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Binary properties of subdwarfs selected in the GALEX survey

Adéla Kawka[1], Andrzej Pigulski[2], Simon O'Toole[3], Stéphane Vennes[1], Péter Németh[1], Andrew Williams[4], Lubomir Iliev[5], Zbyszek Kołaczkowski[2], Marek Stęślicki[2]

[1]*Astronomický ústav AV ČR, Ondřejov, Czech Republic*

[2]*Instytut Astronomiczny, Uniwersytet Wrocławski, Wrocław, Poland*

[3]*Australian Astronomical Observatory, Epping, Australia*

[4]*Perth Observatory, Bickley, Australia*

[5]*Institute of Astronomy, BAS, Sofia, Bulgaria*

Abstract. We describe our programme to identify and analyse binary stars among the bright subdwarfs selected in the Galaxy Evolution Explorer (GALEX) survey. Radial velocity time-series helped us identify subdwarfs with low-mass or compact stellar companions: We describe work conducted on the bright binaries GALEX J0321+4727 and GALEX J2349+3844, and we present a radial velocity study of several objects that include three new likely binaries. We also carried out photometric observations that allowed us to detect long period pulsations in the subdwarf components in two of the close binaries.

1. Introduction

Hot subdwarf stars are found at the blue end of the horizontal branch and are thought to evolve with a thin hydrogen envelope as a result of binary interaction. Approximately half of sdB stars are in close binary systems (e.g., Maxted et al. 2001; Morales-Rueda et al. 2003; Geier et al. 2011), either with a white dwarf or a cool main-sequence companion. This fraction of subdwarfs in close binaries can be explained by population synthesis studies such as those of Han et al. (2002, 2003). Their models evolve binary stars through either the common envelope or Roche-lobe overflow. On the other hand, single sdB stars could be the result of mergers of two low-mass helium white dwarfs.

Since the discovery of pulsations in sdB stars (Kilkenny et al. 1997), the internal structure of sdB stars has become accessible to inquiries. Using asteroseismology the mass and hydrogen envelope thickness have been determined for a number of hot subdwarfs (e.g., Randall et al. 2007; Charpinet et al. 2008). Such studies have shown that most sdB stars have masses between 0.4 and 0.5 $M_\odot$ and thin hydrogen envelopes ($\log M_{\rm H}/M_* \sim -4$).

We have identified a sample of bright subdwarf candidates using ultraviolet photometry from the GALEX all-sky survey and photographic magnitudes from the Guide Star Catalog (GSC2.3.2). Details of the selection criteria are described in Vennes et al. (2011). We have now obtained high-quality spectroscopic observations for ~170 hot subdwarfs and conducted model atmosphere analyses. Vennes et al. (2011) presented the results of their analysis of 52 subdwarfs from this sample that included measurements of their effective temperature, surface gravity and helium abundance. An analysis of the complete sample will be presented in Németh, Kawka, & Vennes (in preparation; see also these proceedings).

We have initiated a follow-up programme aimed at identifying new binary systems among confirmed hot subdwarfs in the GALEX sample. Our first results on two of these binaries, GALEX J0321+4727 and GALEX J2349+3844, were presented in Kawka et al. (2010). Here we report our progress in identifying and analysing the properties of subdwarfs in close binaries.

2. Observations

We observed several bright GALEX targets using the spectrograph at the coudé focus of the 2 m telescope at Ondřejov. We used the 830.77 lines/mm grating with a SITe 2030 × 800 CCD providing a resolution of $R = 13\,000$ and a spectral range from 6254 Å to 6763 Å (Šlechta & Škoda 2002). We also obtained spectra centred on Hα with the coudé spectrograph attached to the 2 m telescope at Rozhen Observatory. We used the 632 lines/mm grating with a SITe 1024 × 1024 CCD providing a resolution of $R = 28\,000$.

We have also started a similar programme in the southern hemisphere using the Wide Field Spectrograph (WiFeS, Dopita et al. 2007) attached to the 2.3 m telescope at Siding Spring Observatory (SSO). The first set of data was obtained between UT 2010 July 14 and 18. We used the B3000 and R7000 gratings in the blue and red, respectively.

