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A Photometric Study of the Double-Mode High-Amplitude δ Scuti Variable Star QS Draconis

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We present the results of our new observations of QS Draconis, a recently discovered double-mode high-amplitude δ Scuti variable, HADS(B) type. We analyzed our CCD BVR photometry for this star, improved the frequencies f_0 and f_1 and pulsation amplitudes, detected the interaction frequencies $f_1 + f_0$, $f_1 - f_0$, $2f_0$, and $f_1 + 2f_0$.

1 Introduction

In this paper, we present the results of our study of QS Draconis, a double-mode high-amplitude δ Scuti variable star, HADS(B) type. Its coordinates in the GCVS catalog (Samus et al. 2007–2012) are $15^{\rm h}21^{\rm m}34\overset{\rm s}{.}69$, $+61^\circ29'22\overset{''}{.}7$ (J2000.0).

The variability of QS Dra (GSC 4181-00046) was discovered by one of the autors (Khruslov 2007) from the publicly available data of the Northern Sky Variability Survey (NSVS, Wozniak et al. 2004). The variable was classified as a double-mode high-amplitude δ Scuti variable star, DSCT(B) type, pulsating in the fundamental and first overtone modes. Khruslov (2007) suggested the following light elements:

HJD(max) = 2451407.680 + 0.0944226 × E (fundamental mode) and

HJD(max) = 2451407.688 + 0.0730446 × E (first overtone mode).

The period ratio $P_1/P_0 = 0.7736$ is typical of double-mode HADS stars (Petersen & Christensen-Dalsgaard 1996).

In the present paper, we use a much longer series of observations that makes it possible to improve the periods and to detect new interaction frequencies, $f_1 + f_0$, $f_1 - f_0$, $2f_0$, and $f_1 + 2f_0$.

2 Observations

Our CCD observations in the Johnson BVR bands were performed at the Tien Shan Astronomical Observatory of the V.G. Fesenkov Astrophysical Institute, at the altitude of 2750 m above the sea level. The time span of the observations is JD 2456364–2456783. The observatory has two Zeiss 1000-mm telescopes. Most of our observations were performed with the eastern Zeiss 1000-mm reflector (the focal length of the system was $f = 13380$ mm before JD 2456500 and 6650 mm after this date; the detector was an Apogee U9000 D9 CCD camera). During the three last nights (JD 2456774, 2456781 and 2456783), we used the newly introduced western Zeiss 1000-mm reflector (the focal length of the system was 13250 mm, the detector being an Apogee F16M CCD camera).

Reductions were performed using the MaxIm DL aperture photometry package. The finding chart (Fig. 1) identifies the variable star, comparison star, and check star. The comparison star was GSC 4181-00052, $15^{\rm h}21^{\rm m}16\overset{\rm s}{.}04$ $+61°28'45\overset{''}{.}2$ (J2000.0), and the check star, GSC 4181-00443, $15^{\rm h}22^{\rm m}04\overset{\rm s}{.}16$ $+61°34'18\overset{''}{.}8$ (J2000.0). The magnitudes of the comparison star are $V = 14\overset{\rm m}{.}129$ and $B = 14\overset{\rm m}{.}529$ (Johnson's system) in the AAVSO Photometric All-Sky Survey (APASS, http://www.aavso.org/download-apass-data) catalog. The R-band magnitudes could be presented only as magnitude differences with respect to the comparison star.

