Photometric monitoring of FUORs and EXORs

Stoianka P. Peneva, Evgeni H. Semkov
Institute of Astronomy, Bulgarian Academy of Sciences
esemkov@astro.bas.bg
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Abstract. The main characteristics of FUOR and EXOR objects are presented. We show a program for photometric monitoring of this kind of objects using observations obtained in NAO Rozhen and Skinakas (Crete, Greece) observatories. The first results from photometric observations of the suspected FUOR V 733 Cep are presented. The possibility for using photographic plate archives is discussed also.
Key words: Stars: pre-main sequence, Stars: circumstellar matter, Stars: individual: V 733 Cep, V 1735 Cyg

Фотометричен мониторинг на обекти от типа на FU Orionis и EX Lupi

Стоянка П. Пенева, Евгени Х. Семков

Представени са основните характеристики на обектите от типа FU Orionis и сходните на тях обекти от типа EX Lupi. Представена е програмата за фотометричен мониторинг на тези и подобни обекти с използване на наблюдателен материал от НАО Рожен и обсерваторията Скинакас на о-в Крит. Показани са първите резултати от наблюдения на предполагаемия фуор V 733 Cep. Разглежда се и възможността за използване на архивните фотографски наблюдения.

1 Introduction

The photometric variability is a widespread property of the Pre-Main Sequence (PMS) stars. Both classes of PMS stars – the T Tauri Stars (TTSs) and the Herbig Ae/Be Stars (HAEBESs) show various types of photometric variability. Very important for investigation of stellar evolution are the outbursts caused by falling of matter from stellar environment on the stellar surface. According to Herbig (1989) the PMS stars undergoing such kind of outbursts can be separated in two subclasses: FUORs and EXORs.

The prototype of FUORs is the variable star FU Orionis, located in the Orion star forming region. The star was brightened by 6 magnitudes in 1936 and for a long time was the only one object of its kind. FUORs are low mass PMS stars defined as a class by Herbig (1977) after discovering of two new FUORs: V1057 Cyg and V1515 Cyg. Herbig (1977) demonstrated that FUOR eruptions almost certainly occur repetitively in all TTS in the course of their evolution. Hartmann and Kenyon (1985) have proposed that the flare-up is a result of a major increase of accretion from a circumstellar disk on the stellar surface (up to 10^{-4} $M_{\odot}/yr$). This accretion disk model can account for main properties of FUORs. According to Reipurth (1990) the main characteristics of FUORs are: location in the star-forming regions and association with reflection nebulae. Photometrically, classical FUORs exhibit a rapid rise in visual brightness of about 4-6 mag followed by a slow decay. Spectroscopic properties of FUORs are F-G supergiant spectra with strong Li I 6707 line, P Cygni profiles at Hα and Na I 5890/5896 lines, and presence of CO bands in

the near infrared spectra. Another spectral feature of FUORs is the gradual change from earlier to later of their spectral type from the blue to the infrared.

Fig. 1 shows the long-term lightcurves of FU Ori, V1057 Cyg and V1515 Cyg (Clarke et al. 2005) The time-scales of rise differ from object to object. For FU Ori and V1057 Cyg the transition to the outburst phase is rapid with duration of the order of 1 yr. In contrast to the rapid rise of FU Ori and V1057 Cyg, for V1515 Cyg the time-scale of rise is about 20 yr. The rate of decrease in brightness during the post-outburst phase is also quit different for different objects. Overall FU Ori has faded by about a magnitude in the blue since the eruption. The decline in brightness of V1057 Cyg is rather abrupt with a time-scale of roughly 10 yr.

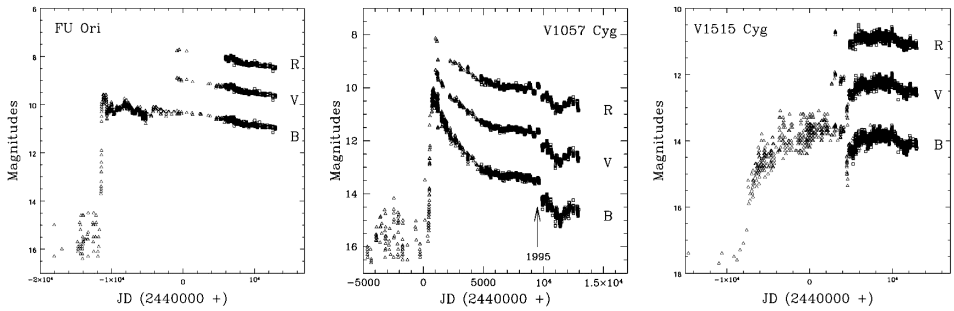

Fig. 1. Light curves of FU Ori (left), V1057 Cyg (middle) and V1515 Cyg (right) from Clarke et al. (2005).

