A slide and photograph have gone on to Mr. Haas, and it is my hope that they will interest him to the extent that he will forget to castigate his errant disciple. The cost of these enlargements is $1.00 each, and of the "stereoscope," between $2.00 and $3.00. The enjoyment which I have received from such a small outlay makes me think that it is about as good an investment as I ever made. I shall no longer have to rely absolutely on those authorities and heroes of my childhood, Messrs. Barbicaine, Arden and Nicholl, but I now feel prepared by the aid of recent science, invoked while seated comfortably before my office desk, to check the accuracy of their findings made while on that strenuous expedition conceived and successfully consummated under the able direction of Mr. Verne.

MADERA, CALIFORNIA, FEBRUARY 12, 1940.

The Orbit of the Pultusk Meteor

By C. C. WYLIE

ARE METEORITES FROM OUR SOLAR SYSTEM?

The question whether fireballs dropping meteorites have been members of the solar system (have been travelling in elliptical orbits), or have come in from the distances of the stars (have been travelling in hyperbolic orbits), is one of great interest to astronomers. Meteorites are the only extra-terrestrial objects we can examine in our laboratories. Chemists can determine their composition, and, by modern methods, physicists can determine their approximate age. Composition is not greatly different from terrestrial rocks, excepting that unoxidized nickel-iron is present, and the age is not greatly different from the oldest terrestrial rocks. If meteorites have been members of the solar system, astronomers must provide for them in their hypotheses of the origin of the solar system. If they have come in from outside of the solar system, we have the interesting implication that our universe is not appreciably older than the earth itself.

THE PULTUSK METEOR

Among the meteorites most commonly referred to as from outside our solar system are those of the Pultusk fall of January 30, 1868. In *Harvard Reprint* No. 84, (POPULAR ASTRONOMY, **41**, 76, February, 1933) Professor Öpik[1] refers to this fall, and makes the statement "the hyperbolic velocity of this meteorite stands practically beyond question, as may be inferred from the careful discussion by Galle." Dr. Galle was one of the leading astronomers of that day, the man who discovered the planet Neptune on September 23, 1846.

[1] See also Hoffmeister, "Die Meteore," pp. 8, 26; Farrington, "Meteorites," p. 213.

Because of an inquiry from one of the physicists working on the age of the Pultusk and other meteorites, and because of the references to the orbit of this meteor as hyperbolic, we have undertaken to calculate its orbit. Unfortunately for the purposes of this study, we were unable to secure a copy of Dr. Galle's original paper which appeared in *Jahresberichte der Schlesischen Gesellschaft für vaterländische Kultur in Breslau* for March, 1868. We do have references to his paper, however, which give the more important results. Dr. Öpik's paper, referred to above, gives a number of results and considerable useful information. The fundamental facts of the path are listed in the von Niessl-Hoffmeister "Catalogue of the Paths of 611 Great Meteors," published in Vol. 100 of the *Denkschriften Akademie Der Wissenschaften In Wien.* Another reference to the path as determined by Galle is given in Haedinger's article in the *London Philosophical Magazine,* **37**, 259, 1869.

Galle's Path for the Pultusk Meteor

The height of the endpoint is given by Galle as 42 kilometers (26 miles). The height of appearance is given as 278 kilometers (173 miles), but a lower height, 171 kilometers (106 miles), is used in calculating the velocity. The duration is given as 6.7 seconds, this being the average of 26 estimates. The observed velocity is given as 27.5 kilometers (17 miles) per second. The altitude of the apparent radiant is given as 44°, and the azimuth as 60° from the south point. The right ascension is given as 13°.5, and the declination as +19°.

Psychological Errors in the Path

The results of Galle on this meteor are about what careful astronomers have obtained from reports of the general public, from his own time to the present. There is no reason for doubting that these figures are the result of correct calculations from the reports of intelligent persons who had a good view of the meteor.

Modern work, however, has shown that reports such as those on which Dr. Galle undoubtedly had to base his path contain important psychological errors. The following paragraphs list some of the evidence.