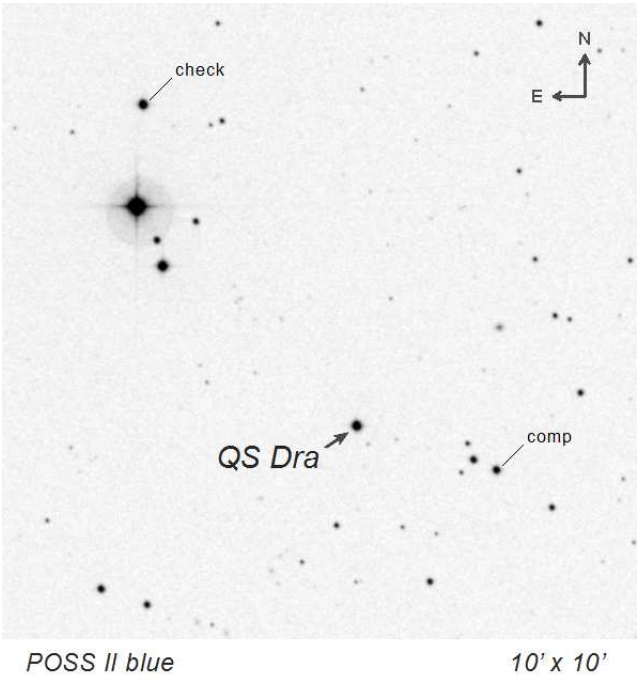

Figure 1.
The finding chart of QS Draconis.

Our observations are available online in the html version of this paper.

3 Results

We analyzed the time series using Deeming's method implemented in the WinEfk code written by V.P. Goranskij. Using our observations of QS Dra, we improved the frequencies f_0 and f_1, detected oscillations corresponding to interaction between f_0 and f_1: $f_1 + f_0$, $f_1 - f_0$, $2f_0$, and $f_1 + 2f_0$. The results are presented in Tables 1 and 2. Table 1 presents light elements of the oscillations f_0 and f_1. The epochs are given separately for each of the three BVR bands because of their being obviously different, especially for f_0 in the B band (the difference is 5 per cent of the period). The improvement of the elements was carried out using the R-band observations, in agreement with the NSVS data; we used the improved NSVS epochs HJD(MaxP_0) = 2451407.6840, HJD(MaxP_1) = 2451407.6894. Table 2 presents all detected frequencies and their amplitudes in B, V, and R bands.

Table 1. Light elements of the oscillations f_0 and f_1

Mode	Period, d	Epoch, HJD 2456565+		
		B	V	R
f_0	0.09442318	0.0738	0.0777	0.0783
f_1	0.07304432	0.0552	0.0555	0.0563

Table 2. Detected frequencies

Mode	Frequency, c/d	Period, d	Semi-amplitude, mag		
			B	V	R
f_0	10.590620	0.09442318	0.1188	0.1073	0.0814
f_1	13.690318	0.07304432	0.1152	0.1041	0.0852
$f_1 + f_0$	24.28086	0.0411847	0.0336	0.0272	0.0223
$f_1 - f_0$	3.0998	0.3226	0.0234	0.0196	0.0155
$2f_0$	21.18128	0.0472115	0.0204	0.0112	0.0088
$f_1 + 2f_0$	34.87155	0.02867667	0.0107	0.0040	0.0038

