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A search for variable stars in Trumpler 24

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Abstract. Trumpler 24 is a comparatively poorly-studied young open cluster. To investigate the correlation between the Be phenomenon and the cluster age, and to study the stellar variability in Trumpler 24, CCD time-series observations were made in 2001, and spectra were obtained in 2002. The results reveal 21 new variable stars, including 3 eclipsing binaries, no Be stars.

Key words. stars: variables: general – Galaxy: open clusters and associations: individual: Trumpler 24 – stars: emission-line, Be

1. Introduction

Since 1997 we have carried out several searches for new variable stars in open clusters (see Sterken et al. 2002). In this framework, two open clusters, NGC 6231 and NGC 7062, have already been observed photometrically with 17 and 15 new variable stars discovered, respectively (Arentoft et al. 2001; Freyhammer et al. 2001). Trumpler 24 is a young cluster of the association Sco OB1, which is an extended system with a rich variety of O- and early B-type stars (Perry et al. 1991). Seggewiss (1968) made a photoelectric study of Trumpler 24 to limiting magnitude $V \sim 9$. He suggested to subdivide Trumpler 24 into 3 subgroups. Heske & Wendker (1984) observed Trumpler 24 in 1983 using *UBV* photometry for stars of magnitude 7–14 and determined a cluster age of 10 Myr. Heske & Wendker (1985) carried out further photometric and spectroscopic observations of Trumpler 24 in 1984, listing 24 new possible variable stars. However, no period information of the variables in Trumpler 24 is given in the literature.

In the present paper, we give the results of our CCD time-series observations for Trumpler 24 in 2001 and spectrographic observations in 2002.

2. Observations and data reduction

2.1. Photometry

Subgroup III of Trumpler 24 (as defined by Seggewiss 1968) was observed between 3 and 9 July 2001 using the Polish 1.3 m telescope at Las Campanas Observatory in Chile. Two segments of 4096 × 2048 pixels (CCD chips 5 and 6) of the CCD array were used. 612 frames were collected in the Johnson *B* band but only 596 good-quality frames were analysed. Figure 1 shows the observed field of Trumpler 24.

The frames were bias-corrected and flat-fielded, and magnitudes of 267 stars in the field were extracted using the `MOMF` (Multi-Object-Multi-Frame) code (Kjeldsen & Frandsen 1992) involving Point-Spread Function/Aperture photometry. Different sequences of apertures were applied to stars of different brightness in order to optimise the point-to-point scatter. Then, differential magnitudes were calculated with respect to a mean light level of each frame, with weights inversely proportional to the point-to-point scatter in the nightly time series. The light curves for all 267 stars were obtained afterwards.

2.2. Spectroscopy

Spectra of 11 variable stars of Trumpler 24 were obtained with the R-C spectrograph at the 1.5 m CTIO telescope during October 9–11, 2002. Most stars were observed with grating 26, at a spectral resolution of 3.8 Å in the wavelength range 3700–5470 Å. A few stars were observed with grating 36, at 1.9 Å spectral resolution in the wavelength range 5765–6694 Å. Both setups included a slit width of 2 arcsec, larger than the average seeing disk size as seen in the focal plane of the telescope, viz. 1.5 arcsec. The standard stars LTT 7987 and LTT 2415 were observed every night providing spectrophotometric calibrations. For HD 322449, GSC 7872 2262 and star V15 (see Table 1) we obtained blue and red spectra and for GSC 7872 2362 only one red spectrum was obtained. For all other objects blue spectra were obtained.

Spectroscopic reductions were carried out in the usual manner, making use of IRAF routines `ccdproc` and `doslit`. He–Ar comparison spectra were obtained typically every half hour, yielding wavelength calibration functions with typical rms of 0.1 Å for grating 26 and 0.01 Å for grating 36.

