V. Fedynsky

Meteors

V. FEDYNSKY

METEORS

FOREIGN LANGUAGES PUBLISHING HOUSE
Moscow 1959

TRANSLATED FROM THE RUSSIAN
by G. YANKOVSKY

DESIGNED BY G. DAUMAN

CONTENTS

INTRODUCTION

On a dark cloudless night one may often see a point flame up and flash through the constellations like a "fallen" star. This is a meteor, from the Greek words *meta*, beyond, and *aiora*, hovering in the air. Formerly, meteors were often called shooting stars or falling stars but now these terms are hardly ever encountered in scientific writings for the reason that there is nothing at all in common between real stars—distant suns—and meteors that flame through the earth's atmosphere.

Meteors flare up as a result of small solid cosmic particles, meteoroids, colliding with the earth at a high relative speed between 10 and 70 km./sec. These particles dash into the upper layers of the atmosphere, heat up, and end in a terminal flare as they disintegrate (Fig. 1). The faster the particle moves and the greater its mass, the brighter is the meteor. Ordinarily, meteors glow at heights of 120 to 80 kilometres above sea level, though large particles may penetrate to lower-lying levels of the atmosphere. Very bright meteors that surpass Venus in brightness are called fireballs or bolides (from the Greek *bolis*, missile). Fireballs penetrate the atmosphere down to 50-55 kilometres, entering the denser layers of air. Here they produce waves of compression and rarefaction and are therefore accompanied by sound phenomena that at times are very powerful.

The sudden appearance of a fireball, its brilliant light, thunder-like claps that attend the flight, and, finally, the huge smoke-like clouds of dust that remain for hours in the sky as the fragmentation products of the cosmic body, even in our day create a lasting impression on those that witness the spectacle. We can easily imagine how mysterious and terrifying to our forefathers were these fireballs which were given such names as "fire snakes," "dragons," and the like.

The largest meteoric bodies that produce fireballs fall to earth as stony and iron fragments. These fragments are called meteorites. Studies of the structure and chemical composition of meteorites provide us with exceedingly important information concerning the nature of matter in the solar system.

Summarizing, we may say that a *meteoroid* (or meteoric body) is a fragment of solid cosmic matter that collides with the earth; the word *meteor* is used to designate both the phenomenon (light) observed in the terrestrial atmosphere when a meteoroid enters it and also the particle itself, while the term *meteorite* is reserved for meteoric bodies that reach the earth. This terminology has meaning as long as we regard meteoroids in their interaction with the earth; however, when we study meteoroids in cosmic space, there is no necessity to use all these terms that define only the interaction of these bodies with the earth at times of collision. Here I shall follow the practice established in scientific literature and call meteoroids in cosmic space simply *meteors* when it is not necessary to specify this concept.

On certain days of the year we observe a phenomenon known as *meteor showers*—a large number of meteors emerging from a single part of the sky. Meteor showers usually get their names from the constellation from which they appear to be emanating.

The study of meteorites that fall to earth, and of meteors that end their existence in the atmosphere is of great importance to modern science. The huge cloud of meteoric matter that surrounds the sun is composed of a whole range

