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GSC 2701-2527, a new multiperiodic high-amplitude Delta Scuti variable

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Abstract. Our BVI photometric observations reveal that GSC 2701-2527 is a high-amplitude δ Scuti star with quite low temperature. The frequency analysis exhibits that it is multiperiodic pulsator. The obtained period ratio f_1/f_2=0.791 is higher than the canonical value. The large value of the period ratio f_1/f_3=0.813 implies nonradial nature of the third mode. Using empirical relations for the δ Scuti stars we determined the global parameters of GSC 2701-2527: luminosity 26.2 $L_\odot$, radius 3.95 $R_\odot$, mass 2.18 $M_\odot$, and distance 506 pc.

Keywords : methods: observational – methods: data analysis – stars: variables: δ Scuti – stars: fundamental parameters – stars: individual GSC 2701-2527

1. Introduction

The δ Scuti stars are short-period pulsating variables located at the intersection of the classical Cepheid instability strip with the MS with periods between 0.02 d and 0.25 d, masses from 1.0 $M_\odot$ to 3.0 $M_\odot$, radii from 1.2 $R_\odot$ to 6.1 $R_\odot$ (McNamara 2000) and spectral types from A to F. The δ Scuti stars are dwarfs or subgiants that have not yet reached the red giant branch with $\log g$ between 3.4 and 4.4 (McNamara 2000; Alcock et al. 2000).

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Nowadays it is assumed that the δ Scuti stars pulsate with a large number of radial and nonradial modes and represent a transition between the Cepheid-like large-amplitude radial pulsation of the instability strip and the nonradial pulsation occurring in the hot half of the HR diagram (Dawson et al. 1995; Breger et al. 1999; Breger 2000). Due to their low-order acoustic and gravity modes (driven by the opacity mechanism acting mainly in the HeII ionization zone) the δ Scuti stars are considered as excellent probes for study of the stellar interiors.

The observations before several decades revealed that the low amplitude δ Scuti stars (LADS) show a large variety of nonradial modes and complex light variability (multiperiodicity, close doublets of frequencies, amplitude variations, etc.) while the high amplitude δ Scuti stars (HADS) were thought as classical radial pulsators, mostly monoperiodic (double mode in some cases, but always radial modes). But recent observational studies show that many HADS stars are also multiperiodic variables or undergo simultaneously radial and nonradial pulsations (Walraven et al. 1992; Garrido & Rodrýguez 1996; Arentoft et al. 2001; Zhou 2002; Poretti 2003; Poretti et al. 2005). The only remarkable difference is that the nonradial modes in HADS stars have a much smaller amplitude (order of magnitudes) than the radial modes and that period and amplitude variations can be considered as small perturbations of a mode always clearly visible in the light curve.

Therefore, nowadays the phenomenology of the HADS stars becomes similar to that of the LADS stars and their role for the asteroseismology increases. Moreover, since HADS stars obey a period-luminosity (P-L) relation, they are used as standard candles to find distances (McNamara et al. 2007). Therefore, any new detection of a HADS star can be a valuable contribution to the asteroseismology and astrophysics.

Due to the short periods, detectable photometric amplitude (ranging from 0.01 mag to several tenths) as well as the high luminosity (absolute magnitudes ranging from 0.4 to 2.5), the oscillations of the δ Scuti stars can be detected from the ground.

A list of pulsating δ Scuti stars can be found in the catalogs of Rodriguez et al. (2004) and Garcia et al. (1995) while lists of pulsating δ Scuti stars in stellar systems are given by Lampens & Boffin (2000) and Soydugan et al. (2011). Recently the discovery of new δ Scuti stars has been accelerating due to large observing programs such as HIPPARCOS, MACHO, ASAS, OGLE, etc.

Applying our code (Dimitrov 2009) for stellar variability detection, several hundred δ Sct candidates were identified from surveying of the NSVS data base. One of them was the object NSVS 8611544 = NSVS 8666435 (also identified as GSC 2701-2527, SAO 70932, BD+30 4323, TYC 2701-2527-1, 2MASS J21070986+3052346, SWASP J210709.87+305234.6). Further we will use the designation GSC 2701-2527.

This paper presents our observations of GSC 2701-2527 and the analysis that allowed us to conclude that it is a HADS variable and to estimate its modes and some global parameters.

