IRSTI 41.19.33; 41.51.27; 41.51.29 https://doi.org/10.26577/ijmph.2022.v13.i2.04

A.A. Solodovnik[1]*, P.I. Leontyev[1], S.A. Sartin[1],
B.M. Useinov[1], D.V. Alyoshin[1], P. Dalin[2,3]

[1]North Kazakhstan University named after M. Kozybayev, Petropavlovsk, Kazakhstan
[2]Swedish Institute of Space Physics, Kiruna, Sweden
[3]Space Research Institute, RAS, Moscow, Russia
* e-mail: buseinov@gmail.com
(Received 9 May 2022; accepted 16 November 2022)

Physical bases of meteor registration methods and the instrument complex of the NKU Observatory

Abstract. One of the actual directions of studying the physical characteristics of near–Earth space is the assessment of the concentration of meteoroids in it, and the time change of this parameter. In this regard, the principles of setting and implementing meteor observations at the observatory of the North Kazakhstan university named after Manash Kozybayev are considered in chronological order. Meteor observations were carried out on the basis of an integrated approach, including the use of meteor patrols, an All Sky camera, a system for recording radio wave reflections from a remote station from meteor tracks, and a camera based on an optical image intensifier. Based on the analysis of the practical experience of using this equipment, the advantages and disadvantages of each of the methods of meteor registration are revealed. It is shown that the use of the latest image brightness amplifiers and wide–angle cameras with the highest possible sensor sensitivity is the most progressive for their optical observations. The closest attention is paid to the analysis of the experience of implementing the registration of plasma meteor tracks in the radio range. The method is based on the selection of reflected (scattered) musical–speech signals of a remote radio station having a specific pulse structure. Comparison of the obtained results on the frequency of meteor phenomena with the data of known observation points allows us to speak about the effective operation of the newly created meteor monitoring system in the radio range. In the final part of the work, ways to improve the efficiency of recording meteor phenomena in the optical range based on the use of the latest radiation receivers are considered.
Keywords: meteoroids, meteor phenomena, monitoring methods, optical registration, radio observations, instrument complex.

Introduction

Meteor phenomena in the earth's atmosphere that occur when relatively small solid celestial bodies (meteoroids) moving at cosmic speeds invade it have been the subject of scientific research since the end of the XVIII century to the present, and scientific interest in them has not weakened. At the same time, despite significant progress in the development of methods and material base of meteor astronomy, and, as a result, a significant increase in knowledge about the nature and statistics of meteor phenomena, there are a considerable number of important issues that need to be considered.

To a large extent, the existence of such issues (and approaches to their resolution) is due to the stochasticity of the phenomenon. Meteors and fireballs are distinguished by the suddenness of their appearance, which, together with the unpredictability of the direction and the high angular velocity of their movement across the celestial sphere, creates specific problems for their registration and, moreover, for detailed study [1–4].

One of the most important practical tasks of meteor astronomy is the determination of the spatial concentration of meteoroids in the vicinity of the Earth's orbit and its changes in time [5–7]. The value of this quantity is influenced by many cosmic factors. At the same time, knowledge of its magnitude is very important, first of all, from the point of view of the safe functioning of the space infrastructure of modern civilization. In addition to this practically significant task, the problem of the most efficient registration of fireballs for organizing the subsequent search for samples of extraterrestrial matter that fell on the Earth's surface in the form of meteorites remains topical [3, 8 – 9].

It is impossible to ignore such a promising task as the registration of meteors generated by extremely friable bodies, as well as icy meteoroids. The fact of the existence of friable meteoroids is confirmed by the data of space missions, and ice bodies − by repeated finds of ice meteorites that fell to the Earth. However, the registration of meteors generated by friable, easily evaporated bodies is hardly possible using the instrumentation of modern meteor astronomy [1–2, 10]. The fact is that in the optical range they are not able to radiate intensely enough. And to apply the method of reflection of radio waves, one should hardly expect from them the appearance of plasma tracks with a sufficiently high concentration of free electrons.

It is quite obvious that the complex of these scientific problems and tasks is interconnected. It is also obvious that their solution should be sought through the development and application of various new methods of monitoring the celestial sphere, and monitoring to the maximum extent automated. Our work is devoted to the consideration of the results of efforts to create and material base for monitoring meteor activity and the subsequent study of its capabilities.

