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Methods and Statistics of TV Observations of Telescopic Meteors

Yu. M. Gorbanev, A. V. Golubaev, V. V. Zhukov, E. F. Knyaz'kova, S. R. Kimakovskii, I. I. Kimakovskaya, S. V. Podlesnyak, L. A. Sarest, I. A. Stogneeva, and V. A. Shestopalov

Astronomical Observatory, Odessa National University, Shevchenko Park, Odessa, 270014 Ukraine

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Abstract—A review of TV and telescopic methods of meteor observations and of the problems of meteor astronomy addressed using these methods is presented. A meteor patrol developed at the Astronomical Observatory of Odessa National University and based on a Schmidt telescope and a TV detector is described. The meteor patrol allows meteor events to be recorded with a time resolution of 0.04 s. The investigated characteristics of the patrol are reported, and some aspects of the methods of observations and reduction employed are considered. The results of observations made during the period 2003–2004 are reported. A total of 368 meteors were recorded on 1093 individual frames during a total patrol time of 679 hours within a $36' \times 48'$ field of view. The statistical data for meteor observations are reported, and classification of meteor images is presented. The specific features of some recorded meteor events are analyzed.

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INTRODUCTION

A specific feature of astronomical observations of meteors is that we know neither the sky area nor the time when an event occurs. Moreover, meteor events in the atmosphere last a few seconds or even less. All this imposes special demands on instruments and methods of observations, which researchers have tried to meet in the practice of meteor studies. Instruments and methods have evolved as new technologies have become available. At the very beginning of the development of observational methods of meteor astronomy, a meteor patrol came into use with the underlying idea that all-sky detectors should always be ready to receive signals from a certain sky area to record a meteor event.

Meteor events have been on the agenda of the Odessa Astronomical Observatory for several decades. Since 1957, three multistation facilities for photographic meteor patrol have been operating at the observatory within the framework of the program of the International Geophysical year (Kramer et al., 1963), and a procedure of reduction of observational data was developed (Babadzhanov and Kramer, 1963). The meteor patrol was discontinued in Odessa in the 1990s for a number of reasons. A new meteor patrol was founded in order to resume regular patrolling of meteor events.

The old meteor patrol, which was based on single-type NAFA 3N/25 cameras (equipped with Uran-9 lenses with diameter $D = 10$ cm, focal length $F = 25$ cm, frame size 18×24 cm, and a $39° \times 53°$ field of view) could photographically record meteors brighter than zero magnitude. According to Kashcheev et al. (1989), the average detection threshold of such meteor patrol facilities corresponds to $-1.5^m \pm 1.0^m$. Fainter meteors could be recorded only with such unique instruments as Super-Schmidt telescopes; however, even their detection threshold did not exceed $+3.5^m \pm 0.3^m$ (McCrosky and Posen, 1961). Faint meteors down to $+12^m$ could be recorded only with radar instruments; however, such facilities record the ionized train and not the optical image of the meteor. Therefore, faint meteors were accessible only for visual telescopic observations. However, such observations, with the meteor remaining within the field of view for a fraction of a second, were burdened with large errors due to observational selection.

A number of tasks in meteor astronomy require not only recording of faint meteors at optical wavelengths but doing this with high spatial and temporal resolutions. A TV method is most suitable for these tasks and is therefore widely used for meteor observations.

Orticon-based TV facilities have allowed extensive volumes of meteor observations to be obtained and the limiting magnitude of meteor patrols to be increased. Malyshev (1992) reported TV observations of meteors carried out in Dushanbe using a facility equipped with a Yupiter-3 objective ($D/F = 1/1.5$, $F = 50$ mm). Observations were performed in the interlacing mode with 625 lines and 25 frames per second. A total of 180 meteor images were obtained in the working $20° \times 30°$ field of view during 35 observing hours. With all its potential, this equipment has a number of drawbacks, in particular, the inertiality of image acquisition, which prevents the use of such observations for the study of meteor “trains” and afterglow.

The advent of CCDs, which operate in TV mode, opened up new horizons for meteor studies. The main advantages of CCDs over photographic observations are the spatial and temporal resolution of these radiation detectors, which allow scientists to study meteor events that last only fractions of a second. Unlike Orticon-based TV facilities, CCD detectors do not suffer from inertiality when recording moving objects.

CCD detectors are now widely used in meteor observations. Stenbaek-Nielsen and Jenniskens (2002) reported the results of observations of a bright Leonid recorded with a CCD detector at a rate of 1000 frames per second. The meteor shifted by less than 1 pixel (1.5 arcmin) between consecutive frames, allowing the dynamics of the meteor process to be traced. However, even such a high spatial resolution (1.5 arcmin per pixel) is insufficient for obtaining accurate positional observations and revealing the fine structure of the meteor event. Computations show that observations with a resolution of less than an arcsecond are suitable for solving a number of problems in meteor astronomy.

With the advent of modern TV and computer technologies, a new class of instruments came into use in meteor astronomy.

Are there analogues of patrol instruments?

Photographic patrol observations of the night sky have been carried out for several decades at the Sonneberg observatory. At present, researchers at this observatory are trying to swap photographic equipment for CCD detectors. They use a PHILIPS chip with a fish-eye lens (Kroll and Fleischmann, 2001; Kroll 2001a, 2001b). Five-minute integration make it possible to record objects down to a magnitude of about 9–10^m, which is necessary for studies of variable stars, meteors, gamma ray burst (GRB) sources, etc.

Other patrol systems allow observers to record stars down to a limiting magnitude of $+8^m$ (Murray et al., 2002) and have fields of view of 40° × 35°.

Four cameras with fish-eye lenses equipped with CCD detectors are used to patrol and record fireballs (Rafert et al., 2001). This system allows objects brighter than -1.5^m to be recorded.

Hawkes et al. (2001) point out that the application of the new technique of TV recording using a CCD will make it possible to study the structure of a meteor event and that large-aperture long-focus optical systems are most suitable to this end.

Pawlowski et al. (2001) reported interesting results obtained using a 3-m telescope equipped with a CCD with a 0.28° × 0.28° field of view. This is the optical instrument with the largest aperture ever used for meteor observations. The radiation detector of this instrument records stars down to a limiting magnitude of $+18^m$ and meteors with a magnitude from $+5^m$ to $+10^m$, which correspond to photometric masses ranging from 10^{-7} to 10^{-9} kg. Based on numerous observations of Leonids in 1999, the above authors concluded that the Leonid meteor stream contains particles in the mass interval mentioned above and that there are more small meteor bodies in the stream than would be expected from cometary ejection stream models. The above authors believe such a telescope to be a powerful detector of sporadic meteors with an average detection rate of more than 140 meteor events per hour.

Telescope parameters are of great importance for planning telescope observations of meteors. Kresakova (1978) addressed this problem and argued that the limiting magnitude of recorded meteors is equal to 11.5^m.

Observational facilities exist that allow video observations of sporadic and stream meteors to be performed and results to be reduced in real-time mode. Such a facility (Taff, 1986) includes two telescopes of a similar type.