2. Observations and data reduction

2.1 The previous observations

The target GSC 2701-2527 has been used as a field (nonvariable) star for determination of the color excess of the Cepheid DT Cyg by Feltz & McNamara (1976) who determined V=9.74 mag, b-y=0.329, E(b-y)=0.093, distance 320 pc. The star is noted as variable by Bernhard & Srdoc (2011).

We found photometric unfiltered (close to R band) data of the target in the NSVS database (Wozniak et al., 2004) as well as SuperWASP database (Pollacco et al. 2006; Butters et al. 2010). The periodogram analysis of these data allowed us to derive the ephemeris

$$HJD(Max) = 2454274.7665247(10) + 0.149427(5) * E. \quad (1)$$

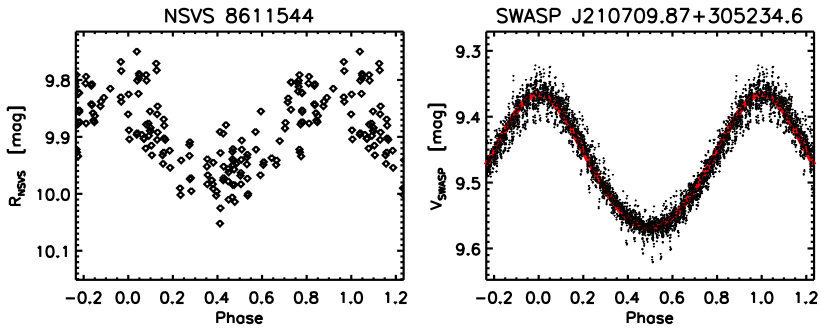

Figure 1. The folded light curves of the NSVS and SWASP data

We phased the NSVS and SWASP data with the ephemeris (1). The shape of the folded light curves (Fig. 1) as well as the derived period implied a δ Scuti star classification.

2.2 Rozhen observations and their preliminary analysis

Our CCD photometric observations of GSC 2701-2527 in BVI bands were carried out on 2010 August 25 at the Rozhen National Astronomical Observatory with the 60-cm Cassegrain telescope using the FLI PL09000 CCD camera (3056 × 3056 pixels, 12 μm/pixel, field of view 27.0 x 27.0 arcmin with focal reducer). The exposures were 40 s in B, 30 s in V, and 20 s in I band. The average photometric precision per data point was 0.01 mag.

The standard *IDL* procedures (adapted from *DAOPHOT*) were used for reduction of the

Table 1. Coordinates, magnitudes and colours of the target and standard stars

Star	GSC ID	RA (2000)	DEC (2000)	V	B-V	V-I	Sp type
Var	2701-2527	21 07 09.87	30 52 34.6	9.64	0.39	0.47	F2
C1	2701-2385	21 07 42.96	30 46 55.9	9.88	0.27	0.30	
C2	2701-2191	21 06 47.78	30 49 39.2	10.79	0.30	0.34	
C3	2701-1362	21 07 30.19	31 02 42.6	9.27	-0.06	-0.10	A0
C4	2701-2362	21 07 12.51	30 49 16.3	11.32	1.08	1.17	
C5	2701-2063	21 07 30.27	30 57 54.6	11.75	0.60	0.71	

photometric data. For transition from instrumental system to standard photometric system we used standard stars of Landolt (1992) and standard fields of Stetson (2000). The standard stars in the observed field (Fig. 2) were chosen by the criterion to be constant within 0.01 mag during the observations in all filters. Table 1 presents their magnitudes and colors V, B-V, and V-I from the NOMAD (Zacharias et al. 2004) and USNO-B1 catalogs while the spectral types are from the SIMBAD database.

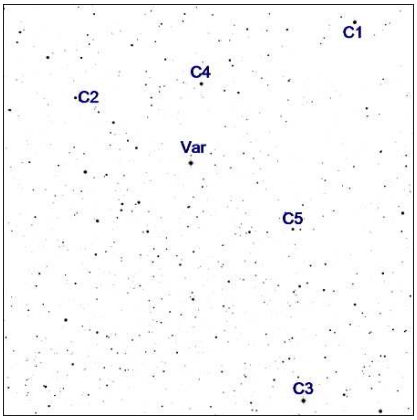

Figure 2. The field of GSC 2701-2527

Rozhen observations of GSC 2701-2527 cover more than two light cycles and Fig. 3 presents the folded light curve phased according to the ephemeris (1).

