SESSION 9

49. METEOR PHYSICS

(Round-Table Discussion and Summary)

Chairman: I. HALLIDAY
(Dominion Observatory, Ottawa, Canada)

Halliday: We are now approaching the end of a busy week – one which has been both scientifically profitable and completely enjoyable for us all. I have been asked to make some comments in the form of a brief summary of our discussions during the first half of the symposium, covering the field of meteor physics. So many topics were presented that my summary must necessarily be incomplete, but I hope it may serve to introduce some further exchange of ideas this morning.

Our basic techniques of observation are generally either optical, such as visual, photographic or spectrographic; or else one of several methods of using meteoric ionization to yield radar records. Even a brief examination of our discussions shows that the theoretical aspects of meteor phenomena are also receiving great attention at present. It seems to me that less time was spent in considering instrumental developments than at some previous meetings. We were, of course, pleased to note the expansion of meteor instrumentation in Japan. The results from the instantaneous-photograph technique employed in the U.S.S.R. are of great interest already and promise even more for the future. Perhaps we are now fully occupied in an attempt to digest the wealth of observational data which has been obtained in recent years, but I hope we can have some discussion today on plans or ideas for new observational techniques. For example, can we realistically hope to observe meteors from orbiting spacecraft to check, among other things, the possible relationship between radiation in the far ultraviolet and radar head echoes?

The ability of the radar method to accumulate large quantities of observations in a relatively short time continues to impress the optical meteor astronomer. It is attractive to employ the radar data for many statistical investigations and we have seen how the echo durations, amplitudes, and range-time distributions may be used to infer physical properties of the meteoroids, certain of their orbital characteristics, and the probable nature of upper-atmosphere reactions involving electrons and ions. The anomalous increase in the frequency of radar echoes observed by several groups in 1963 was of particular interest but a single explanation is not yet acceptable to all. The radar method has its problems, of course, including a wide variety of selection effects depending on factors such as meteor velocity, electron line density, initial trail width, radiant elevation and certain instrumental parameters.

The data from the Harvard Super-Schmidt program on photographic meteors is

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still being applied to many problems, some of them dynamical in nature, and others which involve grouping meteors according to their physical properties. For bright photographic meteors much additional insight can be obtained from their spectra. Descriptions of meteor spectra this week have included normal members of meteor showers, iron meteoroids, and objects which must be classified as peculiar. The presence of molecular bands in meteor spectra is now receiving careful study assisted by an improved knowledge of the spectra of other atmospheric phenomena including rocket re-entries. Much remains to be done in the quantitative analysis of spectral line intensities but steady progress is evident.

It has been said that whereas Freudian psychologists interpret all unsolved problems in terms of sex, and whereas astrophysicists attribute their unsolved problems to magnetic fields, the meteor physicist explains his unsolved problems in terms of fragmentation. I am not prepared to say to what extent any of these approaches may be justified, but perhaps our symposium should be considered competent to discuss the validity of the third approach. Fragmentation has been observed in direct meteor photographs for many years and has been considered this week in at least seven papers dealing with observational and theoretical problems of meteor wakes as applied to both radio and optical observations.

One of our survey speakers concluded that we were still a long way from possessing a thorough and satisfactory theory to explain adequately the physics of the meteor phenomenon. When we stop to consider all the complexities of the entry at high speed of a solid object of unknown composition into a medium itself as complex as the upper atmosphere, it would indeed be surprising if we had solved the entire problem. Our observations, after all, are limited to the detection of the small fraction of the meteoroid's energy which is used for ionization or luminosity. Nevertheless, it must have been evident to us all that much progress has been made. Basic theories of meteoric ionization are sufficiently advanced that attention is now devoted to details such as the effects of the geomagnetic field on diffusion rates. The predictions from theoretical studies of meteor ablation are certainly in much better agreement with observation than they were a decade ago.

In addition to reporting on results already obtained, several of our speakers have indicated the direction in which they suggest further research should proceed. One question which came up several times during the week was whether there is some basic size of small particle, some building block, from which meteoroids are constructed. Perhaps this will be one of the problems to be answered at the time of our next symposium. Wherever that meeting may be held I am sure we agree that it will be almost impossible to surpass the grandeur of the setting or the warmth of the hospitality we have enjoyed this week at Tatranská Lomnica.

Kaiser: I wish to report that at the conclusion of yesterday's formal session, an informal meeting was held to discuss the problem of digitizing radar meteor data. The Harvard groups already have considerable experience in this field, and others, notably in Canada, Australia, the U.S.S.R. and the U.K. have plans in hand. Although our discussions revealed that there are some difficult problems to be solved, I hope that by the time of the next meteor symposium we will have important new results which will only be available when we are able to process automatically the large amount of data which is potentially available from the radar technique.

Elford: May I add that we also agreed to set up a small circulation list for those interested in new radio- and data-handling techniques. Any group who wishes to be on this list can hand their address to me.

Halliday: It would be interesting now to hear of the plans which various groups have for future experiments.

Southworth: The digitizer for 8-station recording has been operating for a year and a half. We are just finishing the computer program for reducing digitized data.

