The Characteristic Period of Pulsation of β Gruis

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Abstract Analysis of photoelectric and visual photometry of the red giant β Gru led to the detection of a 37-day period with a *V*-range of 0.34 magnitude and the consequent reclassification of the star from the type Lc to SRb.

1. Introduction

β Gruis is listed in the *General Catalogue of Variable Stars* (GCVS, Kholopov *et al.* 2004) as an Lc: variable, i.e., a supergiant of late spectral type with irregular variations in *V* ranging from a maximum magnitude of about 2.0 to a minimum around 2.3. *The Bright Star Catalogue* (Hoffleit 1982) lists its spectral type as M5III, while a search of VIZIER (Ochsenbein *et al.* 2000) gives various estimates within the range listed by the GCVS (M3–5 II/III). In addition, β Gru has a well-measured parallax and angular diameter which indicate it to be a red giant and hence more likely to be of the SRb class.

2. Observations

Visual observations of β Gru were made in Argentina from JD 2451451 to JD 2453326 using the Argelander method. Independently, photoelectric photometry was undertaken in Australia from JD 2452906 to JD 2453589. Subsequent correspondence between the authors led to the combining of all the observations for analysis and identification of a characteristic period. (Here the term "characteristic" is used as the light curves of these stars display complex and, at times, irregular behavior. In some instances they have been observed to switch modes and there is still debate about which modes of pulsation predominate.)

The visual observations were made with the unaided eye using a modified version of the Argelander method described in Hirshfeld and Sinnott (1985), in which the visual magnitude of the variable star is derived from the observations against several comparison stars (see Table 1) and using cone vision, which allows small differences in brightness to be detected in bright stars, but taking care to avoid the Purkinje effect that takes place while visually observing bright, red stars (Grouiller

1936). This method can achieve an accuracy of 0.05 magnitude or better under ideal conditions (Otero *et al.* 2001). However, the brightness and color of β Gru, coupled with the availability of only a few nearby comparison stars, made visual estimates challenging. The resulting internal errors could thus be as much as 0.1 magnitude. The emission lines in red giants can also contribute to a different visual response and a systematic deviation from the standard system must be accounted for.

The photoelectric measurements were made with an Optec SSP-5A photometer attached to a permanently mounted 10-cm telescope housed in an observatory with a roll-off roof. For each star, five consecutive measurements of ten seconds integration time each were taken through each filter. As the observatory is situated in an outer suburb of a major (Australian) city, the background sky was measured for each star. When measuring through both *B* and *V* filters the sequence was *V*star, *B*star, *B*sky, *V*sky. Measurements of β Gru were bracketed by the measurements of the two comparison stars listed in Table 2 and were usually part of more extensive observing sessions in which a group of bright, southern semiregular variables and their nearby comparison stars were measured. This allowed atmospheric extinction to be evaluated on each night from the group of comparison stars measured. Calibrations for transformation to standard *V* magnitude and *B–V* color index have been established and are checked periodically. All comparison star values in this paper are taken from the *General Catalogue of Photometric Data* (GCPD, Mermilliod *et al.* 1997), rounded to the nearest 0.01 magnitude.

Corrections were applied to all photoelectric measurements for differences in air mass. The corrected magnitudes were then transformed to standard *V* magnitudes and *B–V* color indices. The errors given for the photoelectric measurements are the deviation of the measured differences in *V* and *B–V* for the two comparison stars from that expected using their GCPD values. The errors listed are thus estimates of the total error after transformation to the international system and include measurement uncertainties, errors in correction for differences in air mass and errors in color correction.

3. Results

As the visual and photometric sets of data overlapped from JD 2452910 to JD 2453326 (there were thirty-six visual observations and eighty-one photometric measurements in the overlapping interval) it was possible to compare them for systematic differences. Each season of visual observations had been separately normalized to the *V* magnitudes. The typical zero point differences were 0.1 to 0.2 magnitude. For the photometric measurements, the average *V* magnitude relative to HR 8657 was 2.062 and that relative to δ^1 Gru (which was measured on the same sensitivity setting of the photometer as β Gru) was 2.065. For the visual observations the average over the period of overlapping observations was 2.090. A small correction of –0.03 magnitude was then applied to the visual observations to adjust them to the photoelectric measurements. The combined data set is given in Table 3.

