22. METEORS AND METEORITES (MÉTÉORES ET MÉTÉORITES)

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INTRODUCTION

The limited space made available for this report by recent regulations of the Executive Committee of our Union does not allow the traditional list of all published papers. Also, it omits the data on detection of cosmic dust, which are now published each year in surveys by the COSPAR Dust Panel. This report is mainly based on completely fresh information contained in numerous letters sent to me.

The accompanying report of our Meteorite Committee is done in the old style, but only a limited number of references are given. Evidence for a terrestrial origin of tektites is becoming stronger every year, and this subject is omitted in order to shorten the report.

Before starting the report, I mention with great regret the death of Prof. Dr Cuno Hoffmeister. His name remains connected forever with the famous period of naked-eye observations of meteors. Another great loss for meteor observers was the death of Mr Koiro Komaki, the President of the Nippon Meteor Society.

GENERAL

The period of this report began with Symposium no. 33 of the IAU, Physics and Dynamics of Meteors, held in Tatranská Lomnica, Czechoslovakia, September 4–9, 1967. The symposium volume was edited by Kresák and Millman with exceptional dispatch and published by D. Reidel Company, Dordrecht, Holland, in 1968. It contains 48 papers and all the discussions.

During the last years, the greatest improvement in our knowledge of meteors was achieved in the interpretation of photographic records of fireballs and in the production and study of simulated meteors in laboratories and in the atmosphere. Also completed were several evaluations and interpretations of quite a number of meteors recorded by multistation high-power radar systems. Interest in meteor spectroscopy is continuously increasing, and there has been a great improvement of the observational data on fainter meteors over those of several years ago, as well as achievement of dispersions better than 100 Å/mm for fireballs. Work done in the physical theory of meteors is mostly based on attempts to explain the difference between the dynamically and the photometrically computed meteor masses. Generally, three mechanisms, progressive fragmentation, frothing, and heatshock, were proposed, and some models computed. It seems that no one of these explanations alone is able to explain all the observed effects both for faint meteors and for bright fireballs. There is still much more to be done in meteor physics. It appears also that the atmospheric constituents and variations are more important than we thought.

Statistical studies of photographic meteor orbits, together with some physical parameters of the meteor phenomenon, give an indication that a greater part of sporadic meteors than recently assumed could be of asteroidal origin. This problem is far from being finally decided. The traditional idea that faint meteors are only of cometary origin and bright fireballs only of asteroidal origin has become untenable.

FIREBALLS AND METEOR PHOTOGRAPHY

Precise photographic data on several hundred very bright fireballs recently became available. Most important in this respect was the continuation of systematic photographic work in a multiple station project of the Smithsonian Astrophysical Observatory in the mid-western United States

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(Prairie Network). McCrosky found a surprising result from his Prairie Network data on fireballs: The bulk densities of the meteoroids computed for these large bodies by equating the dynamic and photometric mass are the same small values as those previously determined for faint Super-Schmidt meteors (0·4 gr/cm^3). A similar value was obtained by Ceplecha (Ondřejov Observatory) for the Příbram fireball, but the bulk density of the recovered meteorites is 3·6 gr/cm^3. It is as though the meteorites were the strong portion of an otherwise weak, loose material. One must choose from two possibilities: (a) the majority of the fireballs are produced by material that is completely different from that of meteorites, or (b) our understanding of the physical processes encountered by a high-speed ablating body is fundamentally wrong. If bodies producing fireballs are similar to meteorites, almost all the kinetic energy of the body must be converted into visible light. But the average luminous efficiency, relatively well known from several different experiments, is two orders lower.

Another important result obtained from the Prairie Network is that there are considerably more large meteoroids (greater than 1 kg in mass) in space than was earlier estimated on the basis of meteorite falls. The data indicate a population of large (pre-atmospheric) meteoroids that is perhaps as much as one hundred times greater than expected. Two possible falls have been observed; despite extensive searching, neither of these has been found on the ground.* This failure to recover meteoritic material, as well as photographic observations of explosion-like break-up in the atmosphere, also indicates that the large meteoroids are friable.

Another photographic network, using one all-sky camera with rotating shutter at each station for recording fireballs, continues activity in Central Europe. Twenty-six German stations directed by Zähringer (Max-Planck-Institut für Kernphysik, Heidelberg) cooperate with twenty Czechoslovak stations directed by Ceplecha and Porubčan. Ceplecha and Ježková (Ondřejov Observatory) compute fireball trajectories for the whole European Network. Several searches for meteorites were organized for bodies with significant computed terminal masses. The lowest observed height of a luminous trajectory was 20 km, for a very bright fireball (−20th magnitude?) on 1969 April 10, over southeast Germany. This fireball might have dropped several tens of kilograms of meteorites. An extensive, but unsuccessful search close to Otterkirchen (Passau) was organized in the summer and autumn of 1969 by Zähringer. No meteorites have yet been found for any fireball within the European Network.