A low-dispersion spectrum of the target (Fig. 4) was obtained on 2011 May 21 by using the focal reducer FoReRo2 attached to the 2-m telescope at Rozhen. CCD camera VersArray 512, grism with 300 lines/mm and slit width of 0.11 mm were used. The spectrum covers the range 5500-7100 A. Its reduction was performed using IRAF packages by bias subtraction, flat fielding, cosmic ray removal, one-dimensional spectrum extraction and wavelength calibration. Emission lines of a Rb source were used for wavelength calibration.

We classified the target on the basis of several considerations.

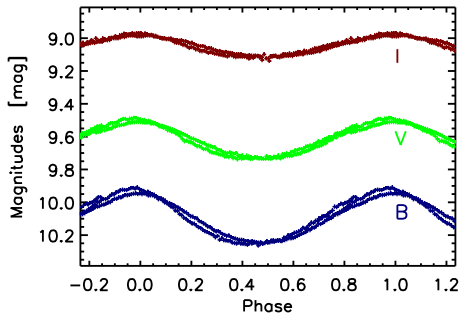

Figure 3. The Rozhen folded light curves of GSC 2701-2527

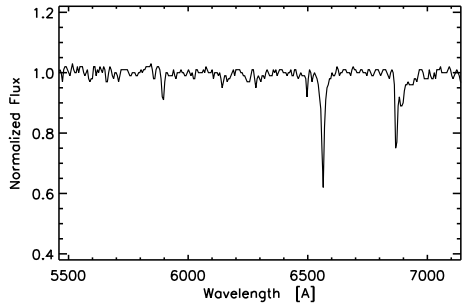

Figure 4. Low-dispersion spectrum of GSC 2701-2527

(a) The folded light curves reveal round minimum, relative sharp maximum (Figs. 4 and 5) and asymmetry that are typical for a δ Scuti star. Moreover, all attempts to model the GSC 2701-2527 light curves by eclipses of close binary configuration turned out unsuccessful.

(b) The derived period 0.149427 d is appropriate for a δ Scuti star.

(c) The lack of a exact repeating of the variability even during the two consecutive light cycles (Fig. 5) is typical for a δ Scuti star.

(d) GSC 2701-2527 becomes redder at the light minima and bluer at the light maxima (Fig. 5) similarly to the δ Scuti stars.

(e) The mean light variability amplitudes of GSC 2701-2527 in B, V and I filters are correspondingly 0.33±0.01 mag (range 10.25-9.92 mag), 0.25±0.01 mag (range 9.74-9.49 mag) and 0.15±0.01 mag (range 9.11-8.96 mag). This means that the target belongs to the HADS-subtype.

(f) The comparison of the low-dispersion spectrum of GSC 2701-2527 (Fig. 4) with those of spectral standards (Jacoby & Hunter 1984) led to the conclusion that our target is of F0-F3 spectral type, suitable for a δ Scuti star. Its color index B-V=0.39 corresponds to temperature around

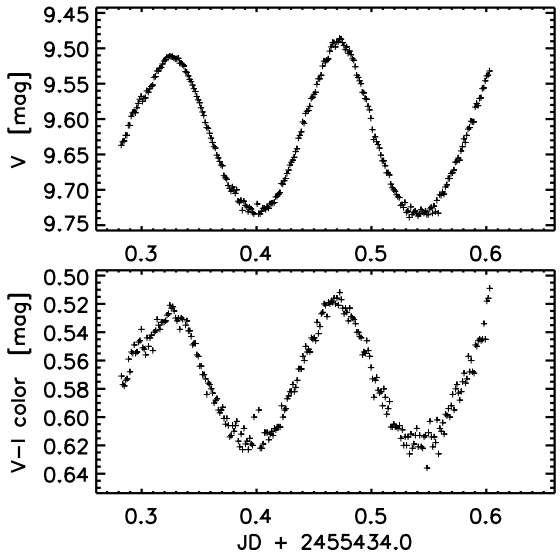

Figure 5. The V light curve of GSC 2701-2527 together with the color curve $V - I$

6600 K. This means that GSC 2701-2527 is one of the coolest δ Scuti stars and its temperature is quite low even for a HADS type star (see Table 2 and Figure 2 of McNamara 2000).