One must mention the hybrid TV system, developed at the *Kosmoten* satellite station in collaboration with the Space Research Institute of the Russian Academy of Sciences and the Special Astrophysical Observatory of the Russian Academy of Sciences (Bagrov et al., 2000, 2003a). The facility in question is a fast wide-angle optical camera for detecting flaring and moving objects. The design of the camera combines a first-generation electron-optical image converter and a matrix CCD detector. This camera allows one to find moving objects and transient events, including meteor events. When operating at a maximum frame rate of 7.5 Hz in the 22° × 18° field of view, the facility ensures a limiting magnitude of about 12^m (in a system that is close to the photometric V band) in the format (1380 × 1024) pixel × 10 bit. The source localization accuracy is about 1 arcmin. The limiting magnitude was found to reach $+8^m$ during full-moon observations with a rate of seven frames per second (Maslennikova, 2003). This fact indicates that the limiting magnitude depends on the sky background. Statistics of meteor observations yields about 150 events per night with each event spanning four to eight frames (Bagrov et al., 2003b).

What problems in meteor astronomy can be solved using the new technique?

Multistation TV observations are carried out at many observatories. Such observations allow trajectories and orbits of meteors to be determined and their radiants to be identified (Suzuki et al., 2003). Some researchers use TV observations of nonbasic meteors to determine the radiants and other parameters of meteors (Zimnikoval, 2003).

TV observations are often performed during major meteor showers, in particular, during Leonids (Fujiwara et al., 2003). Such observations make it possible to numerically determine the inflow of meteor mass during the peaks of meteor stream activity.

Modern telescopic observations (Currie, 1995) allow the activity of meteor streams and the coordinates of radiants to be determined over short time intervals. Pravec (1992) analyzed telescopic observations of the Quadrantid stream. In addition to determining the coordinates of the radiant and the activity level, the above author also points out the presence of long meteor trains. Telescopic observations of the Orionid shower in

Fig. 1. The meteor patrol of the Odessa National Observatory.

1985 led Znojil et al. (1987) to conclude that the concentration of small particles increased in the shower. Telescopic observations of meteors are often used to identify radiation regions of various meteor showers (Yoshida, 1993).

Of great importance is the problem of the accuracy of meteor observations, which was analyzed statistically by Pravec and Bocek (1991).

Double-station telescopic observations of meteors make it possible to determine, e.g., the relation between the optical brightness of the meteor and the properties of its ionized train (Znojil et al., 1985).

It follows from the aforesaid that there are numerous technical solutions that can be applied to observational tasks of meteor astronomy. In this paper, we consider one of these solutions—a combination of telescopic and TV methods, which we applied successfully to meteor observations.

We had to choose equipment for meteor patrol observations. Although short-focus systems are more productive in terms of the number of meteors detected (hundreds of events per night), we adopted a long-focus system (with a focal length of no less than 50 cm) because of the low accuracy of position observations offered by short-focus instruments (on the order of one arcmin). We further abandoned TV tubes (Orticon, etc.) and detectors based on electron-optical image converters, because of the inertiality of the images they produce. These drawbacks would prevent us from studying such phenomena as meteor afterglows and "trains" and would impair the time resolution. We therefore opted for a CCD-based TV detector and a Schmidt telescope.

METEOR PATROL OF THE ODESSA OBSERVATORY

The coordinates of the Kryzhanovka observation station of the Odessa National University are $\phi = 46°33'38.6''$ N; $\lambda = 30°48'23.4''$ E, and its altitude above sea level is 40 m. At present, the meteor patrol has the following configuration (Fig. 1). All observing equipment is detachable and mounted on an APSh-4 equatorial mounting equipped with a guiding stepping drive; there are two short-focus cameras with Industar-I52 and Uran-9 lenses and a 17/30-cm Schmidt telescope (the diameters of the correction plate and mirror, respectively).

Meteor astronomers have always been interested in new panoramic detectors, and at present any new instrument arouses great interest among both amateur and professional astronomers.

Koschny (2003) discusses new video cameras with very sensitive sensors, which allow recording meteor images. The above author compares the quality of images produced by the two cameras Mintron and Watec 120N.

We opted for a Watec LCL-902K monochrome camera. When mounting this camera onto the telescope, we switched off the automatic gain control. The small size of the camera allows us to place it into the focus of the Schmidt telescope without risk of extra vignetting. We did not verify the claimed sensitivity of 0.00015 lux at an aperture ratio of 1 : 1.4, although these parameters are contested by some video equipment experts. We can only claim that our camera can record stars down to $+12.8^m$ magnitude in the photometric V band in the focus of the (17/30-cm) Schmidt telescope.

We used a TV tuner with an eight-bit analog-to-digital converter to digitize the analog signal produced by the camera. The time reference of the computer is performed using the Trimble ACE III GPS unit. The image is recorded with the guiding drive on. In our telescopic system, the half-inch camera has a field of view of $36' \times 48'$. The angular size of a single pixel is 3.8". We found experimentally that our facility was capable of operating in two modes. As is well known, a TV signal contains 625 lines (576 lines with video data) with two half-frames shown consecutively, one of which consists of even lines (the so-called even half-frame) and the other, of odd lines (the so-called odd half-frame). Such an organization of the image input has the following drawback in the case of a moving object: when analyzing the image, the resolution in one of the coordinates cannot be higher than the number of lines in a half-frame. The first mode allows one half-frame to be recorded in 20 ms with no image taken during the subsequent 20-ms dead time. The second mode allows both even and odd half-frames to be read during each 20-ms interval with no dead time at all. Note that we were interested in both modes when planning meteor patrol. Meteor images taken in the first mode have the form of dashes with gaps of approximately the same length as the dashes. In the second reading mode, there are no gaps between the dashes; however, the image has a striped shape, because the first part of the dash is outlined by even lines and the second part by odd lines, and the meteor moves during the readout time. In the case of bright meteors, this feature shows up as a starlike dot in the middle of the meteor dash. This dot is of instrumental origin and can be explained as follows: after the readout of the even half-frame, the system switches to the readout of the odd half-frame, and the point in the middle of the meteor stroke image is read twice. The neighboring pixels are illuminated because of the high brightness, and this results in the appearance of a light dot on the dash. This effect is less conspicuous or totally absent in the case of faint meteors. Fast bright artificial satellites, when the images appear as a dash, exhibit a similar effect. Although the longer dash of the meteor trajectory yields more data points for reduction, we opted for the mode with dead time. What does this mode give us? Along with position observations of meteors, of great interest are the phenomena that occur after the meteor crosses the atmosphere. In the mode with dead time, we can separate these phenomena, which is impossible to achieve in the mode where both the even and odd half-frames are read and displayed—the image of the meteor simply superimposes onto the image of the afterglow of the meteor event.

Thus, the meteor patrol facility is designed to record meteor events that appear in its field of view for several fractions of a second. The determination of the kinematical, dynamical, and photometric parameters of such transient astronomical phenomena imposes special requirements on detectors. These requirements made it necessary to conduct a number of tests in order to analyze in detail the parameters of the detecting equipment.

We first determined an important property of the CCD camera: the dependence of its sensitivity on the wavelength of recorded radiation. To this end, we assembled an experimental facility based on an SF-16 spectrophotometer equipped with a CCD camera instead of the standard photodetector. The measurements showed that the camera is sensitive to radiation with wavelengths above 4000 Å and that its sensitivity increases abruptly up to the maximum level in the vicinity of 7000 Å, where it levels off onto a plateau up to 9500 Å. The sensitivity of the camera then abruptly falls toward 12000 Å.