A network of 12 camera stations is being constructed in western Canada by Halliday (Dominion Observatory, Ottawa) to provide data for the recovery of meteorites and the study of their orbits. Each station employs 5 cameras using 70-mm film and is equipped with a photoelectric meteor detector. Instrumentation of the network should be completed in 1970.

Millman (National Research Council, Ottawa) maintains a catalog of all bright fireballs observed in Canada. Search is initiated whenever there seems to be a chance for the recovery of meteoritic material. He is also making a statistical study of the orbits of meteorite-dropping fireballs.

Olivier (American Meteor Society, Philadelphia) continues to organize the visual observations of fireballs and to compute the height, location, and orbit for many fireballs for which two or more reports are available.

Levin and Simonenko (Schmit's Geophysical Institute, Moscow) determined true radiants of 14 meteorite fireballs. Simonenko also eliminated computational errors in published data for trajectories and orbits of 5 other meteorite fireballs.

Rajchl (Ondřejov Observatory) searched for further possible explanations for the origin of two groups of fireballs. One he recognized to be connected with the "new" comets, on the basis of the inclination distribution, but the other orbital elements do not fit well. He started to compute a non-gravitational jet deceleration acting on part of the parent comet shortly after a split that decreases a and e, with i being constant.

Ceplecha, Ježková, and Novák continue their systematic double-station program for meteor

* McCrosky photographed a meteorite fall from two stations of the Prairie Network on January 4, 1970 at 2h14m17s GMT. G. Schwartz found the first meteorite (bronzite chondrite?) of 9.8 kg within the computed area close to Lost City, Oklahoma. Altogether, 3 meteorites of this fall were recovered up to February 1970.

photography at Ondřejov Observatory, using 30 classical small cameras with rotating shutter, placed at two locations 40 km apart and covering about half the visible hemisphere. This program has been going on for 20 yrs without interruption; in more than 6000 h of exposure time, 40000 glass plates (9 × 12 cm) have been exposed and almost 1000 double-station meteors photographed (mostly sporadic). Only a small part of these data have been reduced and published. Most reductions have been on special bright objects (including the Příbram fireball), in connection with high-dispersion spectra of the same objects, or during special periods like IGY and IGC.

Seven years ago Yabu and Takeuchi from the Nippon Meteor Society began multiple observations of meteors, both visual and photographic, using a baseline of 90 km in the middle of Japan Island. About 50 double-station meteors have been photographed and their reduction is now in progress.

Ayers (NASA Langley Research Center, Virginia) developed two different methods of making photometric measurements of photographic artificial meteors; they can be used for the photometry of natural phenomena as well.

Dohnanyi (Bellcom, Inc., Washington) undertook a statistical analysis of the McCrosky and Posen photographic meteors in an effort to define their distribution more precisely.

Ceplecha (Smithsonian Astrophysical Observatory) studied discrete levels of meteor beginning height in detail. He confirmed the existence of two main levels of beginning height for Super-Schmidt meteors, separated by about 9 to 10 km. Among all possible interpretations of these discrete levels, composition and fragmentation seem to be the most important.

Dalton (NASA Marshall Space Flight Center, Alabama) made a complicated statistical analysis of 413 meteors by Jacchia *et al.*, and of the 333 brightest objects selected from McCrosky and Posen Super-Schmidt meteors.

METEOR SPECTRA, PHOTOELECTRIC OBSERVATIONS AND SIMULATED METEORS

A working meeting on meteor spectra was held at Smithsonian Astrophysical Observatory in Cambridge in April 1969. Its main purpose was to find whether or not the spectra contain any useful information on the composition and structure of meteoritic particles. Even if the conclusion was rather pessimistic, the group recommended that research continue in three different ways: (a) to develop new models of semi-equilibrium for larger bodies penetrating very deep into the atmosphere, (b) to obtain spectra of early portions of faint meteor trajectories, where the free molecular flow regime is certain, (c) to examine the Hα profiles. It was recommended to continue sending a list of all meteor spectra photographed at different observatories to Millman, National Research Council, Canada.

