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Photometric Observations of the δ Scuti Star UV Trianguli and its Evolutionary Status

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Abstract UV Tri was observed photometrically from 1999 to 2000 at the Xinglong Station of the National Astronomical Observatories, Chinese Academy of Sciences, and was also observed with Strömgren $uvbyH_\beta$ filter system at the Sierra Nevada Observatory (Spain) in 2000. From period analyses of the data, three pulsation frequencies, 9.3299 c d^{-1}, 10.8483 c d^{-1} and 3.6035 c d^{-1} were obtained. We derived color indices: $b - y = 0.215$, $m_1 = 0.169$, $c_1 = 0.783$, and $\beta = 2.775$. With these indices and some calibrations, we obtain: $M_v = 2.44$, $M_{\rm bol} = 2.27$, $\log L/L_\odot = 0.99$, and $\log T_{\rm eff} = 3.875$. Evolutionary sequences of stellar models with 1.00–2.00 solar masses, at steps of $0.05\,M_\odot$, are computed. Each sequence consists of 220 evolutionary intervals. From a comparison between the observed and calculated physical parameters we conclude that UV Tri is in an early evolutionary phase before the turn-off point.

Key words: δ Scuti — stars: oscillations — stars: individual: UV Tri

1 INTRODUCTION

UV Trianguli is an 11.0 V magnitude star situated at $\alpha = 01^{\rm h}32^{\rm m}00^{\rm s}$, $\delta = +30°21'.9$ (2000 coordinates). When Shaw et al. (1983) observed the eclipsing binary V Tri from 1982 October to 1983 January, they found UV Tri (a nearby star) to be a new δ Scuti star with a period near 0.1 days. Because of insufficient data they could not give more results, but pointed out the possibility of multiple periods. In this paper, we present more data of the star, and make a comprehensive period analysis to obtain more accurate frequency information, then to determine some physical parameters and calculate appropriate stellar evolution models, and finally, ascertain its evolutionary status.

2 OBSERVATIONS AND DATA REDUCTION

From 1999 November 17 to 2000 January 14 UV Tri was observed, using the red-sensitive Thomson TH7882 CCD photometer (Wei et al. 1990) attached to the 85-cm telescope at the

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Xinglong Station of the National Astronomical Observatories, Chinese Academy of Sciences (NAOC). Depending on the weather condition integration times of 20, 30, or 60 seconds were taken: when both the transparency and the seeing were good, we took the 20-second integration time; when the weather was clear but the transparency and the seeing were both not ideal, then the 60-seconds; in the intermediate situation, the 30-second. During the observation, GSC 2293–1028 was used as the comparison star and GSC 2293–1422, –1027, –1461 and –1456 were used as controls. From 2000 October 24 to November 20, the star was also observed with the WET high-speed 3-channel photometer (Jiang & Hu 1998) attached to the same telescope. Here the integration time was always taken to be 10 seconds and GSC 2293–1331 was used as the comparison star. For both observational runs, the Johnson V filter was used. We resampled and merged all original data into an integration time of 60 seconds, and the average of data points obtained at each night was normalized to zero. Finally, we obtained 6715 data points on 20 nights from 1999 November 17 to 2000 November 20, i.e., over a period of 370 days. The observing times totalled 4.9696 days. The observing log is given in Table 1, where time duration is the length of the observational run (in units of days) during each night, point number is the number of data points obtained during each night. All the data points are shown as one time series in Fig. 1, where the ordinate is the magnitude difference between UV Tri and comparison, and the abscissa is the time (+HJD 2451000 days). The measuring standard error of data obtained with the CCD photometer is about 0.01 mag. No evidence of any variability in the comparison GSC 2293-1028 was found within the error range.

Table 1 Observing log of UV Tri (1999–2000)

Date	Time duration (days)	Point number
1999–11–17/18	0.1052	122
1999–11–18/19	0.1696	197
1999–11–24/25	0.1262	133
2000–01–08/09	0.0709	89
2000–01–14/15	0.1478	95
2000–10–24/25	0.2948	419
2000–10–25/26	0.3841	554
2000–10–26/27	0.0479	70
2000–10–29/30	0.3708	488
2000–10–31/01	0.3924	559
2000–11–01/02	0.4049	584
2000–11–02/03	0.1986	284
2000–11–04/05	0.2681	378
2000–11–11/12	0.2110	251
2000–11–12/13	0.3257	470
2000–11–13/14	0.3181	459
2000–11–14/15	0.3249	468
2000–11–17/18	0.3382	488
2000–11–19/20	0.1779	228
2000–11–20/21	0.2925	379