To verify the reliability of the results obtained, one has to determine the actual frame frequency and analyze its stability. To this end, a special instrument was manufactured for testing the operation of the camera, which we called the "sound–light" converter. This converter is an integrated comparator whose output is loaded onto a light-emitting diode mounted in the collimator in order to control the frequency parameters of the CCD camera. The operation threshold of the comparator (2 mV) ensures the conversion of the input audio signal of the given frequency into rectangular pulses of the current of the light-emitting diode. To form the front and the plateau of the pulse, we used an input RC circuit with the predefined parameters. This instrument allows an audio signal with the given frequency to be generated, which, when converted into a light signal, can be recorded using the operating camera. Conversion distorts the audio signal thus generated; however, we can record the already altered signal. During our experiment, we generate a signal of arbitrary duration with the frequency ranging from 35 to 45 ms^{-1} with a step of 1 ms^{-1}. Figure 2 shows a typical shape of the generated signal. The reduction of the data obtained in this experiment showed that the frequency remained stable up to 0.05 ms^{-1}, and the signal intensity remained stable to within 6%. The signal is then transformed into light flashes and recorded by the detecting equipment (telescope + tuner + camera). The signal detected by the camera is recorded, and, after reduction, we obtain the field-averaged signal intensity. Thus, for each generated frequency, we obtain a time series of intensities. Figure 2 shows the results of the experiment (250 points in 10 s; for each plot, the frequency of the generated signal is given). As expected, large-intensity surges appear when the frequency of the generated signal does not coincide with the detection frequency of the camera. The number of such surges increases with increasing difference between the frequency of the generated signal and that of the detecting equipment. And only when the two frequencies coincide do the surges in the time series cease. As is evident from Fig. 2, such surges cease at a frequency of 40 ms^{-1}. We also repeated the experiment with a frequency from 39.5 to 40.5 ms^{-1} with a step of 0.1 ms^{-1}. A similar pattern shows up even in the case of such a small step. We can thus conclude that the frame frequency is equal to 40 ms^{-1} with an error of no greater than 0.1 ms^{-1}.

STATISTICS OF METEOR PATROL

Tests of the meteor patrol started in June 2003, and regular observations began in August 2003 and continue today.

The optics to be employed in meteor patrol is usually chosen based on the assessment of the efficiency of meteor detection. The main telescope parameters from the viewpoint of the efficiency of meteor detection are the diameter D of the telescope mirror or objective and its focal length F. Of great importance for meteor patrol are the diameter p of the field of view of the telescopic system and sensitivity k of the detector employed. According to Katasev (1966), the number of meteors N recorded using a telescopic system is given by the following formula:

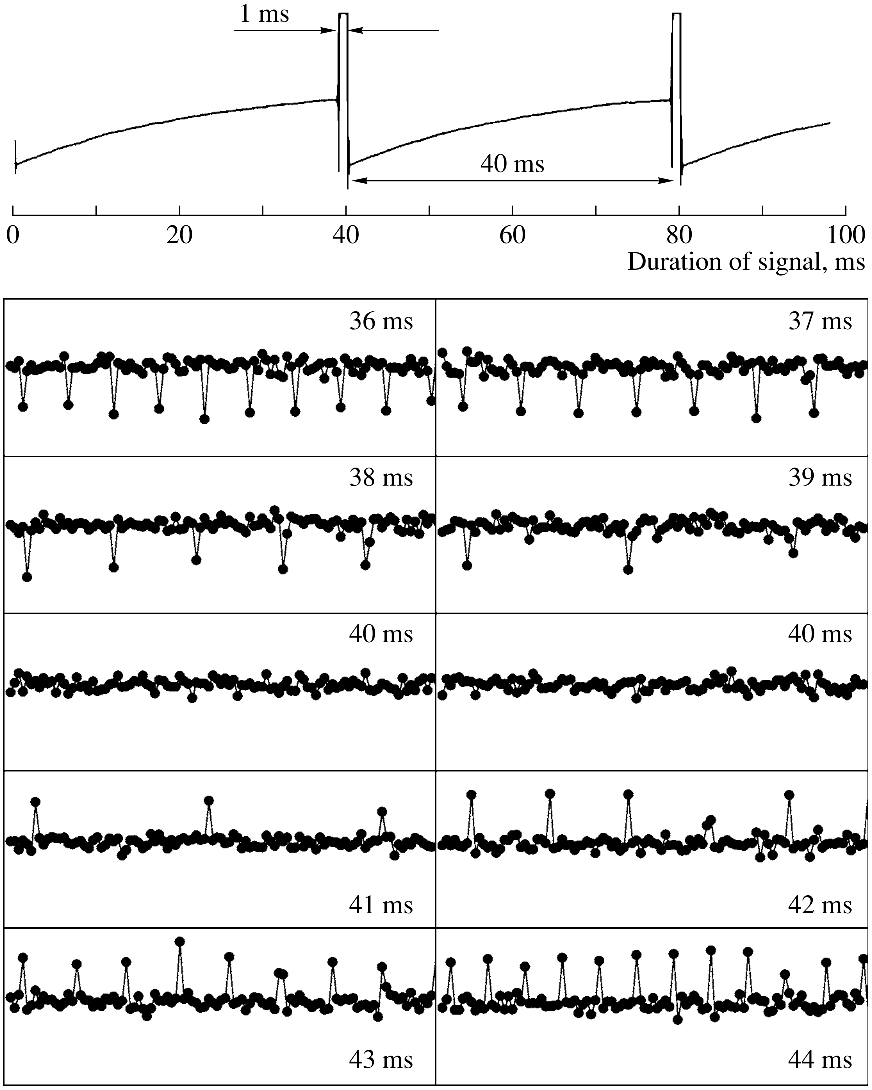

Fig. 2. Typical appearance of the signal generated for testing a CCD detector and the results of the experiment aimed at the determination of the frame frequency.

$$N = 1.15 \times 10^{-7} p^2 t D^{2.87} \left(\frac{D}{F}\right)^{0.21}, \qquad (1)$$

where D is the diameter of the mirror or objective in cm; F is the focal length in cm; p is the field of view in degrees; and t is the time of patrolling in hours. Table 1 lists the data from Katasev (1966) for three optical systems. The last row of the table gives the parameters of the Odessa meteor patrol.

Table 1. Parameters of meteor patrols

Objective	D, cm	F, cm	p, deg	N(in 100 hours)
Schmidt (Mt. Palomar)	45.7	91.1	9	46
Super-Schmidt	24.9	20.3	50	300
Uran-9	10.0	25	51.3	19
Schmidt (Odessa patrol)	17	50	0.78	0.5

Our system has a rectangular field of view (36′ × 48′), and we therefore give in the table the equivalent diameter of the field of view computed for the corresponding area. The coefficient $x = 1.15 \times 10^{-7}$ characterizes the sensitivity of the detecting equipment and the data listed in the table refer to the photographic method of registration using astronomical emulsions. If we used the photographic method to record meteors, we would detect, according to formula (1), one meteor in 200 observing hours.