Halliday continues the regular program of meteor spectroscopy at the Meanook and Newbrook Meteor Observatories. Several of the spectrographs have been equipped with new gratings to secure spectra of greater dispersion than previously possible. The Super-Schmidt photographs of spectrum 210, an iron meteoroid, have yielded a light curve and improved values of the deceleration and orbit for this particle. Gault (Dominion Obs.) measured the decay rate of the forbidden O I line at 5577 Å as a function of height in the photographic spectra of six meteors showing multiple images of the line when photographed with jumping-film spectrographs.

Photographic meteor spectroscopy is being continued by Millman, and a revised world list of meteor spectra is being prepared. It will include spectra of over 1200 different meteors to the end of 1968. In August of 1969, a cooperative program with the Dudley Observatory, Albany, was commenced. This involves the recording of meteor spectra by image orthicon, and a correlation of the data with records made simultaneously by visual, photographic, and radio techniques.

Ceplecha and Rajchl (Ondřejov Observatory) continued photographing meteor spectra. Several dozen spectra, most with dispersions better than 100 Å/mm, were recorded, of which 5 are of extremely good quality. One of them with about 260 spectral lines in the visible region belongs to a fireball that penetrated deep into the atmosphere. The end height of this meteor and its photographed spectrum was 30·06 km with 6·5 km/s velocity, while the velocity at 60-km was 18·4 km/s. The dispersion of the spectrum is 56 Å/mm in the first order for most of the long trajectory. The end mass of the main body was computed dynamically to be about 600 g. Meteorites should have landed. The separation into about 10 fragments is visible during the last 20 km of the trajectory, and the stronger spectral lines of some of the fragments were recorded. Two types of wake are observable in this spectrum: (a) a gaseous one with much lower excitation than that of the head spectrum, (b) a particulate wake having no substantial difference in excitation from that of the head spectrum. The Si II lines 6347 and 6371 Å are observable down to 45-km height and 12 km/s velocity as extremely faint features in comparison with the rest of the spectrum. This spectrum is now being reduced, with another extremely good spectrum of a bright meteor flare and wake containing more than 600 individual spectral lines and many molecular bands in the visible region.

Most of the meteor spectra at the Ondřejov Observatory are complemented by the direct double-station photographic data, and thus accurate heights, velocities, and distances are available for each trajectory point.

Kresák (Astronomical Institute, Bratislava) continued photographic observations of meteor spectra at the Skalnaté Pleso Observatory.

Hirose photographed an infrared meteor spectrum at Dodaira Station of Tokyo Astronomical Observatory on January 4, 1968. The spectrum covers the range up to 8700 Å, and preliminary investigations reveal the existence of emission lines of O I, N I and Ca II in the infrared region. As the meteor was directly photographed at the other 5 stations, detailed analysis, including computation of its atmospheric path, is now going on. In the spring of 1968, the automatic meteor cameras at Dodaira station were converted into spectral cameras with gratings of 150 lines/mm.

Etheridge and Russell (University of Southern California, Los Angeles) made a preliminary comparison of the spectrum of a 1966 Leonid with the spectrum of a 1962 Leonid. Differences, if present at all, are far smaller than those between Leonid and Perseid spectra. Russell obtained 21 spectra; on one of these showing two Perseid spectra, the forbidden oxygen line at 5577 Å appears faintly in the fainter spectrum but not in the stronger. The H and K lines are absent from the spectrum showing the green line. This practically eliminates the possibility that changes in the atmosphere contribute to differences in the green-line strength. Systematic study of the green-line appearance in the 24 spectra obtained in 1969 is pending. In 1969 Russell photographed four Perseid meteors simultaneously with from two to four cameras with polaroids in front of the lenses.

Rajchl developed a model of the interaction zone ahead of the meteor body in the near-free-molecular and transitional flow. He considered ionization, excitation, and recombination within this zone. Among other advantages, this model helps to explain head echoes and the 5577 Å forbidden oxygen emission. The transition to the shock wave during the slip flow could explain the observed inverse proportionality between the Ca II emissions and the 5577 Å oxygen-line intensities.

Three meteor spectra were photographed at Krym Station of VAGO. Astapovič is preparing a list of all meteor spectra photographed in U.S.S.R. to 1967.