3 PERIOD ANALYSIS

We made period analyses to our whole data set consisting of 6715 data points using the program MFA of Hao (1991) and the programs PERIOD (Breger 1990) and PERIOD96 (Sperl 1996). In these programs all the pulsation parameters are obtained using a combination of single-frequency Fourier transforms and multifrequency least squares fitting of brightness residuals

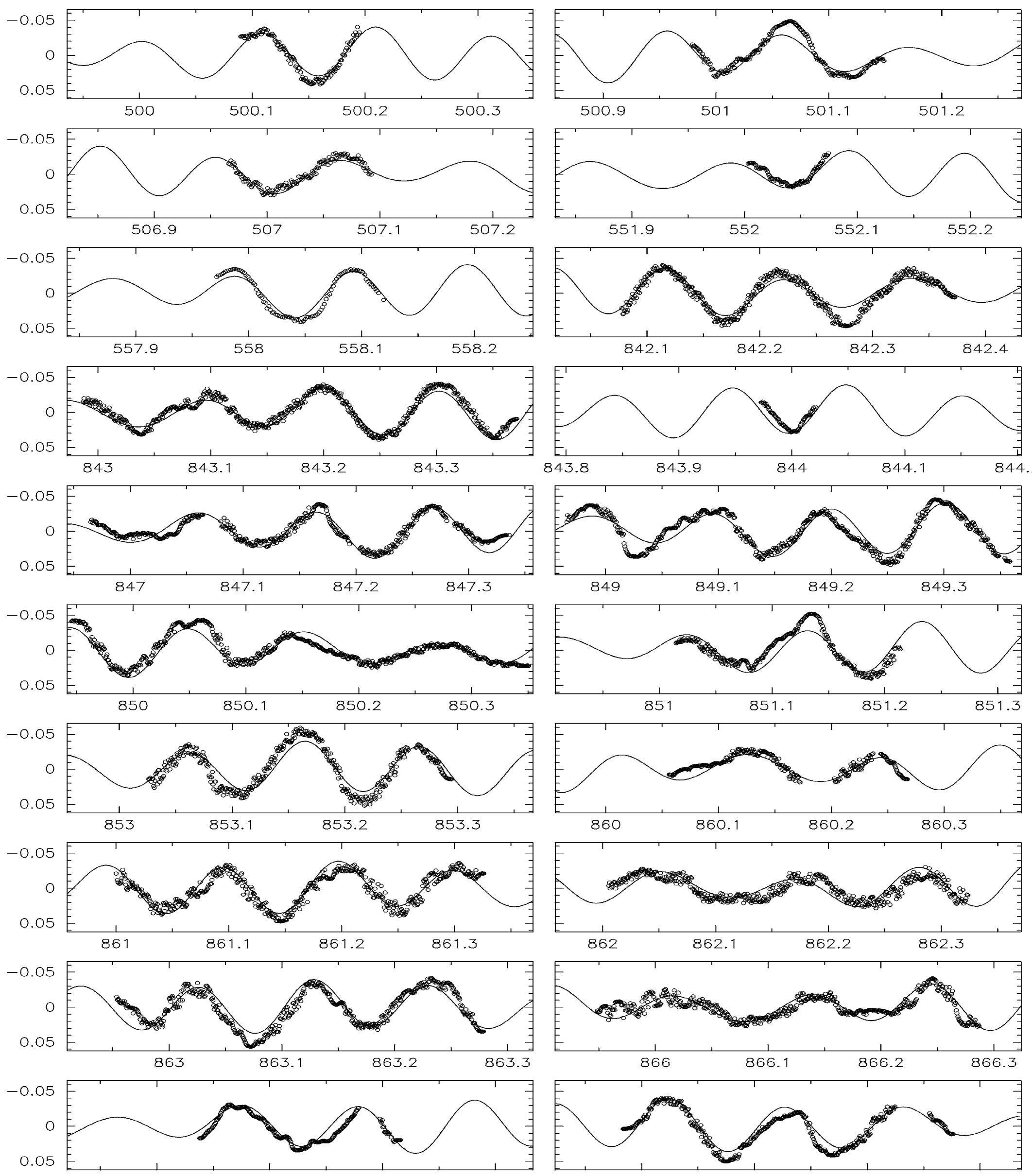

Fig. 1 Data points and fit curves of UV Tri during 1999–2000. The ordinate is the magnitude difference between UV Tri and comparisons. The abscissa is the time (+HJD 2451000 days). The fit of the three-frequency solution given in Table 2 is shown as a solid curve.