Let us recall the results of meteor patrol observations made in Odessa and Dushanbe from July 1957 to December 1959 (Babadzhanov and Kramer 1963) (Table 2). The meteor patrols were performed with several cameras, and therefore in the last column of the table we give the number of meteors recorded by a sin-

Table 2. Statistics of meteor patrolling

Station	Time of patrolling in hours	Number of cameras	Number of meteors		
			total	in 100 hours	per one camera
Dushanbe	744.5	7	394	52.92	7.56
Ghisar	741.5	7	511	68.91	9.84
Mayaki	1394	4	260	18.65	4.66
Kryzhanovka	1036	4	302	29.15	7.29
Botanicheskii sad	949.5	4	242	25.49	6.37
Kryzhanovka (Schmidt)	678.8	1	368	54.21	54.21

gle camera in 100 hours of observations. They are smaller than the values computed by formula (1) given in Table 1 (19 meteors for the NAFA 3C/25 camera). The smaller number of recorded meteors in Mayaki and Dushanbe can be explained by the obturators employed in the meteor patrol equipment kit used at these stations, which decrease the limiting magnitude of the corresponding cameras. However, the crucial factor that determines the limiting magnitude of the cameras used at all stations is, of course, the sensitivity of photographic emulsion. Semiempirical formula (1) was derived for light-sensitive astronomical emulsions, whereas meteor patrols usually employ aerial films, resulting in a smaller number of recorded meteors. The last row of Table 2 corresponds to the data of meteor patrol at the Kryzhanovka observing station for the period from August 1, 2003, though December 27, 2004.

Let us now assess the increase in the efficiency of meteor patrol due to the use of CCD. According to the results obtained by the Odessa meteor patrol in 2003–2004, 368 meteors were recorded during a total patrolling time of 678.8 hours. These observational data allowed us to plot the integrated dependence of the number of recorded meteors as a function of patrol time (Fig. 3). On the average, 55 ± 12 meteors are recorded during 100 hours of the Odessa meteor patrol. Thus, the use of CCDs increases the number of recorded meteors by two orders of magnitude over the photographical method (Table 1).

A meteor is recorded on a single frame as a dash. The length of the dash depends on the apparent velocity of the meteor image in the focal plane of the telescope. Depending on this velocity, our system can record the meteor event as a sequence of images. Figure 4a shows the histogram of the number of frames with meteor images. The maximum number of frames is 11. The distribution peaks at 2–3 dashes (50% of all recorded events) and then falls abruptly. Meteor images in the form of long dashes crossing the entire field of view are rather rare. The meteor image is often located in the corner of the frame; the fraction of such meteors amounts to 20%. Meteors with low angular velocities and the longest trajectories appear in the frame for 0.04–0.44 seconds. If the dash is favorably positioned in the image, the system records the corresponding event from the appearance to the disappearance of the meteor.

The number of reference stars in the frame is a parameter of great importance for the positional reduction of the observational material. Figure 4b shows the histogram of the number of stars used in positional and photographic measurements. The maximum number of stars can be as high as 70; however, the frame usually records 10–20 reference stars, which is quite sufficient for computations.

According to Astapovich (1958), the number of meteors varies with zenith distance, because the number of observed meteors is minimal near the horizon due to the larger distance from the observer and atmospheric extinction. The number of meteors is also min-

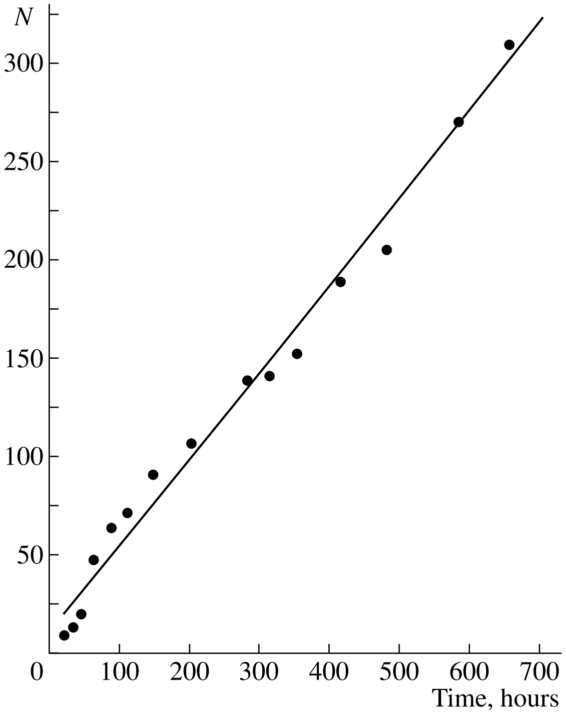

Fig. 3. Dependence of the number of recorded meteors on patrolling time.

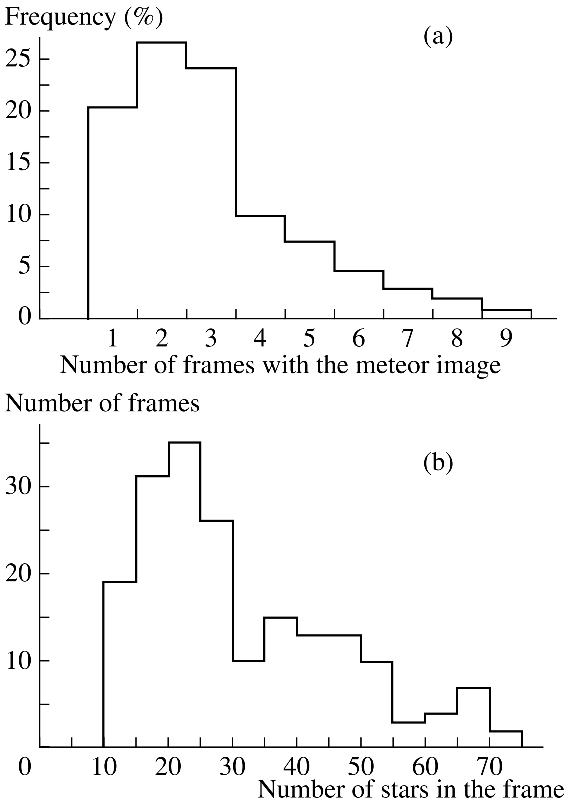

Fig. 4. Distribution of the number of stars and of the number of meteor strokes in the working frame.

imal at the zenith because of the smaller volume of the atmosphere where the corresponding meteor events occur. These facts are believed to imply that the number of meteors has a maximum, and observers indeed see the greatest number of fireballs and common and telescopic meteors at zenith distances of about 60°. Azimuthal variation is due to the fact that most of the meteors are recorded in the direction of the apex and in those of equatorial radiants. Thus, the largest number of meteors is generally believed to be recorded in the southeast at zenith distances of about 60°.

How do our observational data agree with these variations? Figure 5a shows the histogram of the zenith distances of the meteors recorded by our patrol. Observations suffer from a certain selection in the choice of the sky area for patrolling, because the main operating interval of zenith distances was 20–65 degrees. The patrolling was performed less often low above the horizon and at the zenith, and this explains the minimal number of meteors recorded at the corresponding zenith distances. However, the selectivity of the patrol cannot explain the maximum in the distribution in the interval from 45° to 50° (53 meteor events compared to an average of 24 meteors for other intervals at zenith distances from 20° to 65°). This may be the result of the zenith variation described by Astapovich (1958); however, the corresponding interval of zenith distances for telescopic meteors is shifted toward lower values.

Figure 5b shows the histogram of astronomical azimuths at which meteors were detected. Observations were performed in the southern part of the sky, and the maximum of the distribution (270°–280°) is shifted toward the eastern part of the sky and not to the southeast as claimed by Astapovich (1958).

Figure 5c illustrates the diurnal variations of meteor activity according to our patrol data. Such variations are typical of the sporadic meteor component (Katasev, 1966). Figure 5d illustrates the seasonal variation of meteor sporadic activity with a maximum in September–October and a minimum in March–April with surges during meteor showers, which is consistent with other sources (Katasev, 1966).