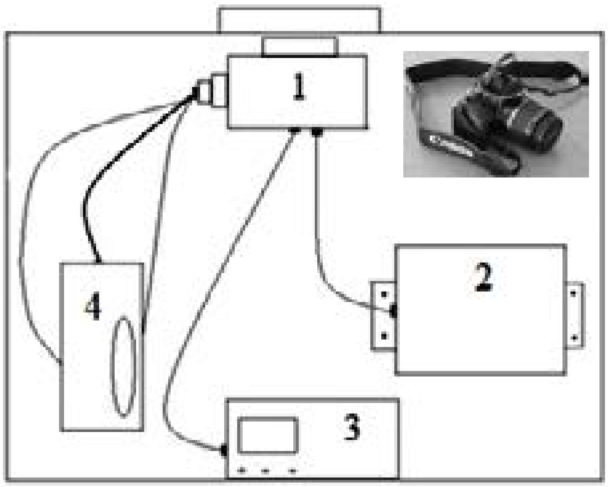
Materials and methods

A. Optical observations of meteors at the NKU Observatory

It is paradoxically, but only very recently real alternatives to the human eye in terms of the efficiency of meteor detection appeared. At the same time, the use of visual methods for observing meteors, despite their historical merits, is a thing of the past. The reasons for this are as the high laboriousness of such an observation process, and, unfortunately, the sufficient subjectivity of the data obtained. Therefore, today visual observations can at best be useful in testing the effectiveness of newly created instrument systems.

On the market of scientific instruments, it is difficult to find equipment, which ready for use for meteor observations. Therefore, researchers, as a rule, use for this purpose either astronomical CCD arrays or digital cameras with appropriate short focus optics [11–12]. One of the traditional approaches to the registration of meteors in the optical range is the use of meteor patrols of various designs. The Center for Astrophysical Research (CAR NKU) used a specially made similar equipment. The appearance of the equipment and its scheme are shown in Figure 1. The basis for creating the equipment (Fig. 1) was the Canon 1000D digital cameras [13].

(a)



(b)

Figure 1 − Model (a) of the NKU Observatory meteor patrol and scheme (b) of the equipment: 1 − Canon 1000D camera; 2 − exposure control unit; 3 − thermostat; 4 − storage device.

The purpose of the patrol device elements is quite clear. Note that all elements were placed in a case with thermal insulation. At the same time, the thermostat ensured the operation of the equipment at low temperatures, in particular, it protected the optical window from fogging.

The experience of using the installation showed the insufficiently high sensitivity of the cameras, which recorded meteors no weaker than 4 magnitude. In addition, at least 7 recording devices are needed to cover the celestial sphere. This requires the creation of a bulky equipment. This forced us to abandon the further application of the considered construction.

Somewhat later, devices of the celestial sphere (or a significant part of it) panoramic viewing were used in monitoring the celestial sphere. One of them is the Arecont Vision Surround Video 180 panoramic camera, which is used in summer for video recording of the twilight segment of the sky and fields of noctilucent clouds. To eliminate the influence of urban development, the camera was installed on a mast 18 meters high.

The image of objects received by the camera can be output to a computer for real–time observation or recorded in video format. Figure 2 shows the snapshot of the twilight segment taken with the Arecont-Vision SurroundVideo 180 series panoramic camera.

Figure 2 − The snapshot of the twilight segment taken with the ArecontVision SurroundVideo 180 series panoramic camera

However, despite the large viewing angle (180 degrees in azimuth and 33 degrees in altitude), due to insufficient sensor sensitivity the camera proved to be of little use for detecting meteor tracks of moderate brightness. Increasing the sensitivity of this device is achievable by changing the settings of the camera control system to a lower frame rate. In normal mode, the camera frame rate is 1.5 frames per second. In this mode, luminaries with a brightness of at least -3^m (Venus, Jupiter) are clearly registered. When the frequency is reduced to 0.1 frames per second, it is quite possible to get images of stars and bright meteors. In this case, it is advisable to use at least two panoramic cameras aimed at the zenith, with sensitivity bands orthogonal to one another. Under this condition, most of the meteors with extended tracks will be registered by the system.

Digital photographic cameras with an extremely wide field of view are used to monitor bright meteors and fireballs, during the passage of which meteorites can fall to Earth. To implement this approach, a fisheye lens (Sigma AF, focal length 10 mm, aperture f/2.8) was purchased. This lens used as a feeding optics for the ST 3200 ME matrix (Fig. 3) [14]. The same picture shows a snapshot obtained using this system.

a) b)

Figure 3 − a) Fisheye lens (top) and ST 3200 ME matrix; b) The image obtained by the camera. The tower of the RC–30 telescope is visible. A meteor is highlighted with a dotted line.

The use of this registration system is most effective in suburban conditions as far as possible from urban illumination. Therefore, the camera was used to shoot meteors by students and undergraduates living in rural areas during the summer holidays.

The most effective in studying the activity of meteor showers was the use of an optical brightness amplifier (due to the possibility of registering weak meteors). It is known, that even the expression of the brightness of meteors in stellar magnitudes (usual for an astronomer) is fraught with difficulties. Their cause is the movement of meteors. At the same time, visual estimates of the meteors brightness (for all their subjectivity) are closer to reality compared to photographic ones. The explanation lies in the inertia of the visual sensation of the eye, which is not characteristic of most physical light receivers. The light of the star and the part of the meteor track acts on the surface of the radiation receiver during completely different time intervals. For stars, this interval is determined only by the choice of exposure. But the image of the meteor track consists of elements, each of which was exposed to light for a much shorter time. Let's imagine that the meteor track fit on 1000 pixels. The duration of the phenomenon was 0.1 seconds. Then the light acted on each of the pixels for no more than 10^{-4} seconds. In any situation, the effect of the action of a fixed light source will be more pronounced. That is, in order to objectively compare the brightness of meteors and stars, you need to take pictures of stars with exposures of approximately the same duration. In this case, only the rare brightest stars will be displayed on the images. Therefore, photographically we can register only the brightest meteors.

