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δ Scuti-type nature of the high-amplitude variable star GSC4619-450

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Abstract

We present the results of spectroscopy and B, V CCD photometry carried out from 2003 to 2005 of GSC4619-450, a high-amplitude pulsating variable discovered by Zhang et al., [Zhang, X.B., Deng, L., Zhou, X., Xin, Y., 2004. MNRAS, 355, 1369]. From this study, the star is classified as a high-amplitude δ Scuti star. A Fourier analysis based on the *B* and *V* photometric data indicates that GSC 4619-450 is a mono-periodic radial pulsator, with a period of 0.13341195 days. From a short time line we find that the pulsating period of this star is increasing rapidly with a rate of 9.1×10^{-2} s/yr, and is thus suggested to be highly evolved and undergoing rapid evolving at the present time. A spectral type of F0 is assigned to the variable considering the results from both the spectroscopy and photometry.

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Keywords: Stars: variable: δ Scu – stars: oscillation – technique: photometry; Spectroscopy – stars: individual (GSC4619-450); Variables; Pulsation; δ scuti; Photometry and spectroscopy

1. Introduction

GSC 4619-450 ($\alpha_{2000} = 01{:}08{:}01.2$, $\delta_{2000} = +84{:}47{:}24.7$, $V = 13.5$ mag) is a short-period, high-amplitude pulsating variable recently discovered by us (Zhang et al., 2004) through a wide-field CCD photometric survey for variable stars in the old open cluster NGC 188 region. The star is located outside the cluster and is identified as a field variable. According to the shape of light variations, the very short pulsating period (about 0.133 days) and the BATC e-i color (see Zhang et al., 2004 for details), it was preliminarily designated as a β Cephei star. Considering the variations in both filters, we found that the amplitudes, $\Delta i = 0.33$ mag. and $\Delta e = 0.54$ mag., are too large compared with regular values in β Cephei variables. Thus this variable remains uncertain in classification, and its properties make it particularly interesting.

In order to investigate the pulsating nature of GSC4619-450 in detail, follow-up observations, including spectroscopy and time-series CCD photometry of this star were carried out from 2003 to 2005. In this paper, we present the results of these observations. Based on the new observations, the classification and physical nature of the variable are discussed.

2. Observations

Photometric observations of GSC4619-450 were secured on eight nights between 2003 December and 2005 October, using the 60 cm reflector located at the Xinglong station of the National Astronomical Observatories, Chinese Academy of Sciences. Data were collected with a Princeton Instruments VersArray 1204B XP 1024×1024 (12μ) CCD camera, which provides a field of view of about $20' \times 20'$, corresponding to a image scale of about $1''.2$/pixel. Broadband B and V filters were used. For the B-band measurements, the exposure time was set at 120 or 180 s, and that for V images varied from 90 to 300 s, according to weather condition. In total, we got 505 CCD images in B and 720 frames in V band. Details of the CCD photometry are given in Table 1.

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Table 1
Journal of CCD photometry of GSC4619-450

Date	HJD(2450000+)	Filter	Points
2003 Dec. 19	2992.98–2993.25	B, V	92
2003 Dec. 20	2993.93–2994.25	B, V	179
2003 Dec. 21	2994.99–2995.24	V	83
2003 Dec. 22	2995.95–2996.24	V	120
2005 Sept. 26	3640.01–3640.14	B, V	98
2005 Oct. 03	3647.02–3647.36	B, V	196
2005 Oct. 04	3648.03–3648.34	B, V	206
2005 Oct. 07	3651.03–3651.39	B, V	251

A preliminary processing of the CCD frames was performed with the standard routines in the IRAF/CCDPROC package. Photometry was extracted using the DAOPHOT package (Stetson, 1987). For the purpose of differential photometry, we used GSC4619-369 ($\alpha_{2000} =$ 01:11:37.3, $\delta_{2000} = +84{:}39{:}01.7$, $V = 12.50$) as the comparison star, while GSC4619-1113 was employed as the check star. The standard deviation of the differential magnitude between the comparison and check stars is better than 0.01 mag in each observation night. Atmospheric extinction was ignored considering the proximity of the program stars. In this way, all the measurements of GSC4619-450 were extracted. The time of all measurements were converted to Heliocentric Julian date. A further calibration was made by adopting the star GSC4619-1518 ($B =$ 10.71, $V = 10.67$, derived from the TYC-2 catalogue, Hog et al., 2000) as a standard which had been followed for more than 200 times along with the above program stars in the 2005 observations.