We have obtained follow-up photometry for several of our targets with the 0.6 m telescope at Białków Observatory (7 objects) and 0.6 m telescope at Perth Observatory (46 objects). Here, we present a summary of observations of GALEX J0321+4727 and GALEX J2349+3844 that were obtained at Białków Observatory. GALEX J0321+4727 was observed during 6 nights between UT 2010 October 9 and November 14 and GALEX J2349+3844 was observed during 6 nights between UT 2010 October 9 and December 4.

3. Binary Parameters

We determined the radial velocities by measuring the centre of the Hα core. The velocities were adjusted to the solar system barycentre. Table 1 updates the orbital parameters for GALEX J0321+4727 and GALEX J2349+3844 that were originally presented in Kawka et al. (2010). Figure 1 shows the new radial velocity curves and residuals to the best-fitting sinusoidal curve. The residuals in the radial velocity curve of GALEX J2349+3844 show systematic deviations revealing an orbital eccentricity $e = 0.06 \pm 0.02$. The short orbital period of the binary implies that it must have evolved through at least one common envelope (CE) phase (Han et al. 2002). The CE phase is expected to circularize the orbit and therefore a measurable eccentricity is not expected for post-CE binaries. Edelmann et al. (2005) reported similar periodic residual patterns for a small number of close post-CE binaries containing a subdwarf also interpreted as

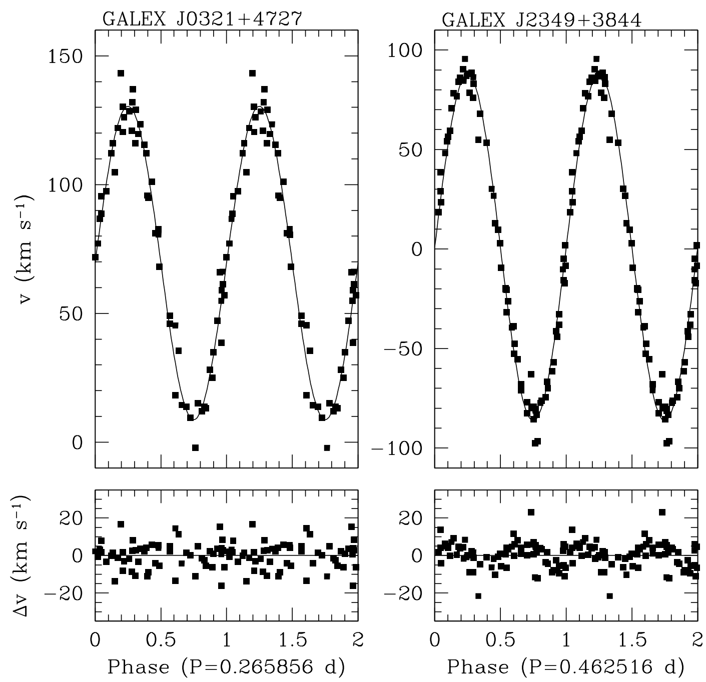

Figure 1. Radial velocity measurements of GALEX J0321+4727 and GALEX J2349+3844 phased on the orbital period. Radial velocity residuals in GALEX J2349+3844 reveal the eccentricity of the orbit.

Table 1. Binary parameters

Parameter	GALEX J0321+4727	GALEX J2349+3844
Period (d)	0.265856 ± 0.000003	0.462516 ± 0.000005
T_0 (BJD 2455000+)	45.583 ± 0.003	45.510 ± 0.002
K (km s^{-1})	60.8 ± 4.5	87.9 ± 2.2
γ (km s^{-1})	69.6 ± 2.2	2.0 ± 1.0
$f(M_{\rm sec})$ ($M_\odot$)	0.00619 ± 0.00009	0.03167 ± 0.00033
e	(0)	0.06 ± 0.02
$T_{\rm eff}$ (K)	27990^{+460}_{-400}	23770^{+330}_{-350}
$\log g$	5.34 ± 0.07	$5.38^{+0.05}_{-0.06}$
log (He/H)	$-2.52^{+0.17}_{-0.22}$	$-3.44^{+0.25}_{-0.30}$

orbital eccentricity. The eccentricity may be the result of past interaction with a third body or anisotropic mass-loss.