Thus, the study of meteor activity requires the use of either large lenses or technical means (sometimes quite complex in amplifying the light flux [11, 15]). At a certain stage of research, we tried to implement the latter direction by proposing to use an electron–optical converter (EOC) on a microchannel plate MPN–8KM to obtain images of meteor tracks [16].

This is one of the best examples of this type equipment, manufactured by the Novosibirsk Instrument–Making Plant (Fig. 4). The device is designed to observe objects in the dark, with natural illumination from the Moon and stars. Interchangeable lenses allow you to change the magnification from $1^{\times}$ to $4^{\times}$. The electronic circuit of the device provides protection of the EOC from short–term illumination by intense sources. The device can operate in the temperature range ± 40° C.

Figure 4 − General view of the MPN–8KM device − on the left (1 − eyepiece with eyecup; 2 − lens; A − lens focusing unit; 3 infrared filter; 4 − battery pack), on the right is a device with a CANON–600D camera.

Important features of the device, which determine the prospects for its application in meteor observations, are the use of the EOC 2+ generation (microchannel image brightness amplifier), as well as the presence of adapters for attachment to photo and video cameras. According to the passport data of the device, the increase in the brightness of the image reaches 20,000 – 30,000 times. From the point of view of the penetrating power of the optics, this is equivalent to increasing the aperture by hundreds of times. In this case, the field of view is about 36 degrees! This value is comparable to the viewing angle of the human eye in visual observations of meteors.

The first observations with the help of the MPN–8KM instrument were carried out on the night of August 12–13, 2015. The date, the epoch of the Perseid maximum, was chosen in order to obtain images of meteor tracks with the highest probability. The receiver was a CANON–1000D camera. The instruments were placed on an azimuthal tripod, since compensation for the daily movement of the luminaries is not required at short exposures. The survey was conducted with the onset of astronomical night, in the absence of clouds at a point located at a distance of about 6 kilometers from Petropavlovsk. When shooting, exposures from 1.6 to 15 seconds were used.

20 images of satisfactory quality were selected for analysis. At the same time, meteor tracks were confidently detected in 6 images (Fig. 5). It is interesting that in two cases the same meteor was recorded on consecutive images. Perhaps this was possible because thanks to the significant amplification of the MPN8KM device. The system allows you to register the afterglow of a meteor trail, despite the short duration of the phenomenon. When using photographic emulsions, this is practically impossible, due to their low sensitivity.

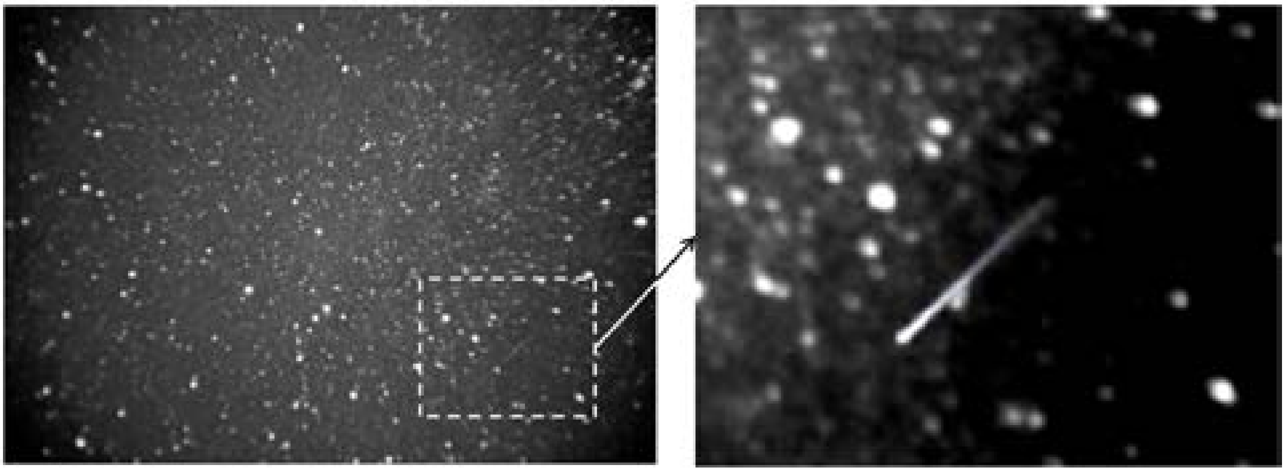


Figure 5 − Image of the starry sky section (the constellation Perseus) 12.08.2015 18h.45m.12s. UTC (exposure 6.0 s). A section with a meteor track is highlighted.

