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Observation of Asteroidal Occultation with Time-inserted Video Recording System

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Abstract Asteroidal occultation, which is the phenomenon such that an asteroid passes in front of a star and eclipses the light, is momentary event, and the observation gives valuable information of asteroids. In order to measure the moment precisely, the author has introduced video recording system that can insert GPS time into each video frame. The system has been installed to the 50 cm reflecting telescope at Tsukuba, and 22 asteroidal occultations have been observed since 2012. This paper reports the observations, which provide information on the size and the shape of asteroids.

Key words : occultation, asteroid, video observation

1. Introduction

Many of astronomical observation are done by still-imaging because the time scale of astronomical phenomena is much longer than the image-exposure time in general. However, there exist phenomena whose time variation is very rapid, and observation by video-imaging of high time-resolution is useful for examining such short time-scale phenomena. It is the great advantage that the sensitivity of recent video camera becomes much higher than before.

Compared with still-imaging observation, it is the fact that the photometric accuracy of video-imaging observation is poor because of the difficulty of calibration, for example, to determine the relation between the count output from the image sensor and the flux of light from the object. However, the time resolution of video-imaging, 1/60 seconds, is the superiority, especially for severe timing observation such as occultation.

Occultation is the phenomenon such that a celestial object passes over another object, and asteroidal occultation is that an asteroid passes over a fixed star in general. During an asteroidal occultation, the shadow of an asteroid crosses over the surface of the Earth, and from observer the fixed star seems to disappear for a short period. It is most important for the observation to measure the moments of disappearance and appearance exactly at occultation. Not only the size of the asteroid along the moving path over the observer can be estimated, but also the shape can be traced out by compiling observations of separate observers.

In this paper, the author first presents the video recording system of Tsukuba and describes the observations of asteroidal occultation in the next section. The results of the analysis are shown in the third section with the method of analysis.

2. Observation

2.1 Time-inserted Video Recording System of Tsukuba

Although the observatory at Ueno is more famous as it has been public since 1931, National Museum of Nature and Science (NMNS) has another telescope at Tsukuba, where all of the research departments of NMNS exist. In 1990 was the telescope, a 50 cm reflector whose focal

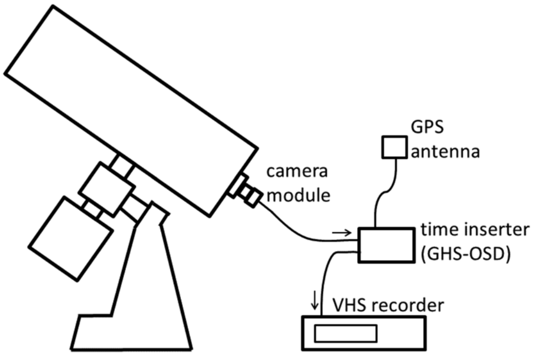


Fig. 1. Configuration of the video recording system of Tsukuba.

Fig. 2. Video image in which GPS time is inserted by GHS-OSD.

length is 6 meter (F/12 Cassegrain), installed at latitude 36:06:05.1 North, longitude 140:06:40.7 East, and altitude of 40 meter.

The video recording system of Tsukuba was introduced in 2012, whose configuration is shown in Fig. 1. The camera module is Watec WAT-100N, 1/2 inch monochromatic CCD camera, that outputs NTSC video signal. The time inserter, GHS-OSD, which is developed by Tsutomu Hayamizu and his colleagues[1,2], superimposes the time obtained from GPS into each video frame such as Fig. 2.

2.2 Prediction of Asteroidal Occultations and the Observation

Observation of asteroidal occultation is highly organized by notable associations such as IOTA (International Occultation Timing Association) including amateur observers. Steve Preston and his colleagues of IOTA provide information of occultations observable on the Earth[3], and Tsutomu Hayamizu, for example, circulates information concerning Japan[4]. Fig. 3 is the examples of prediction, which shows the paths of asteroid's shadow projected by the occulted star on the surface of the Earth.

Table 1 is the list of observations that the author has done since 2012. There were 88 occultations planned to be observed, but accomplished were 22 occultations (25%) due to weather condition. At hazy night, it is difficult to target occulted star fainter than 12th magnitude, especially in the case such as the altitude less than 30 degree that frequently occurs. The fundamental observation of asteroidal occultation is to investigate whether and what time disappearance of target star occurs. It is often that the asteroid itself cannot be seen, because most of asteroids are fainter than 12th magnitude as you can see in Table 1.