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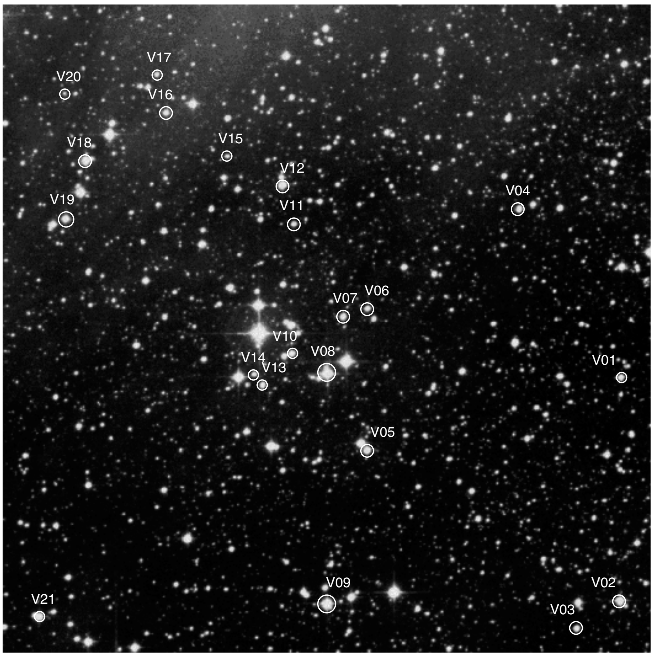

Fig. 1. *Digitized sky survey* image of Trumpler 24 (18′ × 18′, N is up and E is to the left). The circles mark the new variable stars. The field center is at $\alpha = 16^h56^m05\overset{s}{.}2, \delta = -40°39'30''$(2000).

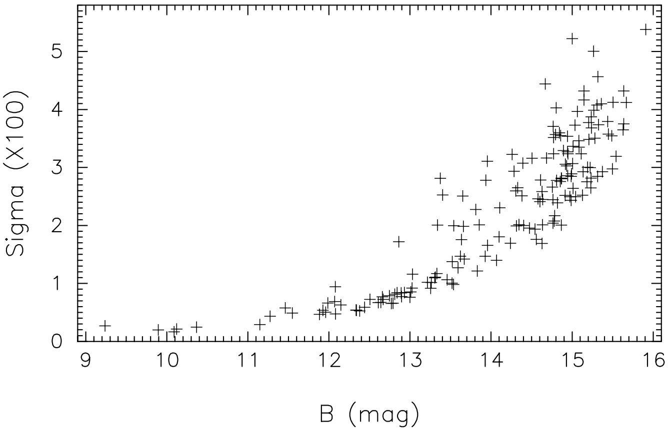

Fig. 2. σ – B diagram of the 166 constant stars of Tr24.

The rms of the sensitivity function obtained with the two flux standards was 0.05 mag for grating 26 and 0.02 mag for grating 36. Corrections for atmospheric extinction were done for every spectrum using average extinction coefficients available for CTIO.

3. Analysis of the light curves

With the light curves of all the stars identified in Fig. 1, the decision whether a star is variable or constant was made as follows. As can be seen in Fig. 3, the scatter in the first two nights is much smaller than that in the remaining four nights, so the data of the first two nights were carefully inspected. From the 267 detected stars we selected 166 constant stars, i.e. those which show only random scatter distribution in the time series and at the same time are not close to the CCD edge or which were not affected by any very nearby stars or by bad columns in the detector. Then, the diagram of σ over B-band magnitude of the 166 constant stars is shown in Fig. 2.

Then, the σ values of the B magnitudes were used to construct criteria for determining the variability of stars with corresponding brightness, according to the domain of average $\pm 3\sigma$ and then applied to the light curves of all stars in the first 2 nights. The stars with points out of this domain are regarded as "Variables", those with points deviating by more than 2σ but less than 3σ are regarded as "Suspected variables", while the others are constants. In addition, the light curves of all 6 nights were also inspected visually in addition to judge the variability of the stars. Finally, 21 "Variable stars" including 3 eclipsing binaries, 9 "Suspected variables", and 237 "Constant stars" were assigned.

For the light curves of 16 variable stars, the program PERIOD98 (Sperl 1998) was applied to calculate the Fourier amplitude spectra. Table 1 lists the 21 new variable stars, with the frequency and amplitude values of 16 variable stars provided, 2 stars showing night-to-night variability, and 3 stars having eclipsing binary signature. The average B-band magnitudes of all variable stars are also given in Table 1. Figures 3 and 4 show the light curves of 18 new variable stars, while Fig. 5 shows the light curves of the 3 eclipsing binaries. Note that the frequency solutions listed in Table 1 are probably not unique due to the relatively small data sets and poor spectral windows. However, the data are sufficiently abundant to detect the variability of these stars and to provide approximate frequencies and amplitudes.