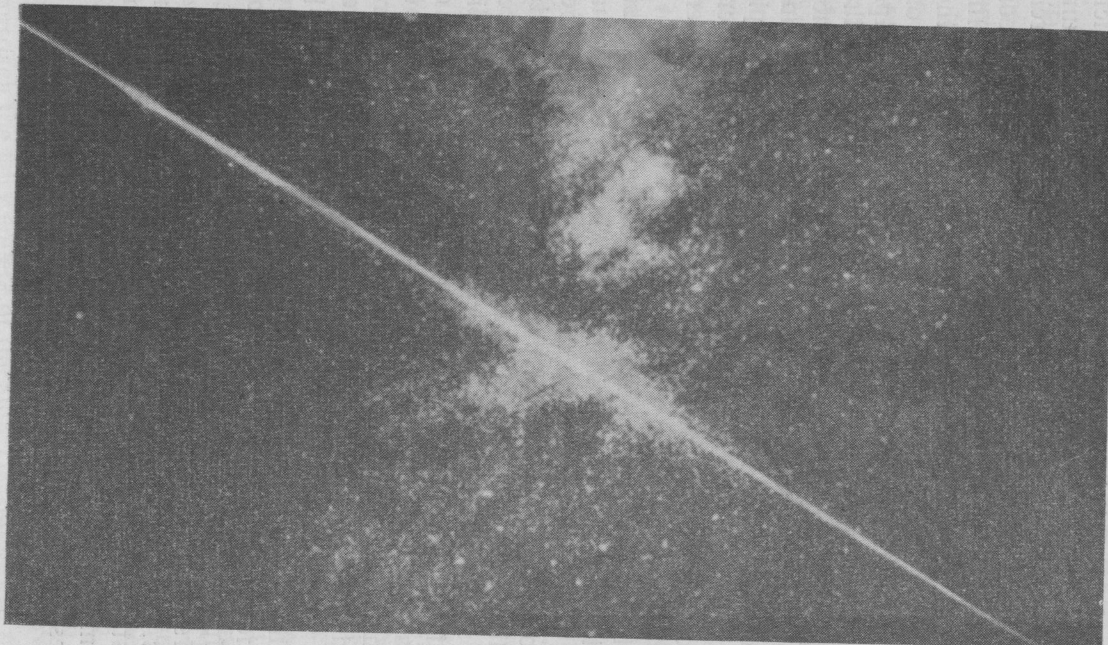

Fig. 1. A bright meteor surrounded by a column of ionized gas

of sizes from huge meteoritic chunks of material to minute meteoric dust particles. This cloud is the medium in which the earth continually moves. It is through this medium that artificial earth satellites and high-altitude research rockets hurtle. And the time is not far off when the meteor cloud will be pierced by the first interplanetary ships. Information about the structure, and the history of the development of this meteor cloud throws light on the past and future of the solar system, it helps us to understand the origin and development of the planets, including the earth we live on. Thus, the science of meteors, or meteor astronomy, is of both scientific and educational interest. This explains the birth and rapid growth of meteor astronomy as a separate branch of scientific knowledge in the nineteenth and especially the twentieth centuries.

A little over 30 years has passed since geophysicists began to take an interest in meteors. It turned out that meteor studies yield very important facts about the upper layers of the atmosphere, the physical state of these strata, about air currents at high altitudes, and the tides produced by the moon and the sun in our terrestrial ocean of air. This information is not only of theoretical interest but of practical value too. At present, high-altitude rockets move through those layers of the atmosphere that are most frequented by meteors. The recently launched artificial satellites of the earth and the future interplanetary rocket ships that will pass through the stratosphere out into space are concerned with meteors too. Engineers designing cosmic ships will have to see that they are protected from encounters with meteors.

Thus, at present meteors are the object of attention and close study of astronomers, geophysicists, and engineers. The aim of this booklet is to give the reader some idea of the present state of the science of meteors.

1. THE SCIENCE OF METEORS—AN HISTORICAL SURVEY

Meteors have been known to man since ancient times. The first documentary records of meteors were found on an ancient Egyptian papyrus written at about 2000 B. C. It is now preserved in the Leningrad Hermitage. The legends and tales of many peoples reflect the primitive views and beliefs connected with the unheralded apparition of fireballs, the flight of meteors and the falling of "stones from the sky." A Greek myth tells how Phaethon stole the fiery horses of his father Helios (the Sun), drove the flaming chariot across the sky and then fell to earth in the form of a huge stone. Actually, this is a poetical narrative of the flight of a huge fireball that ended in the fall of a meteorite. The myth about Phaethon has much in common with the legends of the North American Indians who in far-off times had witnessed the falling of a gigantic meteorite in the Arizona desert and had passed on from generation to generation the legend of the fire god come to earth. In Arabian legends, the Arabian Nights, we find shooting stars mentioned as darts of fire which the angels hurl at demons. Showers of stars are first mentioned in Chinese annals as early as 1768 B. C., and since that time they appear in the numerous annals of China, Korea, Ancient Russia (Rus), and the countries of Western Europe.