In connection with the SAO meteor project, Harvey (NASA Langley Research Center, Hampton, Virginia) is developing instrumentation for and performing studies of meteor spectra. The purpose is to improve understanding of the physics of meteors and to determine meteoroid composition. The program consists of a Meteor Spectral Patrol in Southwestern United States, laboratory simulation of meteoric radiation from impact flash and d.c.-arc tests, and absolute photometry. The Meteor Spectral Patrol is equipped with 14 spectrographs with a Maksutov optical system of $f/0{\cdot}83$ to $f/1{\cdot}3$. These instruments have photomultiplier-triggered shutters that open when meteoritic events occur in the field of view; the resolution is as high as 1 to 2 Å. In the past year the Meteor Spectral Patrol has detected over 250 meteor spectra ranging from 0 to -5 magnitude, of which about 50 have more than 50 lines. Preliminary conclusions are the following: (a) The luminous efficiencies obtained from one flow regime are not directly applicable to another flow regime, and the masses of bright optical meteors have tended to be overestimated. (b) The physics of meteors is significantly different for faint meteors as opposed to bright meteors, and this fact should be considered in the analysis of integrated-light data, particularly in analysis of flaring and fragmentation. (c) The present spectral classification does not apply to faint optical meteors.

Observations of the same meteor by the Havana radar (Southworth, SAO) and by a sensitive

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image-orthicon television system (McCrosky, SAO) have been successful for meteors as faint as $m_v = 7$. A limited discussion of the coincident data confirms that the ratio of ionization to luminosity has been overestimated by about an order of magnitude. Coincident radar and image-orthicon spectral observations are also being made with the same system.

Cook (SAO), Hemenway (Dudley Obs.), and Millman (NRC) are studying observations of the same meteors with the radar and spectrographs at Springhill, Ontario, and with the Dudley Observatory's image-orthicon spectroscope. The observations were made during the 1969 maximum of the Perseids and should guide the analysis of the results obtained at Havana.

Vybornyj (Krym Meteor Station of VAGO, U.S.S.R.) finished construction of a photoelectric device for meteor observations. He has begun to register meteors down to 6th magnitude within a 15 degree field of view. Astavin-Razumin (Kučino Station, U.S.S.R.) finished a photoelectric device to record meteors. The instrument was successfully tested in the laboratory and is now routinely operated for meteor observations.

Hoffman and Longmire (NASA Electronics Research Center, Cambridge) proposed that significant contributions to meteor ion spectra may result from a two-step ionization and excitation mechanism. The first step is the fast ionization of atmospheric molecules in collision with re-emitted molecules, while the second step consists of fast near-resonant charge-exchange collisions that excite the evaporated meteor atoms. Using a first-collision model, Hoffman has found qualitative agreement with meteor observations. He has derived an expression for the spectral luminous efficiency defined for particular spectral lines. The result is velocity independent and proportional to the square of the atmospheric density and the square of the meteoroid radius.

Longmire is studying collisions of Fe^+ ions with N_2 and O_2 by passing an ion beam through a gas target. Preliminary results show that the $3d^64p$ configuration of Fe^+ is readily excited by collisions at an ion velocity of 56 km/s. Decay of this configuration may produce several of the Fe II lines observed in meteor spectra. These lines are detected by ground-based observations, but excitation of their upper levels is indicated by emission of ultraviolet radiation for the same levels. An attempt will be made to determine the velocity dependence of the excitation and to measure the emission cross sections of several lines.

Rajchl has found that for electron densities greater than 10^{10} el./cm, dissociative recombination is more efficient for the ionization decay than the diffusion. He also points out a possible connection between the dissociative recombination of NO^+, O_2^+ and the origin of the infrared emissions. Using a gas-dynamic model, he is searching for the mechanism of energy transfer to excitation and ionization. A significant parameter here is the modified Knudsen number.

Flannery and Levy (Smithsonian Astrophysical Observatory) are engaged in theoretical studies of the excitation and ionization produced in collisions between slow, heavy particles and of electron-ion recombination. Particular reference is made to atoms and molecules of meteoric and atmospheric interests. Multistate and semi-empirical Born calculations are in progress.

Using a plasmatron with 10000 K, Bronšten (VAGO, Moscow) has made laboratory experiments on the ablation of meteorites. A periodical spraying of the melted surface by the incoming air was found to be the main ablation process for large meteoric bodies. Periodic pulsations of the melted surface film were also observed. This effect is qualitatively used to explain the observed meteor flares.

Givens and Page (NASA-Ames Research Center, California) have been performing simulated meteor experiments in a ballistic range, using stainless-steel spheres of 0·6-mm diameter. Observations are made with shadowgraphs, filtered photomultipliers, and spectrographs. Velocities have reached 8 km/s at a Knudsen number of 0·002 (continuum-flow regime). They determined the mass-loss rate and the luminous efficiency. Panchromatic luminous efficiency is 0·002 at 6 to 8 km/s, which compares with 0·01 at 11 km/s from the Trailblazer simulation experiments, and 0·005 at 20 to 40 km/s for laboratory micrometeor observations at TRW Systems. The ablation process is complex: melt from the forebody resolidifies as flanges, increasing the body frontal area, and subsequently breaks away erratically, ultimately to vaporize or decelerate in the wake. Maximum luminosity appears in the wake and extends 250–500 body diameters downstream. Atomic Fe and

Cr lines dominate the spectrum from 3000 Å to 4500 Å, while metallic-oxide bands appear above 4500 Å.