4. Spectroscopic results

Figure 6 shows the spectral energy distributions of 11 objects. The spectral types were first estimated by visually comparing our spectra with a grid of standard stars of spectral types between B2 and K1 from *A digital spectrum classification atlas* by R. O. Gray[1]. Then, a set of digital spectra of MK standard stars were downloaded from `http://stellar.phys.appstate.edu/standards`. These templates, obtained at CTIO with the 1.5 m telescope in the spectral range 3800–5200 Å, but with resolution of 2.6 Å, were degraded to our spectral resolution using the IRAF task `Gauss` prior to classification. A set of continuum normalized templates with spectral types around the visually determined spectral type were scaled and shifted in order to best divide out the spectral features of the data spectra. This was done with the IRAF routine `telluric`. Although this routine was originally intended to remove telluric features, it turned out to be a good tool for spectral classification. The template spectral type that best removed the spectral features was selected as the spectral type of the object. In general, our visual estimate resulted in excellent agreement with the classification obtained with this procedure. Only in two cases, for HD 322449 and star V20, the spectra were too noisy to allow a spectral classification.

[1] `nedwww.ipac.caltech.edu/level5/Gray/frames.html`

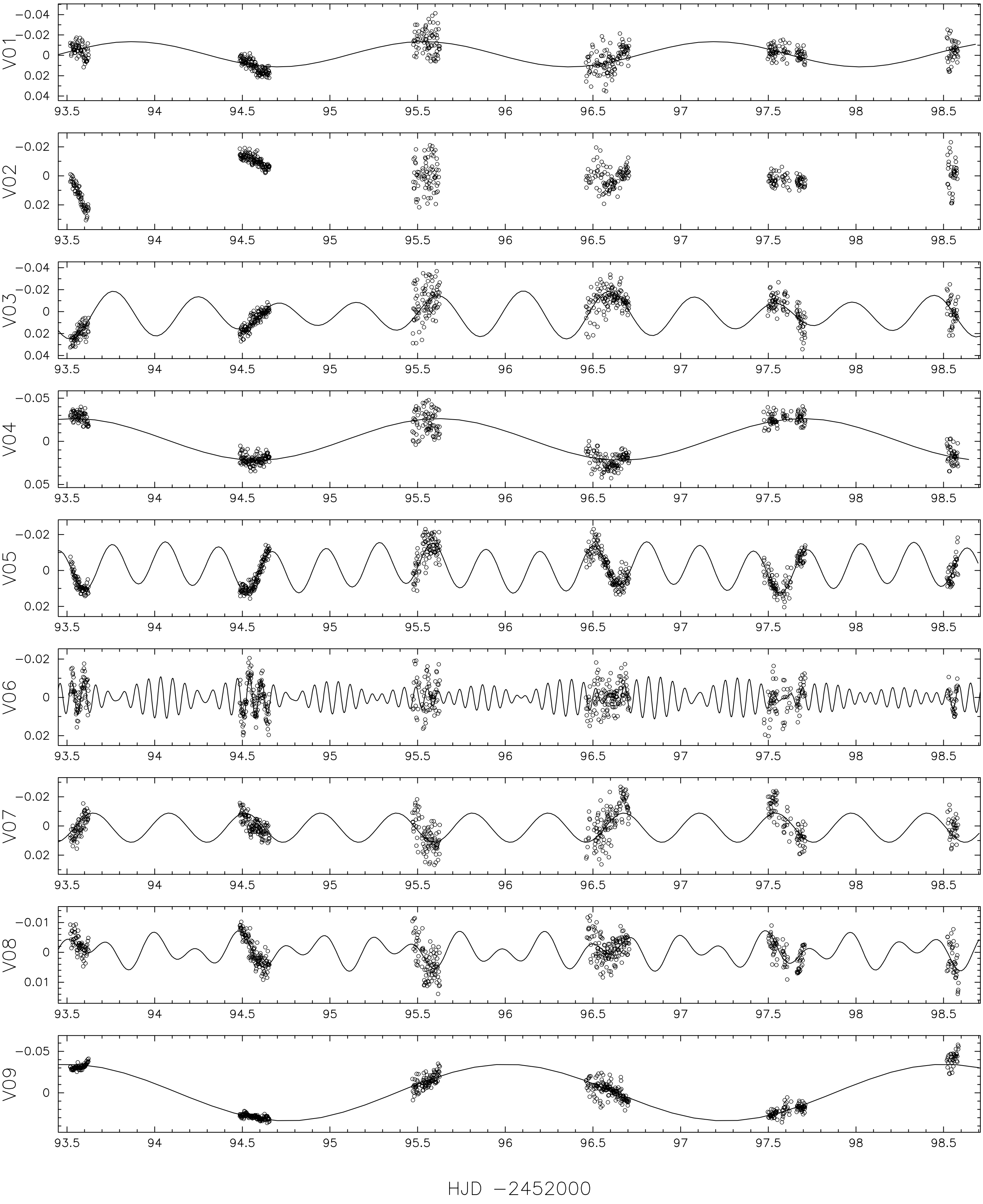

Fig. 3. Light curves of 9 variable stars in Trumpler 24. The open circles represent the observed light curves with HJD–2 452 000 on the *x*-axis, while the *y*-axis gives the differential magnitude in the *B* band. The solid lines show the synthetic light curves constructed with the frequency solutions listed in Table 1.

Table 1. The new variable stars in Trumpler 24: our internal identification, the identification of Heske & Wendker (1984), corresponding GSC or HD number, approximate B-band magnitude m_B, frequencies f (d^{-1}) and amplitudes A (in mmag) of the frequency fit. Stars are numbered according to increasing right ascension. Note that V02 and V13 show night-to-night variability (see text), while V14, V15, and V19 are eclipsing binaries.