(LSR). The details of the period analyses are referenced in Liu (1995, 1996). The computed results are given in Table 2. The frequency is given in cycles per day, the amplitude and standard error of fit are in magnitude, and the phases are normalized to 1.

The three frequencies 9.3299 c d^{-1}, 10.8483 c d^{-1} and 3.6035 c d^{-1} fit the data points very closely (see Fig. 1), where the fit is shown as a solid curve. The power spectra of our whole data set are shown in Fig. 2, together with the spectral window. The power spectrum labelled 'Data' is obtained from the original data. The frequency with the strongest power is the first frequency of 9.3299 c d^{-1}. The power spectrum labelled 'Data−1f' is obtained from the residuals after the first frequency is subtracted from the original data. The frequency with the strongest power is now the secondary frequency of 10.8483 c d^{-1}. The power spectrum labelled 'Data−2f' is obtained from the residuals after the first and second frequencies are subtracted from the original data. The frequency with the strongest power is now the third frequency of 3.6035 c d^{-1}. The power spectrum labelled 'Data−3f' is obtained from the residuals after these three frequencies are removed.

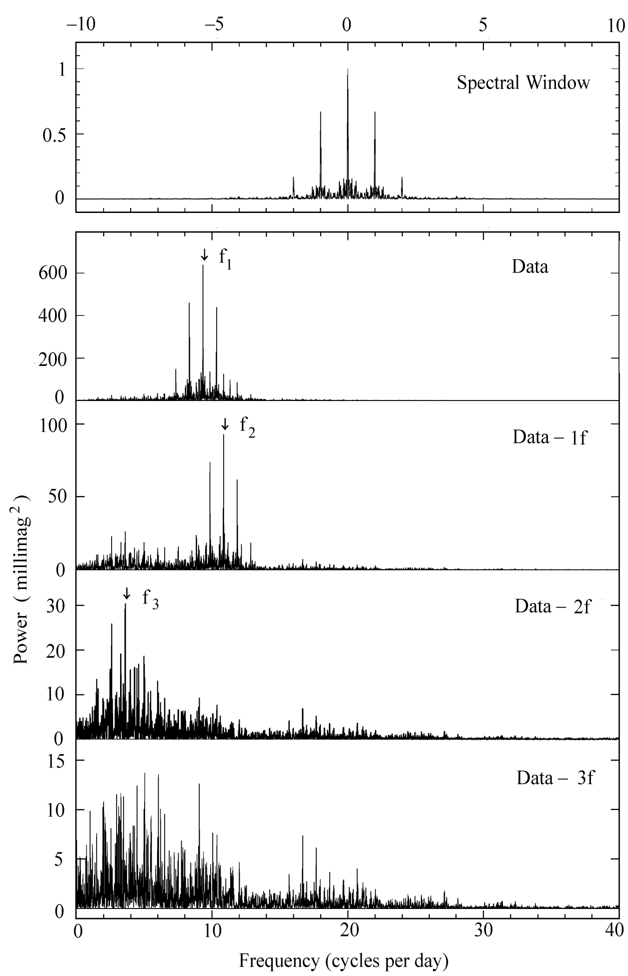

Fig. 2 Power spectra of the 1999–2000 data set of UV Tri. The ordinate is the power (millimag^2). The abscissa is the frequency (c d^{-1}).

Table 2 Pulsation Frequency Solution of UV Tri

Frequency ($\mathrm{c\,d^{-1}}$)	Amplitude (mag)	Phase (0–1)	Standard error of fit (mag)
9.3299	0.025	0.63	0.009
10.8483	0.010	0.44	0.009
3.6035	0.005	0.41	0.009

4 DETERMINATION OF PHYSICAL PARAMETERS AND ESTIMATION OF EVOLUTIONARY STATUS

(1) In order to evaluate some of the physical parameters of UV Tri, we obtained Strömgren $uvbyH_\beta$ photometric data of the star using the 90-cm telescope at the Sierra Nevada Observatory (Spain) on three nights: 2000 January 29/30 and February 2/3 and 3/4. HD 9483, HD 9445, and HD 8826 were used as comparison stars. For UV Tri, 55 *uvby* and four H_β data points were obtained. For HD 9483, 91 *uvby* and seven H_β data points were obtained. For HD 9445, 20 *uvby* and four H_β data points were obtained. For the last comparison, HD 8826, 21 *uvby* and four H_β data points were obtained. We used the same procedure as described by Rodríguez et al. (1997) to transfer our data to the standard system, using ten standard stars. Typical deviations in the transformation were 0.007, 0.009, 0.009 and 0.008 mag for $b-y$, m_1, c_1 and β, respectively. Our results for UV Tri and the three comparison stars are listed in Table 3, along with Hauck & Mermilli's results (1998) for the three comparisons. It can be seen that our results are in good agreement with theirs.