The expected number of meteors in visual observations can be estimated based on the maximum activity of the shower and the height of the radiant [1, 3]. In this case, this number was about 1.3 meteors per minute [16]. Taking into account the size of the observed area (about 30 degrees), this estimate should be reduced to 0.3 meteors per minute. During the total exposure time (159 s), we can expect the registration of approximately one meteor with the naked eye. Photographing meteors on an emulsion would reduce this value by about 4–5 times. It is more difficult to estimate the efficiency of meteor registration by digital cameras. It can be based on a comparison of their sensitivity with photographic emulsions. When shooting the sky, the sensitivity of cameras at the level of 400 – 800 ASA units is used. Taking into account that the sensitivity of astronomical films during long exposures is about 50 ASA units, the number of meteors recorded by a conventional digital camera would be approximately twice as large as in visual observations.

Thus, in the considered experiment, the number of registered meteors exceeds their expected number in visual observations by about 10 times. In comparison with ordinary photographic observations, the gain would be from 30 to 40 times. Even compared to observations with digital cameras, the gain can be up to 4–6 times.

Registration of meteor phenomena in the radio range

Optical methods for observing meteor phenomena are rapidly improving. However, these methods have fundamental limitations − the influence of negative meteorological conditions and illumination of the sky by the Moon. In addition, optical registration of meteors is completely impossible during daylight hours. At the same time, there are quite a lot of meteor showers operating during the daytime [1, 4, 17].

When studying meteor phenomena, their observations in the radio range are most free from photometric and meteorological interference [1, 18–20]. Therefore, in the process of developing the instrument base for meteor observations, a complex, which makes it possible to record meteor tracks in the radio range, was created at the CAR NKU [21].

The physical basis of the method is the existence of a plasma track along the meteor flight path. Such plasma track at altitudes ranging from 100 to 60 km can exist from fractions of a second to tens of seconds, depending on the mass and speed of the body that created the meteor. This is enough to detect a plasma track due to the effect of radio waves reflected from it. Moreover, it becomes possible to study the temporal evolution of the track associated with atmospheric effects on it at high altitudes [1–4]. The ideal for this would be the use of radars. Meteor radar is a good technological approach both for registering the occurrence of a phenomenon, but also for determining the coordinates of an object on the celestial sphere and its speed. However, the required equipment is very specific, its use requires the permission of the special services, and its use in the city is completely prohibited. Therefore, in the practice of a university observatory located in the city, radar observations of meteors are excluded.

There is another approach to the registration of meteor phenomena in the radio range. The functions of the radiation source and the receiver can be separated. The source of radio waves (emitter) can be a powerful radio station operating in the range in which the ionosphere is transparent to radio waves. The observation method is as follows. The transmitting station emits radio waves that scatter on the plasma tracks of meteors. The signal, partially reflected from the track, is accepted by the receiver in the form of a radio pulse, which is then analyzed [18–20, 22].

Then, to register meteors, it is enough to have an external antenna, a sensitive FM (65–108 MHz) radio receiver, a computer for recording and processing information obtained during the observation. Besides that, it is necessary to select the optimal frequencies of the radio range, where there is no permanent presence of local stations, but there are powerful distant stations at distances convenient for meteor reflections. The choice of frequency depends on the geography and the location of the antenna and receiver. The radio station should be located at a distance of 500 – 2000 km from the receiver outside the zone of its direct hearing (up to 50 km).

The reception of the reflected signal of the radio station lasts from fractions to units of seconds, and the time profile of this musical–speech signal (MSS) is characterized by an instantaneous appearance and a smooth decline (signal attenuation). This makes it possible to separate meteor signals (MSS) from signals of a different nature that may appear on the air. Note that the number of MSS depends not only on meteor activity, but also on other factors. These include the number and time of operation of radio stations on this wave, the state of the ionosphere, factors of solar activity.

The instrument complex for recording meteors in the radio range, created at the SKU, includes a dipole antenna 12 meters long, oriented in the north–south direction, a USB FM tuner and a laptop (Fig. 6). In Figure 6, the number 1 indicates the monitor for displaying the status of the workstation. The HDTV program is visible on it, with the help of which the desired FM station is selected. The current waveform record is shown on the laptop screen in real time. Bursts of meteor reflections and interference are visible. Number 2 denotes a network drive that stores observational material in real time for further processing. Number 3 indicates the speakers that allow you to hear the signal from the FM tuner. FM receiver (indicated by number 4) is connected to a laptop that processes data using the standard HDTV program that comes with it. It also serves as a filter that removes most of the interference. The reception was tuned to the transmission frequency 89.8 MHz of the FM station located in Perm, at a distance of 1262 km from Petropavlovsk. To select a station, the program http://www.fmlist.org/ [23] was used, which displays information about all AM and FM transmitters in the world. The number 5 indicates a USB – oscilloscope connected to a laptop. It was used to record oscillograms using the Data Recorder module of the Multi VirAnalyser program.