Researchers that perform visual telescopic observations always try to determine the angular velocity of meteors. Only experienced observers can determine this parameter visually; however, the accuracy of such a determination is low, especially for meteors with high angular velocities. Our observational material makes it possible to determine the length of the dash of the meteor image with an error of no greater than several tens of arcseconds and then, given the exposure time (0.02 s), compute the angular velocity of the meteor. Figure 6a shows the histogram of angular velocities ω of meteors. Before analyzing this dependence, we must apply certain corrections. Our operating field of view has a size of $36' \times 48'$, and a meteor moving at an angular velocity of 20 deg/s would produce an image in the form of a 24-arcmin dash during an exposure time of 0.02 s. The operating field of view may cover this image only partially. The probability of a meteor dash arrangement that allows the coordinates of both the beginning and end of the stroke to be measured decreases abruptly with increasing angular velocity. Such instrumental selection requires corrections to be applied; we therefore performed statistical modeling that allowed us to compute the factor k equal to the ratio of the number of model meteors whose dash lengths could not be measured to the number of meteors whose dash lengths could be measured. Figure 6b shows the dependence of the factor k on the angular velocity of the meteor. As expected, the correction factor is small for meteors with low angular velocities, because a short dash almost always fits entirely within the field of view. The factor increases with growing angular velocity because the larger fraction of long dashes begins or ends beyond the frame. Variations of the size of the model field, random-number generators, and the number of model meteors yield a correction-factor error of no greater than 0.02. We corrected the observed distribution of angular velocity for instrumental selection taking into account the correction factor for each angular velocity (Fig.6c). It is of interest to compare the theoretical and observed number of meteors whose dash lengths cannot be measured. The number of “unmea-

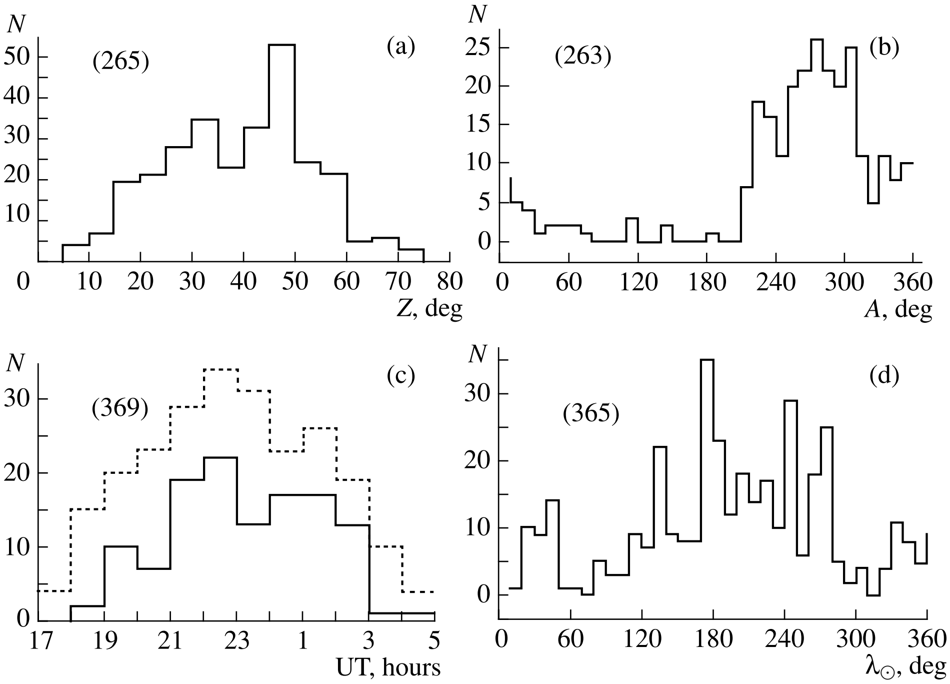

Fig. 5. Statistics of meteor observations, the figures in parentheses give the number of meteors in the sample. The solid and dotted lines in plot (c) correspond to the spring–summer and fall–winter periods, respectively.

surable" dashes among the observed meteors (a total of $N = 367$ events) is equal to 107, whereas the model corrections yield 113 meteors, which is very close to the results of observations. At low angular velocities (7–8 deg/s), the corrected distribution is almost indistinguishable from the observed one, whereas at $\omega >$ 9 deg/s the right-hand part of the distribution increases without affecting the main feature—the maximum in the vicinity of $\omega = 6$–8 deg/s.

OBSERVATION AND REDUCTION PROCEDURE

Regular meteor patrolling is carried out by a team of five observers working in shifts. The period of night when observations are performed is limited by the end of the evening twilight and the beginning of the morning dawn and does not depend on the position and phases of the Moon. The instrument is pointed at the selected sky area and is then automatically guided at the velocity of the diurnal rotation of the sky. The chosen sky area is always to be identified with a sky atlas. The sky area is chosen arbitrarily around the ephemeris radiant at a certain distance from the latter. One patrol session involves recording a 15-minute movie clip and parallel recording of events on the monitor by an operator who can mark the frame numbers. These frames are reviewed after the movie clip has been recorded. Usually, images of artificial satellites of the Earth are recorded in addition to meteor events. If the review of the file ends with the identification of a meteor event, the corresponding clip fragment is cut out with the time stamp of the first frame. As a result of observations, a CD disk is recorded with an AVI film consisting of 50 frames (2 seconds) before the meteor passage, a number of frames with the meteor event proper, and the 50 subsequent frames.

The number of recorded meteors would be even greater were it not for technological gaps between the observing sets, which are unfortunately required for review and archiving of fragments, repointing the telescope, and preparing for the next observing set. The observers were able to perform about thirty 15-minute sets during the best winter nights; i.e., the net patrol time did not exceed 7.5 hours per night. The patrol efficiency should be substantially increased owing to the automatic system of detection and recording of meteor events, which is now in the state of task formulation and development of algorithms of identification of moving objects (including extremely faint ones) in the frame.

Short exposures (20 ms), which are now employed in patrol observations, provide very good temporal resolution for a meteor event but perform poorly in terms of the limiting magnitude. Figure 7 shows the histograms for single frames and for digitally coadded 2-s frame sets (50 frames). The average limiting magnitude is lower for single frames, and the maximum of the distribution (Fig. 7b) is shifted by almost one magnitude. Whereas the limiting magnitude may amount to$13^m$for coadded frames, it is as low as 11.5^m for single frames (Fig. 7a).

We performed the following computations to analyze the quality of star images on digitally coadded

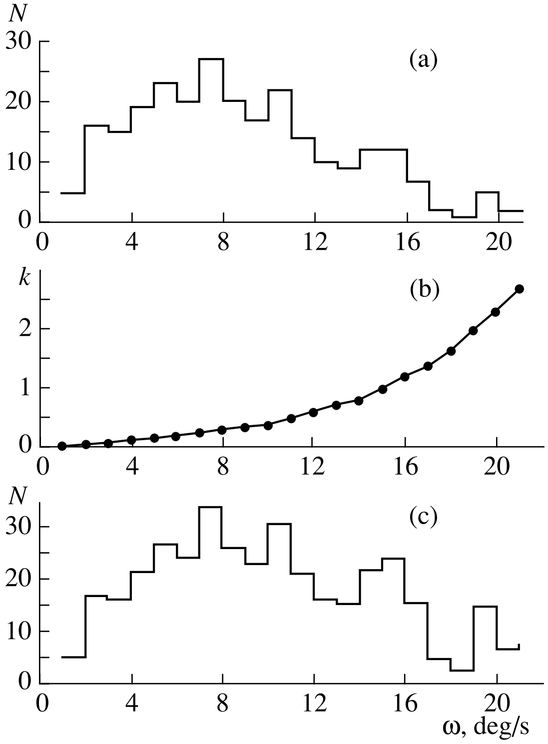

Fig. 6. Distribution of angular velocities of meteors.

