OBSERVATIONS OF STARS OCCULTATIONS BY THE MOON WITH THE "SPALAKH" TELEVISION SYSTEM

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On the television observations of lunar occultations of the stars and reductions made in 2003–2004 at the Astronomical Observatory of the Kyiv National Taras Shevchenko University are reported. Observations are executed with the help of the "Spalakh" system with fixation Universal Time for each frame. On the exact moment of occultations is reported.

INTRODUCTION

More than 80 years the observations of star occultations have been performing at the Astronomical Observatory of the Kyiv National University. The new television system "Spalakh" was created at the Astronomical Observatory [3] for improvement objectivity and accuracy of the occultations observation. The main parameters of the system are: the time resolution is 40 ms, the accuracy time scale is 50 ms, the limit of star magnitude is 12^m. The original software for the system allow digital recording TV signal from sensitive CCD camera with precision of link to UTC scale and processing the observation result.

γ VIRGO OCCULTATION

First observation of star occultation by the Moon with the television system was carried out on July 6, 2003 using the refractor of the Astronomical Observatory of the Kyiv National University. The CCD camera was established in focus of the Repsold refractor guide. The occultation of the SAO 138917 star (29 γ Vir) was observed during 2.9 min. The conditions of the observation are listed below: a dense layer of mobile clouds, the unstable star image, dark limb of the Moon is invisible, a phase of the Moon of 46%, height above horizon 25°, the Sun under horizon at height $-6°$. Precomputation moment [4] of double star γ Vir ($m_\alpha = 3.65, m_\beta = 3.68$) occultation by the Moon is $18^h\ 50^m\ 13^s \pm 6^s$. For processing results of observation the original software was used. It allows to derive the estimations of a star brightness on each frame. Photometric curve was obtained and as a result a duality of the star (γ Vir) was confirmed [1] (see Fig. 1).

Initial maximum of brightness corresponded to a case when we saw two components. Intermediate brightness value was observed for a case when the Moon closed one of the component. The final brightness value corresponded to a case when we saw only background value. Photometric errors were calculated for each interval of star brightness values. The designated ranges of confidential intervals for brightness, which were chosen at the 2.5σ level, are showen as a dashed line in Fig. 1. All values of momentary estimations of brightness lay in the ranges of the confidential intervals except for a point $18^h\ 50^m\ 11.00^s$ UTC. It means that the occultation was held during exposing this frame, and that its time needs to be accepted as occultation time of the first component. Occultation time of the second component is $18^h\ 50^m\ 11.43^s$ UTC. Time of 0.43 s between coverings of stars corresponds to the bottom estimation of distance between components at 0.20 arcsec. For more exact estimation of occultation conditions it is necessary to calculate distance between components and a positional angle of direction center-to-center stars using the orbit elements of the double star. The calculated distance between components of the double star (γ Vir) is equal to $R = 0.74''$ at the moment of observation (2003.52). Formulas (1), (2) were used for calculation of value R between components [2]:

$$R = \rho \frac{\cos(v+\omega)}{\cos(\theta - \Omega)}, \tag{1}$$

$$\rho = \frac{a(1-e^2)}{1+e\cos v}, \tag{2}$$

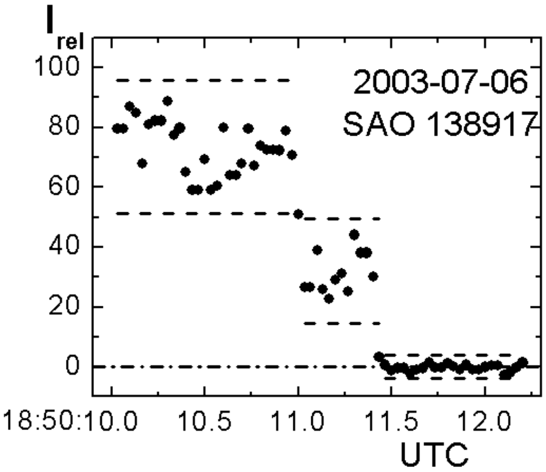

Figure 1. Photometric curve of γ Vir double star occultation on July 6, 2003

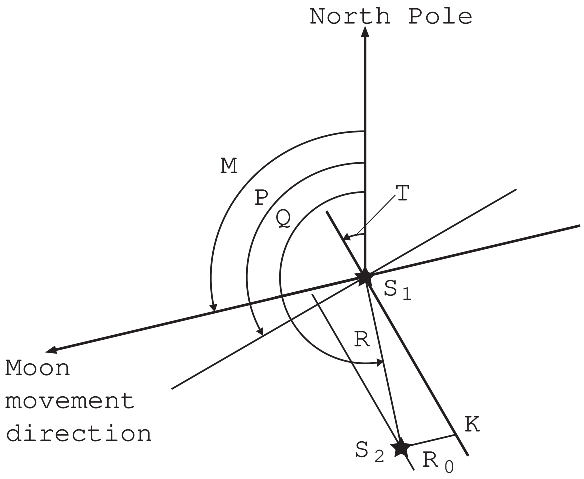

Figure 2. Position of a double star (γ Vir) relatively a direction of the Moon movement

