stars generally increase with decreasing wavelength [4], r band amplitudes represent lower limits for the amplitudes in Johnson V. Therefore, this study confirms that the unusually high amplitudes of some GDOR stars are caused by the superposition of several fundamental frequencies in interaction with their combination and overtone frequencies. Although the maximum amplitude of the fundamental frequencies does not exceed 0.1 mag (V), significantly larger total light-variability amplitudes of up to 0.3 mag (V) can be achieved in this way.

Acknowledgements

This paper made use of data from VizieR catalogue access tool, and of the interactive sky atlas Aladin, CDS, Strasbourg, France, the NASA/IPAC Infrared Science Archive and of the International Variable Star Index (VSX) database, operated at AAVSO, Cambridge, Massachusetts, USA. The author would like to thank Sebastián Otero (VSX) and the referees of the BAVJ for their support and helpful comments.

Table 1: New GDOR variables. The columns denote: Zwicky Transient Facility ID, RA, DEC (J2000), main period (=1/f1) [d] as calculated with PERIOD04, Max (r) [mag], Min (r) [mag], T_{eff} [K]

ID	RA[h m s]	DEC[° ´ ´´]	Main period[d]	Max(r) [mag]	Min(r) [mag]	T_{eff} [K]
ZTFJ014426.76+542442.9	01 44 26.7624	+54 24 42.984	1.911613	15.66	15.73	6114 (StarHorse)
ZTFJ014702.37+641824.0	01 47 02.3736	+64 18 24.012	1.792779	15.08	15.20	6209 (StarHorse)
ZTFJ014932.59+524827.7	01 49 32.5968	+52 48 27.792	1.346405	15.10	15.22	6313 (StarHorse)
ZTFJ015102.78+523010.5	01 51 02.7864	+52 30 10.548	2.177774	15.07	15.12	6802 (StarHorse)
ZTFJ021058.30+550507.7	02 10 58.3056	+55 05 07.764	0.661817	16.65	16.75	6854 (StarHorse)
ZTFJ060012.56+343731.1	06 00 12.5592	+34 37 31.008	1.843114	16.13	16.28	6822 (StarHorse)
ZTFJ155507.85+321420.0	15 55 07.8528	+32 14 20.040	3.509340	14.65	14.85	6907 (StarHorse)