The other class of PMS eruptive objects have for a prototype the variable star EX Lupi and they were named by Herbig (1989) EXORs by the analogy of FUORs. All known EXORs were found in the molecular clouds in star-forming regions. The EXORs have lower luminosities in the minimum light than the FUORs. The EXORs show outbursts with an amplitude up to 5 mag and the outbursts last only a few weeks or months. The outbursts are repetitive with roughly symmetrical light-curves. Near the maximum light their spectra are dominated by emission lines, similar to the classical TTSs and there are no evidences for a P Cygni profiles of $H\alpha$ line. Table 1 contains a list of all known FUORs, EXORs and others FUOR-like objects collected from the literature (Abraham et al. 2004, Herbig 2008, Sandell and Weintraub 2001)

From all objects classified as FUORs only three (FU Ori, V 1057 Cyg and V 1515 Cyg) have detailed photometric observations taken during the outburst and during the set of brightness (Fig. 1.). For most of these objects the time of outburst is not known and only partial photometric observations was published. From the EXORs only the prototype of the group EX Lupi was studied photometrically for a long time period (Fig. 2). The light curve of EX Lupi in 1995-2005 is constructed from visual observations of A. F. Jones. During that period four outbursts was registered. Another well studied object is V 1647 Ori, whose outburst in 2004 evokes a great interest in astronomical community. The main purpose of our investigation is a photometric study of FUOR and EXOR objects without regular observations up to now. We'll try

Table 1. A list of all known FUORs, EXORs and similar objects.

	Object	Outburst	D [pc]	Color	Minimum	Maximum
FUORs	FU Ori	1937	450	B/pg	16.5	9.5
	V1057 Cyg	1970	600	B/pg	16.5	10
	V1515 Cyg	1950	1000	B/pg	17.7	13
	V1735 Cyg	1957-65	900	R	20	15
	BBW 76	<1930	1700	V	12.41	12.12
	V346 Nor	1984	700	V	17.23	16.3
FUOR-like	L1551 IRS 5	?	140	V	20.9	19.5
	Z Cma	?	930	P	11.2	8.8
	RNO 1B/ C	?	850	V	21.6	18.6
	AR 6A/6B	?	800	-	-	-
	PP 13S	<1900	300	-	-	-
	Parsamian 21	?	1800	-	-	-
	Re 50 N IRS1	1960-70	460	-	-	-
	V1331 Cyg	?	550	V	13.08	10.59
	V883 Ori	?	460	I	15.6	14.8
	V733 Cep	1953-84	800	R	20	16
EXORs	EX Lup	-	-	V	14.3	8.5
	NY Ori	-	470	V/vis	<16	13.3
	V1118 Ori	-	470	V/vis	17.6	12.6
	V1143 Ori	-	470	V/vis	16.7	13.5
others	V350 Cep	1975-77	1000	B/pg	<21	13.5
	V1647 Ori	2004	400	V	20	18.1
	OO Ser	1995	311	K	16.1	11.4
	V1184 Tau	<1994	1500	V/pv	19.9	15

to collect more data from $BVRI$ photometry in the future and to search for available photographic observations in the astronomical plate archives.

2 Observations

Our data were obtained in two observatories with three telescopes: the 2-m Ritchey-Chretien-Coude and 50/70/172 cm Schmidt telescopes at the National Astronomical Observatory Rozhen (Bulgaria) and the 1.3-m Ritchey-Chretien telescope of the Skinakas Observatory. Observations with the 2-m RCC telescope were made with VersArray CCD camera (1340×1300 pixcels). Observations with the 1.3-m RC telescope were made with Photometrics (1024×1024 pixcels) and ANDOR (2048×2048 pixcels) CCD cameras. Observations with the 50/70 cm Schmidt telescope were made with ST8 (1530×1020 pixcels) and ST11000 (4008×2672 pixcels) CCD cameras. All frames were taken through a standard Johnson-Cousins set of filters. Twilight flat fields in each filter were obtained every clear evening. All frames obtained with the Photometrics, ANDOR and VersArray cameras are bias subtracted and flat fielded. CCD frames obtained with the ST8 and ST11000 cameras are dark subtracted and flat fielded. Aperture photometry was performed using DAOPHOT routines.