ID	HW	GSC/HD	m_B	f_1	A_1	f_2	A_2	f_3	A_3
V01	225	GSC 7872 0642	12.2	0.60	12.4				
V02	226	HD 322452	10.0						
V03	233	GSC 7872 1268	12.2	2.12	16.0	1.76	6.2		
V04	241	GSC 7872 1440	12.3	0.48	24.2				
V05	257	GSC 7872 1974	11.4	3.28	11.6	0.71	2.8		
V06	258	GSC 7872 1463	12.3	15.80	4.3	13.65	4.0	14.03	2.9
V07	263	GSC 7872 0700	13.0	2.31	10.0				
V08	264	HD 322449	10.8	4.01	3.8	2.31	3.1		
V09	265	HD 322453	9.4	0.40	34.0				
V10	269	GSC 7872 0415	11.7	1.74	5.6				
V11		GSC 7872 1448	13.3	8.90	16.7	10.54	14.0		
V12	271	GSC 7872 1538	10.4	3.77	6.7	6.63	2.8		
V13	274	GSC 7872 1412	12.2						
V14		GSC 7872 0864	14.1						
V15		*	14.2						
V16		GSC 7872 1052	12.5	9.85	25.6	9.11	19.4	2.12	7.0
V17		GSC 7872 2262	14.2	7.56	29.4				
V18		GSC 7872 0632	10.4	12.78	12.2	12.54	4.2		
V19		GSC 7872 2362	11.0						
V20		**	16.1	5.08	146.2				
V21		GSC 7872 1248	10.7	1.56	29.3	0.33	10.2		

* $\alpha_{2000.0}$ = 16:56:19.6 $\delta_{2000.0}$ = −40:34:41
** $\alpha_{2000.0}$ = 16:56:43.5 $\delta_{2000.0}$ = −40:32:56.

We also measured radial velocities of the Balmer lines and the interstellar Na ID lines using the IRAF task `rvidlines`. The velocities were corrected to the heliocentric frame of reference. The spectral types and the radial velocities for our objects are given in Table 2.

The difference in brightness between the blue and red spectrum of star V15 (and also in radial velocities, see Table 2) probably indicates that we observed the red spectrum during eclipse. Follow-up time-resolved spectroscopy is clearly needed for this object.

5. Conclusions

The new observations for the third subgroup of Trumpler 24 yield 21 new variable stars, including 3 new eclipsing binaries. None of these stars were recognised as variables before, except for V06 (No. 258 of Heske & Wendker 1984), who give amplitudes of ~$0\overset{m}{.}2$ in U and ~$0\overset{m}{.}3$ in B and V, whereas we find a range in B of less than $0\overset{m}{.}05$. This decrease may perhaps be explained by the pre-main-sequence character of this star: as the authors point out, flaring on various time scales may occur and the star may now be in a state of quiescence.