ZTFJ162707.55+355443.4	16 27 07.5408	+35 54 43.704	1.919566	14.04	14.17	7554 (StarHorse)
ZTFJ163105.57+423354.8	16 31 05.5752	+42 33 54.900	1.632709	15.12	15.30	6851 (StarHorse)
ZTFJ172939.00+234628.0	17 29 39.0048	+23 46 27.912	1.366635	12.46	12.75	6985 (StarHorse)
ZTFJ173808.52+581507.6	17 38 08.5112	+58 15 07.415	1.292392	11.98	12.30	6945 (StarHorse)
ZTFJ180955.37+402203.8	18 09 55.3728	+40 22 03.828	1.612542	16.05	16.25	7128 (Gaia DR2)
ZTFJ181023.93+391109.2	18 10 23.9352	+39 11 09.276	1.452484	14.75	14.86	7068 (StarHorse)
ZTFJ183723.88+501009.8	18 37 23.8896	+50 10 09.876	1.225560	15.70	15.83	6736 (StarHorse)
ZTFJ183948.90+344910.5	18 39 48.9048	+34 49 10.560	2.084865	14.30	14.42	7368 (StarHorse)
ZTFJ184908.32+111206.5	18 49 08.3256	+11 12 06.552	1.092025	13.72	13.85	6574 (StarHorse)
ZTFJ185426.79+364734.2	18 54 26.7936	+36 47 34.260	1.279631	16.38	16.48	7070 (Gaia DR2)
ZTFJ185904.16+444137.5	18 59 04.1616	+44 41 37.572	1.836971	15.95	16.06	7298 (StarHorse)
ZTFJ185951.35+560127.4	18 59 51.3528	+56 01 27.444	2.116811	13.46	13.60	6688 (StarHorse)
ZTFJ191010.15+510713.3	19 10 10.1592	+51 07 13.368	1.293557	13.75	13.88	6387 (StarHorse)
ZTFJ193116.17+371015.5	19 31 16.1712	+37 10 15.564	1.146261	13.79	13.86	6653 (StarHorse)
ZTFJ193420.39+284241.7	19 34 20.4000	+28 42 41.760	1.579581	15.55	15.66	6976 (StarHorse)
ZTFJ193534.45+381819.3	19 35 34.4520	+38 18 19.332	1.681884	14.91	14.98	6659 (StarHorse)
ZTFJ193918.57+113529.7	19 39 18.5736	+11 35 29.724	1.337043	14.33	14.41	6790 (StarHorse)
ZTFJ194455.98+155412.7	19 44 55.9896	+15 54 12.744	1.390417	14.46	14.57	6489 (StarHorse)
ZTFJ194741.64+324125.1	19 47 41.6424	+32 41 25.152	1.278528	15.28	15.37	6828 (StarHorse)
ZTFJ195924.76+320407.9	19 59 24.7680	+32 04 07.968	1.195954	12.86	12.92	6642 (StarHorse)