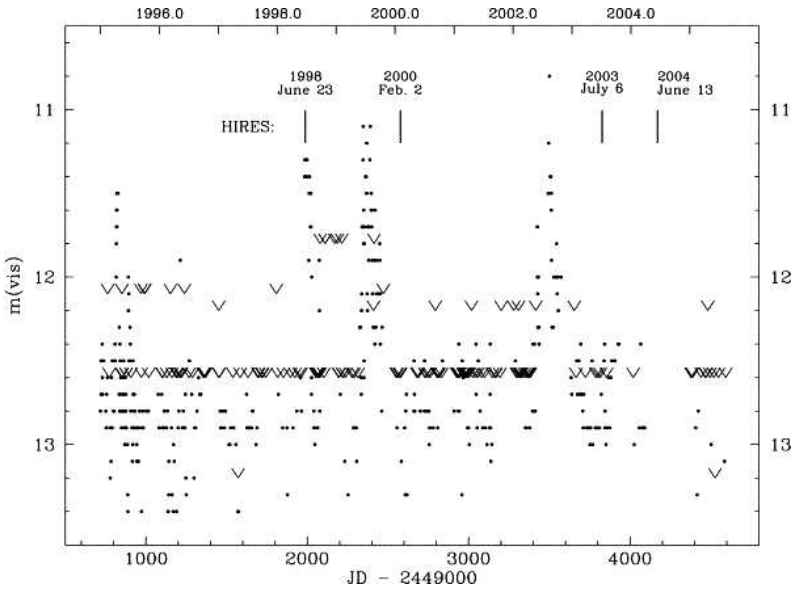

Fig. 2. Light curve of EX Lupi between 1995 and 2005, from visual estimates by A. F. Jones (Herbig 2007).

3 Results

A photometric monitoring of some PMS objects (V 350 Cep, V 1184 Tau, V 1647 Ori and others) was made up to now in the Rozhen observatory (Semkov 2006). In the present paper we report our first results from observations of two objects the FUOR star V 1735 Cyg and the suspected FUOR V733 Cep. In order to facilitate transformation from instrumental measurement to the standard system we tried to calibrate in $BVRI$ bands standart stars in the field of view of the 1.3-m telescope ($8\farcm5 \times 8\farcm5$). For V733 Cep calibration was made during four clear nights in the summer of 2007, and for V1735 Cyg during eight nights in 2005, 2006 and 2007. Standard stars from Landolt (1992) were used as reference. The finding charts of the comparison sequences are presented in Fig. 3 for V 733 Cep and in Fig. 5 for V 1735 Cyg. During standards calibration four new variable stars were discovered, three in the field of V 733 Cep and one in the field of V1735 Cyg.

3.1 V 733 Cep

The variable star V 733 Cep is located in the dark cloud L1216. The star is discovered from Swedish amateur astronomer Roger Persson in 2004. Persson compared together the plate scans from the first and the second Palomar Sky Survey. He noted the presence of the star on the red POSS-II image and its absence on the corresponding POSS-I image. (Persson 2004). The star is visible also on a Palomar Quick-V plate from 1984. R-band CCD image of V 733 Cep was taken with the 88 inch (2.2m) telescope on Mauna Kea, Hawaii, on 2004 October 9. The red magnitude, measured from this observation is of

about $17\overset{m}{.}3$ (Reipurth et al., 2007). Comparing this value with the data from USNO-B catalog Reipurth et al. (2007) conclude that the star has faded by $1\overset{m}{.}6$ in R over a time period of about 13 yr. The authors suspected a possible outburst in the period 1953-1984 and found great spectral similarities to FU Ori itself.

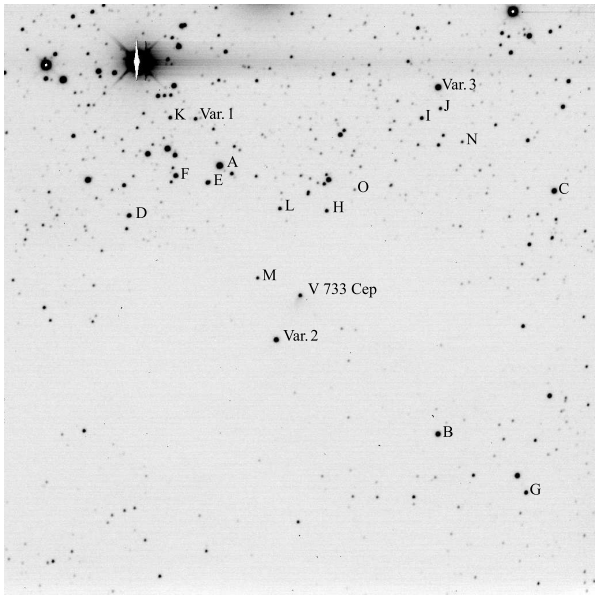

Fig. 3. A finding chart for the *BVRI* comparison sequence around V733 Cep.

