UX VIRGINIS AND ITS NEIGHBOUR

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Abstract. UX Vir has been classified as an RRab star with the period of $P = 0\overset{\mathrm{d}}{.}51292$ on the basis of new $V(RI)_{\mathrm{C}}$ CCD photometry. A new variable star has also been discovered in the neighbourhood of UX Vir, which is most probably a flare star. The positions, reddening and distances have also been derived.

Keywords: Stars: variables: other – Stars: fundamental parameters – Stars: individual: UX Vir – Stars: flare

1. Introduction

Papers like this begin generally with the history of the star under discussion, which contains some basic data: type, period etc. But, in our case these data were completely unkown up to the present. Although the variability of UX Vir was discovered as early as 1919 by Baade (1921), there was scarcely a shade of difference in our knowledge about this star since then.

The discoverer noted that the star varies rapidly: more than 1 photographic magnitude in an hour (between $13^{\mathrm{m}} - 14\overset{\mathrm{m}}{.}5$). Bond (1978), the only previous observer of the star apart from Baade (1921), classified it as F5. These two facts called my attention to this unstudied variable (the star is in this "category" in GCVS).

During my observations I have discovered another variable star in the neighbourhood of UX Vir.

2. Observations and reduction

Since finding charts were not available for UX Vir, the description of its surroundings given by Baade had to be used. Fortunately, it was sufficient for identification. A finding chart is given in Fig. 1. The designations in lower-case letters are the same as in Baade's paper. Table I contains the cross–identification of the stars which are in the HST Guide Star Catalogue.

UX Vir was observed on three nights in 1997 with a CCD camera – built by Wright Instruments with EEV CCD05-20 chip with 770×1152 pixels, see Wright (1990) – attached to the Cassegrain focus of the 1m RCC telescope at the Piszkéstető Mountain Station of the Konkoly

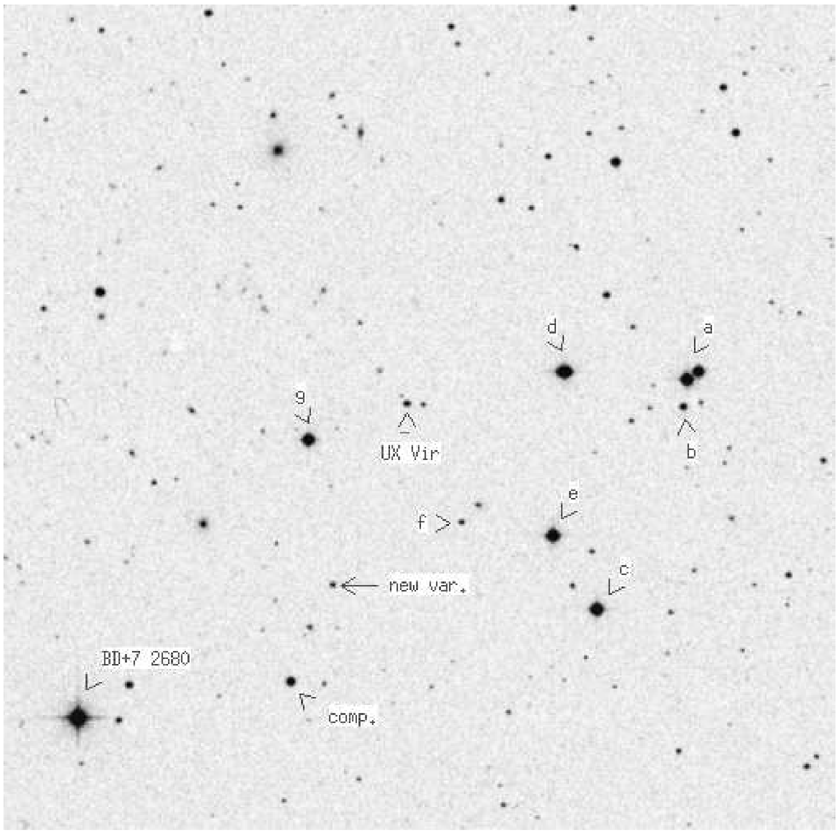

Figure 1. The finding chart for UX Vir from the Digital Sky Survey, its coordinates are $\alpha_{2000} = 13^{\mathrm{h}}40^{\mathrm{m}}36^{\mathrm{s}}$, $\delta_{2000} = +7°8'6''$. North is up, east is left; scale: $15' \times 15'$.