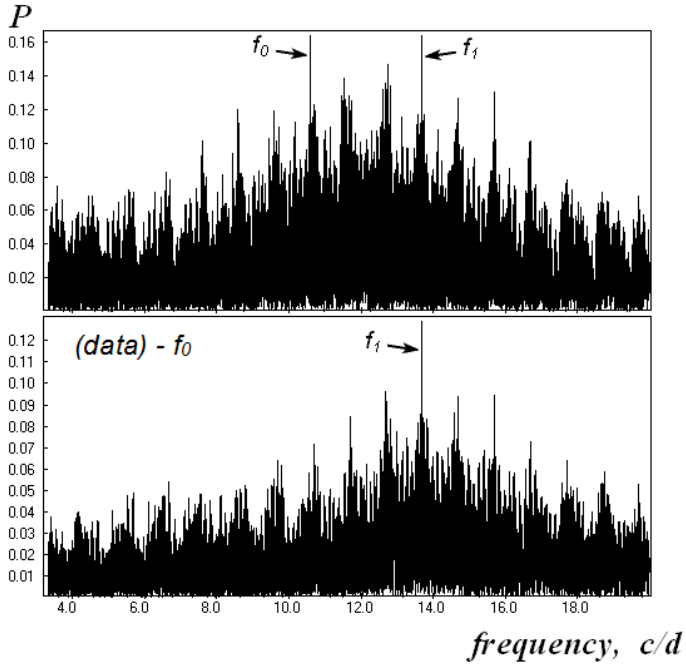

Figure 2.
The power spectra of QS Dra for the frequencies f_0 and f_1, B band.

The light curves of QS Draconis in the B, V and R bands are displayed in Figs. 3, 4, 5. Along with the light curves, we present power spectra of QS Draconis, for the raw data and after subtraction of the fundamental-mode oscillations (see Fig. 2).

The star varies within the following range: the B-band range is $12\overset{\text{m}}{.}71$ – $13\overset{\text{m}}{.}37$; the V-band range is from $12\overset{\text{m}}{.}63$ to $13\overset{\text{m}}{.}16$. The amplitude in the R band is $0\overset{\text{m}}{.}43$ (range from -1.25 to -0.82).

Figure 6 exhibits light-curve variations from one cycle to another during the same night, typical of high-amplitude double-mode δ Scuti variables.

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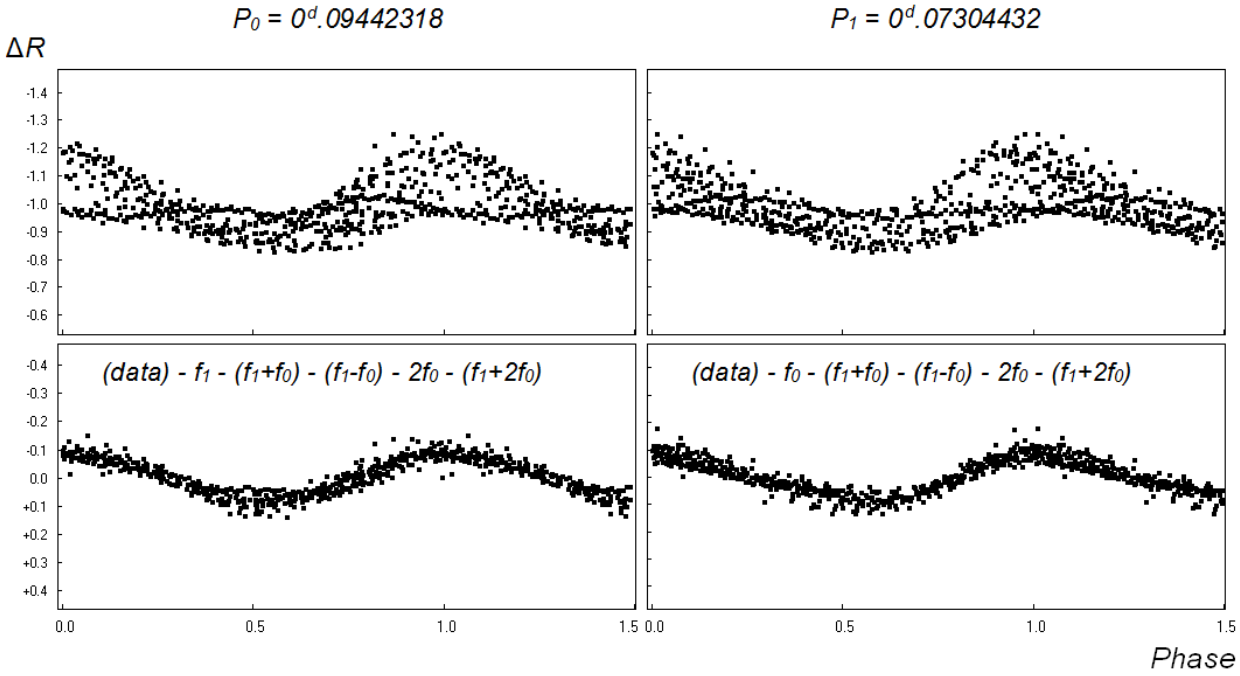

Figure 3.
The light curves of QS Dra, R band. Upper panels: raw data; lower panels: the folded light curves with the other oscillation pre-whitened.