Numerous comparisons have been made using measures on the apparent path of a meteor as pointed out by persons in the same community. The person who sees the entire path in a limited region of sky marked by familiar objects usually points out a path only a fraction of the length pointed out by his friend who has a "splendid view," with the entire path in open sky. (See *Contribution of the University of Iowa Observatory,* No. 9, p. 289; P. A., **47**, 206.)

The von Niessl-Hoffmeister Catalogue, previously referred to, is quoted by those who accept highly hyperbolic velocities for meteors. Seventy-nine per cent of the heliocentric velocities in this catalogue are hyperbolic.

A statistical study of the relations between height of appearance, length of path, geocentric velocity, and heliocentric velocity was made at

Iowa (*Contribution* No. 8, pp. 258-260; P. A., **45**, 209). From these relations several tests could be made as to whether the high heliocentric velocities were real or fictitious. All tests indicated that they were fictitious, due to a fictitious extension of the length of path, so the catalogue is evidence against, rather than for, the reality of the hyperbolic velocities.

A second statistical study using this catalogue was made by Dr. Fletcher Watson, of Harvard. (See *Proceedings of the American Philosophical Society,* Vol. 81, No. 4, September, 1939, *Harvard Reprint,* No. 179.) From a study of the radiants, Dr. Watson found that "the great majority of the bodies listed in the catalogue were moving in direct orbits of low inclination," and also that "it is probable that the velocities in the von Niessl-Hoffmeister *Katalog* are too great and that the bodies listed there were permanent members of the solar system." This is equivalent to saying that it is probable that the high velocities, often found by astronomers who use the reports of the general public on meteors, are not real.

The acceptance of the very great heights of appearance for the Pultusk and other meteors dropping meteorites involves the assumption that the height of appearance of spectacular fireballs is several times that for shooting stars. But the Iowa heights for the appearance of spectacular meteors, as published in *Contribution* No. 6, average lower than the Iowa heights for appearance of shooting stars, as published in *Contribution* No. 4. The British results published in *The Observatory,* Volumes 45-55, show a lower beginning height for spectacular detonating meteors of magnitude about —18 than for shooting stars of magnitude zero and +2. (See *Contribution* No. 8, pp. 263-264; P. A., **45**, 269.) The von Niessl-Hoffmeister Catalogue includes several shooting stars of magnitude about zero. The beginning heights for these are higher than for the spectacular meteors of magnitude —18, or thereabouts, included in the same catalogue. (See *Contribution* No. 8, pp. 263-264.)

These references show that where the same workers have published results for both shooting stars and detonating meteors, the heights of appearance have been found lower for the detonating meteors. Results from continental Europe, England, and America agree on this point. These results indicate also that there is little change in the height of appearance from shooting stars of magnitude zero to the most spectacular detonating meteors. Hence, reports which indicate extraordinary heights of appearance for spectacular meteors must be erroneous, and hyperbolic velocities based on such reports must be erroneous.

Adopting Figures for the Path

With these facts in mind, let us now examine Galle's results, and adopt figures for the path through the atmosphere.

Considering that Galle had a great number of reports, it seems that his figures for the apparent radiant should be approximately correct.

There is no way to check on their accuracy, so they are adopted as he gave them. They are altitude 44°, azimuth 60° from the south point, right ascension 13°.5, and declination +19°.

The height of the end point is affected by two psychological errors, one of which tends to make it too low, and the other tends to make it too high. Galle's figure may be a little high, but there is no way in which we can improve it without the original reports. Let us therefore adopt Galle's figure, which is 42 kilometers (26 miles).

The duration is given by Galle as 6.7 seconds. This is the average of the 26 estimates he used. Öpik, on a re-examination of the estimates, cut the list to 13, ranging from 2.5 seconds to 8 seconds, the average being 4.6 seconds. Experience shows that unless an observer is interviewed very soon after the fall of the meteor, his estimate of the duration tends to be too small. In other words, the average of the estimates received from educated people tends to be a little smaller than estimates received very promptly, or durations based on the re-enactment of the scene. From this and from the fact that Galle adopted a larger figure, it appears that Öpik's figure of 4.6 seconds may be a little small, but we are adopting it rather than the original figure of Galle.