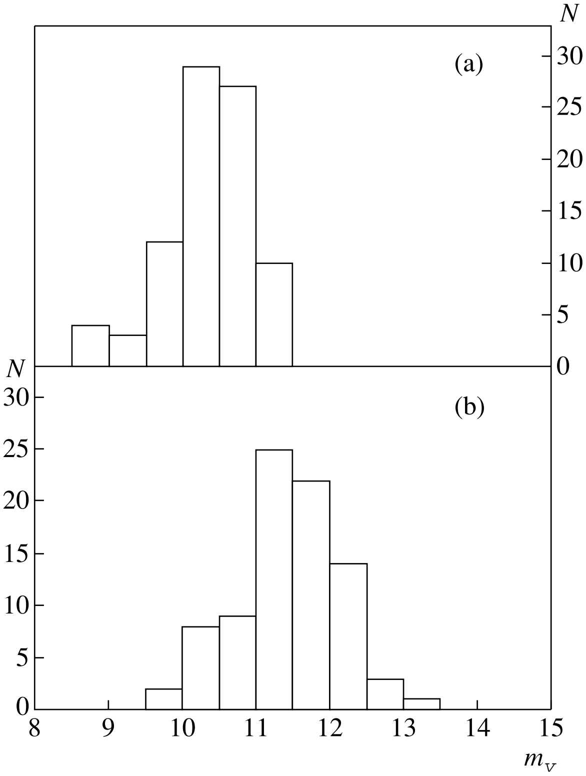

Fig. 7. Distribution of limiting magnitudes for single and coadded frames.

frames. We coadded 200 frames (taken with a frequency of 25 frames per second and a 20-ms exposure) one after another starting with the first frame. Figure 8 shows the results of such a reduction. As the number of integrated frames increases, the average sky background B_{av} stabilizes after two to four seconds of exposure (Fig. 8a), as is evident from the dispersion σ of the background level (Fig. 8b). The dependence of the number of reliably distinguishable stars on the frame, N_{r}, on the number of coadded frames (Fig. 8c) and the dependence of the mean magnitude, m_V, averaged over all stars in the frame (Fig. 8d) (not to be confused with the limiting magnitude) are also very demonstrative. It thus follows that, when reducing TV images, it does not make sense to digitally coadd more than 100 frames (2 s).

The main criterion for selecting the mode and format for recording working movies was the quality of the images of stars and meteors and that of the sky background. The right choice of the background values allows rather faint extended meteor afterglows to be reliably recorded, but at the cost of sacrificing the operating intensity range. Figure 9 shows the histograms of sky background levels for the movies obtained in patrol observations. Thus, the movies recorded in the RGB24 color model (Fig. 9a) had a background level of about 120 units (the total intensity range spans from 0 to 255 units). That is, the operating interval spanned only 135 intensity units, and, to increase it, we adopted, after a number of tests, the YUV9 color model, which allowed us to increase the operating range up to 145 units with a background level of 110 units (Fig. 9c).

Moon light is usually a serious hindrance for recording meteor events, especially for recording faint meteors, during visual and photographic observations. TV instruments with Vidicon, Superopticon, etc., image tubes are also susceptible to overexposure of the operating field of view. Our system allowed us to perform patrol observations even under a full moon.

Figures 9b and 9d show the distributions of the background level in relative units for the color models (RGB24 and YUV9, respectively) for moonlit nights and for morning and evening twilights. Observational practice shows that meteor events can be recorded even during full moon and during twilight. Twilight observations allow so-called daytime meteor streams to be recorded, which could hitherto be recorded only using radar methods (Ueda et al., 2001).

OBSERVATIONAL MATERIAL AND CLASSIFICATION OF METEOR IMAGES

We process our database of meteor observations as follows: we identify and catalog star fields, determine

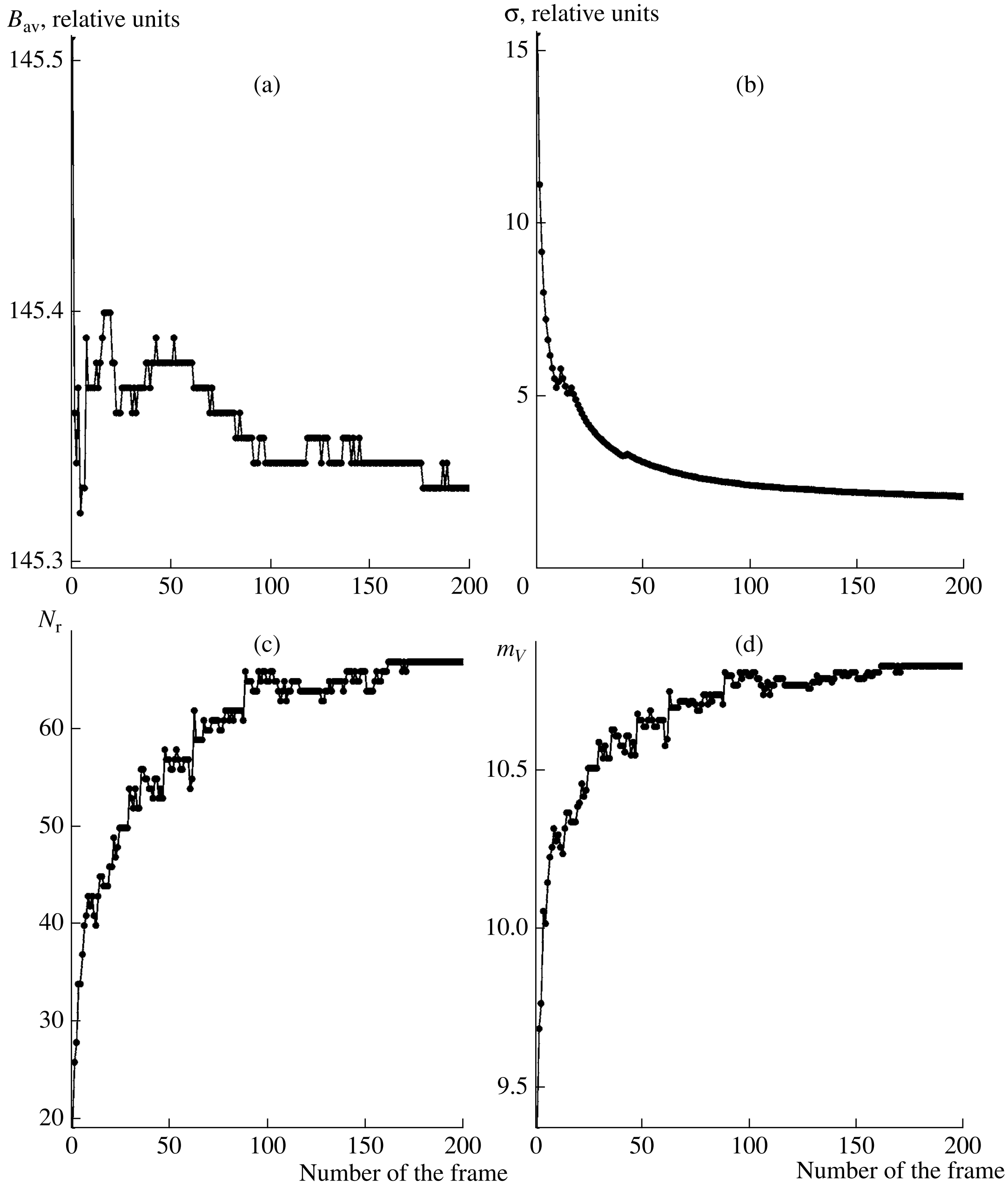

Fig. 8. Graphic illustration of the determination of the optimum number of frames to be coadded.

