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FOUR NEW VARIABLE STARS IN OPHIUCHUS

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Abstract: Four new variable stars were discovered by serendipity in the Ophiuchus constellation during photometric analysis of the NEO Asteroid (1988 PA), pictures taken in July 2010 from A81 Balzaretto Observatory in Rome. Based on their light curves and colour indexes, the stars were classified in their variable class and registered in the Variable Star Index (VSX) hosted in the AAVSO web site, respectively as one eclipsing variable EA-type or short period eclipsing subgroup of RS CVn-type (UCAC3 196-166827), identified as the optical counterpart of 1RXS J180755.7+074717 X-ray source, two eclipsing binaries EW-type (UCAC3 196-166958 and UCAC3 196-167279) and one very likely as pulsating variable High Amplitude δ Scuti type (HADS) or SX Phe (UCAC3 196-167073).

1. Introduction

The new variable stars were recorded during the CCD time-series observing session with a Clear filter of the NEO Asteroid 1988 PA on July 2010, 03th, while crossing through the Ophiuchus constellation. The variability was found in the next evenings during the photometric analysis with MPO Canopus – Variable Star Search – tool, which identified four likely candidates. In order to confirm the amplitude of the light variations and to determine more precise periods, amplitude, colour index and typology, a total of eight observing sessions were made during the following clear nights. The data collected this way allowed us to work out the fundamental parameters of each variable and to register the new variable stars in the Variable Star Index (VSX – AAVSO site).

2. Instrumentation, photometic sessions and methodology

All the observations were carried out from the A81 Balzaretto Observatory in Rome and from the Astronomical Observatory of the University of Siena, located inside the facilities of the Department of Physics, over the time period spanning from 3 to 16, July 2010. In all 8 observing session were held over a time span of 13 days (Table 1). The equipment used for observations is described in Table 2.

Table 1. Observation Sessions and Observers

#	Date July 2010	Observer	N. CCD frames collected	Exp. Time (min)	Filter used
1	3	L. Franco	70	4	C
2	5	L. Franco	32	10	V, Rc
3	8	A. Marchini	105	3	C
4	9	L. Franco	90	4	C
5	10	A. Marchini	51	3	C
6	12	L. Franco	91	4	C
7	13	A. Marchini	74	3	C
8	16	L. Franco	17	10	V, Rc

Table 2. Equipment used for observations

Observer	Telescope	CCD	Field of view and plate scale	Filters
L.Franco	Meade LX200 0.20-m f/5.5	SBIG ST7-XME	20.9 x 13.9 arcmin (1.64 arcsec/pixel)	Custom Scientific (Johnson V, Cousins R)
A. Marchini	Meade LX200 0.25-m, f/6.3	SBIG ST7-ME	14.6 x 9.8 arcmin (2.30 arcsec/pixel) Binning x2	No filter

All the images were calibrated with dark and flat-field frames. Differential aperture photometry was performed with *MPO Canopus* (Warner, 2009b). The V and R magnitudes were calibrated using the method described by Dymock and Miles, 2009 and CMC14 selected reference stars. The same method was also applied to the Clear magnitude, after its conversion to V magnitude, using the transformation coefficients previously calculated. The V and R band frames were acquired in sequence changing alternatively the filters (VRVR...).

Unfortunately no Landolt stars are present in the field of view, so that the comparison stars have been chosen among the few stars in the field of view listed in the CMC14 catalogue with colour indexes J-K (from the

2MASS catalogue) as closest as possible to colour indexes of the variable stars. For an accurate manual selection of the CMC14 reference stars, we used the *Vizier Service* (VizieR, 2010) and *Aladin Sky Atlas* (Bonnarel et al., 2000). The linear relations between the r' magnitude of CMC14 (Sloan DSS filter) and R/V standard magnitude, are the following (Dymock and Miles, 2009):

$$R_c = r' - 0.22 \quad (1)$$

$$V = 0.6278\,(J - K) + 0.9947\,r' \quad (2)$$

The standard deviation of the magnitude of the Landolt stars, from which the equations above have been worked out, are as large as 0.02 and 0.04 mag respectively for Rc and V magnitudes. Using (1) and (2), the resulting V, Rc magnitudes and (V-Rc) colour index for reference stars were calculated. Their final values are listed in the Table 4.