Observations at the indicated frequency were carried out during the daytime and at night during the seasons of 2019 and 2020 and gave interesting results. A large number of events similar to meteor phenomena have been registered. The average number of such phenomena per day was about a hundred, with an average pulse duration of about 0.4 seconds. The most important was to obtain evidence that the recorded pulses are associated precisely with the reflection of radio waves from plasma meteor tracks.

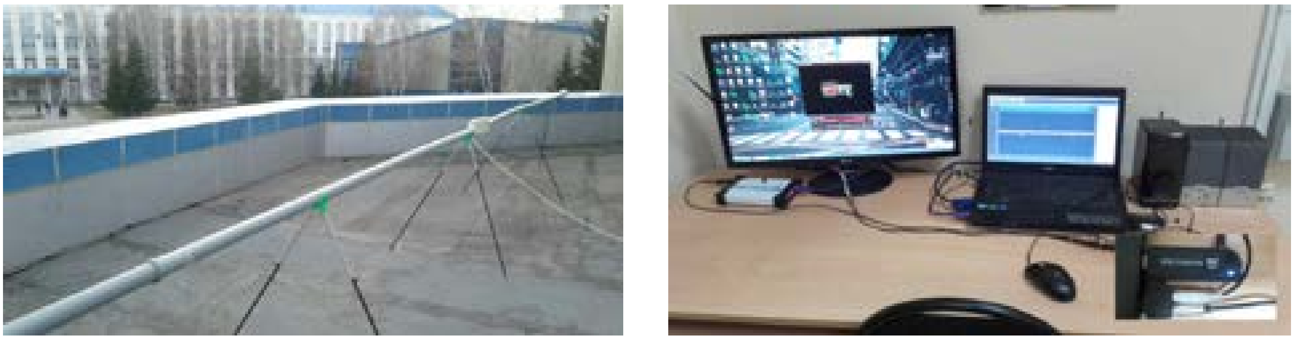


Figure 6 − Antenna (upper part) and an instrument complex for registering meteors in the radio range.

Results and discussion

In optical observations of meteors, it is quite easy to identify their images. In addition to them, only flying apparatuses are fast moving objects in the celestial sphere: satellites and airplanes. Both of them in the pictures are quite different from meteors, and they do not appear in the sky often.

When registering radio waves reflected from plasma meteor tracks, there are difficulties associated with various kinds of interference: natural and technogenic. Important criteria for difference are the temporal structure of the radio pulse and its duration. In this case, it should be taken into account that the parameters of the reflected pulse are determined by the concentration of free electrons per unit length of the plasma track. “Saturated tracks” with an electron density of more than $2 \cdot 10^{14}$ electrons per meter reflect radio waves most effectively (virtually mirror image). Such tracks are created by quite massive particles that generate meteors brighter than 5 magnitude. In this case, radio waves are reflected in much the same way as from a metal surface.

At lower concentrations of free electrons, they talk about “unsaturated” meteor tracks. In this case, it is more correct to talk not about reflection, but about the scattering of radio waves. In both cases, there is an increase in the intensity of the reflected signal, and after it reaches a maximum, a decrease. At the same time, the duration of the reflected pulse is noticeably longer for “saturated” tracks; it can be up to ten seconds. Here, the intensity of the reflected signal gradually increases at the beginning, while its maximum has the character of a plateau. For “unsaturated” meteor tracks, the duration of the reflected pulse does not exceed 1 second.

They are characterized by a very rapid increase in signal intensity, a sharp maximum and its rapid fall according to an exponential law. The relaxation time is 0.3 – 0.5 seconds. In both cases, the reflected radio pulses are characterized by a discontinuous structure (with a characteristic time of hundredths of a second), which is explained by the interference of radio waves reflected from different parts of the meteor track [21].

These signs made it possible to identify meteor radio echoes in the records and study the statistical daily and seasonal patterns of their appearance. Comparing the results obtained with the data of many other observers, it is possible to estimate the effectiveness of the newly created installation and the adequacy of the applied research methodology.

Important features of the daily course of meteor activity are the presence of a morning (about 06:00 local time) maximum and an evening (about 18:00 local time) minimum in the number of meteors. In this case, the time dispersion of the maximum and minimum positions is about 2 hours. It’s clear that sporadic meteors are considered in this case, since the presence of an active meteor shower at the moment can radically change the picture. It is especially important to take this into account for meteor showers with circumpolar radiants (Cassiopeids, Perseids, Draconids, and others). Figure 7 shows the daily distribution of meteor reflections on August 13, 2019, obtained at the CAR NKU.

This distribution compares well with the data of other observers shown in Figure 8.

The dynamics of the daily course of meteor phenomena recorded in the radio range throughout the month is shown in Figures 9 and 10. It is obvious that the month with an active meteor shower will be the most indicative for the study of the correct operation of the system. In this case, an excess of the daily number of meteors in the epoch of maximum will be detected. One of the best periods in this case should be considered August with its giant shower, the Perseids [25].