A plot of these data, Figure 1, shows two intervals of periodicity, one around JD 2452250 and one around 2453000, with irregular behavior at the other times of observation. Analysis was undertaken using the software package PERSEA, which is based on the optimal period search method of A. Schwarzenberg-Czerny (Maciejewski 2005). As illustrated in Figure 2, this gave a period of 37±4 days. The average *V* magnitude and *B–V* index for the combined data were 2.06 and 1.66, respectively, and the total range in *V* magnitude was 0.34. Lc-type variables are described as "irregular variable supergiants of late spectral type having amplitudes of about 1 magnitude in *V*" (Kholopov *et al.* 2004). β Gru, however, is a late-type giant that has displayed "alternating intervals of periodic and slow irregular changes" (Kholopov *et al.* 2004) with a range of about 0.3 in *V* magnitude. This is indicative of the SRb class of variable; the spectral type and measured light curve thus suggest β Gru should be reclassified as an SRb-type variable.

References

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Table 1. Comparison stars used for the visual observations.

Comparison Star	*V magnitude*	*B–V*
α Gruis	1.74	–0.14
α Pavonis	1.93	–0.20
β Ceti	2.04	1.02
α Phoenicis	2.39	1.08

Table 2. Comparison stars used for the photoelectric observations.

Comparison Star	*V magnitude*	*B–V*
δ^1 Gruis	3.96	1.03
HR 8657	5.50	1.32

Table 3. Visual and photometric data for β Gru. The visual data are identified by *e* and the photoelectric by *p*.

Julian Date	*V*	*±V*	*B–V*	*±(B–V)*	*Data*
2451451.700	2.06	0.05			e
2451469.500	2.08	0.05			e
2451788.600	2.16	0.05			e
2451808.500	2.05	0.05			e
2451813.600	2.03	0.05			e
2451826.500	2.06	0.05			e
2451830.500	2.07	0.05			e
2451836.500	2.05	0.05			e
2451858.500	2.14	0.05			e
2451864.500	2.13	0.05			e
2451865.500	2.13	0.05			e
2451869.600	2.15	0.05			e
2451873.500	2.13	0.05			e
2451884.500	2.10	0.05			e
2451896.500	2.03	0.05			e
2451902.500	2.02	0.05			e
2451909.500	2.16	0.05			e
2451922.500	2.14	0.05			e
2452049.900	2.05	0.05			e
2452112.898	2.10	0.05			e
2452145.586	2.09	0.05			e
2452161.656	2.13	0.05			e
2452169.526	2.04	0.05			e
2452195.505	2.12	0.05			e
2452205.642	2.02	0.05			e
2452214.535	1.95	0.05			e
2452216.492	1.93	0.05			e
2452217.554	1.91	0.05			e
2452221.608	1.90	0.05			e
2452222.499	1.93	0.05			e
2452224.497	1.95	0.05			e
2452225.503	1.98	0.05			e
2452228.642	2.05	0.05			e
2452230.646	2.10	0.05			e
2452231.649	2.14	0.05			e
2452232.583	2.15	0.05			e
2452235.533	2.16	0.05			e
2452240.551	2.21	0.05			e
2452241.522	2.21	0.05			e
2452245.511	2.15	0.05			e
2452249.499	2.11	0.05			e
2452253.533	1.97	0.05			e
2452258.583	1.93	0.05			e
2452259.585	1.97	0.05			e
2452261.529	1.98	0.05			e
2452265.510	2.08	0.05			e
2452268.518	2.18	0.05			e
2452270.513	2.20	0.05			e
2452275.522	2.21	0.05			e
2452276.519	2.20	0.05			e
2452282.547	2.11	0.05			e
2452283.511	2.15	0.05			e
2452285.519	2.09	0.05			e
2452286.534	2.06	0.05			e
2452289.519	2.00	0.05			e
2452291.513	1.97	0.05			e
2452298.510	1.93	0.05			e
2452469.877	2.06	0.05			e
2452483.759	2.03	0.05			e
2452492.731	1.99	0.05			e
2452506.858	1.94	0.05			e
2452516.548	2.06	0.05			e
2452520.565	2.13	0.05			e
2452526.858	2.12	0.05			e
2452529.515	2.00	0.05			e
2452530.615	1.91	0.05			e
2452538.678	1.95	0.05			e
2452546.500	2.05	0.05			e
2452549.540	2.12	0.05			e
2452553.533	2.16	0.05			e
2452558.521	2.13	0.05			e
2452559.508	2.02	0.05			e
2452565.544	1.95	0.05			e
2452569.535	1.96	0.05			e
2452570.548	1.96	0.05			e
2452572.618	1.97	0.05			e

(Table 3 continued on following pages.)