We determined the atmospheric parameters of the two subdwarfs by fitting them with synthetic spectra that were calculated using TLUSTY/SYNSPEC codes. For details of the fitting see Németh, Kawka & Vennes (these proceedings). The temperature and surface gravity for GALEX J2349+3844 have been remeasured using the complete Balmer line series. The temperature is 4700 K cooler and the gravity is 0.5 dex lower than originally estimated by Kawka et al. (2010) who relied on Hα only.

We have obtained spectroscopic observations of several other bright GALEX subdwarfs using the Ondřejov 2 m telescope and the 2.3 m telescope at SSO. Most of the objects do not show significant velocity variations, however there are a few interesting cases that deserve further observations. GALEX J2038−2657 is a hot sdO star with a G type subgiant (III-IV) (Németh et al. in preparation). We obtained two spectra, a day apart, that show variable Hα emission. Table 2 lists the number of spectra obtained for each star, as well as the average and dispersion of the velocity measurements. This sample also includes two subdwarf candidates (TYC4000-216-1 and TYC4406-285-1) from Jiménez-Esteban et al. (2011). We added to our sample the "constant" velocity star Feige 66 and adopted its velocity dispersion as representative of 1σ measurement uncertainty at Ondřejov.

Table 2. Summary of radial velocities for a sample of GALEX subdwarfs

Name	Site	N	$< v >$ (km s^{-1})	σ_v (km s^{-1})
GALEX J1526+7941	Ondřejov	5	5.2	25.0
GALEX J0639+5156	Ondřejov	8	98.9	22.0
GALEX J1348+4337	Ondřejov	6	-25.0	14.0
GALEX J1632+8513	Ondřejov	2	-47.9	9.1
GALEX J0747+6225	Ondřejov	8	-76.4	8.8
GALEX J1702+6353	Ondřejov	4	-12.9	8.2
GALEX J1600−6433	SSO	7	53.8	7.3
TYC4000-216-1	Ondřejov	18	36.3	7.1
GALEX J1902−5130	SSO	5	-111.0	5.2
GALEX J1911−1406	SSO	3	-151.9	4.9
TYC4406-285-1	Ondřejov	13	-24.7	4.6
GALEX J1753−5007	SSO	4	-59.8	4.3
GALEX J1736+2806	Ondřejov	21	-11.8	4.1
Feige 66	Ondřejov	10	-3.6	3.9
GALEX J1017+5516	Ondřejov	4	73.6	3.7
GALEX J1632+0759	SSO	2	-52.4	3.3
GALEX J2153−7003	SSO	5	43.0	1.2

Three objects show a dispersion in velocity measurements larger than 3σ including GALEX J0639+5156, which is also a V361 Hya pulsating subdwarf (Vučković et al. these proceedings). The most promising object that shows variable velocity measurements is GALEX J1526+7941. Although we have only obtained five exposures so far, the difference in velocity between two consecutive nights was ~60 km s^{-1}. GALEX J1911−1406 is a hot sdO star; we used HeIIλ 6560.09Å line to measure the radial velocities which do not appear to vary.

GALEX J1736+2806 is a composite sdB plus main-sequence G system (Vennes et al. 2011), and it does not show variability. This is one of the objects for which we obtained a reasonably large number of spectra over a period of two years. Therefore, either the binary is at a low-inclination, or more likely the system passed through a Roche-lobe overflow phase resulting in a wide binary with a long period ∼1000 days (Han et al. 2002).