ZTFJ200140.23+435451.4	20 01 40.2312	+43 54 51.408	1.832853	12.45	12.52	6769 (StarHorse)
ZTFJ201001.90+380233.0	20 10 01.9056	+38 02 33.072	1.469763	15.56	15.66	6380 (StarHorse)
ZTFJ202657.34+305051.6	20 26 57.3480	+30 50 51.648	1.366239	14.59	14.68	6537 (StarHorse)
ZTFJ204350.56+490759.8	20 43 50.5656	+49 07 59.808	1.053723	14.18	14.32	6516 (StarHorse)
ZTFJ205120.92+485141.5	20 51 20.9280	+48 51 41.580	1.174363	15.41	15.55	6444 (StarHorse)
ZTFJ205735.39+161542.8	20 57 35.4024	+16 15 42.912	1.419827	14.46	14.58	6089 (StarHorse)
ZTFJ210253.83+464153.7	21 02 53.8344	+46 41 53.772	2.413572	15.37	15.48	5935 (StarHorse)
ZTFJ211107.32+465831.6	21 11 07.3296	+46 58 31.656	2.075451	15.87	15.98	6010 (StarHorse)
ZTFJ212404.82+610011.3	21 24 04.8240	+61 00 11.304	1.712848	13.79	13.93	6948 (StarHorse)
ZTFJ214026.31+450719.2	21 40 26.3112	+45 07 19.236	1.846739	14.22	14.28	6746 (StarHorse)
ZTFJ214419.56+453023.0	21 44 19.5696	+45 30 23.040	1.266531	14.36	14.46	6648 (StarHorse)
ZTFJ214753.40+245319.3	21 47 53.4048	+24 53 19.356	1.431123	14.70	14.85	6746 (StarHorse)
ZTFJ215720.49+444637.3	21 57 20.4912	+44 46 37.380	1.050543	12.85	12.96	7078 (StarHorse)
ZTFJ220139.53+491542.9	22 01 39.5352	+49 15 42.984	1.284076	13.88	14.00	6328 (StarHorse)
ZTFJ220914.20+550900.3	22 09 14.2056	+55 09 00.396	1.108898	15.32	15.45	6825 (StarHorse)
ZTFJ221425.10+523342.5	22 14 25.1016	+52 33 42.552	1.110983	15.05	15.14	6583 (StarHorse)
ZTFJ221451.07+483018.0	22 14 51.0744	+48 30 18.072	1.923106	13.75	13.87	6542 (StarHorse)
ZTFJ221856.92+491231.7	22 18 56.9280	+49 12 31.752	1.025581	16.06	16.16	6374 (StarHorse)
ZTFJ222146.71+543308.8	22 21 46.7160	+54 33 08.892	1.275157	13.96	14.06	6589 (StarHorse)
ZTFJ224121.27+581726.1	22 41 21.2784	+58 17 26.196	1.325111	15.96	16.12	6491 (StarHorse)
ZTFJ231732.13+533811.4	23 17 32.1336	+53 38 11.436	1.297428	16.86	16.96	6249 (StarHorse)