Our photometric observations of V 733 Cep in the period February 2007 - February 2008 show that the brightness of the star is almost steady. We observed only a low amplitude fluctuations of about $0\overset{m}{.}1$ (R) around the middle values. Using our comparison sequence we measured the plates scans from POSS-II and Quick-V. The corresponding photometric values are: V=$17\overset{m}{.}75$, I=$13\overset{m}{.}77$, R=$16\overset{m}{.}00$, B = $20\overset{m}{.}78$. The light curve of V 733 Cep from all known observations is plotted on Fig. 4. Our photometric data suggest that in the period Feb. 2007 - Feb. 2008 the star brightness is similar to the measured from the POSS-II and Quick-V plates (Fig. 4). This result does not support the hypothesis for a FUOR nature of the V 733 Cep variability. The two observed minima (on POSS-I and on Oct. 2004) can be explained by a variable extinction from the circumstellar environment - a UX Ori type of variability (Semkov et al. 2008).

3.2 V 1735 Cyg

V1735 Cyg was discovered by Elias (1978) in the infrared survey of the IC 5146 dark cloud complex. The object is under the limit of the red POSS-I plate obtained in 1952. But on a Hale Observatories plate taken on 1965 July 5, the

Table 2. Photometric observations of V733 Cep in the period February 2007 - February 2008.

Date	J.D.(245...)	*Ic*	*Rc*	*V*	*B*	CCD	Tel.
2007 Feb 25	4157.212	14.060	16.352	18.190	–	ST-8	Schmidt
2007 Apr 10	4200.582	14.073	16.045	18.191	–	VersArray	2m RCC
2007 Jun 27	4278.519	14.173	16.408	18.406	21.08	Photometrics	1.3m RC
2007 Jul 04	4285.525	14.108	16.331	18.345	21.08	Photometrics	1.3m RC
2007 Jul 23	4305.494	14.023	16.248	18.223	20.75	ANDOR	1.3m RC
2007 Jul 25	4306.512	14.036	16.266	18.267	20.81	ANDOR	1.3m RC
2007 Aug 14	4327.401	14.066	16.021	18.184	–	VersArray	2m RCC
2007 Aug 15	4328.402	14.091	16.039	18.216	–	VersArray	2m RCC
2007 Aug 17	4330.461	14.102	16.087	18.193	21.01	VersArray	2m RCC
2007 Nov 06	4411.217	14.172	16.121	18.239	–	VersArray	2m RCC
2008 Feb 12	4509.235	14.301	16.288	18.380	–	ST-11000	Schmidt

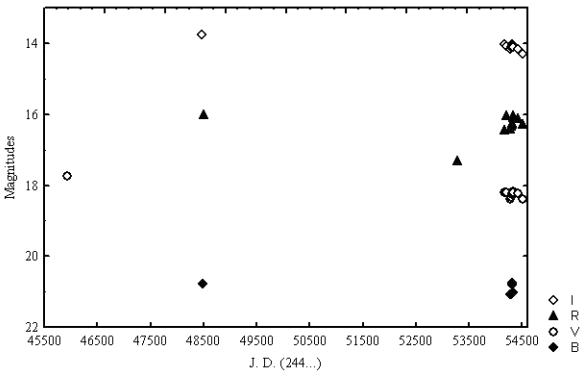

Fig. 4. BVRI-light curve of V733 Cep for the period 1984 - 2008.

object has a similar brightness like on Elias survey. The star appears to have brightened by 5 mag sometime between 1952 and 1965. The measurements made with the multichannel spectrometer on the 5-m Hale telescope show that V1735 Cyg currently has an $R = 15\overset{m}{.}0$ (Elias 1978). On the basis of observed outburst and its spectrum, V 1735 was classified as a FUOR object.

Searching in the plate archive of the 50/70 cm Schmidt telescope of NAO Rozhen we found 148 plates containing the field of V 1735 Cyg. The data for the photographic observations are summarized in Table 3. Since 2003 CCD photometric observations of V1735 Cyg have been made in Rozhen and Skinakas Observatory. The data for the CCD observations are summarized in Table 4. Using the collected photographic and CCD observations we'll try to construct the long-term light curve of V 1735 Cyg and to confirm the FUOR nature of the object.