4. Photometric variations

Based on an analysis of NSVS light curves GALEX J0321+4727 was reported to be photometrically variable (Kawka et al. 2010). The NSVS photometric measurements have relatively large uncertainties and were obtained sporadically, and, therefore, time-series photometry seems preferable. Photometric time series of GALEX J0321+4727 were obtained in *BVRI*. In allowing us to accurately phase the data with our new ephemeris, these time series confirmed the reflection effect of the subdwarf by the cool companion. Figure 2 shows the photometric measurements of GALEX J0321+4727 in the four bands folded on the best orbital period. As expected for the reflection effect, the highest amplitude variations are observed in the I band ($\Delta I \sim 0.08$ mag) and the lowest in the B band ($\Delta B \sim 0.04$ mag). The photometric observations also revealed weaker variations indicating that GALEX J0321+4727 is a pulsating subdwarf. Figure 3 shows the pulsation lightcurve after removing the variations due to the reflection effect. We were able to detect two frequencies in our data: ∼28.0 d^{-1} and ∼6.0 d^{-1} with the respective amplitudes of ∼1.3 mmag and ∼1.4 mmag.

Figure 4 shows the photometric V measurements of GALEX J2349+3844 revealing it to be a pulsating subdwarf. We detected three frequencies in our data: ∼16.5 d^{-1}, ∼12.2 d^{-1} and ∼9.1 d^{-1} with the respective amplitudes of ∼2.9, ∼2.8 and ∼2.2 mmag. The low frequencies place GALEX J0321+4727 and GALEX J2349+3844 among the group of slowly pulsating V2093 Her type subdwarfs (Green et al. 2003). GALEX J2349+3844 is at the red edge of the instability strip of V2093 Her pulsators, while GALEX J0321+4727 is closer to the blue edge.

5. Summary

We are currently conducting a radial velocity and photometric survey of the brightest hot subdwarf stars selected in the GALEX survey. With only two previously confirmed close binary systems, GALEX J0321+4727 and GALEX J2349+3844, our sample appears to have only a ∼10% success rate of detection. However, with the inclusion of the three potentially variable stars, this rate increases to ∼30%. The aims of the photometric survey are to identify new candidates for pulsation studies and for binarity via the detection of the reflection effect. We report the detection of pulsation periods of ∼1-1.5 hrs in the subdwarf stars GALEX J0321+4727 and GALEX J2349+3844. Therefore, the two stars belong to the V2093 Her class of pulsators (Green et al. 2003).

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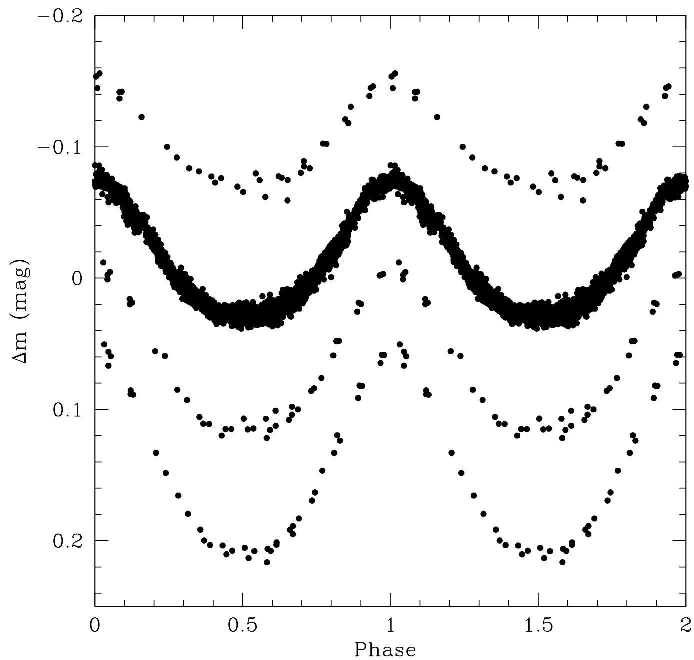

Figure 2. The photometry of GALEX J0321+4727 is phased on the orbital period determined from radial velocity measurements and shows the reflection effect. The photometric bands plotted from top to bottom are *B*, *V*, *R* and *I*.