ZTFJ232622.50+531923.1	23 26 22.5048	+53 19 23.124	1.123398	13.62	13.73	6463 (StarHorse)
ZTFJ233555.89+562902.9	23 35 55.8984	+56 29 02.940	2.343558	15.65	15.75	6901 (StarHorse)
ZTFJ234946.61+520256.8	23 49 46.6200	+52 02 56.868	2.120042	16.06	16.17	7510 (StarHorse)

Table 2: Results of the data analysis with Period04. The columns denote: Zwicky Transient Facility ID, frequency1 [c/d], semi-amplitude1 [mag], phase1 [0...1], frequency2 [c/d], semi-amplitude2 [mag] and phase2 [0...1]

ID	f1[c/d]	amp1[mag]	phase1	f2[c/d]	amp2[mag]	phase2
ZTFJ014426.76+542442.9	0.523118	0.012	0.382	0.403216	0.011	0.271
ZTFJ014702.37+641824.0	0.557793	0.021	0.537	1.271866	0.014	0.331
ZTFJ014932.59+524827.7	0.742719	0.029	0.071	0.435544	0.014	0.976
ZTFJ015102.78+523010.5	0.459184	0.018	0.019	0.489262	0.007	0.876
ZTFJ021058.30+550507.7	1.510992	0.020	0.158	0.503123	0.012	0.958
ZTFJ060012.56+343731.1	0.542560	0.027	0.376	0.521500	0.014	0.693
ZTFJ155507.85+321420.0	0.284954	0.033	0.924	0.594726	0.036	0.709
ZTFJ162707.55+355443.4	0.520951	0.041	0.022	0.647088	0.021	0.354
ZTFJ163105.57+423354.8	0.612479	0.020	0.532	0.517739	0.019	0.802
ZTFJ172939.00+234628.0	0.731724	0.047	0.526	0.889777	0.024	0.356
ZTFJ173808.52+581507.6	0.773759	0.030	0.884	0.459006	0.018	0.040
ZTFJ180955.37+402203.8	0.620139	0.051	0.277	0.721434	0.022	0.320
ZTFJ181023.93+391109.2	0.688476	0.028	0.015	0.806033	0.013	0.553
ZTFJ183723.88+501009.8	0.815954	0.019	0.625	0.798901	0.014	0.389
ZTFJ183948.90+344910.5	0.479647	0.026	0.893	1.043194	0.009	0.846
ZTFJ184908.32+111206.5	0.915730	0.026	0.274	0.786213	0.013	0.058
ZTFJ185426.79+364734.2	0.781475	0.020	0.897	0.868499	0.018	0.983
ZTFJ185904.16+444137.5	0.544374	0.028	0.949	1.591900	0.012	0.973
ZTFJ185951.35+560127.4	0.472409	0.021	0.311	0.633589	0.019	0.413