4 Conclusions

The prototypes of FUORs and EXORs seem to be T Tauri stars with massive circumstellar disks. In both cases the observed outburst is explained by

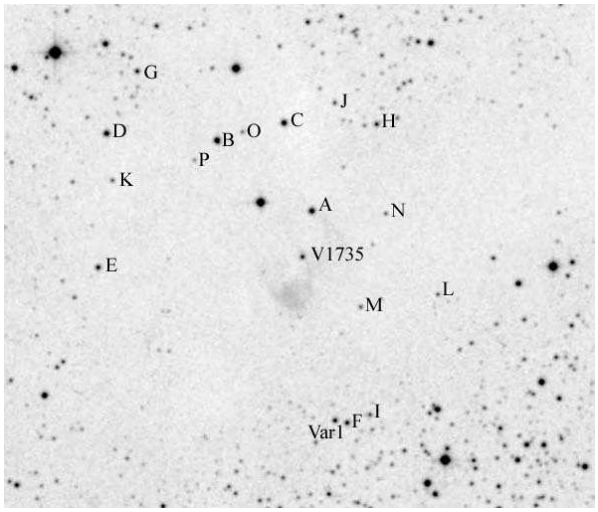

Fig. 5. A finding chart for the *BVRI* comparison sequence around V1735 Cyg.

Table 3. Photographic observations of V1735 Cyg with 50/70/172 cm Schmidt telescope for the period 1980-1994.

Filter	Number of plates
U	11
B	102
V	14
R	7
NONE	14
Total	148

increased accretion from the circumstellar disk. The EXORs are less luminous and less massive than FUORs. In contrast to FUORs EXORs have a T Tauri like spectrum during the maximum light. While the EXORs spend only a few weeks or months in the maximum brightness, the outbursts of FUORs extend some decades. We hope that our study of FUORs and EXORs will be important for the astronomers working in the field of early phases of stellar evolution.

Table 4. CCD observations of V1735 Cyg with the telescopes of NAO Rozhen and Skinakas Observatory.

Year	Telescope	Used nights
2003	2-m RCC NAO Rozhen	1
	50/70 cm Schmidt NAO Rozhen	5
2004	2-m RCC NAO Rozhen	1
	50/70 cm Schmidt NAO Rozhen	7
	1.3-m RC Skinakas Observatory	9
2005	2-m RCC NAO Rozhen	2
	50/70 cm Schmidt NAO Rozhen	1
	1.3-m RC Skinakas Observatory	8
2006	2-m RCC NAO Rozhen	8
	50/70 cm Schmidt NAO Rozhen	6
	1.3-m RC Skinakas Observatory	8
2007	2-m RCC NAO Rozhen	5
	1.3-m RC Skinakas Observatory	5
2008	50/70 cm Schmidt NAO Rozhen	1

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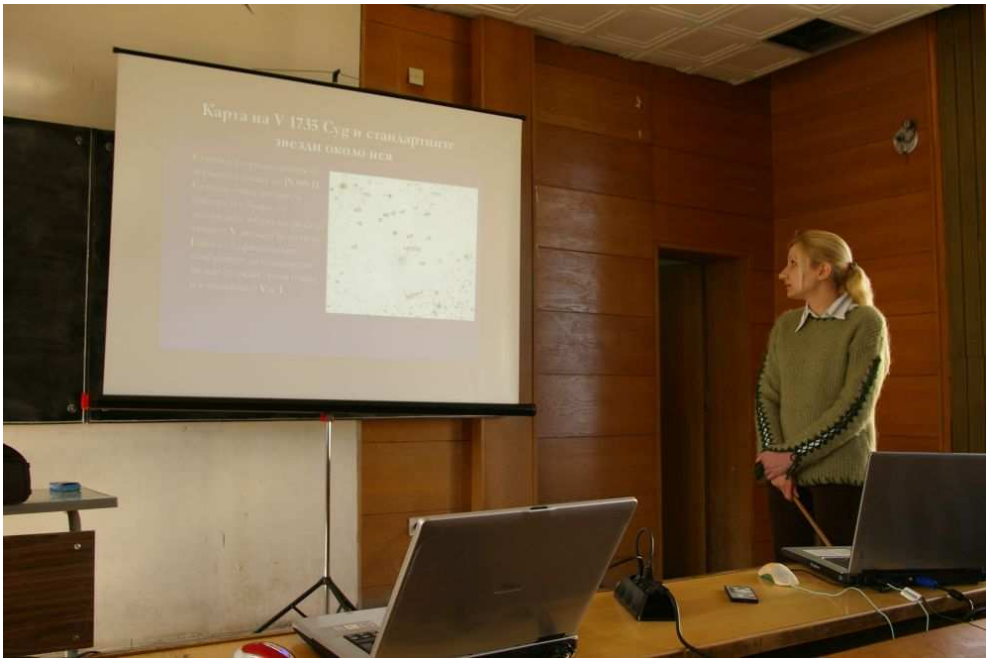
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