Table 3 Color Indices of UV Tri and 3 Comparison Stars

Object	$b-y/\sigma$	m_1/σ	c_1/σ	β/σ	Data source
UV Tri	0.215	0.169	0.783	2.775	present
	15	14	41	16	
HD 9483	0.116	0.161	0.985	2.835	present
	4	5	15	9	
HD 9445	0.252	0.162	0.779	2.722	present
	5	5	15	7	
HD 8826	0.274	0.148	0.459	2.669	present
	4	4	11	12	
HD 9483	0.120	0.141	0.979	2.838	Hauck & Mermilliod (1998)
HD 9445	0.255	0.167	0.788	2.717	Hauck & Mermilliod (1998)
HD 8826	0.267	0.163	0.456	2.671	Hauck & Mermilliod (1998)

(2) For our observed values of the $b-y$, m_1, c_1 and β indices and using the calibration in Crawford (1979), we got an absolute magnitude $M_v = 2.44 \pm 0.10$ mag. With the calibration in Moon & Dworetsky (1985), we obtained an effective temperature $T_{\mathrm{eff}} = 7500 \pm 100\,\mathrm{K}$. We also used other calibrations to evaluate M_v and T_{eff} and found all the different calibrations gave mutually consistent results within the acceptable error range.

(3) The spectral type of UV Tri is not determined spectroscopically. From identical values of the (M-V) and (C-M) indices Shaw et al. (1983) estimated that UV Tri has the same

spectral type, A3, as V Tri. For a main-sequence star with spectral type of A3, the bolometric correction is −0.17 mag (Schmidt-Kaler 1982). Thus the absolute bolometric magnitude of UV Tri is: $M_{\rm bol} = 2.27 \pm 0.10$ mag. From this value and $M_{\rm bol\odot} = 4.75$ mag we have the logarithmic luminosity of UV Tri in solar units, $\log L/L_\odot = 0.99 \pm 0.05$. The logarithmic effective temperature is, $\log T_{\rm eff} = 3.875 \pm 0.006$.

(4) In order to calculate the evolutionary sequence of UV Tri and to ascertain its evolutionary stage, we used the standard stellar structure and evolution code of Luo (1991, 1997). This code uses the latest version of the OPAL opacities (Iglesias & Rogers 1996). The initial composition is X = 0.68 and Z = 0.02. The standard mixing-length theory of convection with α = 1.0 was used. The evolutionary sequences of stellar models with masses from 1.00 to 2.00 $M_\odot$, at steps of 0.05 $M_\odot$, were calculated. Each evolutionary sequence consists of 220 evolutionary phases. For each evolutionary phase the code returns eight physical parameters, namely, age (evolutionary age starting from zero-age main sequence in giga-years), $M/M_\odot$ (stellar mass in solar units), $\log L/L_\odot$ (logarithm of luminosity in solar units), $\log T_{\rm eff}$ (logarithm of effective temperature), $R/R_\odot$ (radius in solar units), $\log T_c$ (logarithm of central temperature), $\log P_c$ (logarithm of central pressure), and $\log D_c$ (logarithm of central density).

(5) Comparing the physical parameters ($\log L/L_\odot = 0.99$ and $\log T_{\rm eff} = 3.875$) obtained from our *uvby* $\rm H_\beta$ observations with those given by the model calculations for different masses, we find a good agreement within the acceptable error range with the two values ($\log L/L_\odot = 1.0034$ and $\log T_{\rm eff} = 3.8706$) calculated for phase 76 of the 1.65 $M_\odot$ model. Therefore we suggest that the phase 76 of the 1.65 $M_\odot$ model may represent the present phase of UV Tri. The 1.65 $M_\odot$ evolutionary track is shown in Fig. 3 and the phase 76 is marked by an asterisk. The eight physical parameters calculated for this point are listed in Table 4: they could be relevant to UV Tri.

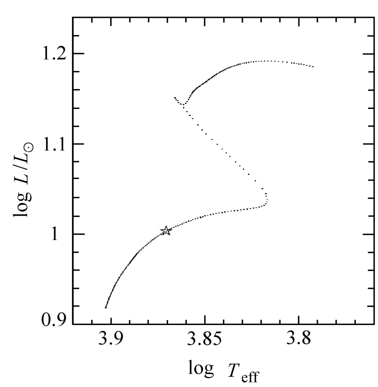

Fig. 3 Evolutionary track of the 1.65 $M_\odot$ model with an initial chemical composition $X = 0.68$ and $Z = 0.02$. The position (phase 76) possibly corresponding to the present status of UV Tri, is marked by an asterisk. The ordinate is logarithm of luminosity in solar units and the abscissa is logarithm of effective temperature.