ZTFJ191010.15+510713.3	0.773062	0.021	0.331	0.961833	0.011	0.028
ZTFJ193116.17+371015.5	0.872401	0.019	0.102	1.066433	0.013	0.616
ZTFJ193420.39+284241.7	0.633079	0.026	0.051	1.608482	0.014	0.628
ZTFJ193534.45+381819.3	0.594571	0.016	0.256	1.444464	0.009	0.270
ZTFJ193918.57+113529.7	0.747919	0.025	0.921	0.720905	0.016	0.741
ZTFJ194455.98+155412.7	0.719209	0.029	0.499	1.653507	0.014	0.789
ZTFJ194741.64+324125.1	0.782149	0.022	0.110	1.366983	0.010	0.106
ZTFJ195924.76+320407.9	0.836153	0.017	0.353	0.712541	0.010	0.143
ZTFJ200140.23+435451.4	0.545598	0.018	0.786	0.315617	0.013	0.786
ZTFJ201001.90+380233.0	0.680382	0.026	0.120	1.505441	0.014	0.319
ZTFJ202657.34+305051.6	0.731937	0.026	0.110	0.828275	0.010	0.464
ZTFJ204350.56+490759.8	0.949016	0.023	0.160	0.171758	0.015	0.389
ZTFJ205120.92+485141.5	0.851526	0.038	0.127	0.753702	0.017	0.973
ZTFJ205735.39+161542.8	0.704311	0.029	0.738	1.791958	0.009	0.377
ZTFJ210253.83+464153.7	0.414324	0.019	0.587	0.541090	0.013	0.816
ZTFJ211107.32+465831.6	0.481823	0.024	0.927	0.417492	0.018	0.206
ZTFJ212404.82+610011.3	0.583823	0.031	0.554	0.554055	0.017	0.407
ZTFJ214026.31+450719.2	0.541495	0.019	0.799	0.715386	0.009	0.218
ZTFJ214419.56+453023.0	0.789558	0.028	0.390	0.879810	0.016	0.236
ZTFJ214753.40+245319.3	0.698752	0.034	0.068	0.544448	0.016	0.093
ZTFJ215720.49+444637.3	0.951888	0.019	0.797	1.111641	0.014	0.127
ZTFJ220139.53+491542.9	0.778770	0.034	0.105	0.917163	0.019	0.709
ZTFJ220914.20+550900.3	0.901797	0.025	0.043	1.400376	0.015	0.795
ZTFJ221425.10+523342.5	0.900104	0.021	0.986	0.851509	0.014	0.010
ZTFJ221451.07+483018.0	0.519992	0.021	0.915	1.530219	0.012	0.421
ZTFJ221856.92+491231.7	0.975057	0.026	0.504	1.120181	0.012	0.116
ZTFJ222146.71+543308.8	0.784217	0.025	0.810	0.147029	0.010	0.399
ZTFJ224121.27+581726.1	0.754654	0.029	0.627	0.778578	0.024	0.591