3. Analysis of Video Observation

An analysis tool for video-imaging file is vigorously developed by Kazuhisa Miyashita, and the software running on MS-Windows, Limovie, is popularly used by observers of occultation worldwide[5,6]. Limovie can digitize NTSC video movie and measure the brightness of a star in each video frame (or video field) automatically with the function that traces the position of a star fluctuating due to atmospheric scintillation, etc.

The occultations that the author can find brightness depression of target stars are of occultation Nos. 14 and 16 in Table 1, while the other occultation events show no decrease of brightness. Fig. 4 is the light curves of the observed occultations, for which measurement is done by aperture photometry. The author adopts the photometry method to measure the brightness of a occulted star with the aperture radius of 12 pixel for star and with the annulus between the radii of 15 and 25 pixel for sky subtraction, which are determined from the seeing size of each star and from the low S/N ratio due to the faintness of the

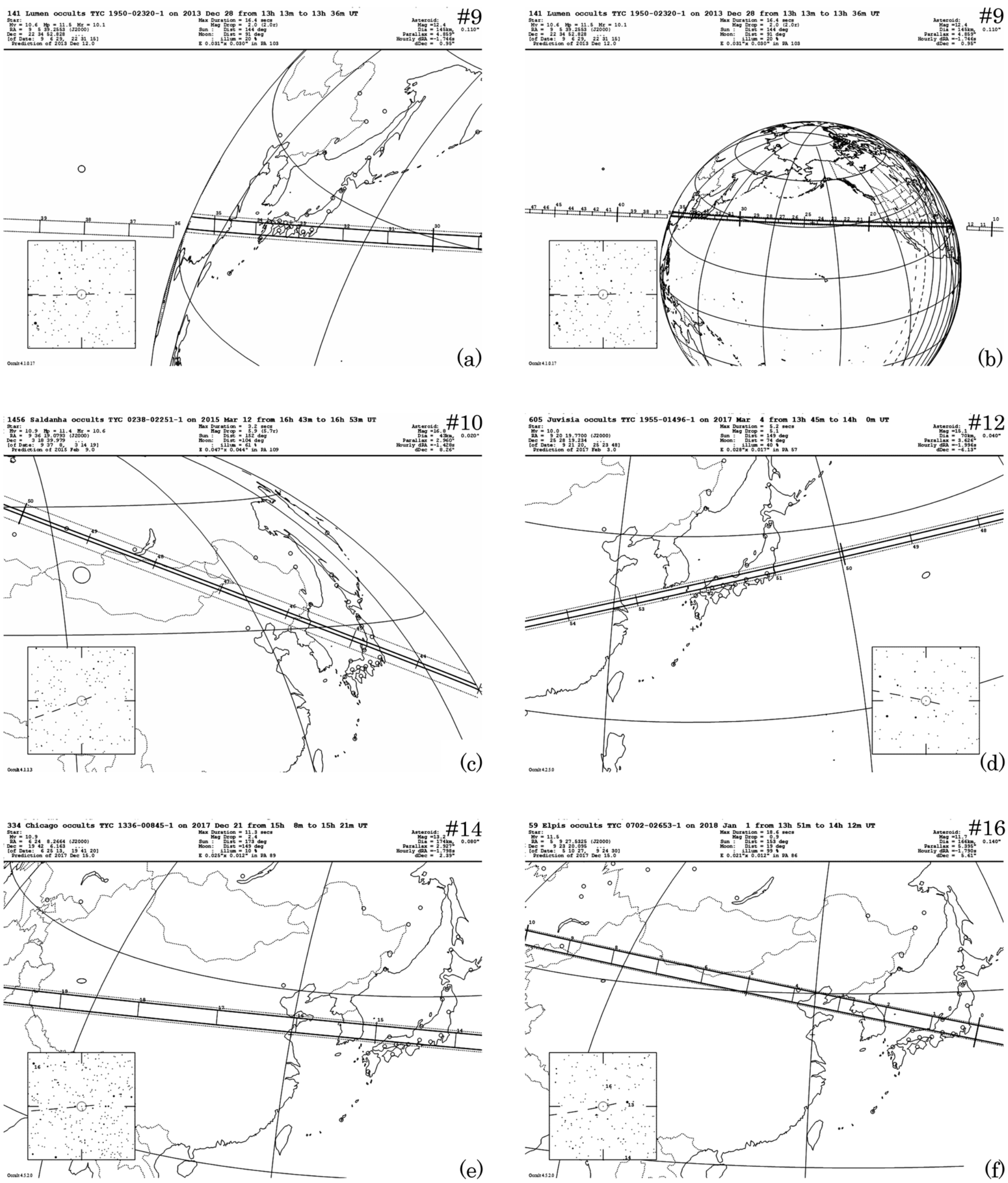


Fig. 3. Maps of predicted path of asteroidal occultation[3)]. The larger the size of an asteroid is, the wider the strip in which the occultation can be observed is. The insets are star charts that show how the asteroid approaches to the occulted star. The number at the upper right of each figure corresponds to the serial number of occultation in Table 1, i.e., Fig. 3a is of the occultation #9 by the asteroid (141) Lumen, for example. Fig. 3b shows that the occultation by (141) Lumen can be observed also at the west coast of the U.S.A.