The fact that no obvious emission line star was found in our spectroscopic sample is consistent with the empirical result found by Fabregat & Torrejón (2000) that clusters younger than 10 Myr are almost completely lacking Be stars. This is also in agreement with the spectroscopic search done by Heske & Wendker (1985) who found, among 60 photometrically variable pre-main-sequence star candidates (therefore possible Be stars), no Be star. Hence, the lack of detected Be stars in Trumpler 24 is another piece of evidence supporting the view that the Be star phenomenon is an evolutionary effect

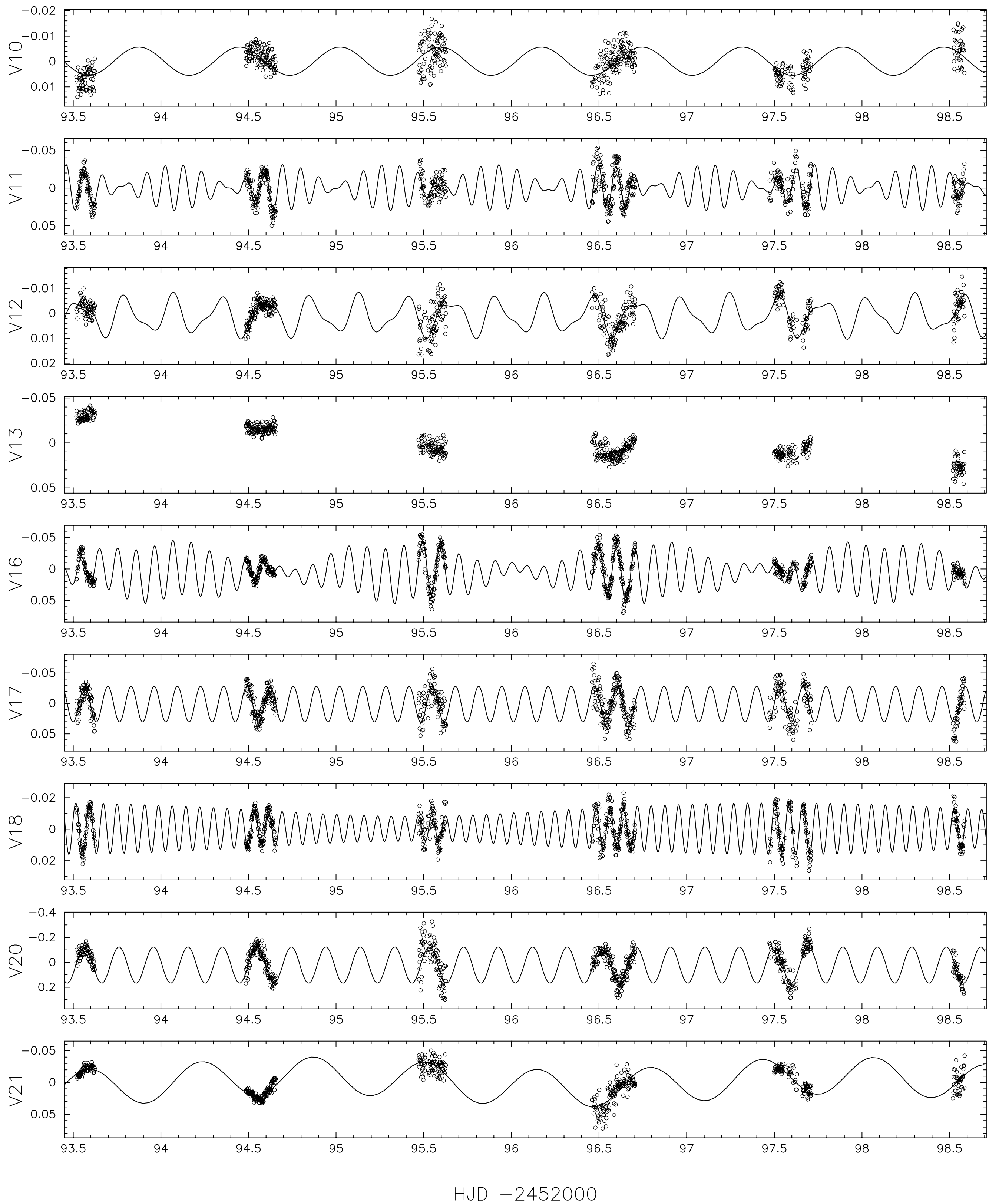

Fig. 4. Light curves of the remaining 9 new variable stars in Trumpler 24, see Fig. 3.

appearing only in the second half of the main sequence lifetime of a B star (Fabregat & Torrejón 2000).