All these results support the suggestion that GSC 2701-2527 is a δ Scuti variable.

3. Frequency analysis

To determine the pulsation modes of GSC 2701-2527 we carried out detailed frequency analysis of the all available data (SWASP, NSVS, Rozhen) by the software *PerSea* Version 2.6 (written by Maciejewski www.astri.uni.torun.pl/~gm/software.html based on the *ANOVA* technique (Schwaezenberg−Czerny 1996)) and obtained the following results.

(1) The term $f_1 = 6.69223$ d^{-1} has a dominant contribution in the light variability (Fig. 6 left). This periodicity is characterized by a weak asymmetry and its harmonics $2f_1$, $3f_1$, and $4f_1$ have small amplitudes (see Table 2).

(2) The removing of the effect of the term $f_1 = 6.69223$ d^{-1} allows to exhibit the contributions of the next terms (right panel of Fig. 6). The amplitudes of the second term $f_2 = 8.46247$ d^{-1} and of the third term $f_3 = 8.228218$ d^{-1} turned out to be comparable and much smaller than that of first term (Table 2).

(3) The obtained period ratio of the two first terms, f_1/f_2=0.791, is higher than the canonical

Table 2. Results of the frequency analysis of GSC 2701-2527

term	freq [d^{-1}]	amplitude [mag]	f_1/f_N
f_1	6.69223	0.201268	
$2f_1$		0.015042	
$3f_1$		0.002868	
$4f_1$		0.000540	
f_2	8.46247	0.015814	0.791
$2f_2$		0.000980	
$3f_2$		0.000992	
$4f_2$		0.000358	
f_3	8.228218	0.014202	0.813
$2f_3$		0.000982	
$3f_3$		0.000036	

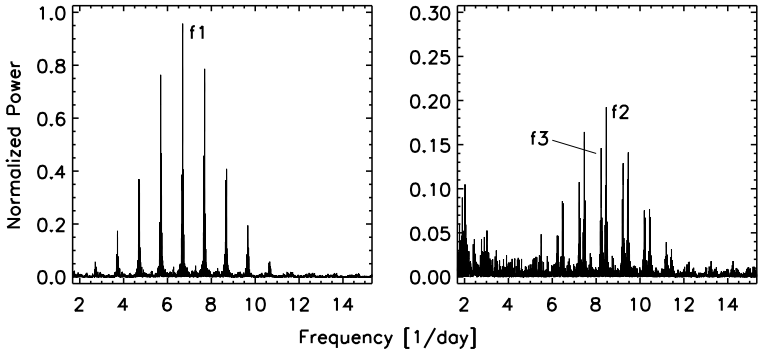

Figure 6. Power spectra of the SWASP data of GSC 2701-2527

0.77−0.78 value corresponding to the ratio of the frequencies of the fundamental (F) and first overtone (1O) radial mode (the value 0.77 corresponds to metal-strong stars with Z~0.01 while the value 0.78 to metal-poor stars with Z~0.001). The obtained value 0.791 of our target is also bigger than the mean empirical period ratio 0.772 for the double mode HADS stars (Poretti et al. 2005) which are thought to undergo radial pulsations. However, there are other examples of HADS stars with bigger value of the period ratio than the expected one (Poretti 2003): V974 Oph (0.786); MACHO 121.22427.551 (0.783); MACHO 114.20368.797 (0.790), V1162 Ori (0.795).

Two main hypotheses are proposed for explanation of the deviations of the empirical period ratios from the standard value 0.77: (i) the radial modes of stars with different metallicity and/or stellar rotation; (ii) the second term is not radial mode (Poretti 2003). High-resolution spectral observations could solve this problem by evaluation of the influence of metallicity or the detection of line profile variations suggesting nonradial modes. Moreover, it was established that period ratios higher than 0.77 are admitted by models with masses above 2 $M_\odot$ (Poretti et al. 2008).

(4) The obtained period ratio f_1/f_3=0.813 is quite bigger than the expected value 0.616 for the 2nd overtone radial mode of δ Scuti stars (Breger 1979). But the value 0.813 of GSC 2701-2527 is almost the same as that found in the HADS star V974 Oph (0.807). Poretti (2003) interpreted the period ratio of V974 Oph by possible nonradial nature of the mode f_3. Due to the almost equal values of period ratios of f_1/f_3 of V974 Oph and GSC 2701-2527 we assume that the same explanation seems plausible also for our target. The much smaller amplitude of the term f_3 of GSC 2701-2527 compared with that of f_1 supports this assumption.