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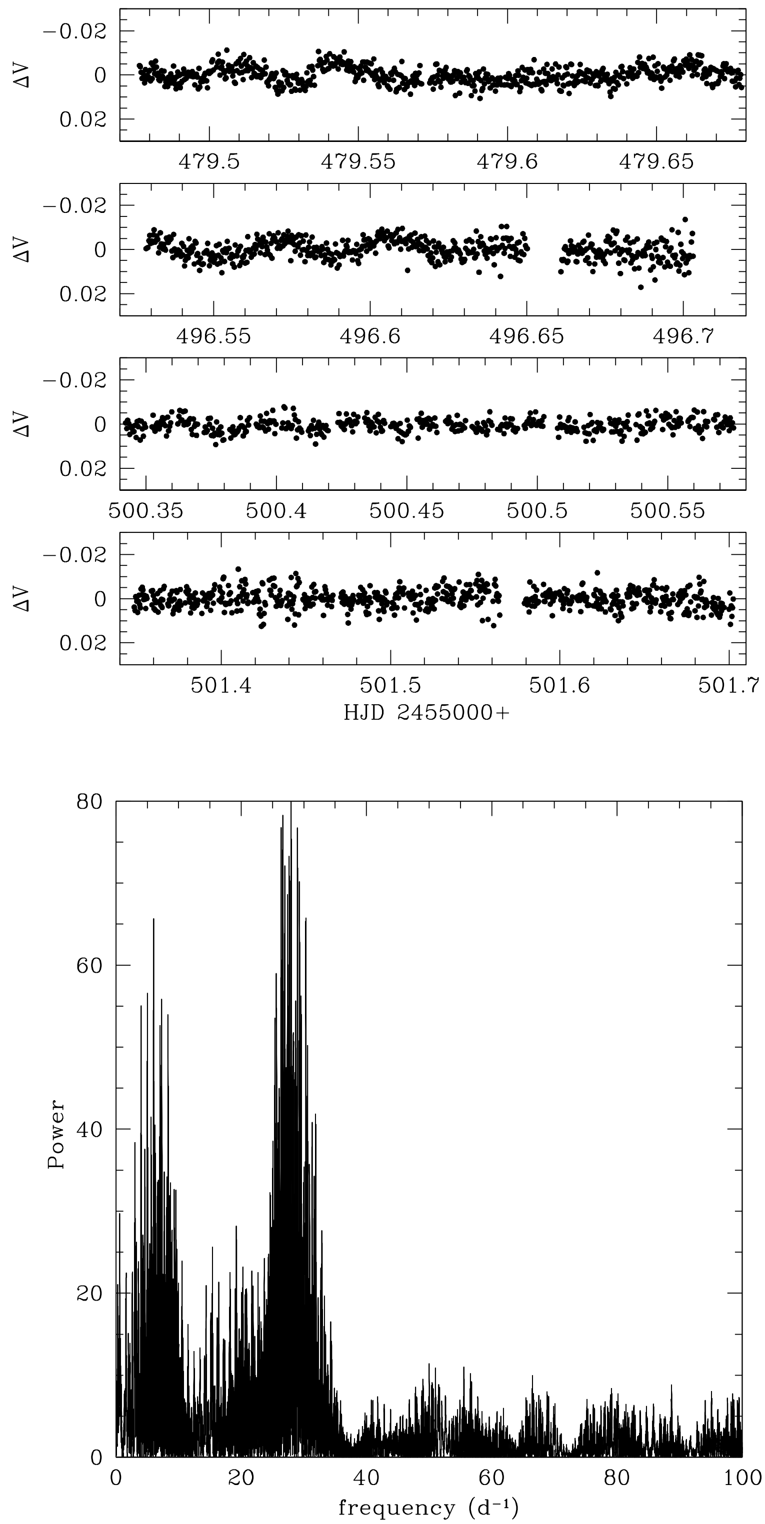

Figure 3. Photometry of GALEX J0321+4727 (*top*) with the reflection effect removed and the power spectrum (*bottom*) showing the main pulsation frequencies.