Table 3. Visual and photometric data for β Gru, continued. The visual data are identified by *e* and the photoelectric by *p*, continued.

Julian Date	*V*	*±V*	*B–V*	*±(B–V)*	*Data*	*Julian Date*	*V*	*±V*	*B–V*	*±(B–V)*	*Data*
2452576.533	1.97	0.05			e	2452906.995	2.24	0.01	1.64	0.01	p
2452578.673	1.98	0.05			e	2452910.004	2.21	0.01	1.68	0.01	p
2452579.583	2.00	0.05			e	2452911.503	2.17	0.05			e
2452582.554	2.02	0.05			e	2452918.942	2.03	0.02	1.66	0.01	p
2452583.544	2.03	0.05			e	2452923.556	2.02	0.05			e
2452584.501	2.05	0.05			e	2452923.986	2.00	0.01	1.68	0.01	p
2452590.503	2.14	0.05			e	2452926.538	1.97	0.05			e
2452594.662	2.15	0.05			e	2452927.501	1.99	0.05			e
2452597.500	2.11	0.05			e	2452928.493	2.01	0.05			e
2452599.534	2.10	0.05			e	2452928.983	2.02	0.01	1.67	0.01	p
2452600.501	2.11	0.05			e	2452931.472	2.07	0.05			e
2452601.542	2.12	0.05			e	2452932.982	2.09	0.02	1.64	0.01	p
2452602.498	2.12	0.05			e	2452934.469	2.09	0.05			e
2452607.511	2.13	0.05			e	2452935.687	2.10	0.05			e
2452610.553	2.14	0.05			e	2452938.980	2.17	0.01	1.66	0.01	p
2452611.517	2.15	0.05			e	2452939.469	2.13	0.05			e
2452615.569	2.14	0.05			e	2452940.467	2.16	0.05			e
2452618.497	2.13	0.05			e	2452945.990	2.25	0.01	1.66	0.01	p
2452623.528	2.13	0.05			e	2452946.474	2.18	0.05			e
2452625.509	2.13	0.05			e	2452946.949	2.23	0.01	1.66	0.01	p
2452628.521	2.16	0.05			e	2452949.478	2.17	0.05			e
2452641.506	2.20	0.05			e	2452950.959	2.20	0.01	1.65	0.01	p
2452644.510	2.20	0.05			e	2452951.960	2.19	0.01	1.64	0.01	p
2452645.526	2.20	0.05			e	2452953.478	2.15	0.05			e
2452652.521	2.14	0.05			e	2452953.969	2.15	0.01	1.67	0.03	p
2452656.517	2.09	0.05			e	2452954.957	2.14	0.01	1.65	0.02	p
2452663.516	2.16	0.05			e	2452955.967	2.12	0.01	1.67	0.01	p
2452749.835	2.15	0.05			e	2452956.955	2.10	0.01	1.66	0.01	p
2452785.897	2.22	0.05			e	2452957.486	2.14	0.05			e
2452792.898	2.16	0.05			e	2452957.974	2.08	0.01	1.67	0.01	p
2452826.757	2.17	0.05			e	2452962.976	1.99	0.01	1.68	0.01	p
2452834.898	2.17	0.05			e	2452965.497	2.09	0.05			e
2452846.688	2.07	0.05			e	2452968.968	1.99	0.01	1.68	0.03	p
2452858.597	2.12	0.05			e	2452969.503	2.07	0.05			e
2452868.740	2.20	0.05			e	2452970.021	2.02	0.01	1.65	0.01	p
2452880.673	2.17	0.05			e	2452974.496	2.04	0.05			e
2452885.560	2.16	0.05			e	2452974.990	2.10	0.01	1.68	0.01	p
2452893.535	2.16	0.05			e	2452975.965	2.12	0.02	1.66	0.01	p

(Table 3 continued on following pages.)

Table 3. Visual and photometric data for β Gru, continued. The visual data are identified by *e* and the photoelectric by *p*, continued.