However, we definitely need more observations for this subgroup of Trumpler 24, including longer time-series photometry, multi-color photometry and spectroscopy to determine the memberships of these stars of the cluster, make spectral classification for the new variable stars, and get more precise frequency solutions of the new variables. More data are

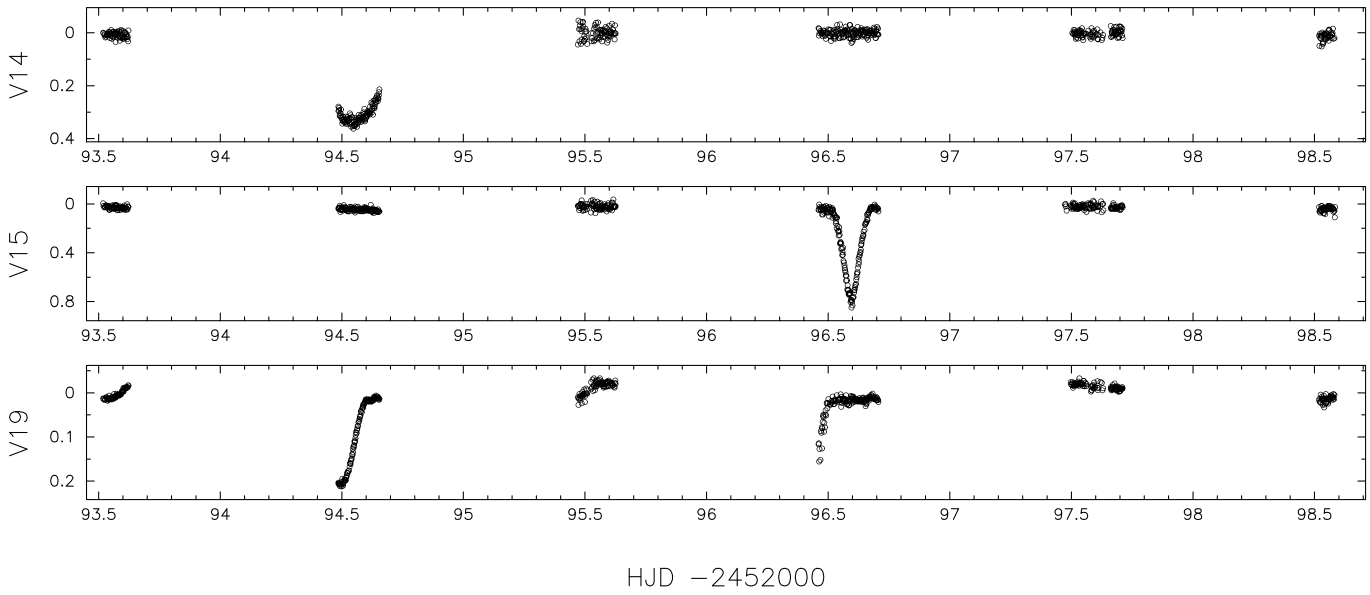

Fig. 5. Light curves of the 3 new eclipsing binaries in Trumpler 24. x-axis is HJD–2 452 000, y-axis is differential B magnitude.

Table 2. Summary of spectroscopic observations and results: UT date, the number of Balmer lines N used in the calculation of the radial velocity in km s^{-1}, the spectral type Sp and when available the radial velocity of the interstellar NaI D lines.

ID	GSC/HD	mm/dd/yy	HJD–2 450 000	exptime (s)	N	$V_{\rm helio}$	Sp	Note
V18	GSC 7872 0632	10/10/02	2557.5469	180	7	−55 ± 7	B2	
V07	GSC 7872 0700	10/10/02	2557.4992	180	7	−62 ± 4	B2	
V16	GSC 7872 1052	10/10/02	2557.5237	180	3	−57 ± 12	F5	
V11	GSC 7872 1448	10/10/02	2557.5382	180	7	−82 ± 10	A7	
V06	GSC 7872 1463	10/09/02	2557.4952	180	10	−48 ± 4	B9	
V05	GSC 7872 1974	10/10/02	2557.5104	180	9	−79 ± 10	A1	
V17	GSC 7872 2262	10/10/02	2557.5104	300	3	−33 ± 8	F3	
V17	GSC 7872 2262	10/11/02	2558.5069	300	1	−47		Hα
V19	GSC 7872 2362	10/10/02	2558.5126	300	2	−55 ± 0	B1	Na ID −13 ± 3
V08	HD 322449	10/10/02	2557.5022	120			K5*	Na ID −5 ± 14
V08	HD 322449	10/10/02	2558.4912	180	1	−9		Hα
V15		10/10/02	2557.5337	300	9	30 ± 11	A1	
V15		10/11/02	2558.5007	300	1	−34		Hα
V20		10/10/02	2557.5509	300			F-type?	