Table I. Cross–identifications for finding chart of UX Vir (see Fig. 1).

Chart designations	GSC number
a*	GSC 314.1093
c	GSC 314.0102
d	GSC 314.0605
e	GSC 314.0725
g	GSC 314.0095
comp.	GSC 314.0013

* A close pair.
(Stars b and f designed by Baade are not GSC stars.)

Table II. Log of observations

Date March 1997	Seeing [arcmin]	Filter	Exp. time [sec]	No. of frames
7/8	3.″5	V	240	25
		V	120	6
9/10	2.″7	B	300	2
		V	240	39
		R_C	200	2
		I_C	50	2
12/13	2.″2	V	240	5
		V	120	24
		R_C	120	5
		R_C	60	24
		I_C	60	5
		I_C	30	24

Observatory. The field of view is $4' \times 6'$ at a scale of $0\overset{''}{.}38$ per pixel. The pixel size is 22.5 μm. The camera was used in 2×2 binning mode. The log of observations is given in Table II. (The individual observational data are available in electronic form[1].) The open cluster M67 was observed as a standard area each night. Every evening and morning dome flats were taken as calibration images and an averaged bias image was made.

The IRAF/CCDRED[2] package was used at the reduction with bias correction and flat fielding. Other corrections were not needed because of the high quality of chip and the high amplitude of the variables. Using IRAF/DAOPHOT/PHOT routine the photometric data were obtained by a single aperture photometry for all object frames. Although, the standards of M67 were processed by a PSF method as well, due to the relatively uncrowded sample of standards the instrumental magnitudes given by aperture photometry were permitted to use according to the following procedure.

The two relatively bright and constant stars in our object frames were tied to the Cousins-system on the best night (12/13 Mar 1997). Since the stars GSC 314.0013, GSC 314.0095 have suitable colours (see Table IV.), they served as comparison and check stars, respectively. The first order extinction coefficients were determined from object frames.

[1] See: http://www.konkoly.hu/staff/benko/index.html
[2] IRAF is distributed by the NOAO

Table III. Evaluated constants for the colour equations (1).

Telescope constants	Zero points*	Extinction coefficients 07/03/1997	09/03/1997	12/03/1997
$\varepsilon = 0.008$	$\xi_V = 4.7556$	$k'_v = 0.2429$	$k'_v = 0.3441$	$k'_v = 0.4236$
$\rho = 1.027$	$\xi_{V-R} = -0.2608$			$k'_{v-r} = 0.1198$
$\iota = 0.933$	$\xi_{R-I} = -0.1334$			$k'_{r-i} = 0.0397$
		$c_v = 0$	$c_v = 0$	$c_v = 1.2016$
				$c_{v-r} = 0.4479$
				$c_{r-i} = -0.2747$

* There were sufficient data to determine these quantities just once due to the application of relative photometry.

The telescope constants and zero points of colour equations were computed from 27 stars in M67 using the standard magnitudes and colours by Chevalier and Ilovaisky (1991). This paper was chosen because their results are in good agreement with recent work (see Montgomery et al. 1993) and because the same filter combination was used as in our work. The following form of colour equations was adopted:

$$\begin{aligned} V &= v - k'_v X + c_v t + \varepsilon(B-V) + \xi_V, \\ V - R_{\mathrm{C}} &= \rho[(v-r) - k'_{v-r}X + c_{v-r}t] + \xi_{V-R}, \\ (R-I)_{\mathrm{C}} &= \iota[(r-i) - k'_{r-i}X + c_{r-i}t] + \xi_{R-I}. \end{aligned} \tag{1}$$

The determined values of the telescope constants ε, ρ, and ι show (see Table III) that the filters reproduce the Cousins-system well. Introducing of the time-dependent term ct was necessary for the night of 12th of March because of the variable quality of the sky which caused a non-linear extinction function. Here t denotes the fraction part of the Julian date. This term involves the temporal variation of the atmospheric transparency. (This term is cancelled in the relative photometry since $\Delta t = 0$ for a frame.) The other designations: k', ξ, X are the first order extinction coefficients, zero points and air mass, respectively. Lower-case letters indicate the observed values and capital letters those transformed into the standard system. The constants used are shown in the Table III.

