Astron. Astrophys. 326, L1–L4 (1997)

ASTRONOMY
AND
ASTROPHYSICS

Letter to the Editor

On the new triple-mode pulsating variable star GSC 4018.1807

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Received 10 March 1997 / Accepted 22 April 1997

Abstract. Variability of GSC 4018.1807 was discovered. The new variable is a triple-mode pulsating star, similar to AC And. Our frequency analysis, based on 895 photographic observations, shows that GSC 4018.1807 has the fundamental ($P_0 = 0^d.66887$), first ($P_1 = 0^d.51265$) and second ($P_2 = 0^d.41103$) overtone pulsation modes as well as non-linear coupling terms ($1/P_1 + 1/P_0$ and $1/P_1 - 1/P_0$). The new variable's period ratio P_1/P_0=0.7664 considerably exceeds those typical for bimodal RR Lyr type stars and the ratio observed for AC And.

Key words: stars: oscillations – stars: individual: GSC 4018.1807

1. Introduction

Bimodality is not a rare phenomenon among pulsating variables. There are many well studied double-mode Cepheids, RR Lyrae and δ Scuti type stars in our Galaxy. We know some multimodal δ Scuti type stars. But, among the diversity of pulsating stars, the unique triple-mode variable AC And stands out. At present, the variability of AC And is very well investigated. The bimodality of this variable (fundamental and first overtone modes) was discovered by Florja (1937). Fitch and Szeidl (1976) found the second overtone mode using photoelectric observations. So AC And is a star that pulsates in three modes at the same time. But the nature of this triple-mode oscillation, the star's evolutionary status and classification within the group of pulsating variable stars are not yet understood completely. An additional unsolved question is the number of similar objects in the Galaxy. Unfortunately, AC And remained the only one star of this type known.

In this paper we announce the discovery of the second AC And type star – the triple-mode pulsating variable GSC 4018.1807.

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Table 1. Comparison stars

GSC	α(2000.0)	δ(2000.0)	B
4018.1661	$0^h06^m14^s.6$	63°19′10″	$11^m.46$
4018.1891	0 04 42.1	63 23 28	12.11
4018.1777	0 05 49.1	63 23 20	12.40

2. Observations and analysis

The variability of GSC 4018.1807 ($\alpha = 0^h5^m42^s.4$, δ = +63°24′15″ (J2000.0); $l = 117°.8$, $b = +1°.0$) was discovered using the positive-negative method on Moscow collection plates taken with the 40-cm astrograph in Crimea. The star was estimated by eye on 895 plates The observations are available in electronic form via an anonymous ftp copy at the CDS. in the photographic B band for the interval JD2432853–49633. The mean error of a single estimate is about 0.1 mag.

The comparison stars are presented in Table 1. Their B band magnitudes were measured with a photoelectric photometer at the 60-cm reflector in Crimea. HD 134 = BD+62°2364 was used as a standard (Kornilov et al., 1991).

The variability range for the new variable is $11^m.35 - 12^m.20$, so the amplitude is about $0^m.85$.

The frequency analysis was made for the set of 721 observations in the time interval JD 2437911–45340. Changes in periods take place for the modes of the new variable, as will be demonstrated below. Thus, to avoid the problems connected with the period changes, we used a sufficiently narrow time interval that included the majority of observations.

The power spectra are presented in Fig.1. The step in frequency is $1.35 \cdot 10^{-5}$ c/d for Fig.1abdf and $1.35 \cdot 10^{-6}$ c/d for Fig.1ce. The spectra in Fig.1c and 1e are parts of Fig.1b and 1d, respectively.

Figure 1a shows the existence of two main oscillations. The first overtone dominates in the spectrum. Its light elements are the following:

$$\mathrm{JD_{max}} = 2442484.29 + 0^d.512650 \cdot E.$$

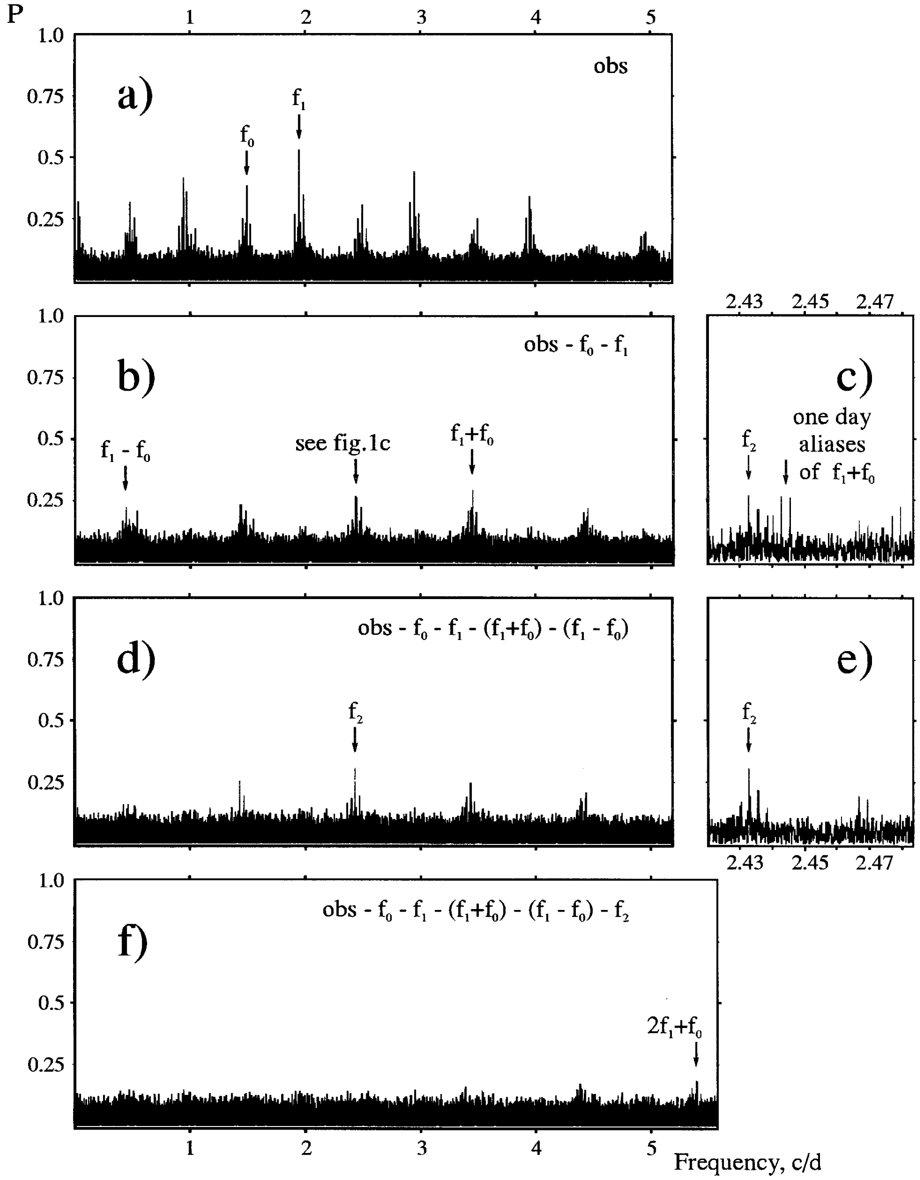

Fig. 1a–e. The power spectra.

The phased light curve is shown in Fig.2.

The fundamental mode has the elements:

$$\mathrm{JD_{max}} = 2441924.47 + 0^d.668879 \cdot E.$$

The corresponding phased light curve is given in Fig.3.

Our interpretation of these two modes as the fundamental mode and the first overtone is based on the period ratio P_1/P_0 = 0.7664. This value agrees well with those predicted by the stellar pulsation theory.

Then, the fundamental and first overtone oscillations were whitened. In Fig.1bc we can see the non-linear coupling terms $f_1 - f_0$ ($P = 2^d.19487$) and $f_1 + f_0$ ($P = 0^d.290218$), and the third oscillation f_2 with the light elements:

$$\mathrm{JD_{max}} = 2443079.48 + 0^d.411034 \cdot E.$$

This is the second overtone, P_2/P_1 = 0.8018. The phased light curve is shown in Fig.4. The existence of the third frequency in spectra can be seen clearly in Fig.1de, where the non-linear coupling terms have been whitened.

Finally, one more frequency, connected with non-linear interaction of the two main modes, is the frequency $2f_1 + f_0$ ($P = 0^d.185311$), marked in the last spectrum (Fig.1f).

In the case of double-mode pulsators (and AC And), the non-linear mode interaction results in two consequences.

1) The existence, in power spectra, of the frequences $f_{ijk} = if_0 + jf_1 + kf_2$, as was demonstrated above.

2) The amplitude of every oscillation is a function of phases of the two other oscillations.

In other words, in the equation

$$\Delta m = A_0 \cos 2\pi(f_0 t + \phi_0) + A_1 \cos 2\pi(f_1 t + \phi_1) + \\ + A_2 \cos 2\pi(f_2 t + \phi_2)$$

we must either add all interaction terms or introduce the dependence on the phase of other two oscillations into amplitudes.