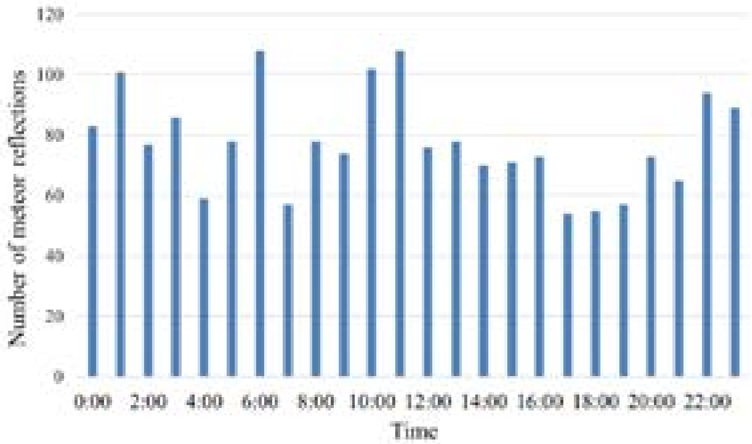


Figure 7 − The daily distribution of meteor reflections on August 13, 2019, CAR NKU, Petropavlovsk

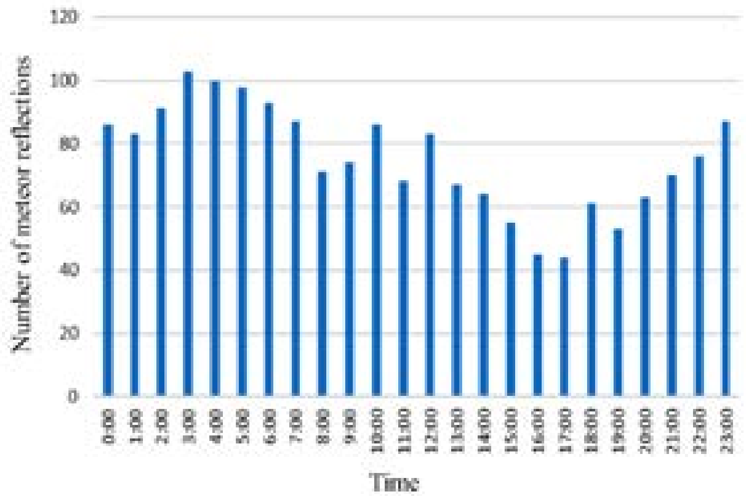


Figure 8 − Daily distribution of meteors for 13.08.2019, data from Mario Bombardini, Italy [24].

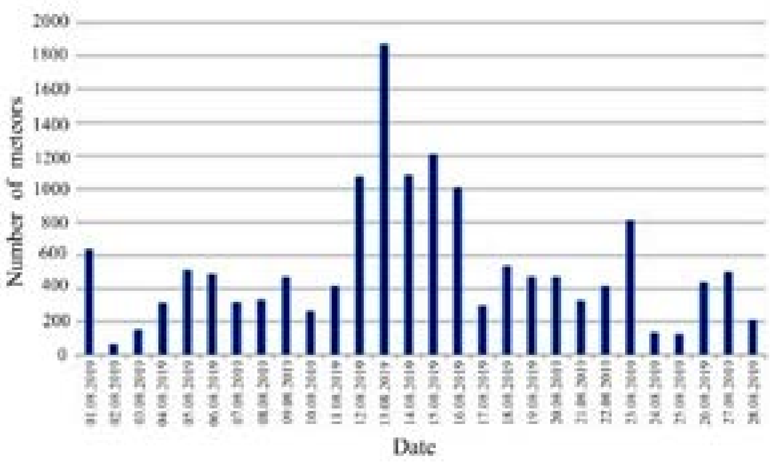


Figure 9 − Distribution of the daily number of meteors for August 2019 according to radio observations at the CAR NKU, Petropavlovsk.

Figure 9 clearly shows a wide maximum of Perseid activity from August 12 to 16 with a sharp peak on August 13. The relatively high meteor activity on August 1 can be associated with the combined action of the Cassiopeid and δ – Aquarid showers near this date, and the increase in meteor activity on August 23 with the simultaneous action of several weak meteor showers. Among them, the poorly studied ϰ–Cygnids meteor shower is best known [25].

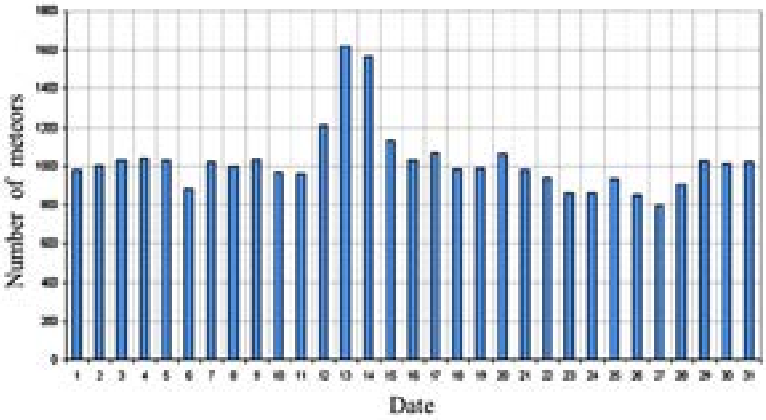


Figure 10 − Distribution of the daily number of meteors for August 2019 according to radio observations by F. Verbelen, Kampenhout (Belgium) at a frequency (49.99 MHz) [26].