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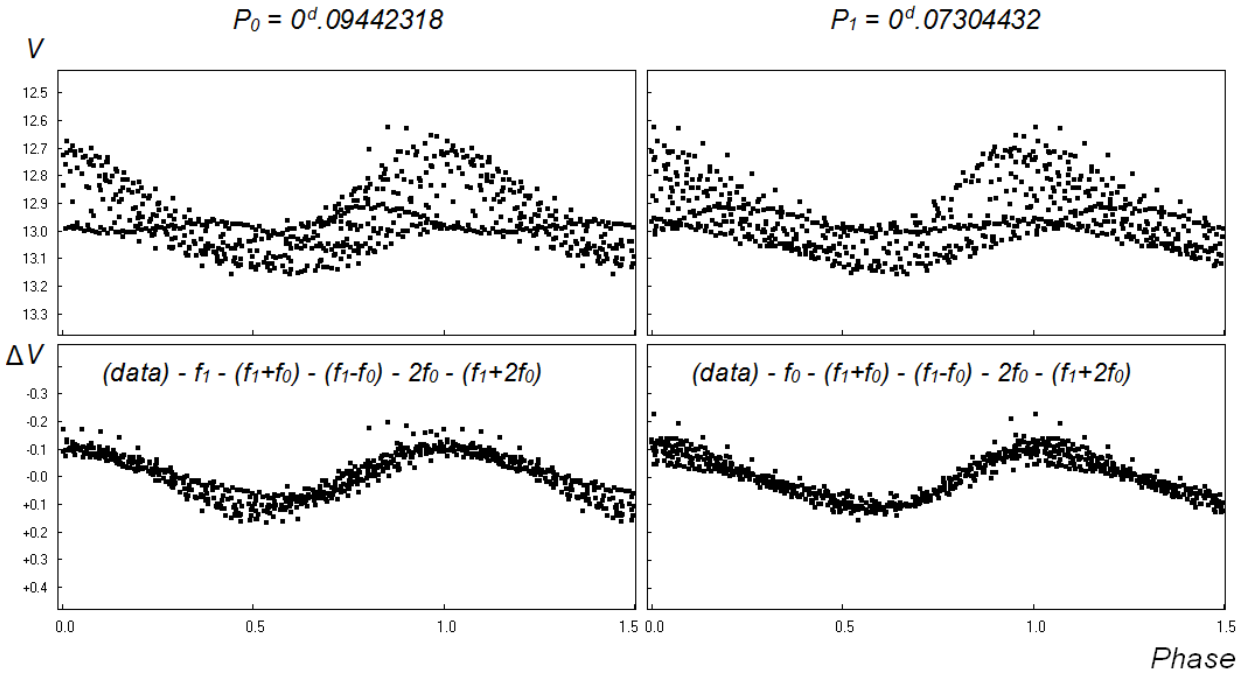

Figure 4.
The light curves of QS Dra, V band.