3. Data Analisys and Result

The times of the maxima and minima were computed using the polynomial fit algorithm implemented in the *Peranso* (Vanmunster, 2007) data analysis software.
With these data we computed, via linear regression, the elements of the ephemeris for each star. In fact, we computed the Start Epoch and the Main Period of each new variable star and their errors. Amplitude was calculated as the mean difference between maximum and minimum values, measured from *Peranso* polynomial fit and errors were estimated as the quadratic sum of the individual standard deviation of the mean.

Period Analysis was performed using ANOVA algorithm (Schwarzenberg-Czerny, 1996), CLEANest algorithm (Foster, 1995) and EEBLS algorithm (Kovacs, 2002), all of them as implemented in *Peranso* and conducing a parallel analysis using *Period04* (Lenz & Breger 2005).

We adopted Sterken and Jaschek (2005) and Percy (2007) as the main references to suggest a classification for the new variable stars we observed.

The Finder Chart (Fig.1) was centred at coordinates (J2000) RA: 18:08:16 Dec: +07:42:12. On the chart the variables and reference stars used for ensemble photometry, are identified with their short name. In the Table 3 and 4 we have report the main data respectively of variable and the reference stars.

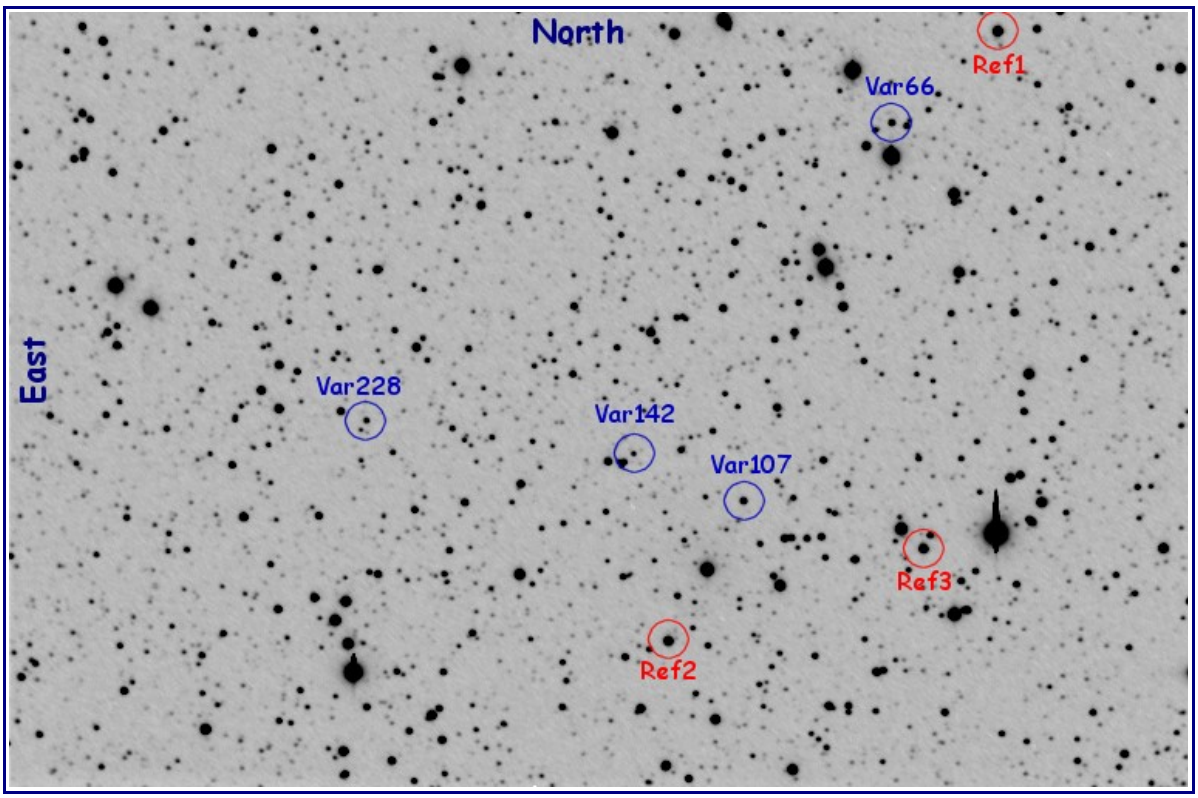

Fig. 1. Finding Chart centred at coordinate (J2000) RA: 18:08:16 Dec: +07:42:12. The field of view is 20.9 x 13.9 arcmin and the plate scale is of 1.64 arcsec/pixel.

Table 3. Main parameters of new variable stars

Short Name	Var66	Var107	Var228	Var142
Catalogue Names	GSC2.2 N020023339630 UCAC3 196-166827 CMC14 180755.6+074711 2MASS J18075569+0747117 1RXS J180755.7+074717	GSC2.2 N020023335570 UCAC3 196-166958 CMC14 180805.9+074027 2MASS J18080597+0740273	GSC2.2 N020023336427 UCAC3 196-167279 CMC14 180832.9+074148 2MASS J18083292+0741486	GSC2.2 N020023336093 UCAC3 196-167073 CMC14 180813.8+074116 2MASS J18081384+0741164