Diogenes of Apollonia, a Greek philosopher of the fourth century B.C., first correctly surmised that meteors are cosmic bodies and that they are "invisible stars that fall to earth and die out like the fiery stony star that fell near the Egos-Potamos River." True, this opinion did not become generally accepted. Together with Aristotle, the majority of the ancient, and later the mediaeval, philosophers and men of learning considered meteors to be a purely atmospheric phenomenon that arises during the ignition of terrestrial emanations when the latter move upwards and approach the fiery sphere of the sun. The huge rock near the

Egos-Potamos River, which was probably actually a meteorite, Aristotle considered to be a stone of terrestrial origin.

The Chinese annals of the ninth-eleventh centuries A. D. report observations of meteors in rather considerable detail. In modern times, these annals were first subjected to scientific analysis by the Soviet astronomer I. Astapovich. It was learned that nearly a thousand years ago many of the now active meteor showers were observed, but since then some streams have vanished entirely. In the old Russian annals, a fireball is first mentioned in the year 1091. In 1202 there is mention of the magnificent Leonid meteor shower. Russian annals give a rather detailed description of the stony shower of June 25, 1290, near the town of Ustyug Veliky. The falling of meteorites that day was attended by a huge and extremely brilliant fireball, by loud reports and quaking of the earth. The woods in the region of Kotovalov Ves suffered greatly from the flight of the fireball and the falling of stony fragments. On May 19, 1421, from Novgorod Veliky came reports of a bright fireball accompanied by powerful sound phenomena and the falling of a swarm of stony meteorites. And these are not the only records.

Despite the gradual accumulation of such facts, for nearly two thousand years men's views on meteoric phenomena did not undergo any essential changes. Following a centuries-long period of stagnation in the development of astronomy meteors were again brought to the forefront of attention at the end of the seventeenth century. In England, in 1686, Halley computed the trajectory of a bright fireball and advanced the view that this phenomenon was caused by a meteoric body of cosmic origin.

In Russia, observations of meteors (and other atmospheric phenomena too) were begun in St. Petersburg by I. Gmelin, G. Kraft, A. Tatishchev in 1734.

The end of the eighteenth century may be regarded as the beginning of meteor astronomy. In 1794, E. Khladny, Corresponding Member of the St. Petersburg Academy of

Sciences, demonstrated convincingly that meteorites fall to earth from interplanetary space. In 1798, two German students, Brandes and Benzenberg, were the first to determine the heights of meteors on the basis of simultaneous observations from two distant points. During his trip to South America in 1799, Humboldt observed a shower of the Leonid meteor stream and from talks with old-timers among the Indians he learned that such showers of "stars" had been observed in 1733 and 1766. From this he deduced a periodicity of 33 years for the Leonids. In 1832, the eastern hemisphere saw a splendid Leonid meteor shower, and in 1833, a beautiful display was observed in the western hemisphere. In 1832, a self-taught astronomer from Kursk, F. Semyonov, observed the Leonids and discovered the phenomenon of radiation of meteors, which is due to the apparent divergence (in perspective) of their paths, though in reality they are parallel in space. He also expressed the view that meteors might be connected with comets. In 1833, independently of Semyonov, the radiation of meteors was discovered by many observers in Western Europe and North America.

The meteor showers of 1799 and 1832-33 evoked great interest in scientific circles and made the French astronomers Arago and Biot take up the study of Chinese, Korean, and Japanese annals. It was found that the Leonid meteor shower had been observed for more than 3,500 years at periods of 33 years. The orbit of the Leonid swarm in the solar system was computed, and it appeared to be similar to the orbits of some of the big comets. However, proof of the intimate relationship between comets and meteors was to come much later.

In Russia, the first systematic observations of meteors were begun in 1852 by Shveitser at the Astronomical Observatory of the Moscow University, and later by Gusev in Vilno. In 1862, Bredikhin, in a paper entitled "On Cometary Tails," summarized the results of Russian and foreign observations of comets and meteors and expressed the view that meteor streams might be ejected from comets. In 1865-66, mass-scale routine observations of meteors were begun in England by Denning, in Italy by Schiaparelli, in the U.S.A. by Newton, and in other countries. This heightened interest in meteors during these years was due to the expected return of the Leonid shower.