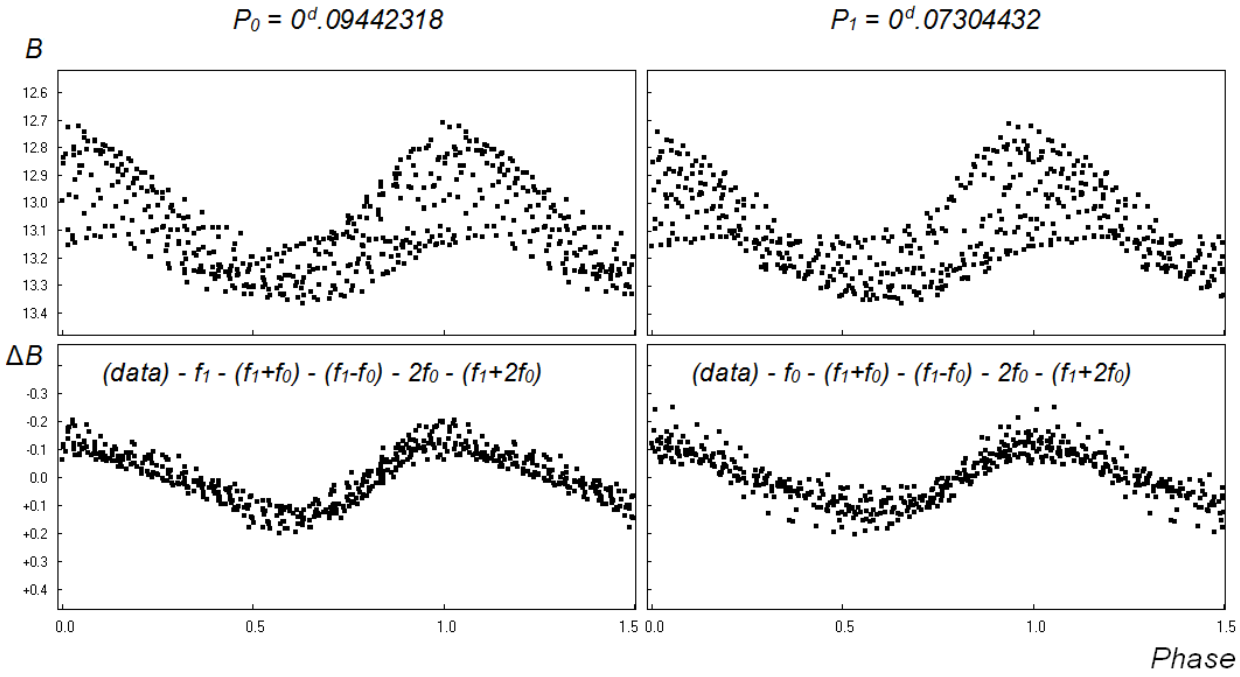

Figure 5.
The light curves of QS Dra, B band.

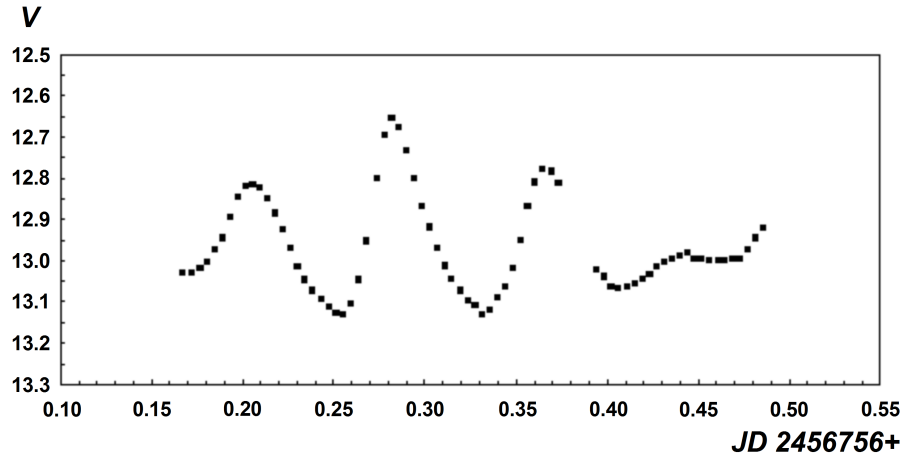

Figure 6.
Observations of QS Dra acquired during a single night of April 8, 2014 (JD 2456756).