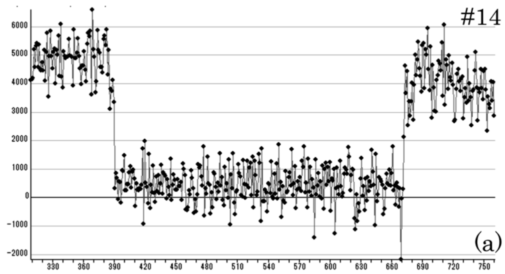
star, while Limovie provides two photometry methods, aperture photometry and PSF (Point Spread Function) photometry. Table 2 is the result of occultation times and durations, which are measured from the depressions that can clearly be seen in Fig. 4.

Although one can only estimate the length of a part of asteroid from an observation, it is possi-

Table 1. List of observations of occultation at Tsukuba*

Occult. No.	Time (UT)	Asteroid				Target star				Max. t (sec)
		Name		Mag.	D (km)	Name	R. A.	Dec.	Mag.	
1	2012-11-03 15:44	(3667)	Anne-Marie	15.9	23	TYC 3360-00908-1	05:46:08.2	+ 46:11:53	9.9	3.0
2	2012-12-26 19:37	(70)	Panopaea	13.7	122	TYC 0299-00103-1	13:17:17.4	+ 01:26:09	11.7	5.4
3	2013-05-09 17:42	(635)	Vundtia	15.3	100	PPMX 10694794	19:11:39.4	− 08:41:14	11.9	19.5
4	2013-08-09 15:03	(3828)	Hoshino	16.4	20	TYC 5233-02137-1	22:33:25.2	− 00:18:44	8.5	1.8
5	2013-10-11 18:55	(3132)	Landgraf	16.8	39	2UCAC 38946743	06:28:55.6	+ 20:16:17	11.1	4.0
6	2013-11-17 09:28	(916)	America	15.3	35	TYC 6334-00298-1	20:33:36.4	− 17:29:11	10.1	1.2
7	2013-11-29 13:16	(1112)	Polonia	13.9	36	2UCAC 43401495	04:22:31.0	+ 33:04:13	11.8	3.0
8	2013-12-02 09:16	(1112)	Polonia	13.9	36	TYC 2375-01334-1	04:19:43.7	+ 32:52:22	11.9	3.0
9	2013-12-28 13:33	(141)	Lumen	13.0	135	PPMX 5161751	09:05:39.3	+ 22:34:53	10.6	15.3
10	2015-03-12 16:45	(1456)	Saldanha	16.8	46	UCAC 4-467-042558	09:36:19.1	+ 03:18:40	10.9	3.3
11	2015-10-09 12:39	(266)	Aline	11.9	102	TYC 1183-00461-1	00:28:17.4	+ 19:39:08	10.6	10.1
12	2017-03-04 13:51	(605)	Juvisia	15.0	72	UCAC 4-578-045790	09:20:19.8	+ 25:28:19	10.0	5.3
13	2017-03-04 16:30	(46)	Hestia	13.6	124	TYC 6191-00003-1	15:58:59.3	− 18:44:04	11.9	12.0
14	2017-12-21 15:14	(334)	Chicago	13.2	170	UCAC 4-549-026551	06:24:08.3	+ 19:42:06	10.9	11.0
15	2017-12-22 18:31	(614)	Pia	14.1	31	2UCAC 36605510	06:10:47.8	+ 13:46:09	11.6	3.0
16	2018-01-01 14:00	(59)	Elpis	11.7	173	TYC 0702-02653-1	05:09:27.5	+ 09:23:20	11.5	19.4
17	2018-01-02 19:21	(32532)	Thereus	20.2	77	TYC 4851-02299-1	08:09:38.0	− 02:07:27	10.7	3.7
18	2018-06-03 16:48	(2813)	Zappala	16.4	37	TYC 5706-01200-1	18:54:59.3	− 08:59:56	9.4	3.0
19	2018-06-04 15:29	(579)	Sidonia	12.5	90	HSOY 578256951	14:41:40.4	− 06:57:35	12.1	9.8
20	2018-07-01 15:11	(4035)	1986WD	16.6	58	HSOY 107769848	19:19:31.0	− 09:58:54	12.1	3.5
21	2018-07-01 15:55	(677)	Aaltje	14.6	41	TYC 5225-01455-1	22:14:40.3	− 02:23:15	10.3	9.1
22	2018-07-02 12:12	(3405)	Daiwensai	15.1	25	TYC 5692-01818-1	18:38:26.6	− 08:36:19	9.4	2.5