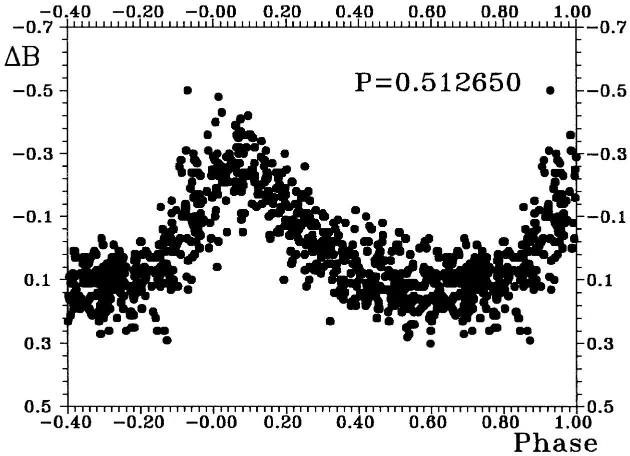

Fig. 2. The first overtone mode. The fundamental and the second overtone modes as well as non-linear coupling terms ($1/P_1 + 1/P_0$ and $1/P_1 - 1/P_0$) have been whitened.

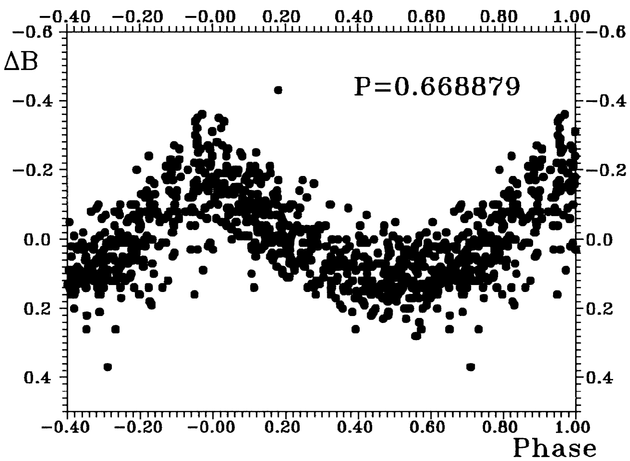

Fig. 3. The fundamental mode. The first and the second overtone modes as well as non-linear coupling terms ($1/P_1 + 1/P_0$ and $1/P_1 - 1/P_0$) have been whitened.

So, maximum amplitude of the first overtone (about $0^m.8$ peak-to-peak) is observed near the maximum of the fundamental mode, and minimum one (about $0^m.35$), near the minimum of the fundamental mode. Similarly, the amplitude of the fundamental oscillation changes approximately between $0^m.8$ and $0^m.2$. For example, the second-overtone phased light curves near the maxima and near the minima of the other two modes are shown in Fig. 5. Unfortunately, we had to use broad phase intervals ($0^p.24$) to plot the figures. The amplitude varies from $0^m.4$ to about $0^m.1$ (near the detection limit).

3. Period changes

As already mentioned, not all of the 895 observations were used for frequency analysis. It was made because the fundamental and the first overtone periods change considerably during the observations interval.

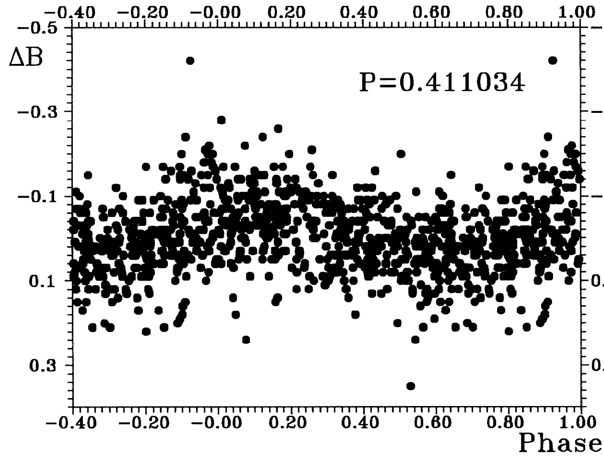

Fig. 4. The second overtone mode. The fundamental and the first overtone modes as well as their non-linear coupling terms have been whitened.

If frequency analysis is held for the whole data range, similar results will be obtained. But the earliest and the latest estimates appear to deviate significantly from the average light curves. In order to investigate periods changes, the observations were divided into two sets. The results of the analysis are shown in Table 2. The mean error of period determinations for the first and second sets of observations is about $0^d.00001$.

If the phased light curves, on the base of the first set of observations, are drawn with the periods of the second set and vice versa, then these curves will be considerably worse. This fact also proves that the period changes take place. It is necessary to mention that changes in period of the second overtone are within the errors of determination.

The Fourier coefficients of the observed oscillations for the same two data sets are presented in Table 3. The epoch of phase zero is JD2440000. The frequency $f_{120} = f_0 + 2f_1$ was not found when the observations had been divided into two sets.