ZTFJ231732.13+533811.4	0.770755	0.021	0.490	0.972783	0.017	0.678
ZTFJ232622.50+531923.1	0.890156	0.027	0.729	0.634331	0.012	0.427
ZTFJ233555.89+562902.9	0.426702	0.024	0.724	0.505294	0.012	0.150
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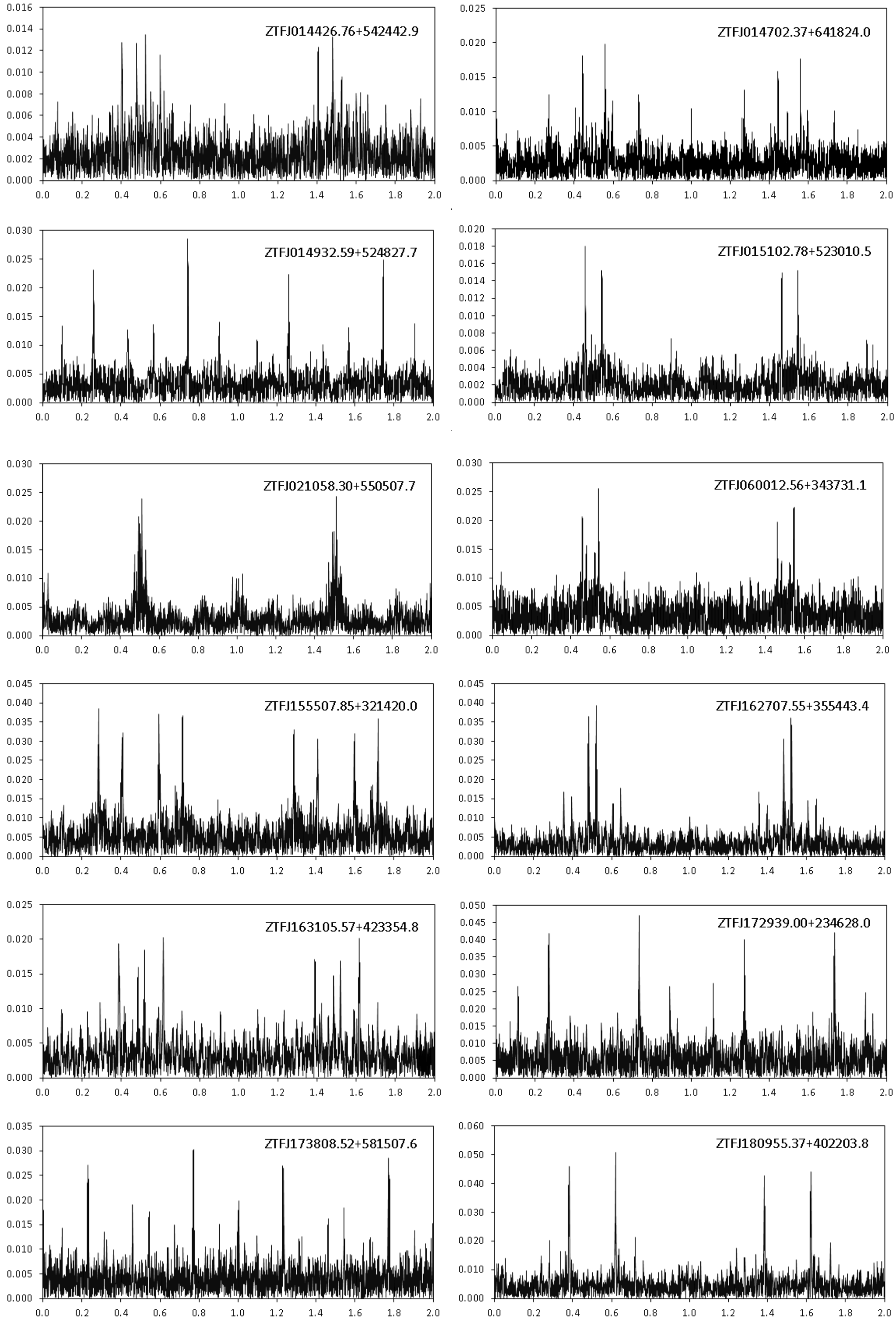
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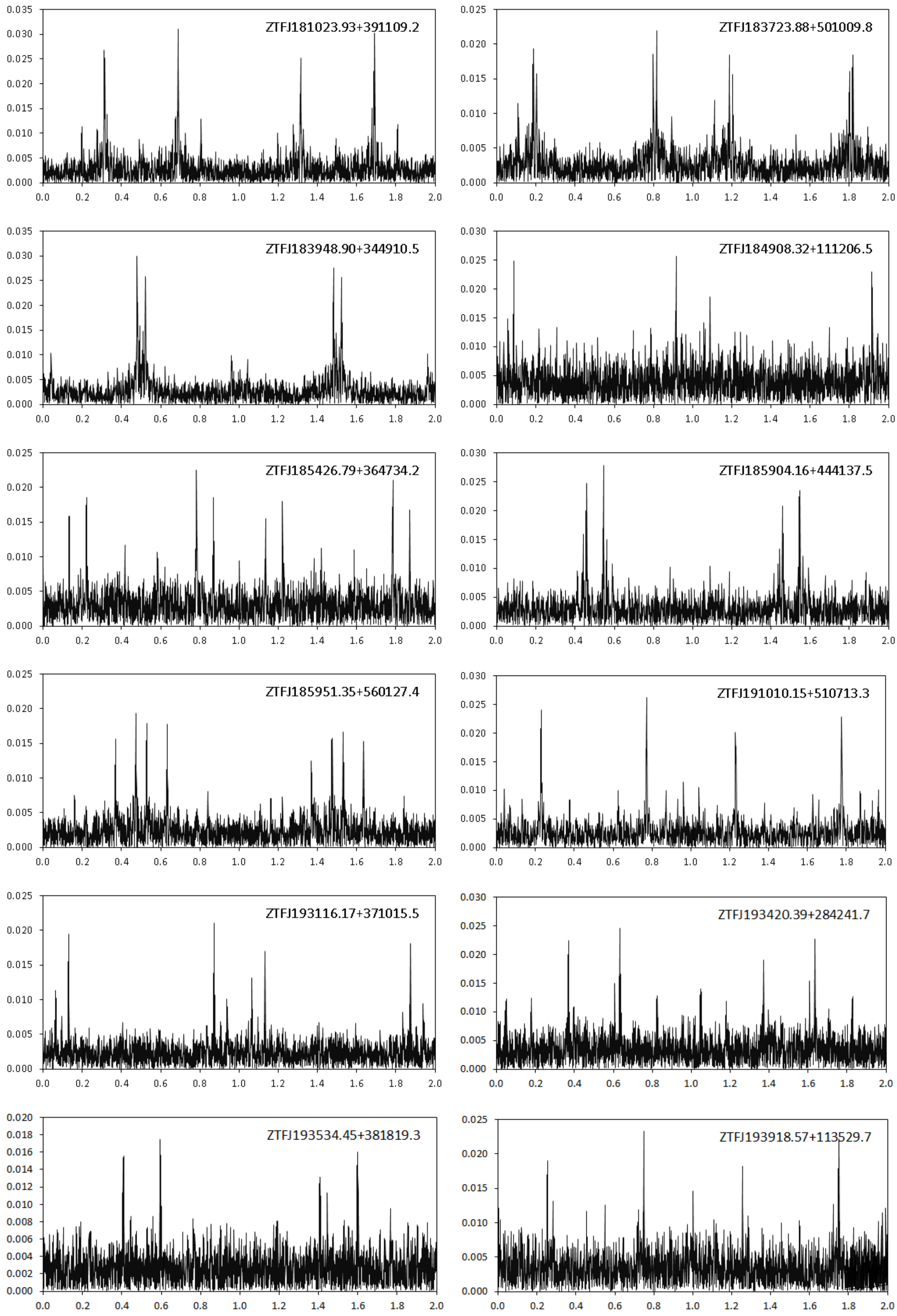
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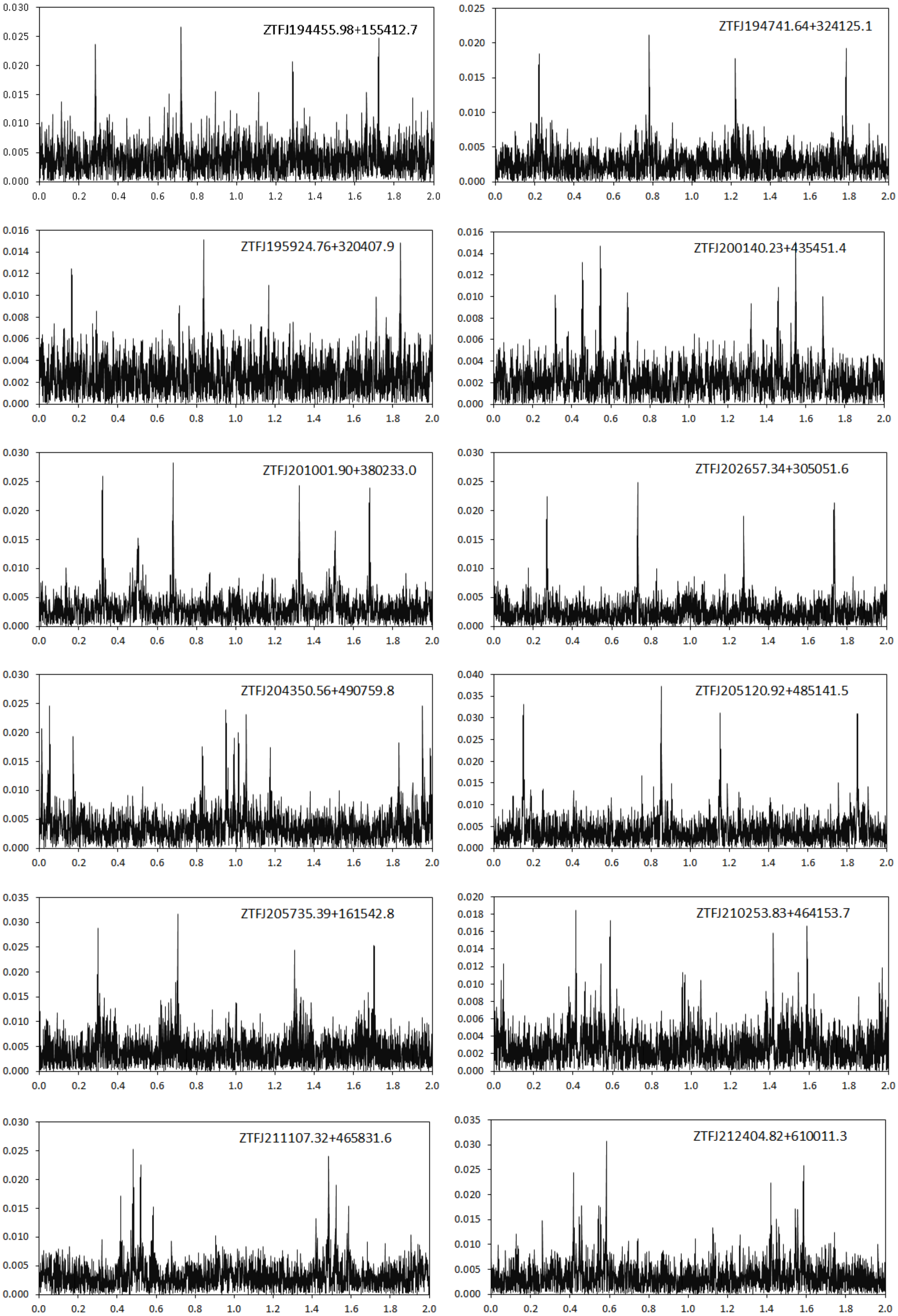
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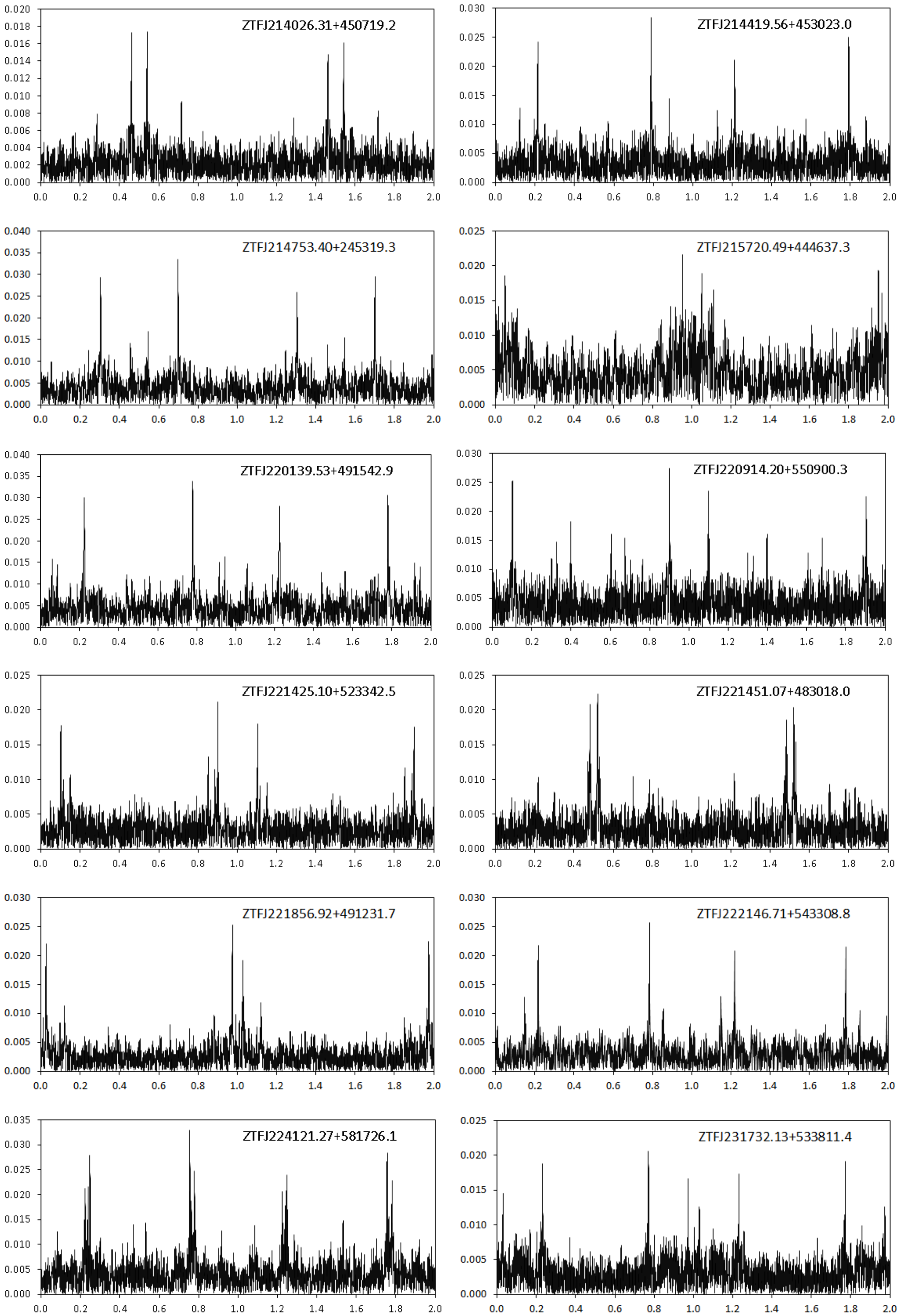
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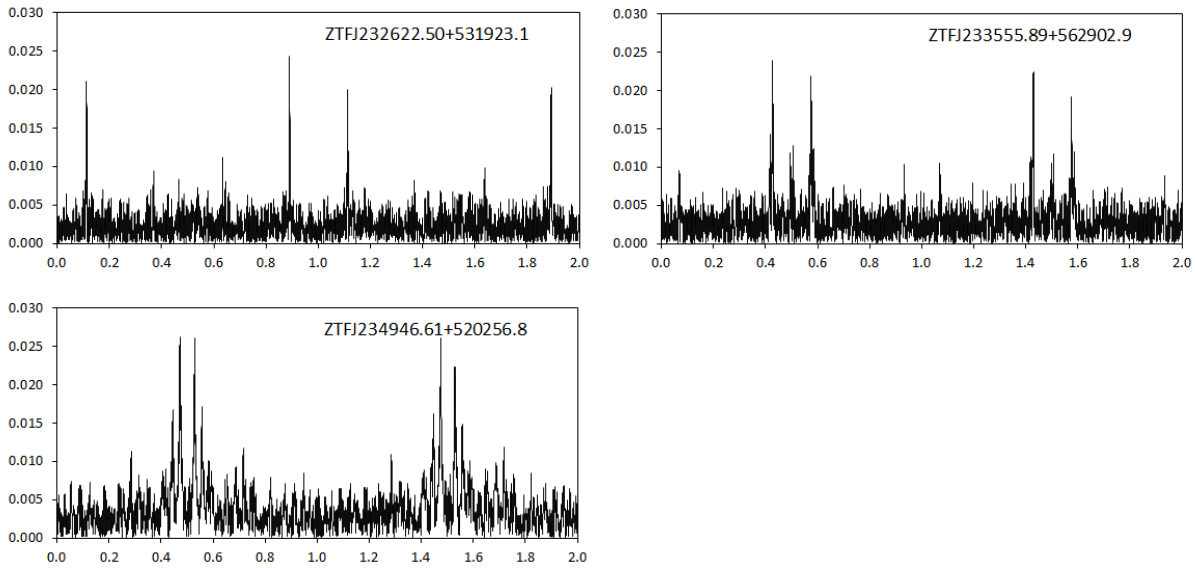
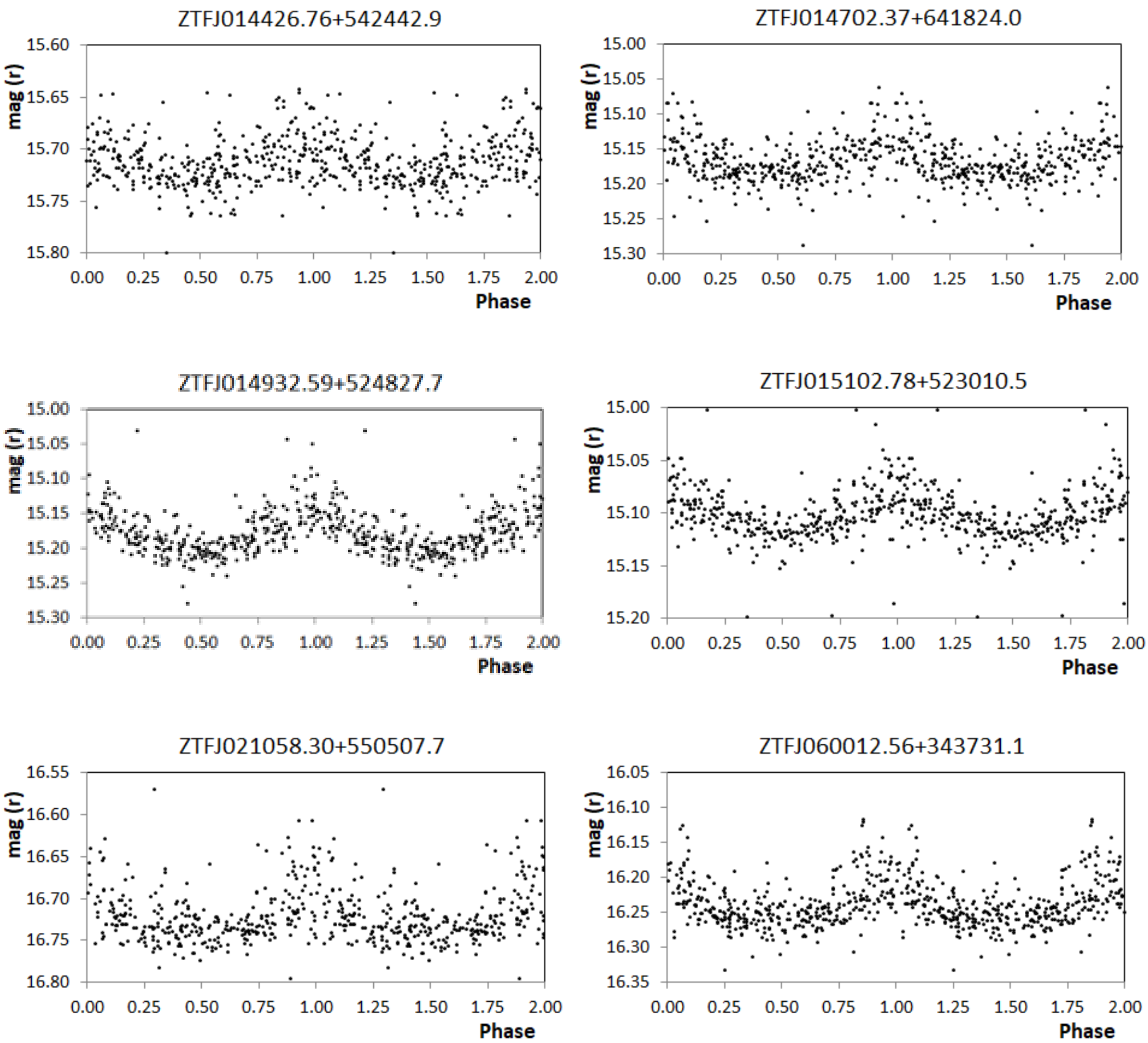
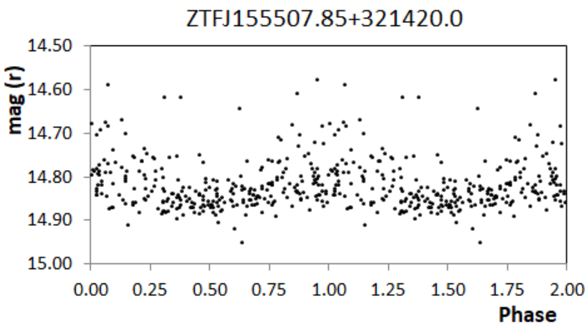


Figure 1: Fourier spectra in the frequency range of 0 to 2 c/d, as obtained with PERIOD04.

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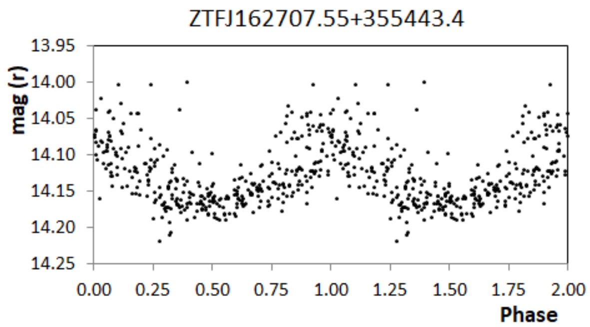
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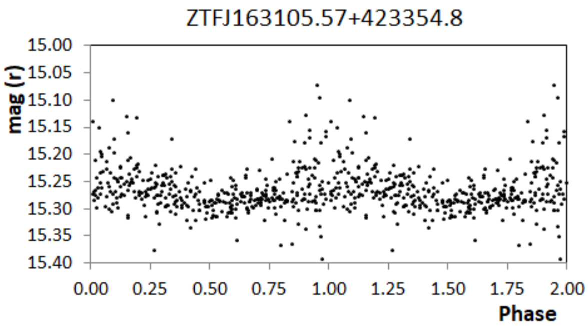
mag (r)
Phase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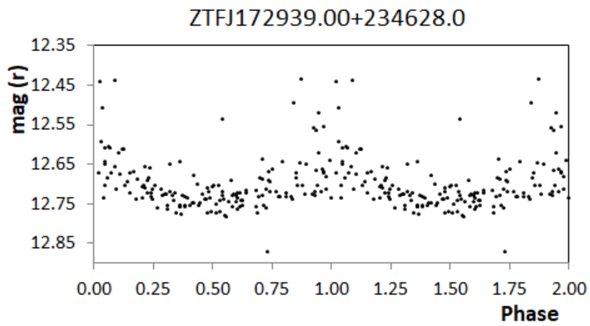
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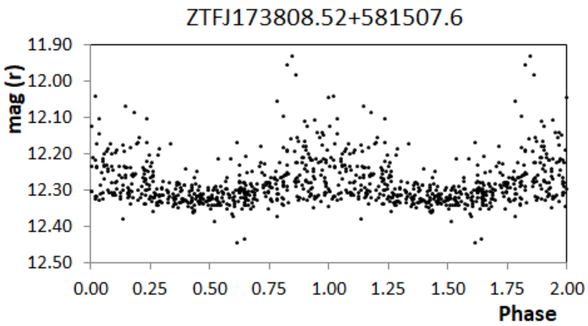
Phase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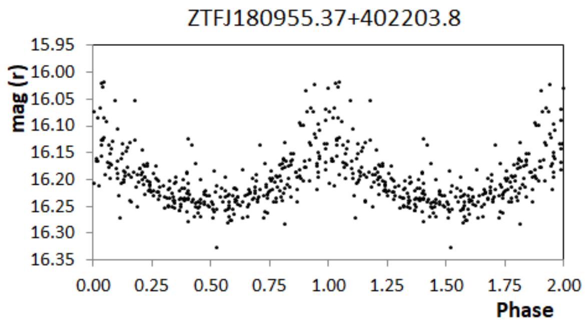
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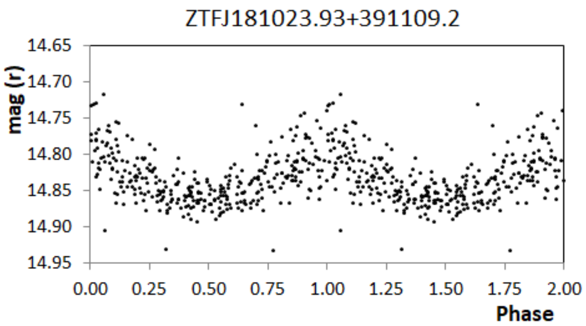
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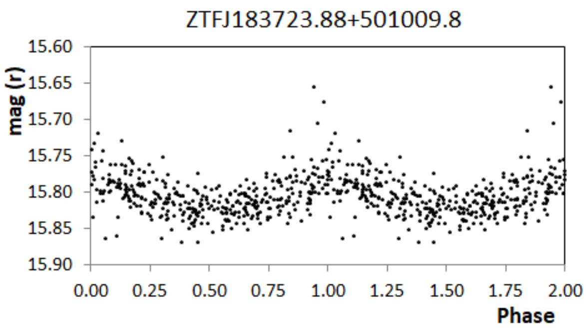
Phase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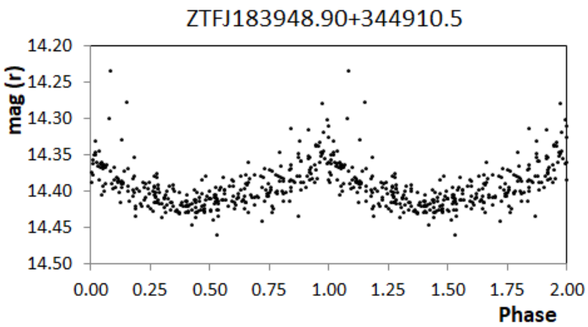
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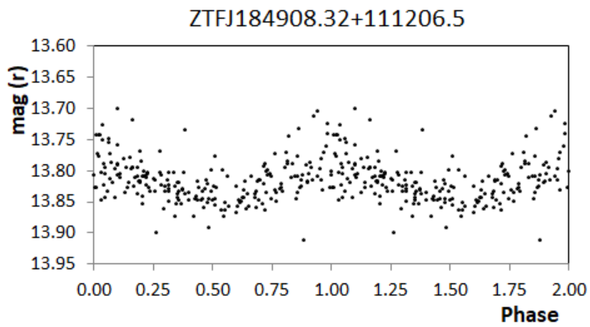
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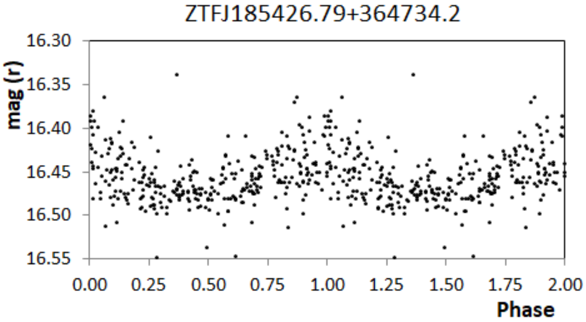
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16.45