It should be pointed out that the ratios around 0.81 are rather near to the 0.80-0.81 ratio found in the double mode Cepheids pulsating with 1O and 2O radial modes as well as in some double-mode HADS stars (Musazzi et al. 1998).

Although the expectation of the red part of the instability strip to show a fundamental mode while the hotter variables to indicate overtone pulsations (Breger 1979) our cool δ Scuti target GSC 2701-2527 reveals multimode variability. The three obtained main frequencies are bigger than 5 d^{-1} and surely confirm the classification of GSC 2701-2527 as δ Scuti pulsator, particularly as a multiperiodic HADS star. Longer data strings are required to confirm the established pulsation modes.

4. Global parameters of the target

In order to obtain the global parameters of GSC 2701-2527 we used the following relations for the pulsating stars:

(a) Empirical period-luminosity relation of McNamara (2000) for HADS

$$M_V = -1.969 - 3.725 \log P \tag{2}$$

or that of McNamara et al. (2007) for solar type composition

$$M_V = -1.969 - 3.725 \log P \tag{3}$$

where P is in days;

(b) The masses M of the δ Scuti stars (in solar masses $M_\odot$) can be calculated from the relation (Cox 1999):

$$\log M = 0.46 - 0.10 M_{bol}; \tag{4}$$

(c) The main relation for the pulsating stars

$$P(\rho/\rho_\odot)^{1/2} = Q \tag{5}$$

where the pulsation constant Q depends on the physical parameters of the star by the expression (Breger & Bregman 1975)

$$\log Q = -6.454 + \log P + 0.5 \log g + 0.1 M_{bol} + \log T_{eff} \tag{6}$$

and the Q values are 0.033 and 0.026 days for the radial fundamental and first overtone modes, respectively (Breger 1990).

Using the foregoing empirical and theoretical relations we obtained estimates of some global parameters of GSC 2701-2527.

The relation (2) gives for the target M_V=1.12 mag. It should be noted that the $P - L$ relation of Poretti et al. (2008) gives almost the same value M_V=1.18 mag. Using the visual magnitude value V=9.74 (Table 1) we calculated a distance of d=506 pc to GSC 2701-2527.

Taking into account bolometric correction of BC=0.085 (appropriate for T=6600 K) we obtained the absolute magnitude of GSC 2701-2527 M_{bol}=1.205 mag. This value is almost in the middle of the absolute magnitude range 0.4-2.5 mag of the δ Scuti stars. The corresponding luminosity is L=26.2 $L_\odot$. Assuming T=6600 K we determined the target radius of R=3.95 $R_\odot$.

The mass of GSC 2701-2527 determined by the relation (3) is M=2.18 $M_\odot$. Thus, GSC 2701-2527 can be considered as a target supporting the supposition of Poretti et al. (2008) that period ratios f_1/f_2 higher than 0.77 are allowable for stars with masses above 2 $M_\odot$.

The surface gravity corresponding to the determined values of the target mass and radius is $\log g$=3.58. This value is slightly smaller than the value $\log g$=3.71 obtained by the empirical relation (4) for P=0.149427 d and Q=0.033. The surface gravity of GSC 2701-2527 is in the range 3.4 to 4.4 of $\log g$ for δ Scuti stars (Alcock et al. 2000).

5. Conclusions

The period value, light curve shape and amplitudes, color changes and spectral type are clear signs of GSC 2701-2527 belonging to the high-amplitude δ Scuti variables. It is one of the coolest δ Scuti stars with temperature around 6600 K. But the values of the other global parameters of GSC 2701-2527 (M_{bol} = 1.205 mag, L = 26.2 $L_\odot$, R = 3.95 $R_\odot$, M = 2.18 $M_\odot$) fall well in the ranges for δ Scuti stars.

The frequency analysis revealed that GSC 2701-2527 is a new example of a HADS variable with multiperiodic pulsations. The obtained period ratio f_1/f_2=0.791 is higher than the canonical value. The large value of the period ratio f_1/f_3=0.813 implies nonradial nature of the third mode. Additional observations are necessary for a more detailed study of these pulsation modes.

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