the time of the beginning of exposure and equatorial coordinates of the image center, and compute the corresponding zenith distance and azimuth. We perform positional and photometric measurements of the images of stars and meteors. In this paper, we report a preliminary classification of meteor images. According to Babadzhanov and Kramer (1963), the instantaneous images of meteors can be classified as follows:

type I—“point” meteors;

type II—spindle-shaped meteors with a manifest longitudinal size;

type IIa—strokelike meteors;

type III—droplike meteors;

type IV—meteors consisting of a bright head and long “wakes.”

The images of meteor events obtained in our patrol observations are not instantaneous, because, according to Babadzhanov and Kramer (1963), 5.6×10^{-4}-s exposures must be used taken with a frequency of 20 ms^{-1}. Therefore, the meteors recorded during our patrol observations appear as dashes (Fig. 10), but the classification suggested by Babadzhanov and Kramer (1963) nevertheless fits our observational data.

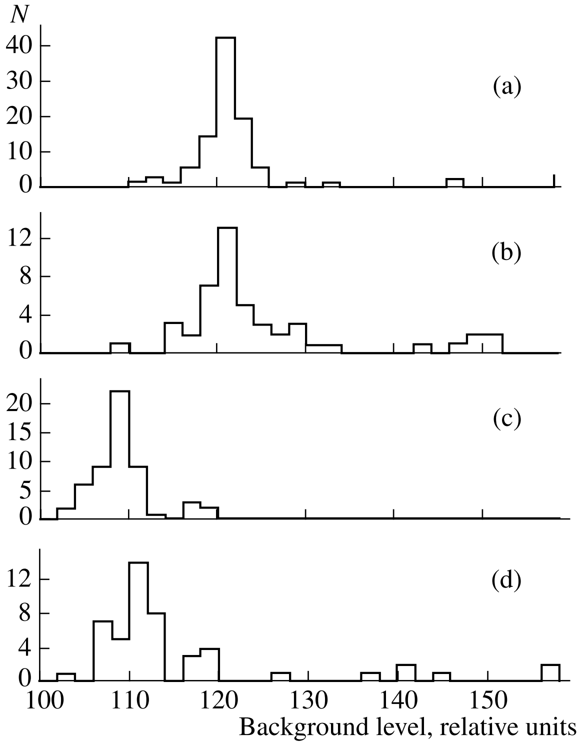

Fig. 9. Histograms of the sky background level for various observing modes.

The images of meteor nos. 13, 255, and 270 (hereafter the numbering of meteors corresponds to the working catalog of TV telescopic meteors) belong to type II, i.e., are spindlelike.

The next series, consisting of meteor nos. 35, 64, and 120, are typical representatives of type IIa objects, i.e., dashlike meteors (the angular velocity of meteor no. 35 is equal to 1.64 deg/s).

Meteor nos. 112, 118, and 224 can be classified as type III—i.e., droplike—meteors. Their images have characteristic and reliably identifiable "tails," and such meteors have the shape of drops when recorded with instantaneous exposures.

It should be pointed out that observational data are represented mostly by meteors that are fainter than zero magnitude, whereas only very bright meteors could be recorded if instantaneous images were obtained by the photographic method (Babadzhanov and Kramer, 1963). Moreover, it was not possible to record meteor afterglows with the photographic method, because the afterglow image was located in the same part of the movie clip as those of the meteor and its "tail." In our case, where the afterglow shows up in the next frame and does not coincide with the meteor image, we have an opportunity to study this phenomenon in detail. By the meteor afterglow, scientists mean the glow and ionization observed in the Earth's atmosphere along the trajectory of the meteor body after its passage. Typical representatives of this class are meteor nos. 30, 227, and 229—here we mention both bright and fainter objects. The afterglow phenomenon is not typical of all meteors, and detailed studies are needed to understand the mechanisms that determine its emergence and lifetime. Of the classification mentioned above, type IV is most appropriate, with long tails interpreted as integrated light of the tail image and afterglow.

We should point out the meteor images that appear anomalous compared to the bulk of observational data. Let us mention some of them. For example, meteor no. 4, which in the first frame appears as a typical meteor image. In the next frame, 0.04 s later, the image has moved along the direction of motion; however, a second dash has appeared behind the main dash in the same trajectory. The second meteor dash was recorded in the third frame but has faded abruptly in the fourth frame. This phenomenon can be interpreted as the fragmentation of an interplanetary dust particle in the Earth's atmosphere into two approximately equal parts, one of which, having slowed down, moved in the wake of the other. Another example of a similar phenomenon is provided by meteor no. 392, which appears as two separate dashes in several frames—a pattern that is indicative of two parts of a fragmented dust particle, which have the same velocity along the trajectory portion considered. Such events clearly indicate not only quasi-continuous fragmentation of faint meteors but also a possibility of their breakup into two fragments.

A paired meteor is also a possibility; however, the time intervals for such events are substantially longer, amounting to several seconds or more. Possible cases may be signaled by the following observational facts: two or three meteors with similar trajectories are recorded with a time shift within 15 minutes in the same movie. Meteor no. 137 was recorded 2.6 s after the passage of meteor no. 136, and the trajectories of the two meteors are parallel and located a distance of 17 arcmin apart. Meteor no. 138 was recorded moving along the trajectory of meteor no. 137 with a lag of 12 min 30.24 s. These meteors appear to represent a group of dust particles that moved in interplanetary space in similar orbits. The existence of such groups was pointed out by Apati et al. (1981), who reported the results of recording impacts of dust particles with dust-particle detectors mounted onboard the *Intercosmos-14* satellite. The above authors claim that there are groups consisting of two to six dust particles (a group was assumed to be responsible for impacts recorded during 10 s). Apati et al. (1981) believe that the continuous fragmentation of meteor bodies takes place in the upper atmosphere. For meteors recorded using our meteor patrol, we can determine not only the time intervals between the events but also the direction of motion, which provides additional information. Whereas meteor event nos. 136 and 137 can be interpreted as fragmentation in the atmosphere, meteor nos. 137 and 138, which were more than 12 minutes apart, moved as separate particles before colliding with the Earth's atmosphere.