16.50
16.55
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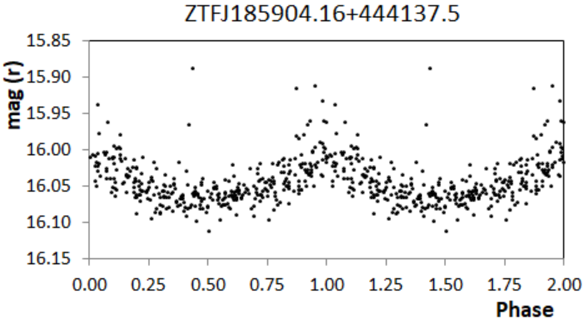
Phase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15.95
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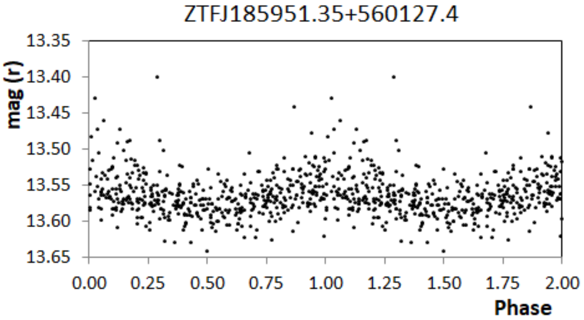
Phase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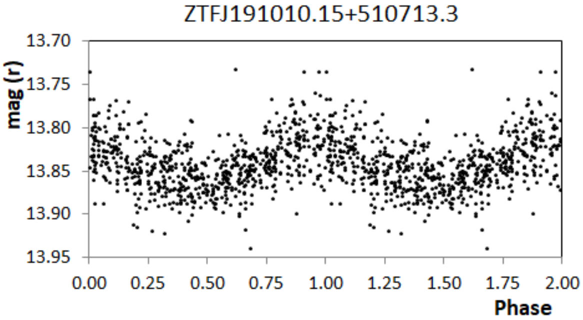
Phase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13.85
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13.95
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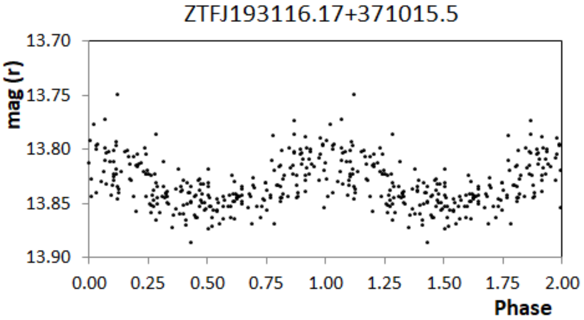
Phase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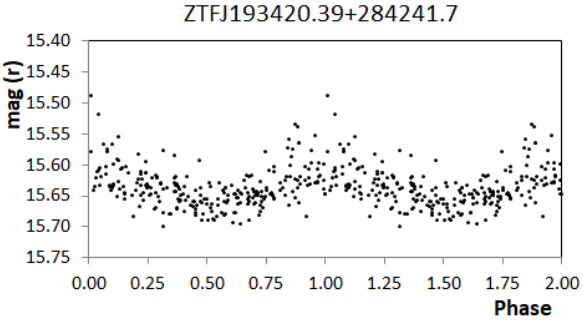
Phase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mag (r)
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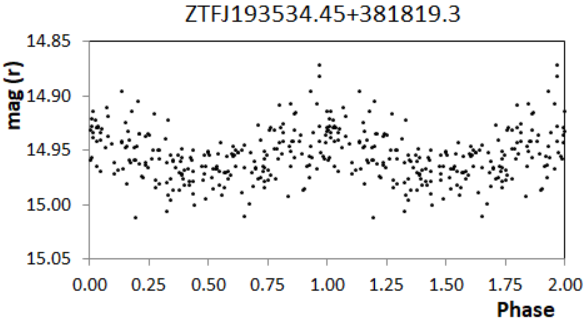
Phase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14.95
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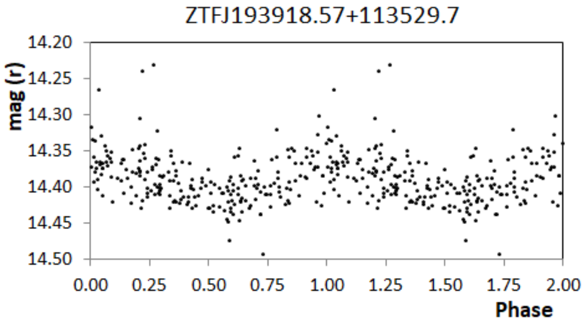
Phase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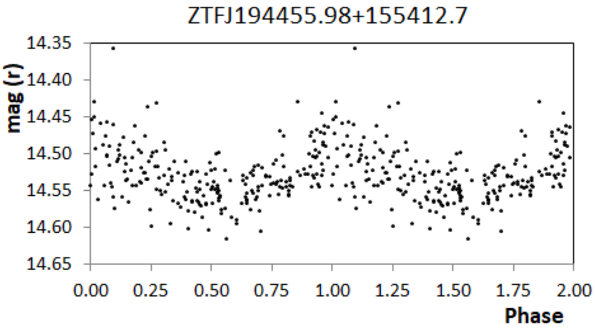
Phase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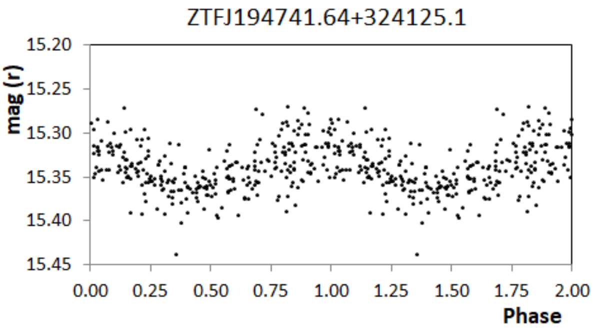
Phase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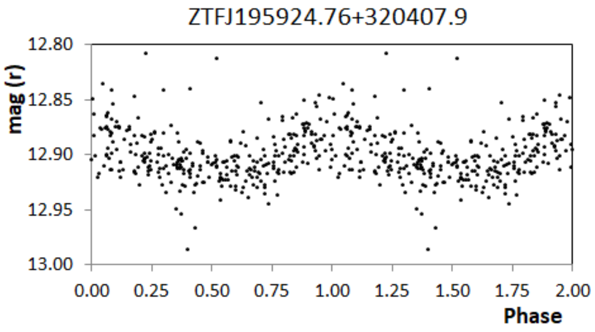
15.45
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
Phase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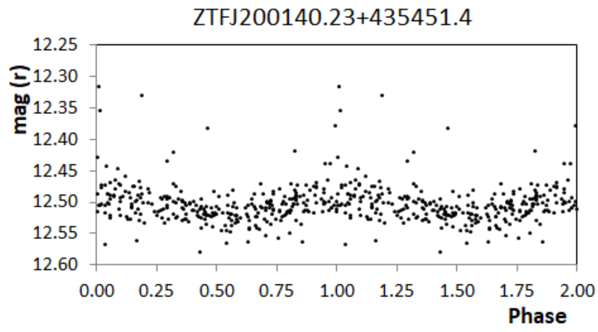
Phase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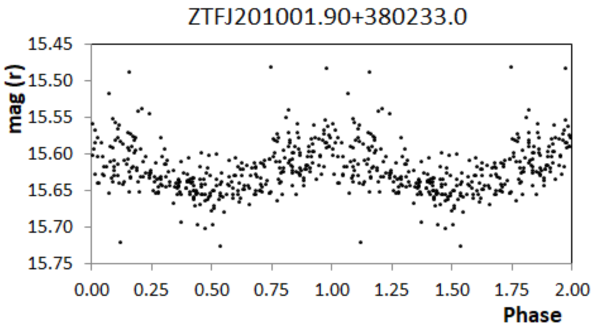
Phase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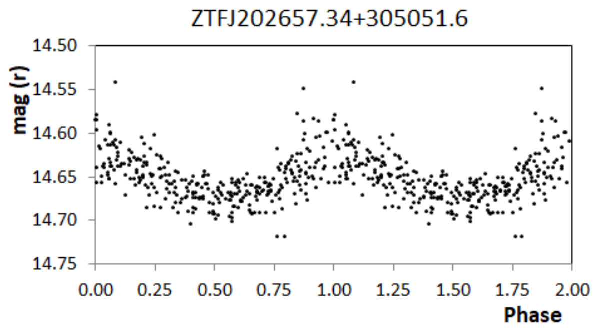
Phase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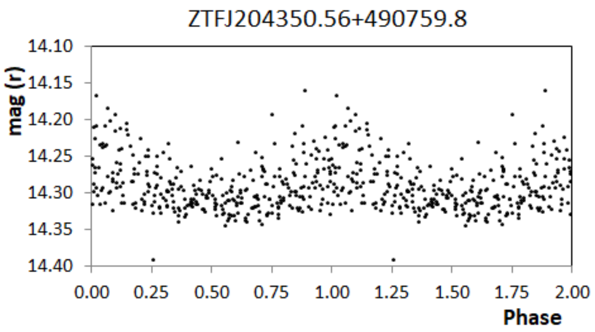
Phase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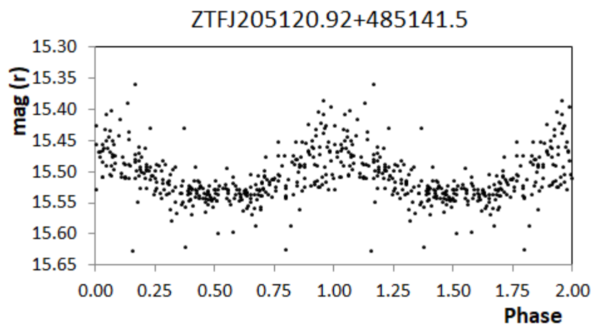