4. Discussion

GSC 4018.1807 is a unique star. The only similar object known at present is the triple-mode pulsating variable AC And. Although the periods of AC And are typical for RR Lyrae type variables, Kovács and Buchler (1994) could not describe the observed oscillations with reasonable RR Lyrae models. In the majority of cases, investigators considered AC And as a Population I star with the mass about $1.3 - 3.1 M_\odot$ (Fitch and Szeidl 1976; Cox et al. 1977; Cox et al. 1978). Models show that the star with a greater period ratio has a greater stellar mass if chemical compositions of the two stars are the same and the fundamental mode periods are similar (see Peterson 1978). The new variable can be a Population I star (galactic latitude $b = +1^\circ.0$). So, it is possible that GSC 4018.1807 is a more massive star than AC And, as the period ratio ($P_1/P_0 = 0.7664$) is greater than the ratio for AC And modes ($P_1/P_0 = 0.7383$), and the difference in the fundamental mode periods (which would have the opposite effect) is not so considerable.

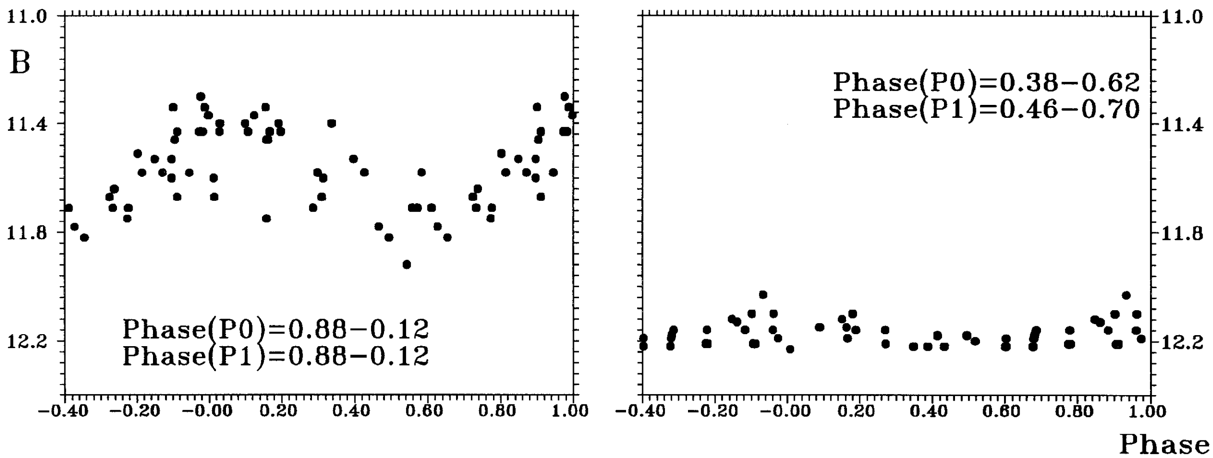

Fig. 5. The second-overtone phased light curves near the maxima of the fundamental and the first overtone modes (left) and near their minima (right).

Table 2. Changes in periods

	Number of obs.	Interval of obs., JD24...	P_0	P_1	P_2
First set	332	32853 – 39145	$0^d.668854$	$0^d.512638$	$0^d.411025$
Second set	563	40071 – 49633	0.668882	0.512655	0.411034
All data	895	32853 – 49633	0.668872	0.512646	0.411031

Table 3. Fourier coefficients for two data sets. The epoch of phase zero is JD2440000.

Oscillation			First set			Second set		
i	j	k	P_{ijk}	A_{ijk}	ϕ_{ijk}	P_{ijk}	A_{ijk}	ϕ_{ijk}
1	0	0	$0^d.668854$	$0^m.124$	0.08	$0^d.668882$	$0^m.131$	0.12
0	1	0	0.512638	0.183	0.99	0.512655	0.181	0.01
0	0	1	0.411025	0.066	0.04	0.411034	0.041	0.10
1	1	0	0.290209	0.059	0.95	0.290221	0.058	0.02
-1	1	0	2.19491	0.042	0.89	2.19490	0.044	0.79

The discovery of the variability of GSC 4018.1807 leads us to the next assumption. It is possible that young, rather massive stars, pulsating with the periods typical for the RR Lyrae type, exist in the Galaxy's disk. Relation of these stars to Cepheids or δ Scuti type stars is probable.

It is important to continue the observations of AC And and GSC 4018.1807 as well as theoretical research (mass determination, evolutionary status, relation to other types of the pulsating variables). The author wishes to turn special attention of the theoretical investigators to this group of stars.

5. Acknowledgements

The author would like to thank Dr. N.N. Samus for his help and attention to this research, to express gratitude to Drs. S.Yu. Shugarov and V.P. Goranskij for discussions and for software used for periods determination, and to Dr. L.N. Berdnikov for useful discussion. This study was partially supported by the Russian Foundation for Basic Research through grant No. 97-02-16739.

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