VSX Names and AAVSO AUID	VSX J180755.6+074711 000-BJV-953	VSX J180805.9+074027 000-BJV-954	VSX J180832.9+074148 000-BJV-955	VSX J180813.9+074116 000-BJW-505
Coordinates UCAC3 (J2000)	18 07 55.691 +07 47 11.82	18 08 05.974 +07 40 27.35	18 08 32.925 +07 41 48.61	18 08 13.855 +07 41 16.41
Period (days)	0.861209 d ± 0.00013	0.360914 d ± 0.00014	0.373738 d ± 0.00023	0.087227 d ± 0.00001
Maximum(V)	14.87 mag ± 0.01	14.60 mag ± 0.01	15.66 mag ± 0.01	15.92 mag ± 0.02
Primary minima(V)	15.15 mag ± 0.01	14.91 mag ± 0.01	16.01 mag ± 0.02	16.42 mag ± 0.04
Secondary minima (V)	14.97 mag ± 0.02	-	15.94 mag ± 0.01	-
Max Amplitude (V)	0.28 mag ± 0.01	0.31 mag ± 0.01	0.35 mag ± 0.02	0.50 mag ± 0.05
Color Index (V-Rc)	0.26 mag ± 0.05	0.39 mag ± 0.05	0.36 mag ± 0.05	0.21 mag ± 0.05
Suggested var. type	EA or RS CVn	EW	EW	HADS or SX Phe

Table 4. Reference stars used for ensamble photometry - (*) computed with (1) and (2) relations.

ID	CMC14 Name	RAJ2000	DEJ2000	r'(CMC14)	J-K (2MASS)	V (*)	Rc (*)	(V-Rc)
Ref1	180748.2+074850	18 07 48.214	+07 48 50.28	12.76	0.33	12.90	12.54	0.36
Ref2	180811.2+073756	18 08 11.211	+07 37 56.96	13.00	0.38	13.17	12.78	0.39
Ref3	180753.1+073938	18 07 53.114	+07 39 38.29	13.09	0.37	13.26	12.87	0.38

In the next sub-sections we shall analyse in detail the data of the single variable stars.

3.1 Var66 (UCAC3 196-166827)

The data from the first night of observations showed a part of a typical light curve of an eclipsing variable around the minimum. The next session (two nights later) showed another snippet of the light curve that seemed to drop to a secondary minimum. These elements allowed to compute a rough ephemeris good enough for planning the following observing sessions. For this star we observed and measured, with the polynomial fitting algorithm tool in *Peranso*, respectively three primary minima and one secondary minimum. These values have been reported in the following Table 5.