The spectroscopy was taken on January 8, 2004 with the 2.16 m telescope also at the Xinglong station. The spectra were obtained by using a zeiss universal spectrograph which provides a reciprocal dispersion of 200 Å mm^{-1}. A Tektronix 1 k × 1 k CCD was used as detector, and He–Ar lamp was used for wavelength calibration. The exposure began at UT 14:23:54. With the exposure time of 900s, the HJD time corresponding the mid-exposure is 24530013.1054. The spectrum was reduced following the usual procedures with the IRAF package.

3. Results and discussions

In Fig. 1, we present the time-series B and V light curves. The rapid and high-amplitude pulsating-like variations are clearly shown. This confirms the discovery reported before. The Zeiss 1-D spectrum of GSC4619-450 is plotted in Fig. 2. It shows that the variable could not be a early B star as claimed in our earlier work. A spectral type of F4 was further assigned to the star. As such, the variable could not be classified as a β Cephei-type but an RRc or δ Scuti star. Considering the quite short period of its light variation, GSC4619-450 is very likely a high-amplitude δ Scuti star.

To investigate the nature of oscillation of GSC4619-450, we merged all the data obtained so far in both B and V band, and carried out a frequency analysis using the algorithm Period04 (Lenz and Breger, 2005). Following Breger et al. (1994), we selected only those peaks with amplitude signal–noise (S/N) larger than 4.0 for further discussion. The noise levels at each frequency were computed using the residuals from the original data when all the trial frequencies were pre-whitened.

In Fig. 2 we present the spectral window as well as the step-by-step amplitude spectra conducted from each of the B and V data. Each spectrum panel in the figure corresponds to the residuals with all the previous frequencies pre-whitened. The bottom two panels show the final residuals of the B and V data, in which the dashed lines represent the confidence curve with S/N = 4.0. Table 2 gives the main results of frequency analysis. Based on these results, fittings to the observed B and V light curves were made as shown in Fig. 3. It is clear that the synthetic light curves seem to reproduce the observations satisfactorily.

The Fourier analysis yields six peaks with S/N larger than 4.0 in both the B and V data. Among which, the first peak at $f = 7.49559$ c/d, corresponding to a pulsating period of 0.1344118 days, obviously dominates the original amplitude spectra of both the B and V data. The other five frequencies can be identified as the 2nd to 6th harmonics of the primary frequency. It suggests that the variable could be pulsating strictly in single frequency. This also supports our classification of the variable since the mono-periodicity is common in high-amplitude δ Scuti stars (Rodriguez et al., 1997). The frequency feature also shows that the star is in radial pulsating with the fundamental frequency at $f_0 = 7.49559$ c/d. The other five derived frequencies can be interpreted as $2f_0$, $3f_0$, $4f_0$, $5f_0$ and $6f_0$). Applying the formula $Q = P(\rho/\rho_\odot)^{1/2}$, and taking $Q = 0.03277$ (Fitch, 1981), the mean density of the star could be estimated as $\rho/\rho_\odot = 0.06$. This value is quite smaller than that of the normal F-type stars. It indicates that the star GSC4619-450 is a highly evolved δ Scuti variable.

The new data set completely covered 15 light maxima, the corresponding timings were determined by applying polynomial fits to the light curves. In the same way, seven times of light maxima were derived from the 2002 BATC data. For those detected in two colors (B & V or i & e), we take the average values. All these times of maximum light are listed in Table 3. With these data, a classical O-C method is applied so as to study the probable period changes. Adopting a initial epoch $T_0 = 2453651.1362$ (the data has the best precision) and $P = 0.1334117$ derived from the frequency analysis, we got the following linear and quadratic ephemerides:

$$HJD_{\mathrm{Max}} = 2453651.1358(4) + 0.13341136(8)E$$
$$HJD_{\mathrm{Max}} = 2453651.1365(1) + 0.13341281(9)E + 1.93(11) \times 10^{-10}E^2$$

The O-C residuals for all the times of maximum light with respect to the linear and quadratic ephemerides are given in Table 3. In Fig. 4, we present the O-C diagram of the period analysis. It strongly suggests that the star