The Leonids did not disappoint astronomers and in 1866-68 produced a marvellous display. In 1866, Schiaparelli established a genetic connection between the Leonid and Perseid meteor streams and comets and hypothesized the disintegration of comets under the action of solar attraction. Meanwhile, Bredikhin was developing his own ideas and by 1881 had completed a theory of the ejection of meteoric particles from cometary nuclei. The ideas developed by Schiaparelli and Bredikhin are to this day the basis of all studies dealing with interrelations between comets and meteor streams.

In 1882, Kleiber wrote the first Russian monograph on meteors published two years later in St. Petersburg.

At the end of the nineteenth century up-to-date astrophysical methods began to be used in meteor studies. The first photograph of a meteor was obtained in Prague in 1885. In 1893, Elkin at the Yale Observatory in the U. S. A. and, independently, Sternberg at the Moscow University Astronomical Observatory, applied a rotating shutter to determine the angular velocity of meteors. Much later, in the 1930's, this method of determining meteor velocities found wide application and is still used. In 1901, Sikora in Tashkent was the first in Russia to organize systematic photography of meteors. In 1904, Blazhko obtained the first spectrogram of a meteor at the Moscow University Astronomical Observatory.

Beginning with the 1920's interest in meteors greatly increased in connection with studies of the upper layers of the atmosphere. This period coincides with the rapid development of Soviet meteor astronomy. During the past thirty odd years Soviet science has made great strides in meteor research. The first collective efforts of Soviet astronomy amateurs in meteor studies got under way in 1921. This work has been going on successfully to the present day. In 1925, Astapovich worked out an extensive programme of meteor studies and began routine observations. This remarkable series of observations covered a period of over 25 years and, together with a similar series of observations carried out by Maltsev, Sytinskaya and other Soviet observers, as well as those of Denning (England) and Hoffmeister (Germany), represents an extremely valuable contribution to our knowledge of the nature of meteors.

In the U.S.S.R., from 1925 on, a number of special expeditions for meteor studies were sent to the southern part of the country (the Caucasus and Central Asia) where climatic conditions are favourable for obtaining extensive factual material. The first scientific conference on the study of comets and meteors was held in 1935. Since then Soviet investigators of comets and meteors have met many times to discuss their work. During recent years, conferences were held in Kiev (1951), Stalinabad (1952), and Odessa (1955, 1957).

Soviet scientists have done much interesting and important work in meteor astronomy. The attainments of Soviet scientists in meteor astronomy are in large measure an indication of the present-day level of the subject.

During the past 30-35 years, this branch of astronomy has also undergone a rapid development in other countries. Meteor associations have sprung up in England, Czechoslovakia, the U.S.A., Canada and New Zealand.

One of the most important problems whose solution has been sought, since the 1920's, in a large number of studies both in the U.S.S.R. and in other countries is that of the interaction of meteoroids and the atmosphere and a study of atmospheric structure from meteor observations.

As early as 1923, Lindemann and Dobson in England applied an approximate physical theory of meteors to the study of the structure of the upper layers of the atmosphere.

In 1931, N. Ivanov, a Soviet radio engineer and amateur astronomer, published a paper in which, on the basis of experimental data, a correlation was established for the first time between meteoric phenomena and ionization of the terrestrial atmosphere. That same year, observations were conducted in the U.S.A. that established the same relationship between these two phenomena.

In 1935, the author together with Stanyukovich laid the foundation for the study of physical conditions in the upper atmosphere from meteor photographs. A special photographic meteor patrol was begun in 1938 at the Stalinabad Astronomical Observatory, now reorganized into the Institute of Astrophysics of the Academy of Sciences of the Tajik S.S.R. In 1956, the meteor patrol of the Institute of Astrophysics in Stalinabad was considerably improved, and in 1957, in connection with the International Geophysical Year, new meteor patrols were established in the Institute of Physics and Geophysics at Ashkhabad and at the astronomical observatories at the universities of Kiev and Odessa.