Table 5. Times of minima of Var66 (UCAC3 196-166827)

HJD	Error	Type	Observer
2455381.448243	0.00344	Min I	LF - Discovery
2455387.478134	0.00379	Min I	LF
2455390.492417	0.00656	Min II	LF
2455394.366442	0.00392	Min I	LF

The Start Epoch and Period have been computed by means of linear regression of the primary minima times, obtaining the following value for the ephemeris, with a root-mean-squared-error (RMSE) of 0.00066 d:

Start Epoch (HJD): 2455381.448739 d ± 0.00125
Period: 0.861209 d ± 0.00013

Analysing the time series data with the EEBLS algorithm tool as implemented in *Peranso*, we have obtained a period of 0.861292 d, very close to the previous value. Furthermore from the filtered sessions we have measured a mean V apparent magnitude of 14.94 mag ± 0.04 and a mean Rc band of 14.67 ± 0.03, with colour index (V-Rc) of 0.26 ± 0.05, which is typical of F5/F6V star (Pickles, 1998).

The mean range of the light variations in the V band spans from the maximum at 14.87 mag ± 0.01 and the minimum at 15.15 mag ± 0.01, with a peak-to-peak amplitude of Av = 0.28 mag ± 0.01.

Very close to the coordinates position of this star, *Vizier Service* (VizieR, 2010), reports the X-ray source 1RXS J180755.7+074717 from the ROSAT All Sky Survey Faint Source Catalog. The total positional error of this X-ray source is 23", including 6" systematic error. Thus this eclipsing variable is thought to be very likely the optical counterpart of 1RXS J180755.7+074717 X-ray source. The X-ray emission may indicate a chromospheric activity (Richards & Albright, 1993).

Based on the the light curve shape (phase plot is shown of Fig. 2), we initially classified this star as an eclipsing binary of EA-type on the VSX-AAVSO site. The subsequent identification with a X-ray source and one distortion effect of the light curve (near phase 0.50-0.65) suggest a classification as a short period subgroup of RS CVn system. To solve any doubt would be required spectroscopic and other photometric observations to detect the presence of Ca II (H and K) emission lines and to confirm the distortion waves in the light curve.

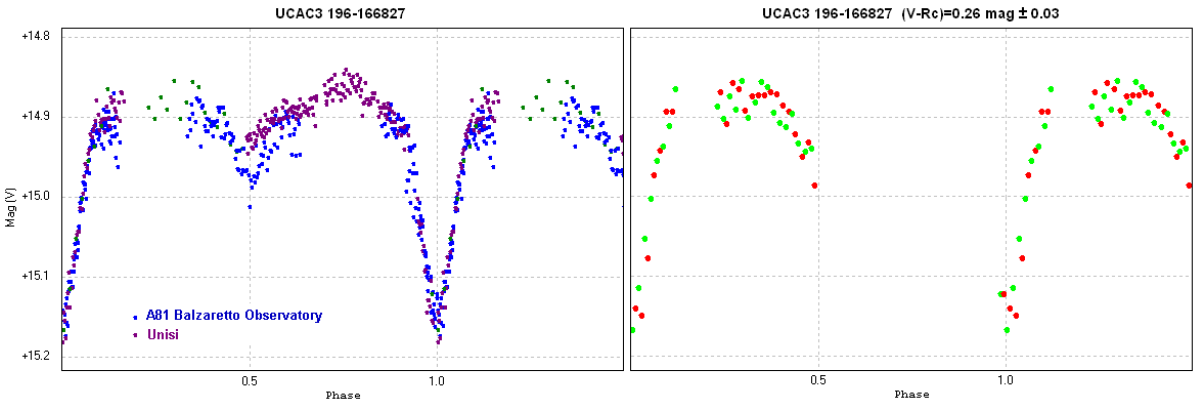

Figure 2. Phase plot of the star V66 (UCAC3 196-166827). On right the V and Rc magnitudes obtained adding to the Rc magnitudes the mean colour index value (0.26).

3.2 Var107 (UCAC3 196-166958)

We had initially assumed this star was a δ Scuti pulsating star, based on the period, amplitude variations and mean colour index. Subsequently, a more accurate analysis of colour index, shows no appreciable change in colour, as you would expect from a pulsating star. Moreover, the light curve shapes resembles very much that of an eclipsing variable star EW-type. The maximum and minimum are both symmetrical and no appreciable difference between primary and secondary minimum is evident. For this star we have observed and measured, with the polynomial fitting algorithm tool in *Peranso*, respectively seven maxima and eight minima. These values have been reported in the following Table 6.