Friichtenicht and his colleagues (TRW Systems, Inc.) measured the luminosity, ionization, and spectra of iron particles accelerated to 20–40 km/s and interacting with air, argon, N_2, and some other gases. They found the luminous efficiency not dependent on velocity and roughly comparable to that from other laboratory and meteor estimates.

Ayer, McCrosky, and Shao are analyzing 10 artificial iron and nickel meteors launched into the atmosphere by rockets and by shaped-charge accelerators. Velocities from 8 to 16 km/s were achieved for "meteoroids" of about 1 g. The results for iron suggest little change from the previous value of $\tau = \tau_0 v$ ($\log \tau_0 = -18{\cdot}1$ cgs and 0 magnitude) obtained from an earlier experiment. The luminous efficiency of nickel is less well determined but is certainly lower than that of iron, perhaps by a factor of 3 at 10 km/s. McCrosky examined meteors with spectra consisting of Fe radiation, but without D lines of Na I. He concluded that they are possibly derived from a source other than that which produces iron-nickel meteorites.

RADAR METEORS

An analysis of radar meteors by Southworth (Smithsonian Astrophysical Observatory) shows that attenuation of Fresnel oscillations is often caused by fragmentation. This phenomenon is common among even the faintest radar meteors (10^9 electrons/cm). His study of 10000 radar meteors with from 5×10^9 to 3×10^{11} electrons/cm at the maxima of their ionization curves shows the following: (a) The heights of radar meteors are nearly independent of magnitude and similar to Super-Schmidt heights. (b) Manning's initial radii are much more nearly correct than Öpik's. (c) Rapid recombination of the electrons is very important for meteors below a limiting height. This limit rises with increasing electron density. Fresnel-pattern analyses confirm the recombination rate of N_2 and O_2. Recombination invalidates all previous estimates of the ratio of ionization to luminosity.

The meteoric program of the Upper Atmosphere Research Section, National Research Council of Canada is based in Ottawa, the observing station being the Springhill Meteor Observatory. The meteor patrol radar was operated continuously from October 1957 to January 1968. The reduction of 10 years of data is continuing, and results are appearing in a series of papers by Millman and McIntosh. Special studies using these records have also been made by Štohl and Šimek. Subjects being investigated include the mass-distribution index for meteoroids recorded by radar, the heights of radar echoes, the physics of the ionization of meteor trails, and the structure of specific meteor showers. In particular, a 12-year study of the Leonid shower is being carried out. Final corrected rates of meteor echoes are being determined for each hour of every day in the year. These are being compared with a large number of visual meteor observations made by teams during the period 1957–1968. Advanced planning has commenced to set up identical meteor radar patrols at Ottawa, Ontario, Canada and Newcastle, New South Wales, Australia (Ellyett and Keay). The data readout will be automated, utilizing online computers, and the whole program will be coordinated to provide a comparison of the rates in the northern and southern hemisphere.

Ellyett and Keay prepared a complete report on the radar meteor survey undertaken in New Zealand from 1963 to 1965, which has now been thoroughly examined; the complete rate data and major findings will appear soon in the Memoirs of the Royal Astronomical Society. Ellyett analyzed 2·5 million meteor echoes from New Zealand and another 15 million from Canada. He established conclusively that Lindblad's idea of an inverse relationship with sunspot number is correct.

Brown and Elford (University of Adelaide) have examined, theoretically, the growth and decay of the radio echo from an irregularly ionized trail. This work has shown that the rate of decay is strongly affected by wind shear, and that the shears known to occur at meteor heights acting on irregularly ionized trails are sufficient to explain the scatter in the observed diffusion coefficients at a given height.

Pupišev, Andrianov, Belkovič, Tochtasev, Kurganov (Radio Astronomy Laboratory, Kazan, U.S.S.R.) studied the problems of meteor radar selectivity as well as those of the systems for meteor observations by oblique scattering, taking into account the initial-radius effect. The nature of monthly variations in meteor-distribution parameters is being investigated. Systematic measurements of density distributions of sporadic-meteor incident fluxes over the celestial sphere for a number of years are carried out to obtain seasonal and secular variations.