* From SIMBAD.

also needed to get the orbital solutions of the new eclipsing binary systems. We hope to achieve this in the near future.

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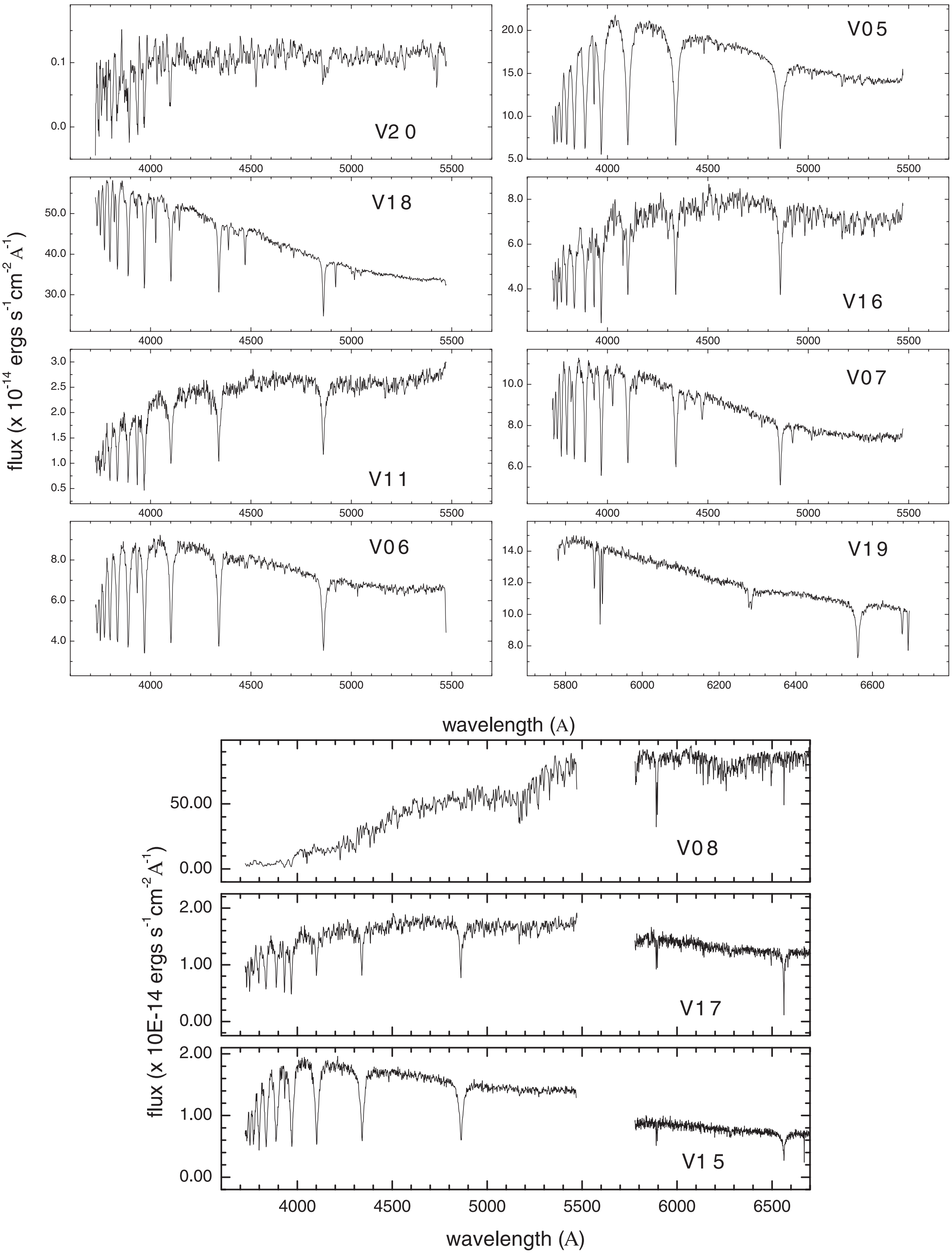

Fig. 6. Spectra of 11 variable stars in Trumpler 24. The lower panels were obtained with the blue and red gratings.

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