Systematic photographic studies of meteors were begun at the Harvard Observatory (U.S.A.) in 1936 under the leadership of F. Whipple and, later, also Jacchia and other investigators. Exceedingly important results were produced. Special credit goes to American investigators for the development and application of new superhigh-speed cameras that make it possible to photograph faint meteors, i.e., practically all those that are detected by the unaided eye. The observational data obtained were used to compile tables of the state of the upper layers of the atmosphere up to 120 kilometres (density, temperature, etc.). It was found that on the one hand there are dense, mechanically very firm meteoric bodies, and, on the other, a whole class of loose bodies that easily break up in their passage through the upper atmosphere, which to some extent resembles the flight of snowflakes through the air.

A very detailed physical theory of meteor flights in the atmosphere was developed by Levin. A summary of this work was recently published (1957) by the author in a special monograph. At the present time, many scientists are working on the physical theory of meteors.

A second important problem that has engaged the attention of researchers during the past 25 years is the nature of the meteoric bodies themselves. In this respect very important is the obtaining of meteoric spectra that tell us about their chemical composition.

In 1932, Millman (Canada) published the first survey of meteoric spectra and since that time has been successfully engaged with his associates in the study of meteoric spectra with prismatic and diffraction spectrographs.

Since 1934 the U.S.S.R. too has been successfully developing spectrographic methods in meteor studies.

Studies of meteor glow have been in progress in the U.S.S.R. since 1935. They were begun by Sytinskaya who in 1940 worked out a method of determining the meteoric mass from the brightness.

Systematic and fruitful visual and photographic observations are carried out in Czechoslovakia at the astronomical observatory in Ondřejov and at other places. Important work on the nature of meteoric bodies and meteor showers and also on methods of study has been carried out in Czechoslovakia by Guth, Link, Plavec, and Ceplecha. We must also note the many years of systematic meteor investigation carried out by Hoffmeister in Germany and in Southern Africa that have produced interesting results.

One of the latest methods in meteor studies that has produced a great range of results is the radar technique.

Radar was first used for meteor observations in 1945 by Hey and Stewart in England. Regular radar studies of meteors were organized in 1946 with the participation of Blackett and Appleton. A huge modern radio observatory has been created near Manchester—the Jodrell Bank Experimental Station of the University of Manchester headed by Lovell. Meteor studies here are conducted both night and day in any weather, often in fog and rain.

In 1946, Chechik and Levin carried out the first Soviet radar observations of the Draconid meteor shower and since 1957 such observations have been in progress at stations in Kazan, Kharkov, Tomsk, Stalinabad, and elsewhere in accordance with the programme of the International Geophysical Year. Particularly outstanding results in radio observations of meteors have been obtained by a group of workers of the Kharkov Polytechnic Institute under B. Kashcheyev. Besides England and the U.S.S.R., radio observations of meteors are conducted in Czechoslovakia at the Observatory at Ondřejov, in Canada, where an extensive series of observations has been undertaken by Millman and McKinley, in Australia, India, New Zealand, the U.S.A., Sweden and Japan. Everywhere, radio observations of meteors are now providing the principal factual material, which when linked up with visual and photographic observations helps us to learn more about meteoric matter and its interaction with the earth.

The International Geophysical Year (1957-1958) posed to meteor workers a series of special problems, chief among them being that of the action of meteoric bombardment on the state of the ionosphere. This called for international observations of meteors which during this period were organized according to a special programme. Particularly active in this respect were the Soviet Union and Canada. At the same time, the launching of the Soviet and American artificial earth satellites made it possible to begin a direct study of the density of the meteor cloud in the environs of the earth by means of recording the impacts made by minute meteoric bodies (micrometeorites) on special sensing devices carried by the satellites. This greatly extended the potentialities of the science of meteors.

At present, meteor astronomy is a rapidly developing branch of science on the border-line of astronomy, geophys-