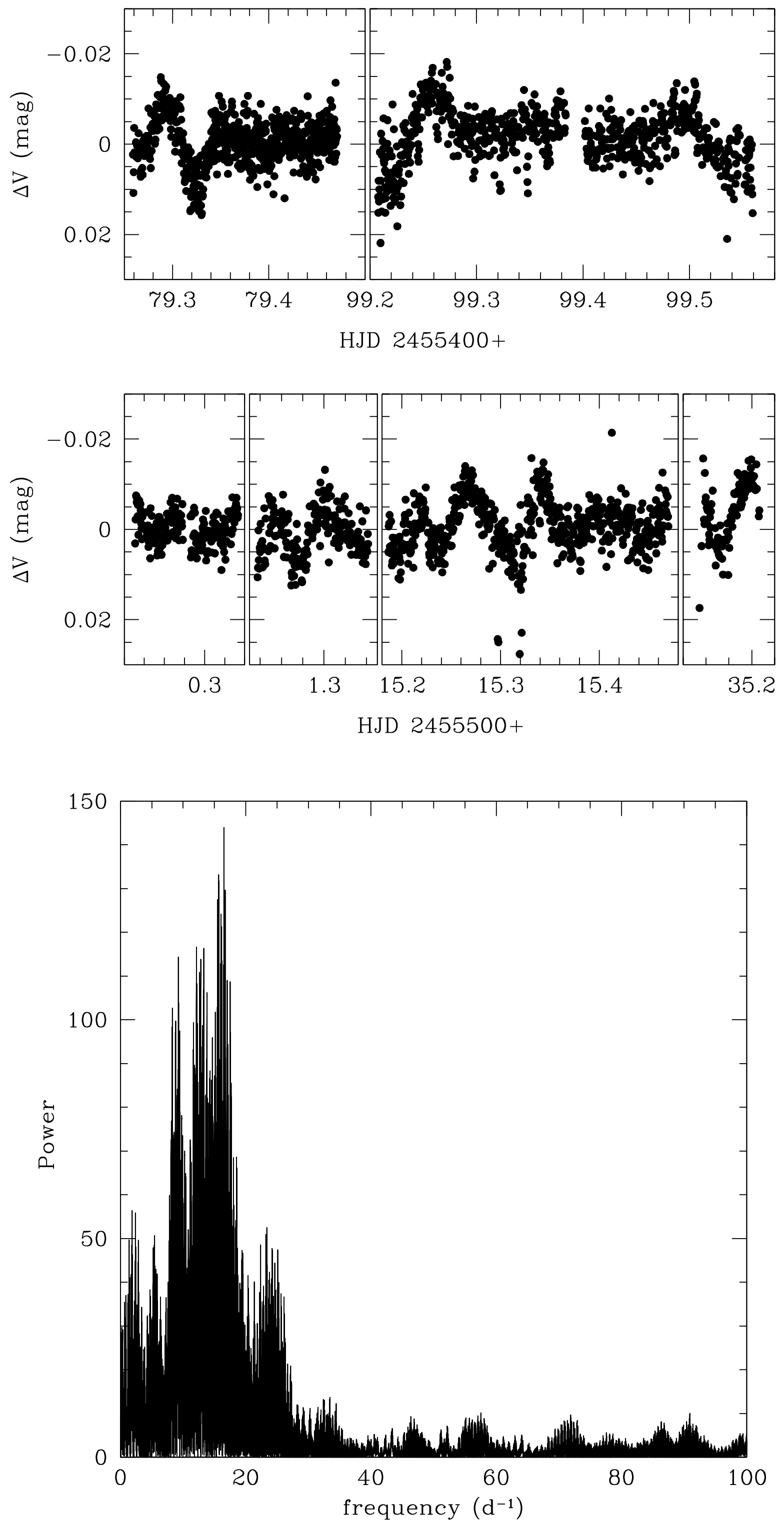

Figure 4. Photometry of GALEX J2349+3844 (*top*) and the power spectrum (*bottom*) showing the main pulsation frequencies.