The Meteor Physics Section of the Institute of Atmospheric Physics of the Italian National Research Council is developing, under the guidance of Verniani, a multistation radar system for studying meteors and the Earth's upper atmosphere. The project has three main purposes: (a) to determine systematically the temperature and density of the atmosphere as a function of height in the 70–100 km region, (b) to study the physical characteristics of meteors in the mass range $10^{-2} - 10^{-4}$ grams and to measure their flux, (c) to study the details of the interaction of meteors with the upper atmosphere.

At the Radioastronomy Laboratory in Kazan, Sidorov, Belkovič, Kostylev, and Michajlov have been investigating the problems of radiowave scattering by meteor trains of various densities as well as amplitude-phase reflection characteristics by mathematical modeling that takes into account ionization variation, the diffusion coefficient, and the initial radius along the meteor trajectory. Belkovič and Kurganov have developed a statistical theory of meteor radio reflections that considers various effects as completely as possible.

In the period 1967–1969 a new radar system for meteor-echo observations was designed and built at the Institute for the Research on Electromagnetic Waves of C.N.R., Florence, Italy (Ronchi-Abbozzo). The receiving system is completely automatized to detect and count echoes.

Plavcová (Ondřejov Observatory) has reduced recent observations of Geminids and derived the distribution of the particles with their mass. With the help of amateur groups, Plavcová, Šimek and Beránek are organizing simultaneous visual and radar observations. The meteor radar of the Ondřejov Observatory was recently expanded to three receiving stations to obtain the orbits of individual meteors. The new equipment is now tested. The first steps toward digital recording of all the radar data have been taken.

Hoppe (Jena, German Democratic Republic) started a program of simultaneous visual and radar observations in Jena. Some factors affecting the duration of radar-meteor echoes, in particular the dependence on the radiant position, were analyzed by Hajduk (Astronomical Institute, Bratislava). Jones (University of Western Ontario) investigated the meteoroid mass distribution both theoretically and experimentally, using forward/and back-scatter radars, and found a slight mass dependence of velocity necessary to reconcile radio and previous optical data. The mass-distribution index is found to be close to 1·7. A device to measure short-scale ionization fluctuations along radio meteor trains has been constructed, and projects for the photoelectric and image-orthicon observation of meteors are under way. Forsyth and Vogan (The University of Western Ontario) have measured absorption in the ionosphere (below the meteor levels), using three frequency measurements of radar meteor echoes.

Maanders (Eindhoven Technical University, The Netherlands) announced that a station has been built in a quiet place near Eindhoven; it operates at a frequency of 39·5 MHz with a pulse transmitter of 25 kw peak power. With this station the entire meteor activity is being observed. Třísková (Geophysical Institute, Prague) has suggested a model of radiant distribution that effectively characterizes the sporadic meteor activity.

PHYSICAL THEORY

When theoretical equations are applied to the meteor phenomena, one assumption is usually made: the air density is a known value given by some standard atmosphere. Recently, it became known that the air density for typical meteor heights can vary as much as 60% from the standard atmosphere in a very short time. This should be kept in mind as a serious source of errors when theory is applied to meteor observations.

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The existence of a large difference between the dynamic and the photometric masses of photographed meteors was also recently recognized for fireballs. This has led to many attempts at explanation. However, the sum of information available from meteor photographs, together with present knowledge of the physics of the meteor phenomena, is insufficient to determine uniquely the physical parameters that describe a meteoroid. The range of solutions consistent with the data heretofore available extends from low-density meteoroids of minimal structural integrity to meteoroids whose structure may be similar to that of some chondritic meteorites. The success of all these models rests on the introduction of a new variable in the classical equations. The variables – progressive fragmentation, frothing, or thermal shock – are not in themselves limited by any known parameter of the meteoroid, and thus sufficient leeway is provided to explain almost any of the observed phenomena of fainter meteors. However, the new data available for very bright fireballs seem to be more favorable to the low-density interpretation of a significant part of the faint-meteor data.

A review of the structure and fragmentation of meteoroids was written by Verniani in 1969. He attempts to examine all the present observational, theoretical, and laboratory data on the luminous and ionizing efficiencies of meteors, with the aim of establishing a mass scale. Equating the dynamic and the photometric masses, he finds the average bulk density to be 0·3 g/cm^3. He concludes that the paramount importance of progressive fragmentation, the behavior of abrupt-beginning meteors, and the low density of nearly all meteoroids (even of large ones) support the interpretation of a porous, fragile structure for most of these.