A new real-time computer invented for the project by Dr. Mario Schaffner can be programmed with one punched card. Present plans for its use include observations of head echoes, of very brief echoes, and of very faint echoes, which will be resolved from the cosmic noise by integrating successive pulse returns.

McIntosh: In conjunction with Ellyett and Keay in Australia we hope to establish identical radar equipments at approximately the same latitude in the Northern and Southern hemispheres. The equipments will employ automatic digital processing of the meteor data. Long-term variations in meteor rates will be studied. Also, information on radiant distribution and mass distribution will be obtained and analysed.

Babadžanov: We plan a future development of the method of instantaneous exposure for the study of meteor physics, and particularly the use of this method for meteor spectrography.

Ceplecha: We plan to use $f=750$ mm cameras 1:6·3 with instantaneous exposure, some of them with gratings. There will be more than 40 cameras and we hope these will be in action by 1970. This program will yield data on very bright meteors only.

Kresák: At the Skalnaté Pleso Observatory we intend to improve the techniques of photographing meteor spectra, but no original instrumentation is anticipated.

Millman: We hope in the future to investigate, at the National Research Council in Ottawa, new applications of such techniques as photo-electric recording outside the visible range of wavelength, image converter recording and the use of closed-circuit television systems.

Hemenway: During the first Harvard conference on meteors we showed some image orthicon pictures of meteors using borrowed equipment. Recently we have been able to purchase such equipment and plan to attempt time resolved studies (30 pictures/sec) of meteor spectra using video tape recording.

Whipple: At SAO we plan to use image-tubes for optical images simultaneously with the radar, possibly to 9th magnitude.

Sidorov: Further work at the Radio Astronomical Laboratory of Kazan State University will be concentrated in two programs. The first one is the continuation of investigations of individual radiants and velocities of fast meteors by the forward-scattering method. The main problem is digitizing the observations, since we have experienced considerable trouble in their analysis.

The second is the determination of the radiant-density distribution over the celestial sphere using a radar with a rotating aerial. It is desirable to carry out a similar project South of the equator.

Nazarova: We plan to investigate interplanetary dust, not only by means of acoustical detectors but also by other types, to obtain the space density of particles, their velocity, mass and direction of motion. My personal plans include an attempt to collect meteoric dust by means of satellites and rockets.

Kaiser: I think we should ask our colleagues working with rockets to study cosmic dust particles by impact collection techniques to acquaint themselves with the problems of ablation theory which have been discussed at our meetings. In this way we may obtain evidence about the physical processes of meteor flight through the atmosphere.

Hemenway: Many countries are beginning or have begun high-altitude dust collection programs with balloons and rockets: Sweden, Germany, U.S.S.R., U.S.A., Canada, Japan, and others. Three recoverable micrometeorite-impact experiments are planned during the Apollo program and guest experiment or space may be available.

We hope that some of the problems of dust collection and detection, identification and analysis can be resolved with the help of the COSPAR cosmic dust panel.

Millman: At the National Research Council in Ottawa we have a long-range program for the study of micrometeorite detecting and collecting techniques, making use of the Canadian Black Brant rockets fired from the Churchill Rocket Range, Manitoba. We will welcome suggestions for the exchange of small equipments for placing on our own rockets and on the rockets fired by groups in other countries.

Lindblad: In Europe several research groups are currently engaged in rocket studies of micrometeorite dust by acoustical, collecting and light-scattering techniques. The three groups engaged, the Lund Observatory, the Max Planck Institut für Kernphysik, and the Meteorological Institute, Stockholm, all strongly feel that these experiments should be performed simultaneously, so that detailed intercomparison of the fluxes may be carried out. The rockets will be launched from the Kiruna rocket range of the European Space Research Organisation.

Bronšten: I want to call your attention not only to the difficulties associated with cosmic dust sampling by means of rockets and satellites, but also to the necessity of good theory covering such experiments. We cannot go directly from the number of particles collected to the real space density of these particles in the free atmosphere. This comment could be applied, e.g., to the joint American-Swedish experiments in 1963 for collecting particles from noctilucent clouds and meteors by means of rockets at heights of 70–90 km.

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Hemenway: With respect to Dr. Bronšten's comment, we plan to utilize high-velocity wind tunnels with particle injection to measure rocket particle-collector efficiencies as a function of appropriate parameters.

Whipple: The old problem of collecting dust from fireballs or meteorite falls is extremely difficult but could be valuable if anyone has the strength and courage to organize such a collection program on a large scale.

Elford: There is one other technique mentioned during the conference that I would like to comment on. This is the use of pulsed lasers for studying dust concentration in the upper atmosphere. At the present time the results are conflicting. At Adelaide we are about to commence this type of observation and intend to integrate the returned echoes over small-range intervals in order to improve the statistics.

Southworth: It would be very useful to separate the laser from the detector, so as to find the height of the scattering material by triangulation.

Elford: This is a difficult experiment since the laser beam has a very small angular width and both transmitting and receiving equipments have to be directed with considerable precision.

Kaiser: Does not the pulsed laser technique solve the problem of height determination?