Table 6. Times of maxima and minima of Var107 (UCAC3 196-166958)

HJD	Error	Type	Observer
2455381.478552	0.00376	Max	LF - Discovery
2455383.464498	0.00802	Max	LF
2455383.544764	0.00718	Min	LF
2455386.437504	0.00270	Min	AM
2455386.525093	0.00462	Max	AM
2455387.433787	0.00391	Max	LF
2455387.521598	0.00288	Min	LF
2455388.425062	0.00322	Min	AM
2455390.406810	0.00323	Min	LF
2455390.496913	0.00357	Max	LF
2455390.590798	0.00337	Min	LF
2455391.398037	0.00346	Max	AM
2455391.487477	0.00218	Min	AM
2455394.373324	0.00447	Min	LF
2455394.458833	0.00622	Max	LF

The Start Epoch and Period have been computed by means of linear regression of all the minima without any distinction from primary and secondary minima, being indistinguishable each other. The resulting period was

then multiplied by a factor of two, obtaining the following value for the ephemeris, with a root-mean-squared-error (RMSE) of 0.00289 d:

```
Start Epoch (HJD):     2455383.549361 d  ± 0.00244
Period:                       0.360914 d  ± 0.00014
```

Furthermore from the filtered sessions we have measured a mean V apparent magnitude of 14.76 mag ± 0.04 and a mean Rc band of 14.37 ± 0.03, with colour index (V-Rc) of 0.39 ± 0.05, which is typical of G5/G8V star (Pickles, 1998). The mean range of the light variations in the V band spans from the maximum at 14.60 mag ± 0.01 and the minimum at 14.91 mag ± 0.01, with a peak-to-peak amplitude of Av = 0.31 mag ± 0.01. Based on the light curve shape (phase plot is shown of Fig. 3) we suggest to classify this star as an eclipsing binary of EW-type.

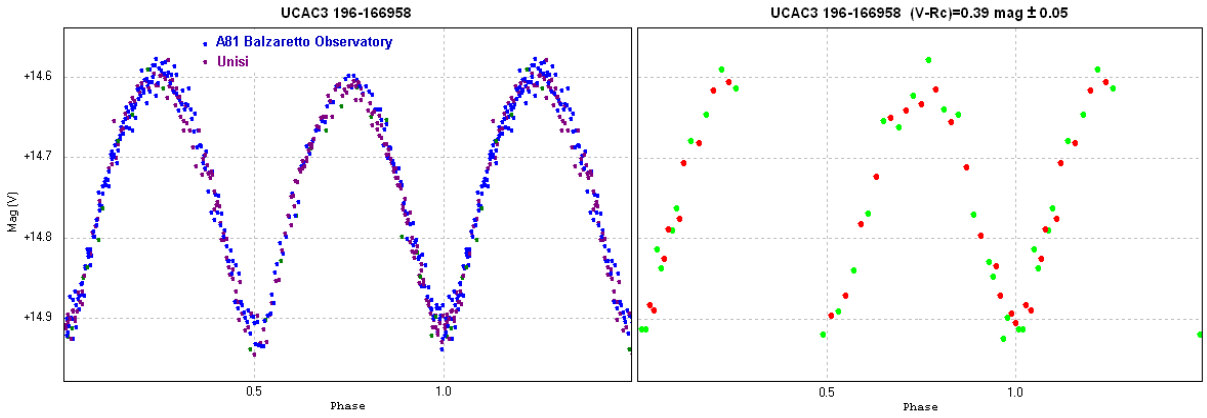

Figure 3. Phase plot of the star V107 (UCAC3 196-166958). On right the V and Rc magnitudes obtained adding to the Rc magnitudes the mean colour index value (0.39).