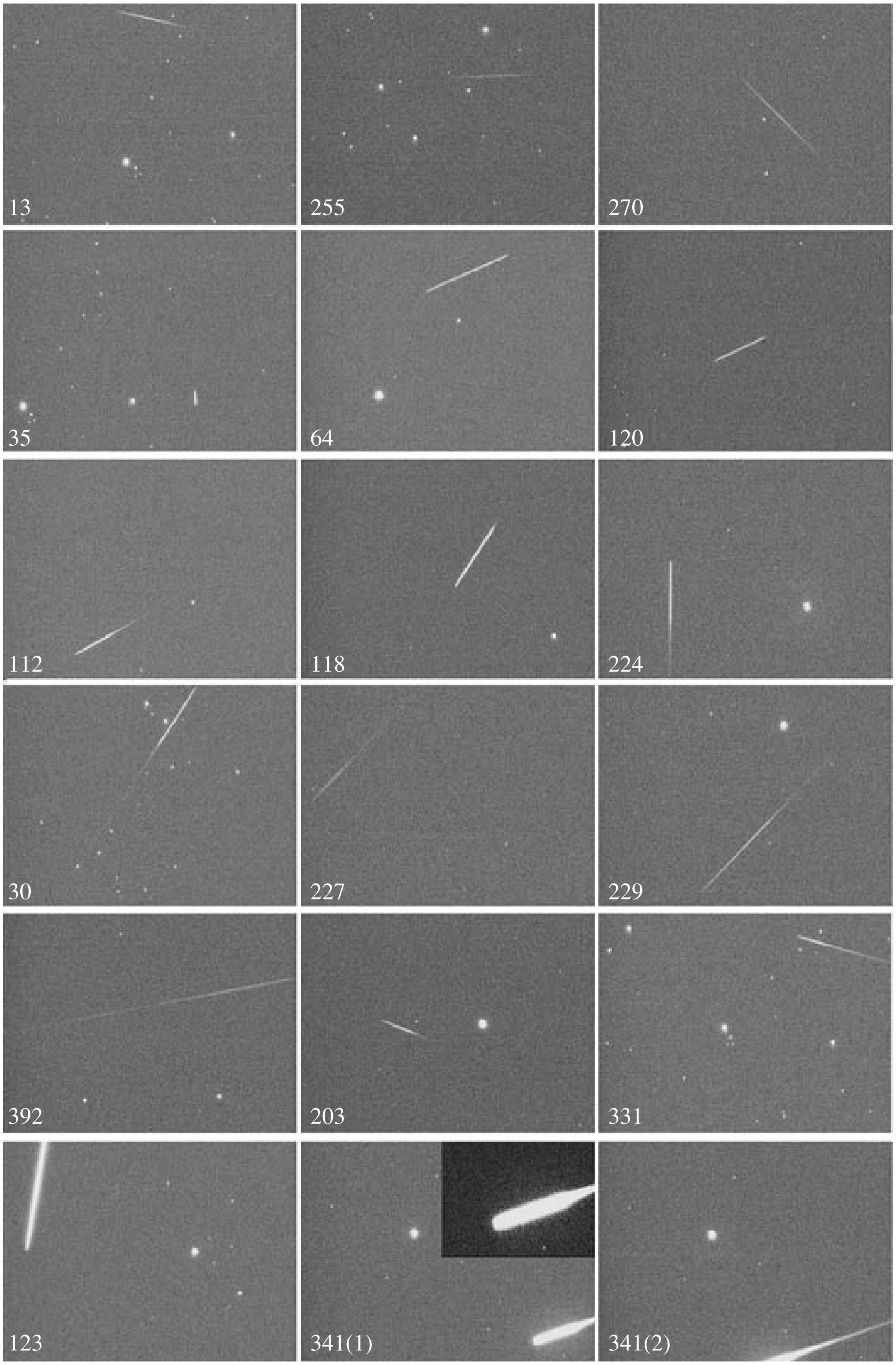

Fig. 10. Typical meteor images.

Of interest is also another anomalous case (meteor no. 203). The meteor image is nonuniform along the trajectory (the first half of the stroke is brighter than the second half). Such an anomalous pattern shows up in five frames, and, in addition, the meteor possesses a bright “tail.” We interpret this phenomenon as periodic light variations with a frequency that is a multiple of the frame frequency of our detector. Periodic light variations are definitely associated with the physics of the meteor event, with the density, composition, and structure of the dust particle—all this must show up on the light curve of the meteor. Thus, meteor no. 331 represents a class of meteor images remarkable in that, unlike 98% of standard meteor images (with gaps between strokes equal in length to the strokes themselves), it appears diffuse and blurred along the direction of motion. The images of objects such as meteor no. 331 can be explained by the effect of the composition and structure of the dust particle on the process of its intense fragmentation during its burnout in the Earth's atmosphere.

The fraction of bright meteors (of about zero magnitude) in our observational data is rather low, primarily due to the small field of view of the telescope and the relatively small number of such meteors. In our sample, such objects are represented by meteor no. 123, whose stroke image did not fit completely into the frame. The meteor left a bright afterglow in the next frame. A more spectacular event was produced by meteor no. 341: although the meteor passed in the corner of the frame, it produced a short stroke that was entirely within the frame. The inset figure shows a magnified image of this meteor (the bright star in the center of the frame is γ Geminorum, $m_V = +1.9^m$). The image exhibits a conspicuous bright asymmetric "tail" and bright afterglow observed for more than 2 seconds.

Photographic instruments rather rarely detect such phenomena as stationary meteors and, moreover, the confidence of identification remains somewhat uncertain. The TV method allows the dynamics of the event development to be reliably displayed for stationary meteors, which is impossible to achieve with CCD detectors with large integration time. Martynenko et al. (1978) presented an image of a stationary meteor of α-Perseid stream photographed by L.B. Shmelev on August 12, 1972. The image of such a meteor has a diameter of about 5′; if observed with a telescopic TV system, this meteor would produce an extended image in many frames. During our observations, we did not record any pointlike stationary meteor, but we obtained the images of five meteors with very short strokes (with angular velocities below 1 deg/s). Such meteors were classified as stationary when observed visually or in patrol observations with short-focus cameras.

Finally, we must point out the recorded (more than twenty events) processes of the emergence and final stages of meteor events. Whereas the end of a meteor event for the meteor class considered is not particularly remarkable, the process of the "birth" of a meteor is the least studied phase of its development. We are able to analyze meteor events frame by frame and can therefore argue conclusively that the emergence of a meteor stroke is preceded by the formation of a hazy spot in the field of view with a size that is two to three times greater than the diameter of the meteor image. When analyzing faint photographic meteors, Lebedinets (1987) points out that "…anomalous meteors are produced by highly nonuniform parent meteor bodies from which a cloudlet of debris separates at one moment near the point where the meteor appears. This cloudlet lags with respect to the parent meteor body and is the main source of meteor light for some time (the 'initial flash')." This appears to be the phenomenon recorded by our telescopic TV patrol. The study of this phenomenon requires accumulation and analysis of observational data, and this is just what the meteor team is doing here at the Odessa Astronomical Observatory.

CONCLUSIONS

The results of observations demonstrate new fields of use and the prospects of the TV telescopic method for the study of the nature of meteor bodies and various processes that accompany their flight in the Earth's atmosphere. We are now developing a technique of positional and photometric measurements for stellar and meteor images. In this paper, we have mentioned only the most interesting events. Our observational data is of evident interest for subsequent reduction from the viewpoint of topical problems of meteor astronomy. Among the latter, we should point out the following opportunities for single-station observations: determination of the equatorial coordinates of the meteor radiant point using the Stanyukovich method in order to study the radiant areas of faint meteor showers; determination of the relative deceleration of meteor particles; and the analysis of the interrelation between the glow of meteor events with meteor "tails" and afterglow.

At present, we have assembled a second TV facility, which is now in the stage of going into operation and which will allow us to perform double-station observations of meteors.

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