Comparison of the radio observations results of the meteor phenomena frequency presented in Figures 9 and 10 shows their good mutual agreement. Thus, it can be argued about the achievement of a fairly confident registration of meteors by the radio echo method with the help of instruments available at CAR NKU.

Conclusions

We think that the combination of both optical and radio observations of meteor phenomena will be most effective in studying the features of the distribution of meteoroids in the vicinity of the Earth's orbit. At the same time, as noted, the methods of optical registration of meteors require their further development. And there are several possibilities here.

So the use of the new camera CANON 2000 D [27] could be an alternative to installing a meteor patrol. This camera in combination with a wide–angle lens CANON ZOOM LENS EF–S 10–22 mm has proven itself in the implementation of a panoramic view of the twilight segment in the summer. The field of view of a CANON 2000 D camera with a wide–angle lens is more than 90 degrees in azimuth. The camera has a higher sensitivity compared to previous models. With its help, an extensive set of high–quality images of noctilucent clouds in the 2021 season was obtained. In the same season, test observations of the Perseids were also carried out (Fig. 11), which made it possible to obtain high–quality images of meteors.

Figure 11 − Perseid meteors images taken with CANON 2000 camera with CANON ZOOM LENS EF–S 10–22 mm lens.

These results give good prospects for the implementation of new generation meteor patrols. In the future, it is planned to install three such cameras on a common tripod using a tracking module.

The use of an optical image brightness amplifier in the investigation of little–studied weak meteor showers is very promising. At the same time, observations of meteors of the ϰ–Cygnids shower are the most promising. In addition, with the use of this amplifier, it is planned to conduct experiments on the registration of meteors in the near infrared range. This is associated with the possibility of the registration of the meteors generated by extremely friable bodies, as well as icy meteoroids.

In addition, to register bright meteors and fireballs, a new All Sky camera ASI224VC with an Arecont 1.55 lens was purchased (Fig. 12 on the left). The camera is equipped with a protective acrylic dome and can work offline with recording information on a micro SD card. The field of view of this camera is 180 degrees [28].

Figure 12 − All Sky ASI224VC camera with Arecont 1.55 lens.

However, the highest expectations are associated with the new highly sensitive CANON RF camera [29], the use of which will make it possible to perform video recording of meteor phenomena with characteristics that are noticeably superior to their visual observations. Unlike previous models, this camera is distinguished by a very high light sensitivity, which makes it possible to register meteors up to 7–8 magnitudes. The use of this camera in conjunction with the tracking device Sky–Watcher Star Adventurer will greatly expand the possibilities of optical monitoring of meteor phenomena.

References

1. Babadzhanov P.B. (1987) Meteory i ih nabljudenie [Meteors and their observation] M.: Nauka.
2. Bronshtjen V.A. (1985) Fizika meteornyh javlenij [Meteors and their observation] M.: Nauka.
3. Bronshtjen V.A. (1987) Meteory, meteority, meteoridy [Meteors, meteorites, meteorids] M.: Nauka.
4. Rendtel J., Arlt R. Handbook for Meteor Observers. International Meteor Organization, Potsdam, 2015.
5. Southworth R.B. (1967) Spase density of radio meteors. Spec. Rept. Smithson. Astrophys. Obs. No. 239. P. 75–97.
6. Harris A. W., D'Abramo G. "The population of near–Earth asteroids". Icarus, 257, (2015): p. 302–312.
7. Voloshhuk Ju.I. (1989) Meteority i meteornoe veshhestvo [Meteorites and meteor matter] Kiev.
8. Ortiz J. L., Madiedo J. M., Morales N., Santos–Sanz P., and Aceituno F. J. (2015). "Lunar impact flashes from Geminids: analysis of luminous efficiencies and the flux of large meteoroids on Earth". Monthly Notices of the Royal Astronomical Society, 454, 344–352.

9. Korec M. (2015). “QHY (5L–II–M) CCD camera for video meteor observation”. In Rault J.–L. and Roggemans P., editors, Proceedings of the International Meteor Conference Mistelbach, Austria, 27–30 August 2015. IMO, pages 85–89.

10. Ott T., Drolshagen E., Koschny D., and Poppe B. (2016). “PaDe – The particle detection program”. In Roggemans A. and Roggemans P., editors, Proceedings of the International Meteor Conference, Egmond, the Netherlands, 2–5 June 2016. International Meteor Organization, pages 209–213.