3.3 Var 228 (UCAC3 196-167279)

The light curve shows the presence of a primary and secondary minimum and no appreciable variations of the colour indexes. The latter evidence strongly suggest an eclipsing variable star likely of EW-type. For this star we observed and measured, with the polynomial fitting algorithm tool in *Peranso*, respectively five maxima, four secondary minima and two primary minima. These values have been reported in the following Table 7.

Table 7. Times of maxima and minima of Var 228 (UCAC3 196-167279)

HJD	Error	Type	Observer
2455381.427298	0.00477	Min II	LF - Discovery
2455381.514075	0.00648	Max	LF
2455383.398845	0.02051	Max	LF
2455383.495289	0.01555	Min II	LF
2455387.412116	0.00392	Min II	LF
2455387.507637	0.00502	Max	LF
2455387.597404	0.00333	Min I	LF
2455390.404785	0.00410	Min II	LF
2455390.497783	0.00526	Max	LF
2455390.585969	0.00430	Min I	LF
2455394.415726	0.00768	Max	LF

The Start Epoch and Period have been computed by means of linear regression of all the minima without any distinction from primary and secondary minima. The resulting period was then multiplied by a factor of two, obtaining the following value for the ephemeris, with a root-mean-squared-error (RMSE) of 0.00406 d:

```
Start Epoch (HJD):     2455381.432426 d   ± 0.00393
Period:                       0.373738 d   ± 0.00023
```

Furthermore from the filtered sessions we have measured a mean V apparent magnitude of 15.77 mag ± 0.04 and a mean Rc band of 15.42 ± 0.03, with colour index (V-Rc) of 0.36 ± 0.05, which is typical of G0/G8V star (Pickles, 1998). The mean range of the light variations in the V band spans from the maximum at 15.66 mag ± 0.01 and the minimum at 16.01 mag ± 0.02, with a peak-to-peak amplitude of Av = 0.35 mag ± 0.02. Based on the light curve shape (phase plot is shown of Fig. 4) we suggest to classify this star as an eclipsing binary of EW-type.

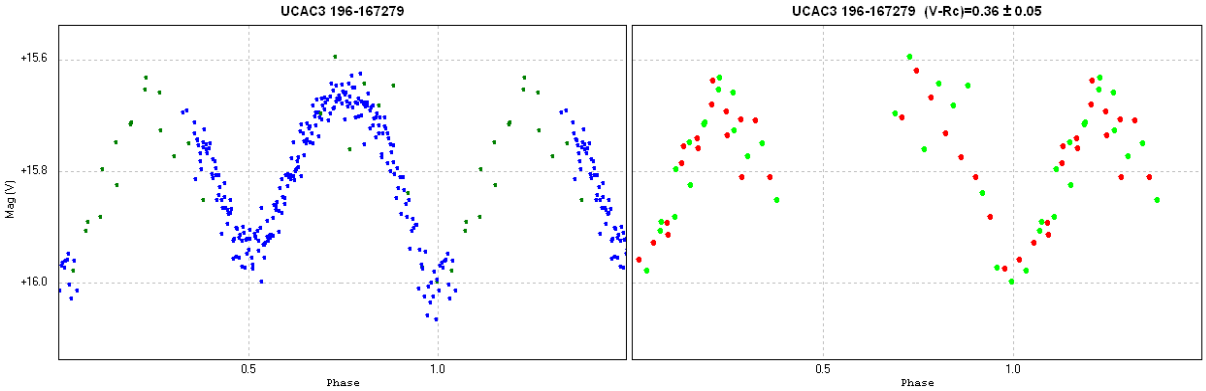

Figure 4: Phase plot of the star V228 (UCAC3 196-167279). On right the V and Rc magnitudes obtained adding to the Rc magnitudes the mean colour index value (0.36).

3.4 Var142 (UCAC3 196-167073)

The asymmetrical light curve suggests this variable is a pulsating star; this suggestion is strongly supported by a valuable colour index variation during the maximum to minimum cycle. For this star we have observed and measured, with the polynomial fitting algorithm tool in *Peranso*, eleven maxima. These values have been reported in the following Table 8.