* Column (1): serial number of occultation, (2): event time of occultation around Japan, (3–5): name, magnitude, and diameter estimated from previous observations of occulting asteroid, (6–9): name, right ascension, declination, magnitude of occulted star, (10): predicted duration of occultation at maximum.



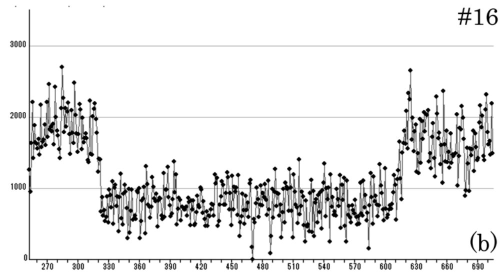


Fig. 4. Light curves of observed asteroidal occultations. The horizontal axis is video frame number, and the vertical axis is brightness. The remaining brightness in each depression is of the respective asteroid itself.

Table 2. Result of occultation times and durations

Occult. No.	Asteroid	Occultation time (UT) Video recording time (UT)	Duration (sec)
14	(334) Chicago	2017-12-21 15:14:12.70–15:14:22.08 15:09.00.00–15:17:00.00	9.38
16	(59) Elpis	2018-01-01 14:00:09.33–14:00:19.11 13:57:00.00–14:03:00.00	9.78

ble to trace out the shape of an asteroid if many observations at different locations are assembled. Fig. 5 is the figures that are made by Tsutomu Hayamizu[7)], who is a coordinator of Japanese observation of occultation and compiles the observations. You can see from the figures that