Julian Date	*V*	*±V*	*B–V*	*±(B–V)*	*Data*
2452977.002	2.14	0.01			p
2452978.981	2.18	0.02			p
2452979.988	2.21	0.01			p
2452981.518	2.05	0.05			e
2452984.008	2.21	0.02			p
2452984.980	2.22	0.01			p
2452985.515	2.13	0.05			e
2452986.984	2.18	0.01			p
2452987.517	2.16	0.05			e
2452987.981	2.14	0.02			p
2452991.525	2.17	0.05			e
2452991.997	2.07	0.02	1.68	0.03	p
2452993.996	2.00	0.01	1.7	0.02	p
2452995.547	2.10	0.05			e
2452996.017	1.97	0.01	1.66	0.02	p
2452996.988	1.95	0.01			p
2452998.013	1.93	0.02			p
2452998.990	1.94	0.01			p
2452999.992	1.92	0.02			p
2453001.000	1.91	0.02			p
2453001.985	1.92	0.01			p
2453004.003	1.92	0.01			p
2453004.547	1.97	0.05			e
2453004.996	1.94	0.01			p
2453005.988	1.96	0.03	1.69	0.05	p
2453006.984	1.96	0.01			p
2453008.008	2.00	0.01			p
2453015.991	2.16	0.02			p
2453016.519	2.09	0.05			e
2453016.986	2.16	0.02	1.68	0.03	p
2453017.977	2.18	0.01			p
2453018.976	2.17	0.03			p
2453019.980	2.20	0.02			p
2453022.975	2.17	0.03			p
2453024.974	2.14	0.01			p
2453026.976	2.13	0.01			p
2453028.975	2.08	0.04	1.7	0.03	p
2453030.967	2.09	0.02			p
2453032.505	2.00	0.05			e
2453037.973	2.01	0.05			p
2453046.963	2.04	0.01			p
2453047.963	2.07	0.02			p
2453053.951	2.15	0.04			p
2453055.950	2.12	0.02			p
2453058.944	2.16	0.03			p
2453132.315	2.09	0.03			p
2453161.092	1.97	0.01	1.64	0.01	p
2453184.035	2.02	0.03			p
2453215.994	2.02	0.02	1.65	0.01	p
2453228.954	2.08	0.01			p
2453237.097	2.00	0.02	1.66	0.01	p
2453244.988	2.00	0.02	1.66	0.01	p
2453253.963	2.02	0.02			p
2453263.922	1.96	0.02			p
2453264.499	2.02	0.05			e
2453266.937	1.96	0.01	1.66	0.01	p
2453267.990	1.94	0.02			p
2453269.054	1.94	0.01			p
2453273.483	1.93	0.05			e
2453280.486	1.94	0.05			e
2453281.956	2.02	0.01			p
2453282.476	1.97	0.05			e
2453284.015	2.02	0.03	1.66	0.01	p
2453286.947	2.07	0.01			p
2453289.492	2.06	0.05			e
2453293.972	2.07	0.01			p
2453295.738	2.11	0.05			e
2453295.971	2.05	0.02	1.67	0.02	p
2453296.988	2.04	0.03			p
2453298.476	2.07	0.05			e
2453302.976	1.98	0.03			p
2453305.474	1.95	0.05			e
2453307.989	1.96	0.02			p
2453309.509	1.92	0.05			e
2453311.969	1.98	0.01			p
2453316.526	1.96	0.05			e

(Table 3 continued on following page.)

Table 3. Visual and photometric data for β Gru, continued. The visual data are identified by *e* and the photoelectric by *p*, continued.