11. Solodovnik A.A., Maugazina A.O. (Chehija) K voprosu ob jeffektivnosti primenenija cifrovyh prijomnikov izluchenija k registracii meteornyh javlenij [On the effectiveness of the use of digital radiation receivers for the registration of meteor phenomena] Materialy mezhdunarodnoj nauchno–prakticheskoj konferencii «Jeffektivnye instrumenty sovremennyh nauk 2016» Chehija, Praga, 22–30 aprelja 2016, Praha Publishing House «Education and Science» s.r.o. Chehija, p. 38 – 42.

12. Askarova M.M., Sartin S.A., Terehin N.S., Varkushina M.A. (2019) Primenenie imejushhegosja v centre Astrofizicheskih issledovanij oborudovanija dlja nabljudenija meteornyh potokov [Application of the equipment available at the Astrophysical Research Center for observing meteor showers] Vestnik SKGU im. M. Kozybaeva, g. Petropavlovsk, p. 78–82.

13. Harakteristiki zerkal’noj kamery Canon EOS 1000D. https://prophotos.ru/devices/canon–eos–1000d/spec (accessed on May 12, 2022).

14. Harakteristiki PZS – matricy SBIG 3200 ME astrokamera–sbig–stf–3200me–class–2 (accessed on May 12, 2022)

15. Bagrov A.V., Bolgova G.T., Leonov V.A. (2003) Televizionnyj monitoring meteornyh javlenij dlja izuchenija jevoljucii meteornyh potokov [Television monitoring of meteor events to study the evolution of meteor showers] Kinematika i fizika nebesnyh tel. №4. P. 265268.

16. Solodovnik A.A., Maugazina A.O. (2016) Opyt primenenija jelektronno–opticheskogo preobrazovatelja MPN – 8KM v astronomicheskih nabljudenijah [Experience in the use of the electron-optical converter MPN – 8KM in astronomical observations] Materialy mezhdunarodnoj nauchno–prakticheskoj konferencii «Jeffektivnye instrumenty sovremennyh nauk 2016» Chehija, Praga, 22–30 aprelja, Praha Publishing House «Education and Science» s.r.o – Chehija, p. 33 – 38.

17. Lovell B. (1958) Meteornaja astronomija [Meteor astronomy] M.: Fizmatgiz.

18. Lebedinec V.N., Korpuskov V.N., Sosnova A.K. (1971) Issledovanie meteornyh potokov radiolokacionnym metodom [Radar survey of meteor showers] Trudy IJeM – Obninsk: Izd–vo IJeM, № 24. p. 100 – 113.

19. Kashheev B.D., Lebedinec V.N. (1961) Radiolokacionnye issledovanija meteornyh javlenij [Radar surveys of meteor phenomena] M., 124 S.

20. Janches D., Swarnalingam N., Plane J. M. C., Nesvornэ D., Feng W., Vokrouhlickэ D., and Nicolls M. J. (2015). “Radar detectability studies of slow and small zodiacal dust cloud particles: II. A study of three radars with different sensitivity”. Astrophys. J., 807:1, 13.

21. Sartin S.A., Solodovnik A.A., Useinov B.M., Zhukeshov A.M., Amrenova A.U. (2020) Opyt registracii otrazhenija radiosignalov ot plazmennyh meteornyh trekov v observatorii SKGU [Experience in recording the reflection of radio signals from plasma meteor tracks at the NKZU Observatory] Scientific Journal al-Farabi Kazakh national university. Series Physical. SSN 1563-0315, eISSN 2663-2276, №1 (72). p. 49–57.

22. Kaiser T.R. (1955) The interpretation of radio echoes from meteor trails. Spec. Suppl. J. Atm. Terr. Phys, Vol. 2, P. 55–56.

23. FMLIST – database of worldwide FM radio, DAB and TV. https://www.fmlist.org/ul_login.php 05.05.2020. (accessed on May 12, 2022)

24. RMOB – radio meteor observing bulletin. https://www.rmob.org/index.php (accessed on May 12, 2022)

25. Kulikovskij P.G. (1971) Spravochnik ljubitelja astronomii [Astronomy Lover’s Handbook]. M.: Nauka.

26. Felix Verbelen. Radio meteors August 2019. https://www.meteornews.net/ (accessed on May 12, 2022)

27. Harakteristiki zerkal’noj kamery Canon EOS 2000D [Canon EOS 2000D SLR Camera Features] **canon.ru**›cameras/eos–2000d/specifications/ (accessed on May 12, 2022)

28. All Sky kamera harakteristiki [All Sky Performance Camera] https://astronomy–imaging–camera.com/product/asi224mc (accessed on May 12, 2022)

29. Harakteristiki bezzerkal’noj kamery Canon EOS RP [Canon EOS RP mirrorless camera specifications]. https://www.canon.ru/cameras/eos-rp/specifications/ (accessed on May 12, 2022)

Funded by Al-Farabi KazNU.