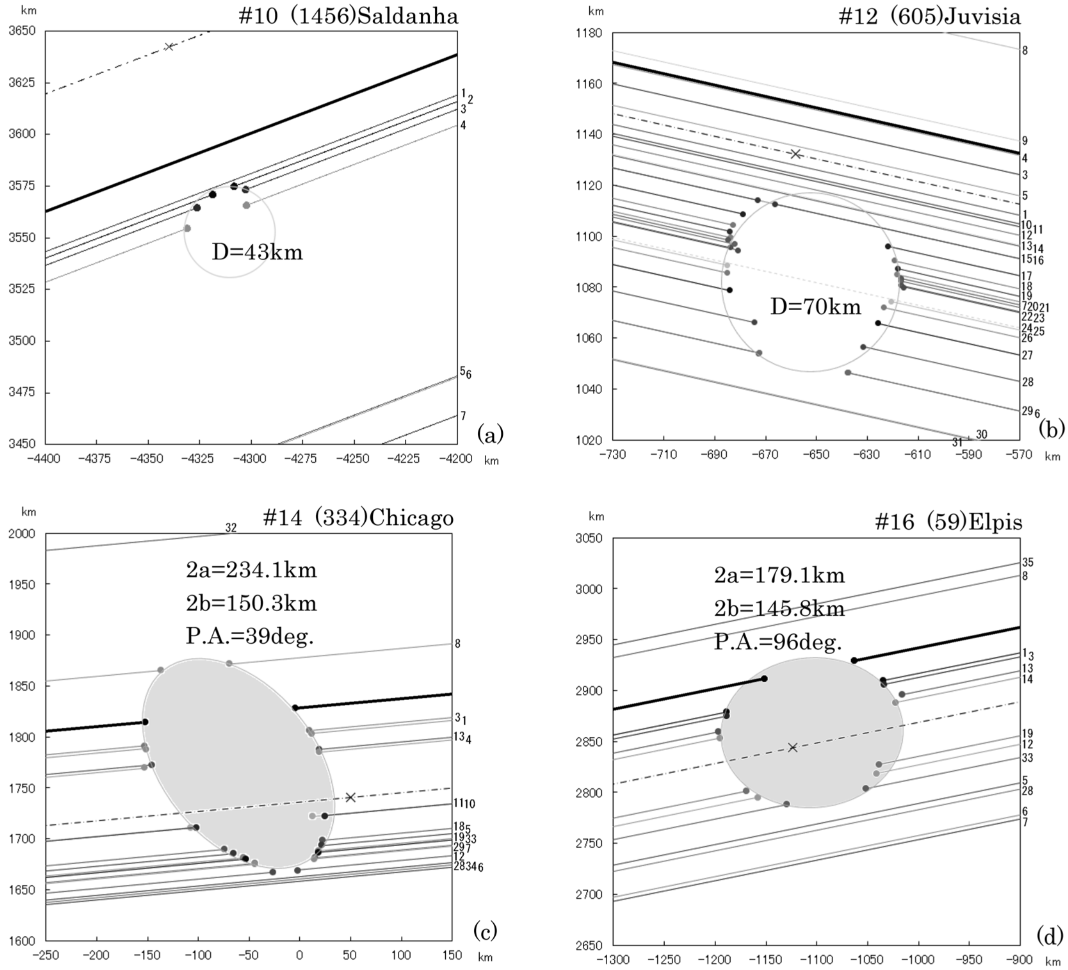


Fig. 5. Compilations of Japanese observation of asteroidal occultation by Hayamizu[7]. The number at the upper right of each figure corresponds to the serial number of occultation in Table 1, i.e., (a) #10, (1456) Saldanha, (b) #12, (605) Juvisia, (c) #14, (334) Chicago, (d) #16, (59) Elpis. The thick lines are the author's observation, and the thin lines are Japanese colleagues', which are identified by the number noted outside of each figure*. The dash lines are the center lines of prediction. Circles of Figs. 5a and 5b show the diameter estimated prior to the observation, and ellipses of Figs. 5c and 5d show the size and the position angle of the asteroid fitted by this observation, though the actual shape is not a ellipse in general.

* (1) Uchiyama, Sh., (2) Takashima, H., (3) Aikawa, R., (4) Hashimoto, A., (5) Watanabe, Ha., (6) Owada, M., (7) Ikari, Y., (8) Yaeza, A., (9) Oribe, T., (10) Watanabe, Hi., (11) Terada, T., (12) Yamamura, H., (13) Sasanuma, N., (14) Kitazaki, K., (15) Terakubo, K., *et al.*, (16) Morikawa, T. and Seo, H. (17) Sato, M. and Kunishi, M., (18) Asai, A., (19) Ida, M., (20) Watanabe, M., (21) Kawawaki, S., (22) Yoshihara, H., (23) Kasebe, H., (24) Imatani, T. and E., (25) Nakashima, Y., (26) Akazawa, H., (27) Ninomiya, O., (28) Ito, T., (29) Uchiyama, Sa., (30) Suzuki, H., (31) Inou, M., (32) Sato, H., (33) Ishida, M., (34) Kawakita, A., (35) Tomioka, H., (36) Uehara, S.

the observations with no occultation also contribute to reveal the shape of an asteroid. Sometimes the target star of occultation is not a single star but a pair of stars that are too close to recognize them separately. In such a case, two shadows of an asteroid drop onto the Earth like Fig. 6, and then we realize that the target star is a close binary. The details of the newly discovered

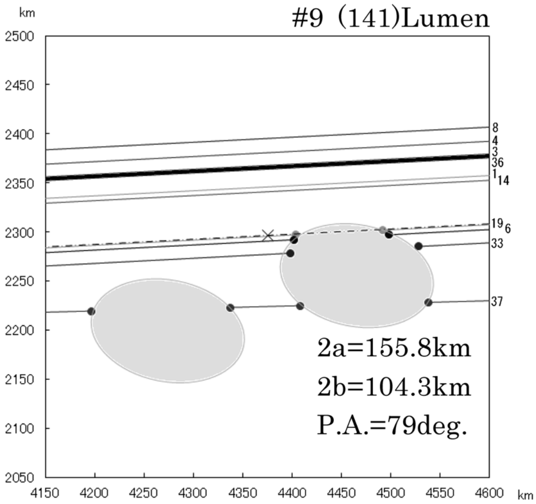


Fig. 6. Observations of occultation #9 compiled by Hayamizu[7]. The thick line is the author's observation, and the thin lines are colleagues', which are identified by the same numbers as Fig. 5. The number 37 is George, T., who observes the occultation in the strip of Fig. 3b at the U.S.A. and detects the target star is a close binary[8].

binary of Fig. 6 is described in Sôma et al (2014)[8].

4. Summary

The author introduced video recording system that can insert precise time in each video frame in order to observe astronomical phenomena of rapid variation. By the video system and the 50 cm reflecting telescope at Tsukuba, 22 asteroidal occultations have been observed since 2012. The observations bring information on the size of asteroids, and on the shape in case simultaneous observations are done at different locations. A close binary was found as a by-product of observation.

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