Julian Date	*V*	*±V*	*B–V*	*±(B–V)*	*Data*
2453317.981	1.99	0.01	1.65	0.01	p
2453324.982	1.98	0.02			p
2453325.952	1.96	0.03			p
2453326.485	2.02	0.05			e
2453328.999	2.00	0.01			p
2453330.966	2.01	0.02			p
2453331.980	2.01	0.03			p
2453332.981	2.03	0.01			p
2453333.978	2.00	0.01			p
2453341.989	2.05	0.01			p
2453343.994	2.06	0.01			p
2453353.993	2.06	0.03			p
2453355.997	2.06	0.01			p
2453359.988	2.05	0.01			p
2453364.022	2.01	0.01			p
2453364.986	2.02	0.01			p
2453367.985	2.03	0.03			p
2453376.991	2.03	0.01			p
2453378.988	2.04	0.04			p
2453379.978	2.02	0.04			p
2453382.991	2.05	0.02			p
2453383.976	2.05	0.03			p
2453386.979	2.04	0.04			p
2453387.976	2.08	0.01			p
2453388.974	2.07	0.03			p
2453391.976	2.08	0.01			p
2453392.995	2.09	0.02			p
2453393.973	2.05	0.04			p
2453394.976	2.08	0.02			p
2453395.974	2.02	0.01			p
2453399.970	2.02	0.02			p
2453400.963	2.03	0.01			p
2453401.966	2.02	0.01			p
2453413.954	2.04	0.01			p
2453414.962	2.02	0.04			p
2453416.954	2.05	0.02			p
2453417.960	2.05	0.01			p
2453453.281	2.08	0.01			p
2453480.279	1.96	0.04			p
2453502.322	2.11	0.02			p
2453506.337	2.12	0.02			p
2453570.967	2.07	0.02			p
2453573.984	2.10	0.01			p
2453584.991	2.06	0.03			p
2453588.938	2.03	0.04			p

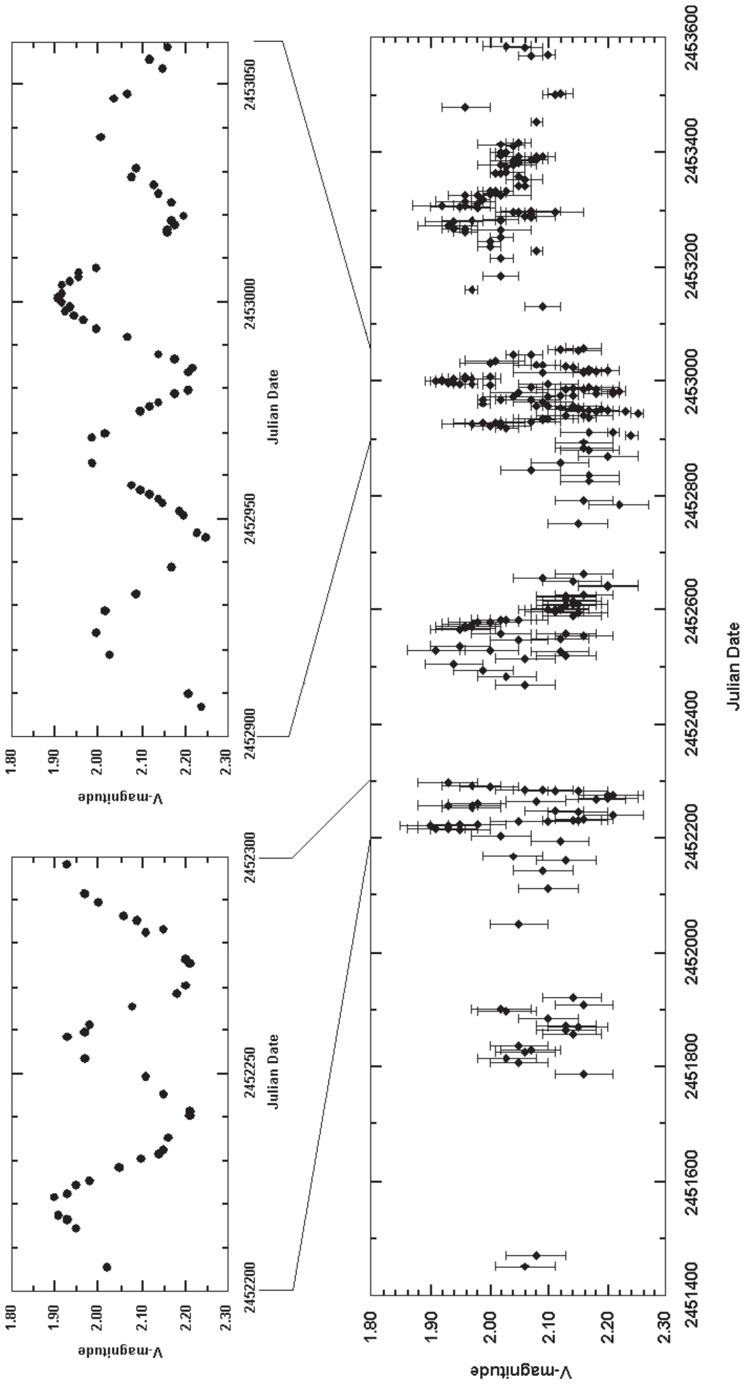

Figure 1. Light curve for β Gru as plotted from data given in Table 3.