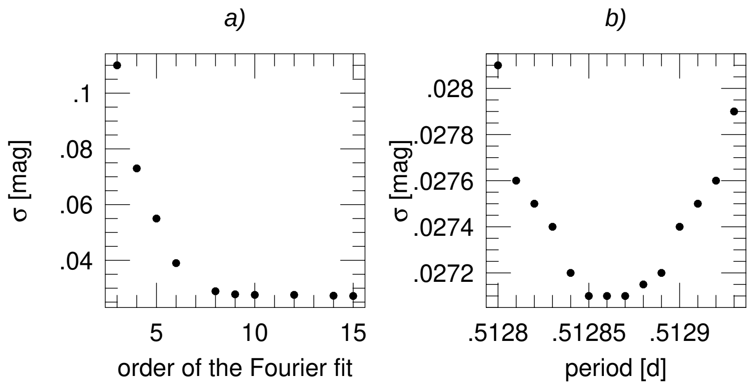

Figure 2. *a)* The fitting error (standard deviation of the least mean squares method) vs order of Fourier fit.*b)* The standard deviation of the Fourier fit vs trial period.

3. Discussion

3.1. UX Virginis

In order to have the most accurate photometry of our variable stars, differential photometry with respect to comparison stars was performed. Since we have only sparse data, a phase dispersion method (PDM) was chosen for the first period search. The strongest peaks in the IRAF/PDM periodogram belong to the one day aliases of the real period. After the coarse period estimation a more detailed time series analysis was carried out. The observed points were interpolated by parabolas which were fitted to small segments of existing data, then Fourier fits of different order were applied to these interpolated data. For these manipulations the programs described in Jurcsik and Kovács (1996) and kindly supplied by the authors were used. Fig. 2a shows the fitting errors σ(=standard deviation of the least mean squares method) versus order of Fourier fit. A 10th order fit was chosen. In the end the following ephemeris was determined:

$$\begin{aligned} \mathrm{HJD_{max}} &= 2450517.4878 + 0\overset{\mathrm{d}}{.}51286 \times E \\ &\qquad \pm 0\overset{\mathrm{d}}{.}0010 \qquad \pm 0\overset{\mathrm{d}}{.}00001, \end{aligned} \tag{2}$$

where the error is estimated by folding the data by a series of nearby periods and inspecting at what point the quality of the light curve is significantly compromised. The result was checked also by computing the standard deviation of the 10th order fit depending on the trial periods (see Fig. 2b).

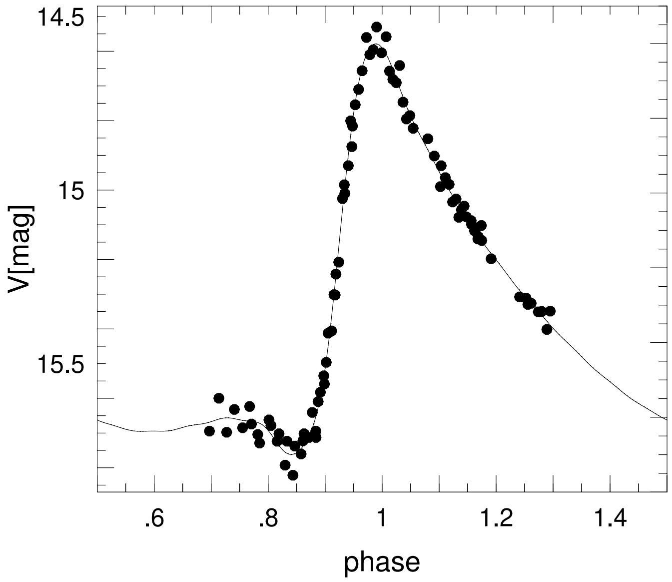

Figure 3. V phase diagram of UX Vir folded on the period of $P = 0\overset{d}{.}51292$. The size of symbols correspond to errors given by IRAF/PHOT package (internal errors). The continuous line shows the 10th order Fourier fit of the smoothed curve.