where a is the major semiaxis, e is the eccentricity, v is the true anomaly, ω is the angle between node and periastron, Ω is the positional angle of the line of nodes.

Figure 2 shows the occultation conditions. Points S_1, S_2 are components of a double star. Line S_1K shows the position of the Moon limb at the moment of first component occultation. T is the positional angle of the line S_1K. The Moon moves with a velocity V in a direction with positional angle M. Distance R_0 (equals S_2K) is determined by the time between coverings of components, and parallel to the Moon velocity vector. It is equal to

$$R_0 = \frac{R \sin(\theta - T)}{\sin(M - T)}. \tag{3}$$

$T = P - 90°$ without taking into account a profile of a regional zone. Here P is an ephemeris positional angle of occultation. For our case $P = 157°$ and if to put $T = 67°$ for difference 0.43 s in the moments of occultation we shall derive a value of distance between components $R = 0.48''$ that essentially differs from the ephemeris data. It is possible to explain such difference by lunar limb profile. It is possible to observe the occultation consistent with the ephemeris data if assume that the positional angle of lunar limb is equal to 53°. It means that in this place the lunar limb has an additional inclination in 14° to local horizon.

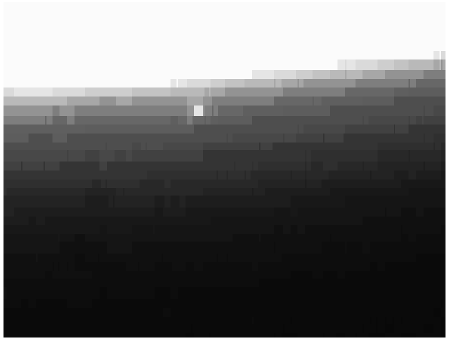

Figure 3. Part of frame during occultation of SAO 77 775 star (4.8 mag) by the Moon bright limb

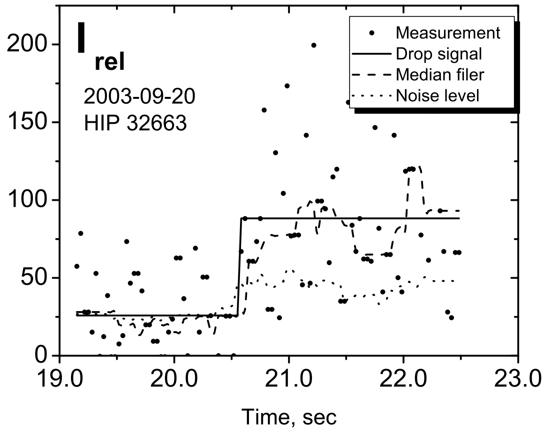

Figure 4. Photometrical curve of occultation near reappearance of HIP 32663 star. The event time is determined with a help combination of three criteria: drop signal assumption, median filtration, and noise level

SAO 77775 OCCULTATION

This observation is interesting because the disappearance not brilliant star (4.8^m) on the bright limb was registered. The conditions of observation are: a good atmosphere transparency, a strong sky background, the phase of the Moon is equal to 47%, the height above horizon is equal to 60°, the Sun height under horizon is equal to −12°. Figure 3 shows the part of recording frame near event. The star had been visible up to the lunar limb without regard to a significant difference in brightness that has allowed getting sharp estimation for occultation time. The estimation of event time was obtained by frame-accurate viewing of record. It was equal to $02^h\ 30^m\ 52.44^s$ UTC.

HIP 32663 OCCULTATION

This observation is interesting because it was managed to register the reappearance of extreme faint star (10^{m}). Conditions of observation were: a good atmosphere transparency, the dark limb of the Moon is well seen, the phase of the Moon is equal to 37%, the height above horizon is equal to 42°, the Sun height under horizon is equal to −23°. Figure 4 shows the part of occultation photometrical curve near star reappearance. In this case, the moment of event approach is insufficiently evident, and application of special mathematical methods of processing for its definition is required.