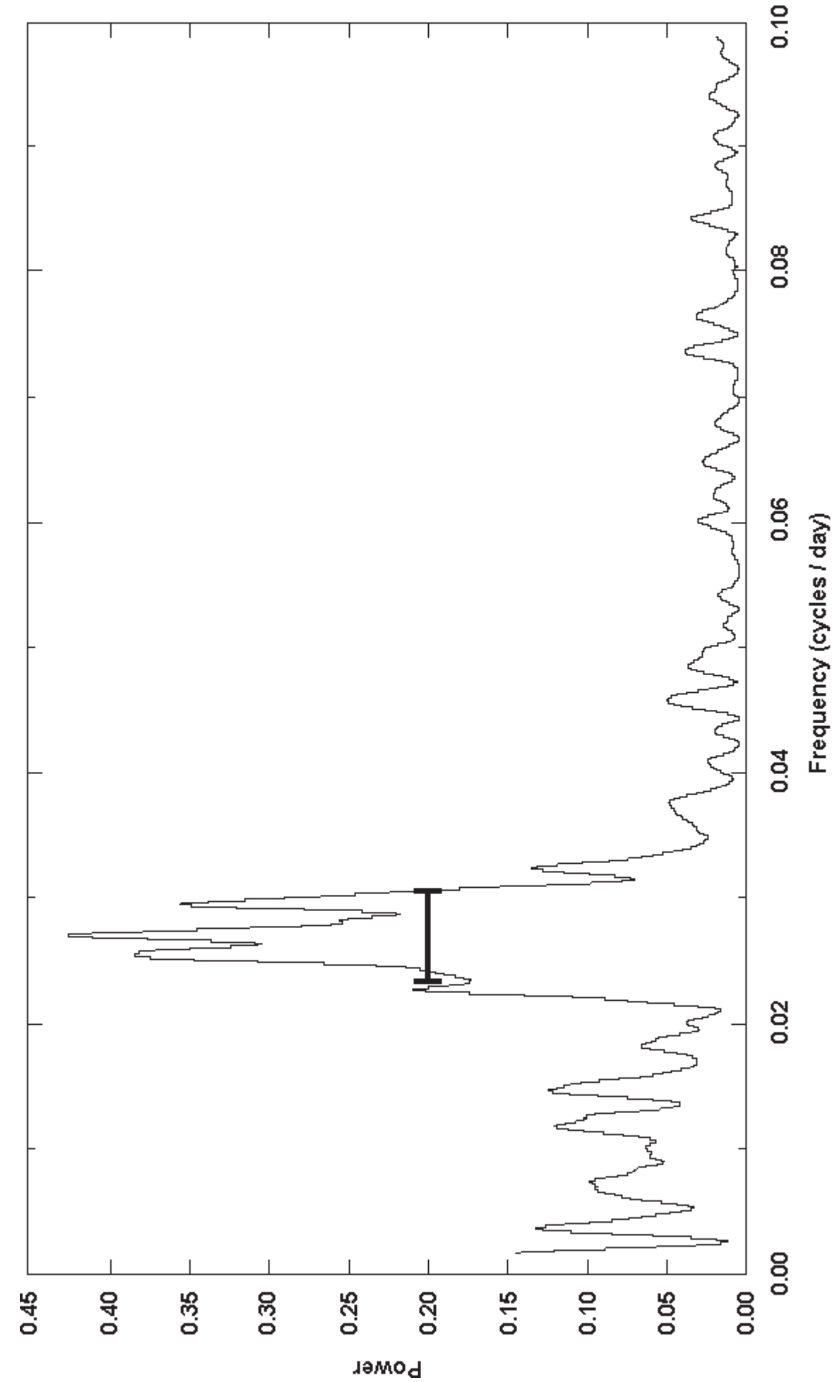

Figure 2. Periodogram from analysis of β Gru data showing broad peak centred on 37 days with a FWHM of about 8 days.