McCrosky and Ceplecha are investigating the effects of thermal and pressure stresses on meteorites in flight. For strong meteoritic stone, bodies with $R > 10$ cm are unlikely to fragment under thermally induced stresses, and those with $R < 50$ cm will not suffer from pressure fragmentation. They conclude that these effects cannot provide a general explanation for the apparent low density of most fireballs observed by the Prairie Network. The negligible terminal mass (ballistic) of most fireballs offers further evidence that these objects are distinct from meteorites.

Allen and Baldwin (NASA Ames Research Center, California) have worked out a frothing ablational model for Super-Schmidt meteors. They do not need the low-density fragile material to explain the faint meteor anomaly. At the same time, the computed luminous-efficiency factor is found to vary substantially with velocity: above 35 km/s, it is close to that recommended by Verniani, but below 25 km/s it increases to about six times greater.

Baldwin has been investigating faint-meteor ablation processes, using the data of Jacchia, Verniani, and Briggs. Factors contributing to apparent low meteoroid densities that have been considered are the following: production and accumulation of low-density froth during atmospheric flight; delay in light production due to the time required to slough off the froth and vaporize debris in the wake; and variations in meteoroid properties accompanied by differences in luminous efficiency. Recently, these meteors have been found to separate into classes when the ratio of photometric mass to ablation mass is plotted versus the heat of ablation. This classification corresponds roughly to that found by Ceplecha using a method based on beginning heights of luminosity and on the ratio of photometric mass to dynamic mass.

Padevět (Ondřejov Observatory) computed several ablation models in an attempt to explain the difference between dynamic mass and photometric mass on the assumption that the main body loses material in the form of small equidimensional particles continuously fragmented from the surface and exposed to the action of undisturbed atmosphere. However, the results were not satisfying, and he is now developing a more complex model that takes into account the interaction of the flow field behind the main body with the fragmented particles.

Simonenko studies theoretically the behavior of small particles separated from a meteor body after the beginning of intensive evaporation. She constructed light curves for different types of fragmentation, using special nomograms. Analyzing then the meteor light curves observed, she concluded that one of the principal mechanisms of fragmentation of meteor bodies is a separation from the parent body of particles of the order of 150μ in size. The particles appear to be solid, and Simonenko suggests they are structural elements of meteor bodies.

Cook (Smithsonian Astrophysical Observatory) is isolating the Super-Schmidt meteors that behave in accordance with classical theory both in their trajectories and in their light curves. As a class, these show a rather small dispersion in the two constants (one in the deceleration equation, the other in the ablation equation) required to fit the theory.

Kostylev, Tochtaseev, and Aminov investigated meteor-particle flight regimes and ablation by mathematical modelling based on assumptions concerning the structure and physical properties of the particles. Various ionization mechanisms for different interaction energies, as well as the effect of meteor velocity on the ionization coefficient, were studied. Hoppe (Jena) successfully applied his fragmentation theory to a meteor of -5 magnitude splitting into 3 pieces observed at 55 km height.

METEOR ORBITS AND SHOWERS

Anders (Enrico Fermi Institute, Chicago) made more Monte Carlo calculations of meteorite orbits. It seems that approaches to Jupiter cause many difficulties, particularly for orbits of the Příbram type. Sometimes such orbits even become retrograde. A solution of this problem is urgently needed.

At the Astronomical Institute of the Slovak Academy of Sciences, Bratislava, problems of the cometary and the asteroidal origin of short-period meteors were investigated. Kresák applied orbital criteria to distinguish between the two types of meteors, and he compared the distribution of meteor orbits with those of the comets and asteroids and established differences in the observed physical characteristics of meteors moving in orbits of different type. Štohl investigated the connection between the distribution of sporadic-meteor orbits and the annual variation of meteor rates, using simplified models of radiant distribution. The differences between the orbits of extremely bright fireballs and those of ordinary meteors were shown by Kresák to be essentially due to selection effects previously unaccounted for. The reality of hyperbolic meteor orbits was critically examined by Štohl, who found that even the perturbation origin within the solar system is unsound.

Andrianov (Kazan) measured radiants and meteor velocities by oblique scattering. Methods of determining meteor-orbit parameters are being worked out and the problems of measurement accuracy and selectivity are being examined. The singularities of element distributions in high-velocity meteor orbits are being studied.

Sekanina (Smithsonian Astrophysical Observatory) has developed a new method for analyzing the dynamical properties of meteor streams. It is based on the Southworth-Hawkins D-criterion of the similarity of two orbits in terms of the differences in their Keplerian elements, but the statistical rather than the determinate concept is accepted for the definition of a stream. The method emphasizes the significance of the character of the D-distribution of meteors with respect to the mean orbit of a stream. The empirical D-distribution for each stream is assumed to consist of an intrinsic Maxwellian D-distribution of the stream and of a contaminating sporadic background. Model calculations suggest that the D-dispersion increases in value secularly as a result of planetary perturbations. A relation between the mean age of a stream and its D-dispersion is likely. Several new meteor showers have been discovered by his search program among the Radio Meteor Project collection of orbits. In particular, meteor streams associated with the minor planets Icarus, Adonis, Hermes, Apollo, and 1968 AA have been detected. In addition, some meteors of the sample have orbits resembling those of comets not previously associated with major streams.