Southworth: The problem is whether there may not be an atmospheric process involving a finite time in responding. In that case, the height derived from the delay of the return would be greater than the real height.

Levin: The papers on the physical theory of meteors presented at this Symposium show that during recent years main attention has been directed to the use of computers to improve the physical theory by taking into account processes of secondary importance, and to consider size-intervals of meteor bodies in which two processes are of comparable importance and therefore an analytical solution is difficult or impossible. In all these calculations compact meteor bodies are considered. It seems to me to be very important to develop the physical theory for very porous froth-like bodies and for bodies of extremely irregular shape like branchy corals or moss.

I regard the process of fragmentation of meteor bodies as even more important than is recognized now. Therefore further studies of this process seem to be necessary. It is impossible to predict the course of fragmentation for an individual meteor particle but statistical regularities of the fragmentation process must exist and they should be studied. These statistical regularities are probably somewhat different for different meteor streams and also probably vary with the mass of meteor particles. Therefore fragmentation must be carefully taken into account when the mass-distribution exponent '*s*' is determined from visual or radar observations.

At the present time the best data on the mass distribution of ordinary meteors are probably those based on photometric masses of photographic meteors (or meteors observed photo-electrically). Serious complications with the luminosity coefficient discussed in the survey paper by Ceplecha are important for fireballs brighter than about −5th magnitude while for fainter meteors the photometric masses are sufficiently reliable.

The development of the physical theory of fireballs is also important. The fireballs penetrate into denser layers of the atmosphere and therefore for them the free molecular flow is replaced by the formation of a shock wave. Some first steps in the development of this theory were made by Bronšten but further studies are very desirable.

Belkovič: At Kazan University we have obtained the mass law exponent from photo-electric observations, measuring areas under light-time curves. In this case we do not depend on the shape of the light-time curve. The resulting value of $s = 2{\cdot}5$ is close to the one obtained from radar observations.

Lebedinec: In a paper presented at the COSPAR meeting in Vienna, 1966, we have shown that, in the case of spherical symmetry of the meteoroids, meteors of 0^m–5^m cannot lose their mass by evaporation only. They should melt throughout and fragment. Now we have demonstrated that, due to the flow of the melted layer, the duration of the complete ablation of such particles is essentially independent of their rotation. Thus the observed fragmentation of meteors of 0^m–4^m may be explained for solid particles of higher density as well as for the dustballs. Further investigation of the fragmentation process is of primary importance.

Ceplecha: In my paper (1966, *Bull. astr. Inst. Csl.*, **17**, 347) I showed that the conventional luminous equation is not valid, and that the 'photometric masses' are as bad as the 'dynamic masses', if we deal with all the Super-Schmidt meteors as one statistical group.

Bronšten: The theory of Dr. Lebedinec may be very good, but every theory, especially for such a complicated problem, must be verified by an experiment.

Hajduk: Concerning the determination of the mass distribution function, we have heard of the difficulties in using echo durations only. Now we are trying to use both durations and amplitudes. It seems that this could be the right way to proceed because of the different dependence of both durations and amplitudes on the atmospheric height.

Belkovič: It is always difficult to obtain the mass-law exponent value s from the distribution of long-duration echoes because of wind distortion. I think the best method is that which is based on amplitude distributions, taking into account the initial radius effect.

Halliday: We have had many references to the Poynting-Robertson effect. Now we may recall that two years ago at the symposium in Cambridge Dr. Shapiro emphasized that the very existence of this effect was based on the assumption that the particles were spherical. Are there further comments on this assumption?

Levin: I should like to remind you that Dr. Radzievskij pointed out that for non-spherical particles or for big bodies the effect of radiation will increase the speed of rotation. Hence it may also affect the rate of fragmentation.

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Whipple: I also urge theoretical studies of rotation of meteoroids by solar radiation and solar wind. Furthermore there are important electromagnetic effects on very small particles that require more theoretical studies.

Levin: Different groups have obtained different distributions of radio meteor orbits. It is obviously due to different ways of correcting for the selectivity of the radio observations. I would like to ask whether we can hope that in the near future these discrepancies will be eliminated.

Southworth: The problem seems to me to be physical – an insufficient knowledge of the meteor's interaction with the atmosphere. I do not yet know how the corrections should be made.

Elford: I would like to direct a question to Dr. Southworth concerning the rate of decay of radar echoes. A number of workers use the decay rate of underdense echoes to infer the height of the reflection point. I understand that Dr. Southworth measures the rate of decay of echoes from several points on the one meteor trail and I wonder whether he would comment on his observations.

Southworth: The Smithsonian project has a large number of meteors with decay rates observed at several points on the trajectory. The differences in height between these points are accurately known, so that it ought to be possible to derive the atmospheric scale height, but the scale heights so found show an extreme scatter. It is clear that heights above sea-level derived from single decay rates would have an uncertainty of at least several kilometers.

A sufficient explanation is to be found in wind shears. These shift the principal Fresnel zone to a different part of the trajectory, which normally had a different initial number of electrons. Thus the observed decay rate contains the effects of irregularities in line-density as well as diffusion.