Table 8. Times of maxima of Var142 (UCAC3 196-167073)

HJD	Error	Type	Observer
2455381.415725	0.00192	Max	LF - Discovery
2455381.503542	0.00140	Max	LF
2455386.387535	0.00127	Max	AM
2455386.475240	0.00166	Max	AM
2455387.435784	0.00133	Max	LF
2455387.522931	0.00130	Max	LF
2455388.392931	0.00186	Max	AM
2455390.400216	0.00121	Max	LF
2455390.487636	0.00108	Max	LF
2455391.360007	0.00109	Max	AM
2455391.447364	0.00106	Max	AM

The Start Epoch and Period have been computed by means of linear regression of all time of maxima, obtaining the following value for the ephemeris, with a root-mean-squared-error (RMSE) of 0.00062 d:

```
Start Epoch (HJD):     2455381.416076 d   ± 0.00043
Period:                      0.087227 d   ± 0.00001
```

From the filtered sessions we have measured a mean V apparent magnitude of 16.28 mag ± 0.04 and a mean Rc band of 16.07 ± 0.03, with colour index (V-Rc) of 0.21 ± 0.05, which is typical of F0/F5V star (Pickles, 1998). The mean range of the light variations in the V band spans from the maximum at 15.92 mag ± 0.02 and the minimum at 16.42 mag ± 0.04, with a peak-to-peak amplitude of Av = 0.50 mag ± 0.05. Furthermore we have computed mean amplitude variations in the V and R band from three independent values of the differences between maximum and minimum. The final values are A_V = 0.56 ± 0.04 and A_R=0.44 ± 0.06. The colour index

(V-Rc) varies from 0.12 ± 0.07 at maximum to 0.24 ±0.01 at minimum The magnitude uncertainty is estimated as the standard deviation of the independent values as said before. The phase plot is shown on Fig 5.

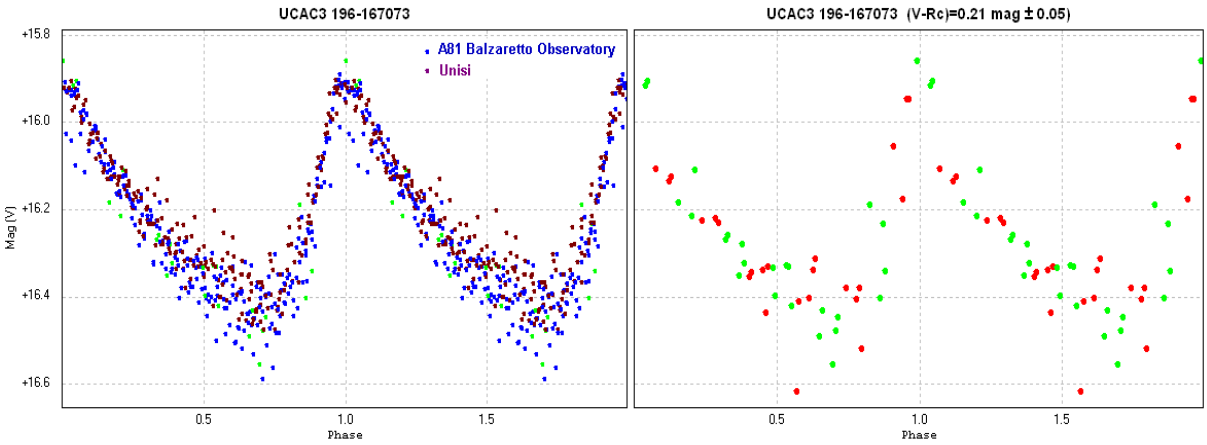

Figure 5. Phase plot of the star V142 (UCAC3 196-167073). On right the V and Rc magnitudes obtained adding to the Rc magnitudes the mean colour index value (0.21).