Lindblad (Lund Observatory, Sweden) applied Southworth's D-criterion program to all published photographic orbits of meteors, including those graphically reduced by McCrosky and Posen. He found 43% of all meteors to occur in streams, many of them previously identified. He also found many new streams: 12 correspond to previously identified visual streams of Denning or McIntosh.

The investigation of the internal structure of meteor streams by Porubčan (Astronomical Institute, Bratislava) showed that in permanent showers no condensations up to the dimensions of about 10^3 km and no meteor twins are present. A filamentary structure of the meteor stream formed by Comet Halley was suggested by Hajduk (Astr. Inst., Bratislava) as an explanation of long-term semiregular variations of meteor rates and peculiar changes in the annual curve of activity during the past 50 years. Some features appearing in a stream structure as a consequence of its evolution were pointed out by Kresák. Work on this problem, based on the dispersion of shower radiants, is in progress. New methods to distinguish dispersed showers from the sporadic background were designed both for the photographic and the radio-echo observations by Porubčan and Hajduk.

Guth (Ondřejov Observatory) computed perturbations of Jupiter on a meteoric stream uniformly distributed along an orbit with half the period of revolution of Jupiter, with aphelion beyond Jupiter's orbit, and with an inclination of 19°. This was the case for the meteor stream of Comet Pons-Winnecke 1915 to 1927. Strong perturbations in all elements are the reason for the non-stability of such a stream, which is dispersed during the very short time of two revolutions.

VAGO, U.S.S.R., organized a special expedition to the Arctic region for observation of the possibly abundant return of the Leonids in 1967. The results showed that the Leonids in 1967 did not exceed 8 meteors per hour. Leonids 1967 were also observed by radar in Frunze, U.S.S.R.

Lindblad continued systematic simultaneous observations of Perseids with radar and with a team of visual observers. He now has 17 years of Perseid observations by the same radar and the same visual group.

Alpha Lyrids were observed visually by VAGO members at Semachinsk Astrophysical Observatory, U.S.S.R., in 1969. About 4000 meteors were recorded, and their radiants determined. Telescopic observations of this stream were also made.

Skrivanek (Air Force Research Laboratories) investigated the Perseid meteor stream during August 1968. Four high-altitude particle-collection rockets were launched before, during, and after the visual peak of the shower. Preliminary results do not indicate any difference between data from rockets flown before and those during the peak of the shower.

Znojil (Brno Observatory) studied the structure of meteor streams, mainly Perseids and Cassiopeids, in the interval of 6–8 m, using recent observations of about 7000 telescopic meteors.

VISUAL OBSERVATIONS

Olivier (American Meteor Society, Philadelphia) is preparing a third daily-hourly rate catalog for naked-eye meteors, to supplement the two already published by him in the *Smithsonian Contributions to Astrophysics*. He is also preparing a paper on telescopic meteors reported from 1950 to 1969 to American Meteor Society.

In recent years, many meteor observations have been obtained in Japan. More than one hundred visual observers are active, and nearly 30000 visual meteors are observed every year.

Visual observations were made at Krym Meteor Station of VAGO with use of a method of calibrated counting. During a 3-yr period, they observed about 12000 meteors, which are now being reduced.

Šulc (Brno Observatory) is studying the errors in the treatment of visual meteor observations by the independent counting method. He uses optically simulated meteors, together with an independent counting method modified by Kvíz. He found that the necessity for observer independence in the group is well satisfied and that the source of error is mainly due to the appearance of meteors in different parts of the field of view, combined with the "straight-line shape" of the phenomenon.

Kresáková (Astronomical Institute, Bratislava) has investigated the angular velocities of meteors and combined them with the results of telescopic meteor observations. She points out that the velocity effect on the visibility and apparent magnitude of meteors is weaker than that accepted by the authors using results from experiments with optically simulated meteors, mainly because the latter method does not account for the occurrence of wakes and trains.

Hajduková (Komenský University, Bratislava) used visual observations of meteors through color filters to obtain information on the color indices of ordinary meteors too faint for photographic spectra to be obtained.

ZDENĚK CEPLECHA
President of the Commission

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