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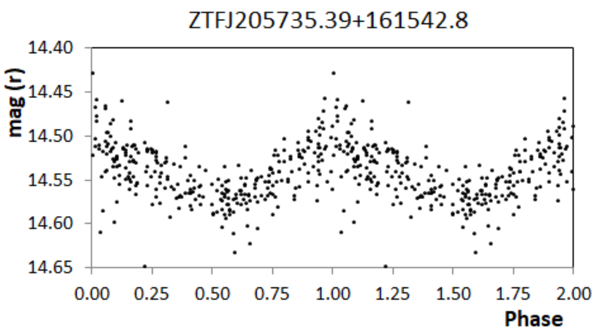
Phase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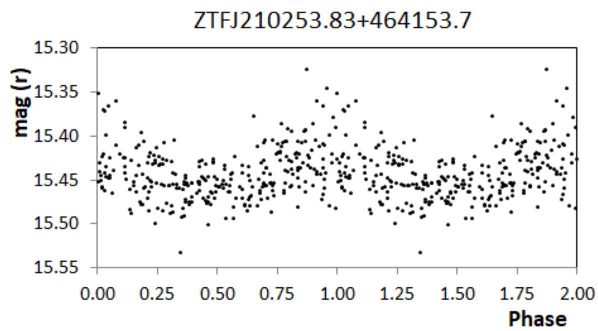
Phase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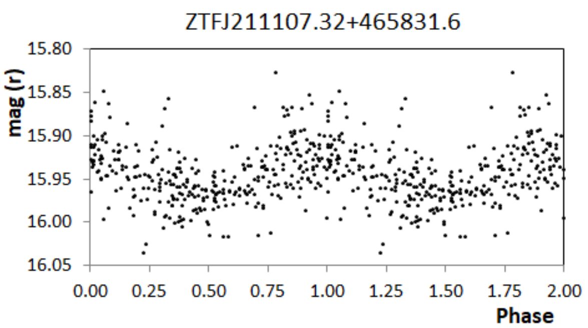
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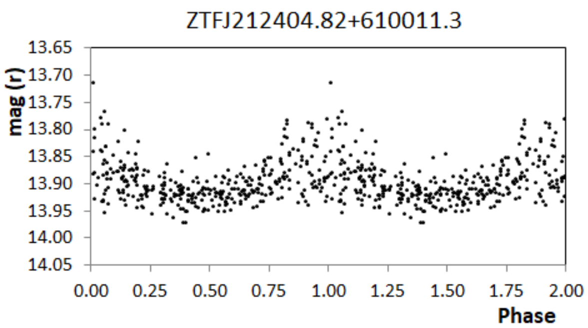
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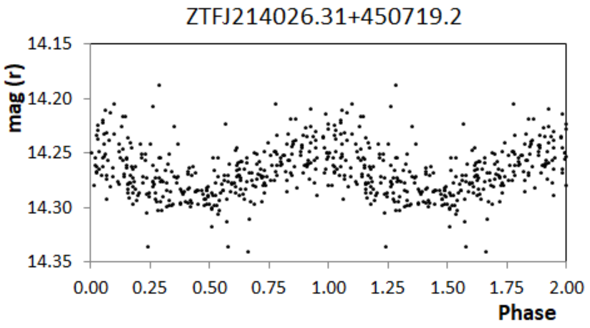
Phase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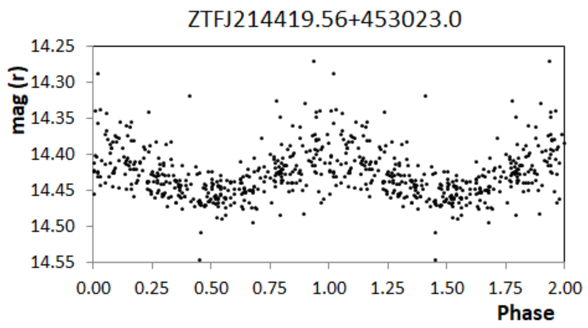
Phase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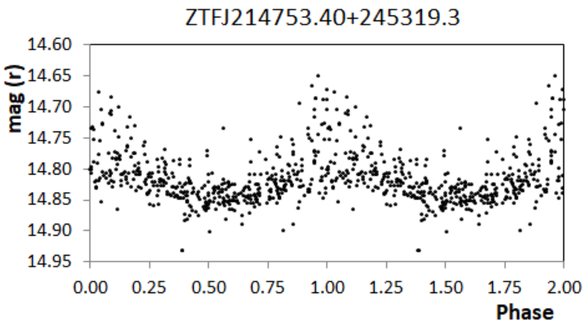
Phase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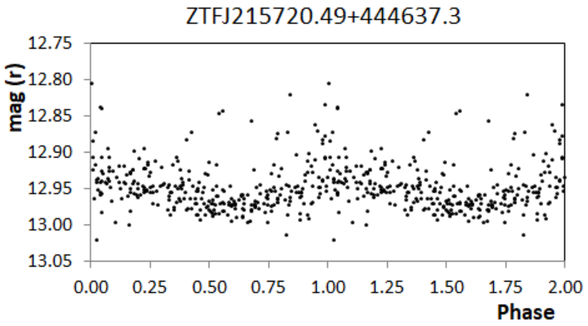
Phase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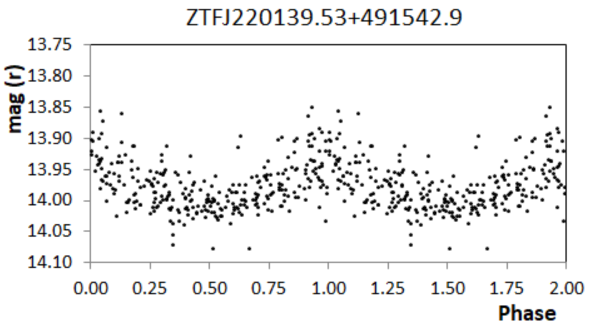
Phase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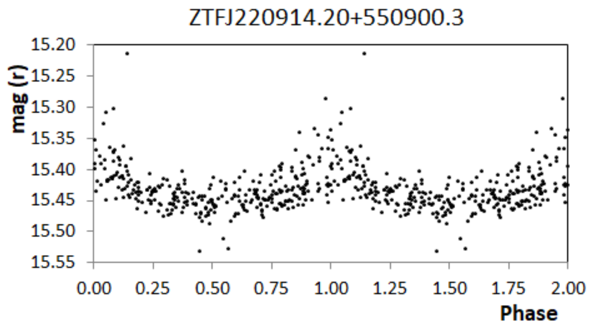
Phase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15.45
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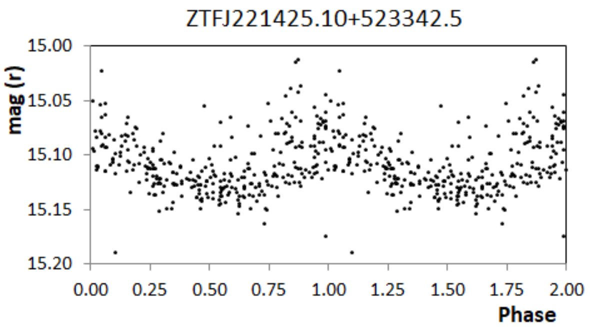
Phase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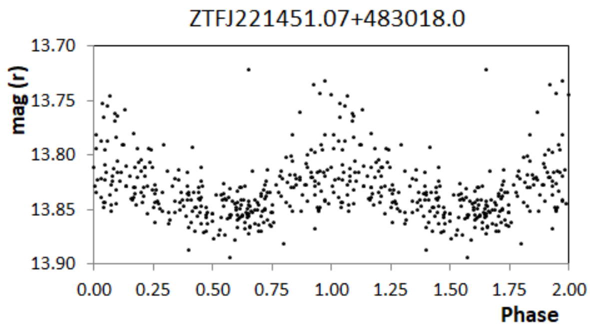
Phase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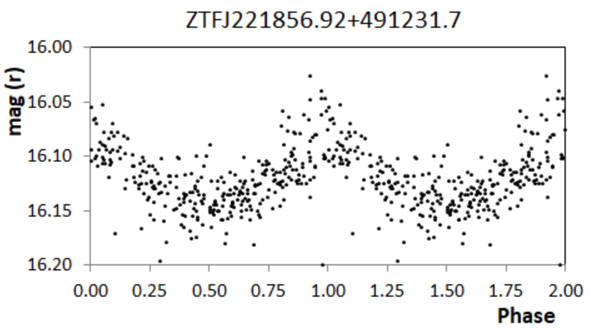
Phase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mag (r)
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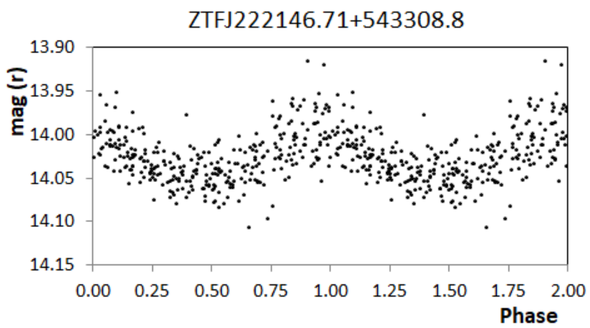
16.20
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
Phase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Phase

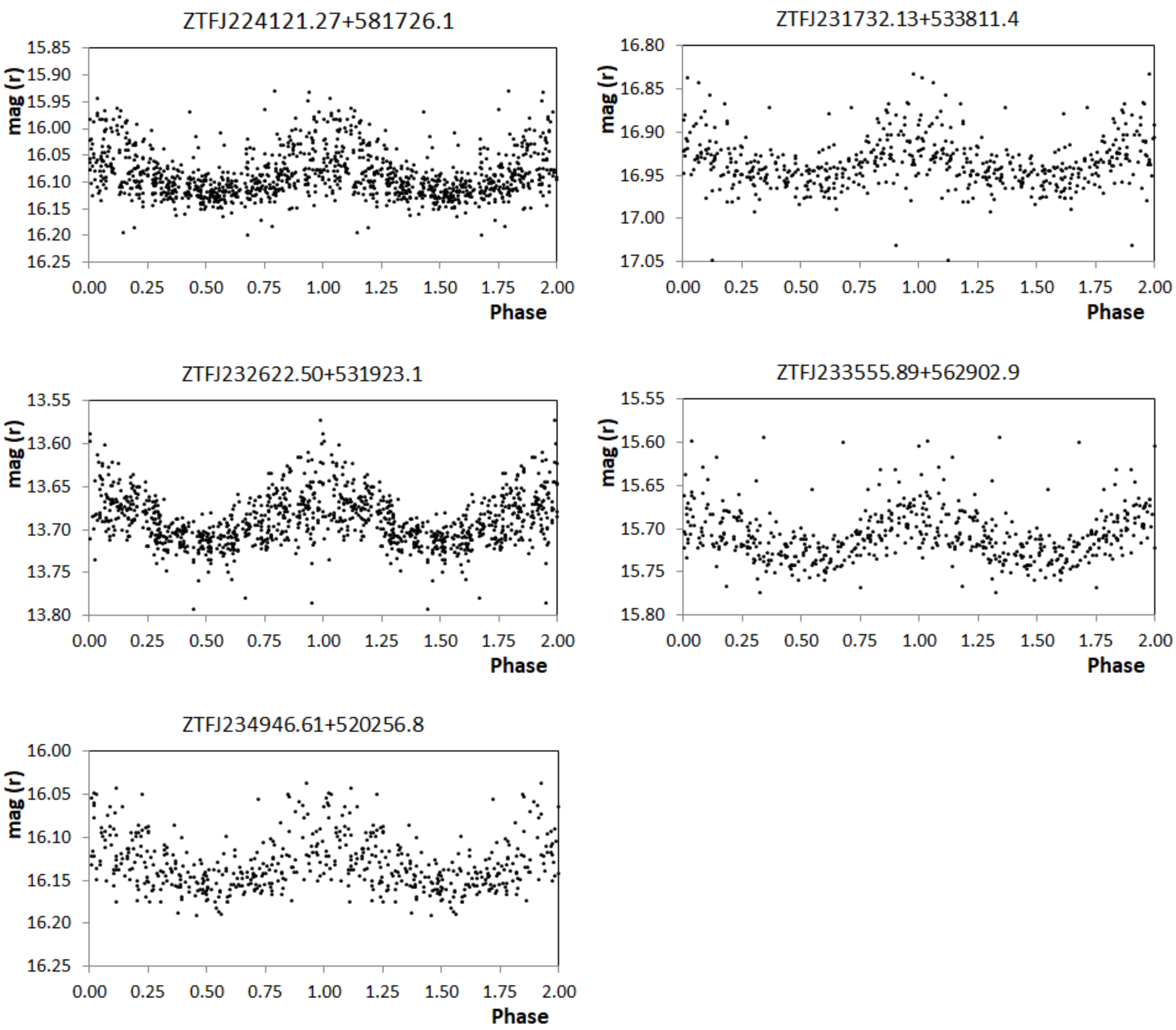

Figure 2: Folded light curves of the 51 new GDORs using the periods given in Table 1.

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