Fig. 3 shows the ΔV phase diagram obtained by folding the data by (2). The character of light variation: the period, amplitude ($15\overset{m}{.}768$ – $14\overset{m}{.}569$ in V) and the shape of the light curve clearly indicate a fundamental mode pulsating RR Lyrae (type RRab). The previously obtained spectral type F5 is also typical for an RR Lyrae star.

Using our data, the distance of UX Vir can be estimated. Mateo et al. (1993) showed that accurate reddenings can be obtained for ab-type RR Lyrae from their mean $V - I$ colour over the phase interval of minima. They found the mean intrinsic colour $(V - I)_0 = 0\overset{m}{.}58 \pm 0\overset{m}{.}025$ to be roughly independent of chemical abundance. Applying this and the observed colour $\overline{V - I} = 0.595 \pm 0.01$, as well as the formula of Dean et al. (1978) which relates $E(V - I)$ to $E(B - V)$ we find $A_V = 0.03$ for UX Vir.

On the basis of the observed mean magnitude $\overline{V} = 15\overset{m}{.}207$ and adopting $M_V = 0.69 \pm 0.1$ for the halo RR Lyrae absolute magnitude (Tsujimoto et al. 1998), I obtain the distance $\sim$ 8 kpc of UX Vir. Given its position in Galactic coordinates ($l = 335\overset{\circ}{.}44$, $b = 66\overset{\circ}{.}85$) it has been found that UX Vir lies $\sim$ 7.4 kpc above the Galactic plane at a galactocentric distance of $\sim$ 9 kpc (assuming $R_\odot = 8$ kpc). Its position relative to the Galactic plane shows that UX Vir belongs to the halo population.