The frequency analysis was performed by means of standard Discrete Fourier Transform algorithm as implemented in *Period04* (Lenz & Breger 2005) package with subsequent pre-whitening steps, which also includes multifrequency least squares fitting of the parameters. The asymmetry in the shape of light curve generates the presence in the spectrum of the harmonics 2f and 3f of the fundamental. Frequency spectrum in the range (0-50) c/d and the fit model, obtained from data taken on July 2010, 09th, are shown in the Fig.6, while the strongest frequencies are listed in Table 9. Fitting uncertainties was estimated with Monte Carlo Simulation method as implemented in *Period04*. The phase differences $\Phi_{21} = \Phi_2 - 2\Phi_1 = 4.54 \pm 0.08$ (rad) is quite well according to distribution of δ Scuti type (HADS) and SX Phe in the Φ_{21} – P plane (Antonello et al. 1986; Poretti, 2000).

Table 9. Frequencies found in the spectrum of Var142 (UCAC3 196-167073)

#	Frequency (c/d)	Amplitude	Phase
f_0	11.4651737 ± 0.0007330	0.2073 ± 0.0034	0.1515 ± 0.0024
$2f_0$	22.9290176 ± 0.0803682	0.0807 ± 0.0031	0.0259 ± 0.0115
$3f_0$	34.3920608 ± 0.0057706	0.0310 ± 0.0029	0.9379 ± 0.0176

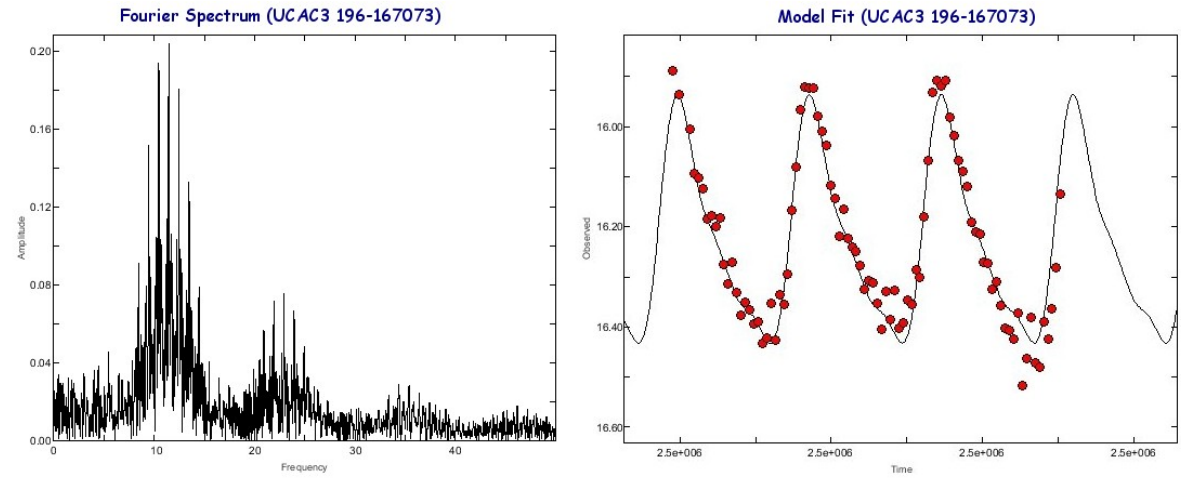

Figure 6. Fourier Spectrum and Model Fit obtained on observing session of July 2010, 09th.

Based on photometric data and period analysis, this star seems to be an High Amplitude δ Scuti (HADS); nevertheless there are many common features with SX Phe variables too. Since the stars of the latter class

belong to Population II (Poretti, 2000), spectroscopic observations could solve unambiguously the true class of this variable.

4. Conclusions

We reported the discovery by serendipity of four new variable stars in the Ophiuchus constellation. The variability was found during the photometric analysis of a NEO Asteroid pictures taken on the previous night. Subsequent observations have led to more precise periods and fundamental parameters. Based on this parameters, we suggest to classify the new variables as three eclipsing variables (one as EA-type or RS CVn-type and two as EW-type) and one very likely as High Amplitude δ Scuti or SX Phe type. The first eclipsing variable (UCAC3 196-166827) is thought to be very likely the optical counterpart of 1RXS J180755.7+074717 X-ray source and this supports the hypothesis of an RS CVn system.

A teaching animation that simulates the three discovered eclipsing variable stars is available on YouTube (http://www.youtube.com/watch?v=_xjrqwJr2zA).

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