Table 4 Physical Parameters Obtained from Theoretical Calculations at Phase 76 of the 1.65 $M_\odot$ Model

Age (Gyr)	$M/M_\odot$	$\log L/L_\odot$	$\log T_{\rm eff}$	$R/R_\odot$
0.8958	1.65	1.0034	3.8706	1.9512
$\log T_c$	$\log P_c$	$\log D_c$		
7.3239	17.2370	1.9172		

5 CONCLUSIONS AND DISCUSSION

The main results obtained by us are given in Tables 1, 2, 3 and 4 and shown in Figs.1, 2 and 3. All of these show that UV Tri is a δ Scuti star with three pulsation frequencies (9.3299 $\rm c\,d^{-1}$, 10.8483 $\rm c\,d^{-1}$ and 3.6035 $\rm c\,d^{-1}$) and is at an early evolutionary phase before the turn-off point. Besides the three frequencies, we can see some other frequencies in the power spectrum (see Fig. 2), but they are too weak to be singled out.

Although the observational results are in agreement with theoretical calculations at phase 76 of the 1.65 $M_\odot$ model, we do not think that UV Tri is at present precisely located at this point. This is because the estimated values of M_v and $M_{\rm bol}$ are uncertain by about ± 0.1 mag, and that of $T_{\rm eff}$ by about ± 100 K. So we really have $M_v = 2.30 - 2.50$ mag, $M_{\rm bol} = 2.20 - 2.40$ mag, $T_{\rm eff} = 7400 - 7600$ K, and hence $\log L/L_\odot = 0.97 - 1.02$, $\log T_{\rm eff} = 3.869 - 3.881$. It means that all the calculations for phases 60–80 of the 1.60, 1.65 and 1.70 $M_\odot$ models are consistent with the observed values and so any of these points could be regarded as representing the present status of UV Tri.

In general, the computed curve with three frequencies fits all the light curves very well, but there are noticeable deviations in some short time intervals, such as HJD 2451501.05–.10, HJD 2451842.25–.30, HJD 2451851.07–.15, HJD 2451868.24–.29, HJD 2451869.06–.18 and HJD 2451869.23–.26 etc. (see Fig. 1). Furthermore, the data points are undulatory in the ascending branches before some maxima, such as HJD 2451843.05–.10, HJD 2451847.00–.06, HJD 2451849.05–.09, HJD 2451850.00–.05 and HJD 2451851.08–.12, etc. (see Fig. 1). These phenomena may result either from instrumental effects or from some intrinsic property of UV Tri. The third frequency of 3.6035 $\mathrm{c\,d^{-1}}$ has a low amplitude and is located in the low frequency region, so it is possible that this frequency might result from some instrumental effect. For this, further more detailed observations of UV Tri are required.

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References

Breger M., 1990, Comm. in Asteroseismology, Austrian Acad. Sciences, Vienna, 20, 1
Crawford D. L., 1979, AJ, 84, 1858
Hao J. X., 1991, Publ. of Beijing Astron. Obs., 18, 35
Hauck B., Mermilliod M., 1998, A&AS, 129, 431
Iglesias C. A., Rogers F. J., 1996, ApJ, 464, 943
Jiang X. J., Hu J. Y., 1998, Acta Astron. Sinica, 39, 438
Liu Z. L., 1995, A&AS, 113, 477
Liu Z. L., 1996, A&AS, 119, 55
Luo G. Q., 1991, Ph.D Thesis, Univ. of St. Andrews
Luo G. Q., 1997, Chinese J. Comp. Phys., 14, 652
Moon T. T., Dworetsky M. M., 1985, MNRAS, 217, 305
Rodríguez E., Gonzalez-Bedolla S. F., Rolland A. et al., 1997, A&A, 324, 959
Schmidt-Kaler Th., 1982, In: K. Schaifers et al., eds., Landolt-Börnstein New Series, VI/2b, Astronomy and Astrophysics, Berlin: Springer-Verlag, 453
Sperl M., 1996, Dalta Scuti Star Newsletter, 10, 5
Shaw J. S., Fraquelli D. A., Martins D. H. et al., 1983, IBVS, No. 2289
Wei M. Z., Chen J. S., Jiang Z. J., 1990, PASP, 102, 698