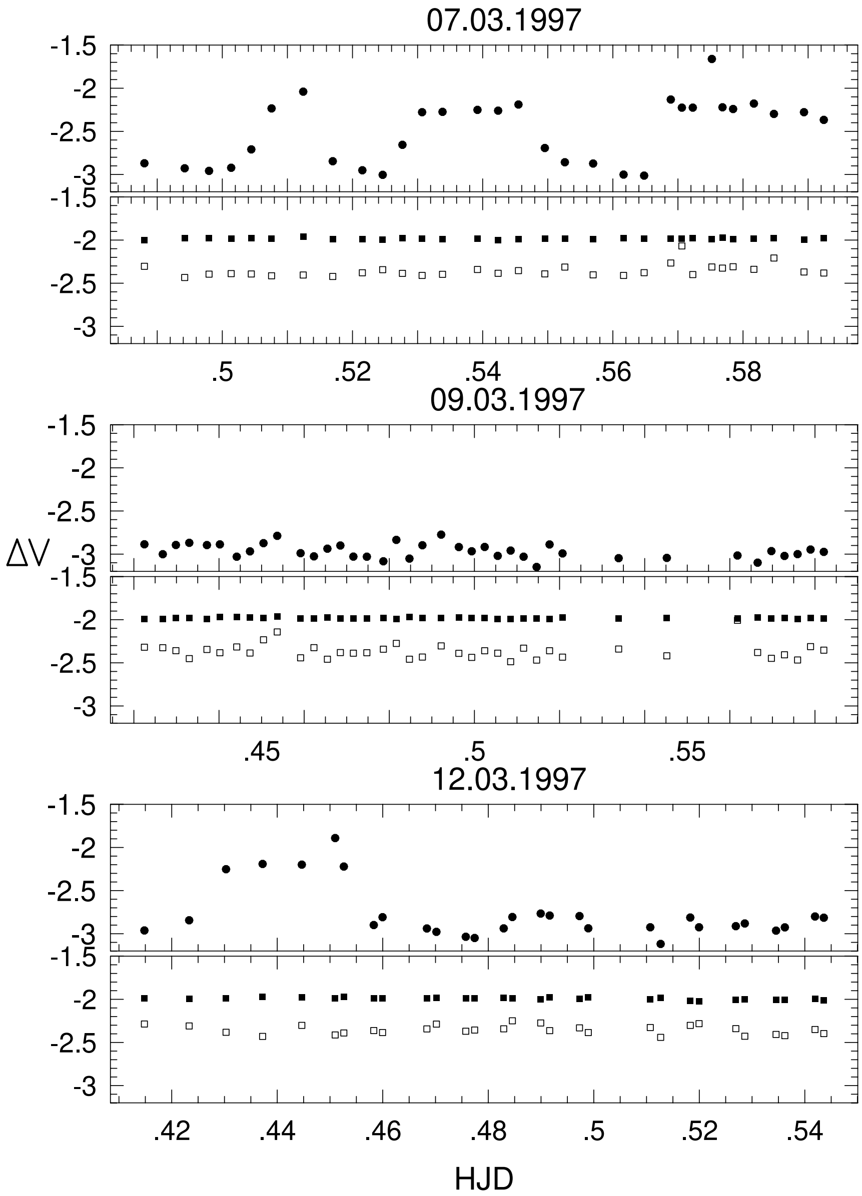

Figure 4. The ΔV light curves of the GCS 314.0013 minus new variable (points in upper panels) and comparisons GCS 314.0095 minus GCS 314.0013 (filled squares in bottom panels). The empty squares in bottom panels show GCS 314.0013 minus f, where the magnitude differences are similar values to variable−comparison ones. The size of symbols indicate the internal errors.

Table IV. Magnitudes and colours transformed into the standard system. Signed errors are internal ones.

Name	V [mag]	$B-V$	$V-R_{\mathrm{C}}$	$(R-I)_{\mathrm{C}}$
GSC 314.0095	11.487 ± 0.001	0.65 ± 0.01	0.236 ± 0.002	0.386 ± 0.004
GSC 314.0013	13.479 ± 0.003	1.05 ± 0.02	0.454 ± 0.003	0.571 ± 0.005
f	15.83 ± 0.01	0.05 ± 0.05	-0.05 ± 0.02	0.10 ± 0.03
UX Vir (min)	15.77 ± 0.01		0.20 ± 0.02	0.39 ± 0.03
UX Vir (max)	14.569 ± 0.005		-0.073 ± 0.005	0.17 ± 0.01
new var. (min)	16.51 ± 0.02	0.87 ± 0.05	0.55 ± 0.08	0.38 ± 0.1

3.2. Properties of the new variable

I searched SIMBAD database for objects within 10 arcminutes of position UX Vir. The only star reported by SIMBAD was BD+7°2680 in our area which is bright and non-variable. However, the data of 7/8 March and 12/13 March clearly show a star near UX Vir to be variable. In Fig. 1. this star is denoted by "new var."

The equatorial coordinates for this new variable were measured using the Digitized Sky Survey. The determined position is: $\alpha_{2000} = 13^{\mathrm{h}}40^{\mathrm{m}}41\overset{\mathrm{s}}{.}76$, $\delta_{2000} = 7°5'12\overset{''}{.}28$. The presumed relative accuracy is $1\overset{''}{.}5$ estimated from the accuracy of the determination of center of stars in IRAF/DAOFIND routine (~ 0.1 pixels). The positions of the nearby stars in GSC were used for reference.

From the character of the light curve (Fig. 4.) the variation is most probably due to flare activity of the star. It may be proven by colours of the brightening: $\sim 1^{\mathrm{m}}$ in V, $\sim 0\overset{\mathrm{m}}{.}5$ in R_{C} and practically no changes in I_{C}. Moreover, the decreasing parts of the suspected flare events show approximately exponential pattern, but they have quite complex behaviour. The time-scale of the light variation (about 1^{m} magnitude in V in 10–12 minutes) also leads to the same conclusion. Furthermore, the out-of-flare colours (Table IV, evaluated from the light curve in the night of 9/10 March) belong to a K type star. These indicate that the star is a dK flare star.

With the help of the empirical calibration formula for late type stars given by Bessell and Stringfellow (1993) the absolute magnitude from $V - I_{\mathrm{C}}$ colour index is $M_V = 6\overset{\mathrm{m}}{.}179$. This leads to the distance 1.2 kpc if the interstellar reddening is ignored according to our previous conclusion. So, the star lies 1.1 kpc above the Galactic plane at a galactocentic distance $\sim$ 7.5 kpc. Although the Galactic disc for dK stars extends to 2 kpc, this high distance from the plane is unusual for flare stars, since they are relatively young objects.

In summary, UX Vir is a new member of the group of RR Lyrae variables. Its position indicates that it lies in the galactic halo. In the CCD frame of UX Vir a red star was detected with considerable flare activity.

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