Three methods of event time definition at presence of strong fluctuations of a signal recommended themselves well. The first method is approximation of measurements of the star brightness by drop function. Three parameters have been finding from the least squares method: levels of a signal before and after event and position of spasmodic change. Other method uses median filtration of photometric magnitude, as it does not deform fronts at spasmodic changes of a signal level. This fact is very important to correct determination of occultation time. The third method is a method of noise level measurement. It measures a dispersion of a signal

Table 1. Summary table of occultation observation with "Spalakh" television system

N	Ephemeris Data, YMD	Ephemeris Time, UTC hh mm ss	Star Identification	Star mag	Star Spectral class	Event	Telescope	Remarks	Measuring time, UTC hh mm ss
1	20030706	18 50 11	SAO 138917	2.8; 3.5	K7; F0	DD	R	Double star	18 50 11.00; 18 50 11.47
2	20030919	02 30 49	SAO 77775	4.8	K0	DB	R		02 30 52.44
3	20030920	01 11 40	HIP 32663	10.0	K0	DD	R	Extremely faint star	01 11 41.58
4	20040402	19 29 19	SAO 99321	6.8	G5	DD	R	HD 93993	19 29 15.27
5	20040427	20 37 55	SAO 80456	9.1	G5	DD	R	BD +22 2004	20 37 52.43
6	20040428	18 57 17	DM +19 2239	9.6	G0	DD	R		18 57 20.50
7	20040428	20 28 05	SAO 98724	9.6	A5	DD	R	Variability/Duplicity	20 28 07.04
8	20040428	21 12 48	SAO 98725	9.3	A	DD	R	Variability/Duplicity	21 12 52.56
9	20040501	19 49 55	SAO 119245	6.1	K0	DD	R	Variability/Duplicity	19 49 54.36
10	20040504	21 30 41	SAO 158855	6.6	F6V	DU	A		21 19 44.40
11	20040625	19 29 07	SAO 119340	8.5	F5	DD	R	Variability/Duplicity	19 29 06.64
12	20040626	19 33 16	SAO 139178	8.0	F8	DD	R	Variability/Duplicity	19 33 16.74

Event:
First character shows the phenomenon:
D – disappearance; R – reappearance.
Second character shows the lunar limb:
D – dark limb event; B – bright limb event; U – event during an eclipse of the Moon.
Telescope:
A – the AZT-14 reflector ($D = 0.5$ m, $F = 7.7$ m), Lisnyki;
R – the Repsold refractor ($D = 0.2$ m, $F = 4.0$ m), Kyiv.

in a sliding window, which is centered on the given point. The combination of these three methods has allowed identifying the moment of star reappearance confidently. Maximum time error is equal to 0.09 s. It consists of accuracy of the system and an error of a frame number choice for which there comes event of star reappearance. It was obtained values of time of the reappearance as $01^h\ 11^m\ 41.58^s$ UTC.

SAO 158855 OCCULTATION

This occultation was observed during a full lunar eclipse time. Conditions of observation were: a not good transparency of an atmosphere, a strong sky background, the height above horizon is equal to 28°, the Sun height under horizon is equal to −23°. Unfortunately, the star image was essentially unstable. The estimation of event time was received by frame-accurate viewing of record. It was equal to $21^h\ 19^m\ 44.40^s$ UTC. Uncertainty for choosing event frame is equal to 2 frames. The result error is 0.13 s.

Other observations of star occultations were typical, therefore, their detailed descriptions are not given. The results of all observations are collected in the summary table (see Table 1).

DISCUSSION

First results of observation with a "Spalakh" system show significant potential of system. There are such evidences about this: bad weather conditions and bright lunar limb, and a considerable part of faint stars in observation. The software for occultation processing allow determining number frame of event better than one frame and also the faint star for dark limb occultation. Accuracy for bright limb occultation strongly depends on weather conditions. 80% of all observations have the maximal accuracy, which is determined by accuracy of the "Spalakh" television system.

[1] *Aitken R. G.* New General Catalogue of Double Stars.–Washington: Carnegie Institution, 1932.–**II**.–P. 730–732.

[2] *Couteau P.* L'Observation des étoiles doubles visuelles.–Flammarion, 1978.

[3] *Kleshchonok V. V., Buromsky M. I.* First results of observations with astronomical television complex "Spalakh" for fast processes registrations // Visnyk of Kyiv University.–2004.–**42**.

[4] The ephemeride lunar occultations.–Tokyo, International Lunar Occultation Centre, 2002.