As indicated in an earlier paragraph, if the figure for the height of the end point is in error, it probably is too high. This would tend to make the path too short and the velocity too low. If Öpik's figure for the duration is in error, it probably is too small. This would tend to make the velocity too high. Possible errors in our adopted figures for height of the end point, and duration, should tend to counteract, or eliminate one another.

The height of appearance, as we have said, was given as 278 kilometers (173 miles), but a lower height, 171 kilometers (106 miles), was used in calculating the velocity. This height is affected by two psychological errors, both of which tend to make it too high. Reports on almost any spectacular meteor include some which place the beginning at a very great, or even an infinite, height. Let us compare Galle's figures with others for detonating meteors.

For the brightest detonating and stone dropping meteors of the von Niessl-Hoffmeister Catalogue the median height of appearance is about 67 miles, but the studies previously quoted show this is too high. For the brightest detonating meteors reported in *The Observatory,* the median height of appearance is about 57 miles. For the Iowa paths of detonating meteors, based on measures from interviews, the height of appearance is about 50 miles.

Galle's figure for height of appearance is obviously impossible, but without the original reports there is no way in which we can eliminate the psychological errors. Indeed we probably could not, even with the reports at hand. The beginning height must have been, however, about the same as for similar meteors in modern times, that is about 50 miles.

The problem is simplified by the fact that this height varies little from bright shooting stars to the spectacular detonating meteors. Let us adopt the figure which was found for the meteor which dropped the world's record stone near Paragould, Arkansas. This figure, which is above the average of those published in *Contribution* No. 6, is 52 miles.

Using the adopted figures for height of appearance, height of disappearance, angle of fall, and duration, the apparent velocity was calculated. It was found to be 8.1 miles per second, which is a low velocity, in agreement with reports that the meteor was travelling very slowly just before disappearance.

Adopted Path

Height of appearance	52 miles
Height of end point	26 miles
Length of path	37.4 miles
Azimuth of apparent radiant	60° from south
Altitude of apparent radiant	44°
Right ascension of apparent radiant	13ʰ5
Declination of apparent radiant	+19°
Apparent velocity	8.1 miles

Corrected Radiants and Velocities

Correcting the apparent radiant and apparent velocity, the geocentric radiant and velocity were obtained. Correcting these for the earth's motion, the heliocentric radiant and velocity were obtained. These are as follows:

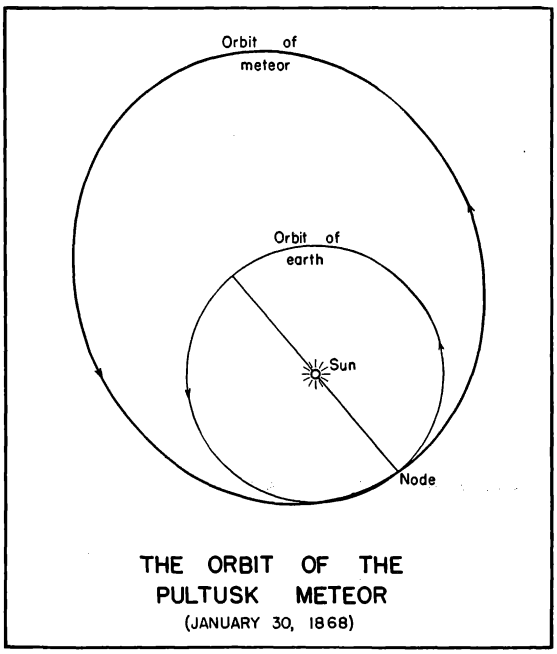
Right ascension of geocentric radiant	4ʰ6
Declination of geocentric radiant	+ 6°7
Geocentric velocity	4.2 miles
Right ascension of heliocentric radiant	31ʰ5
Declination of heliocentric radiant	+13°6
Heliocentric velocity	22.4 miles

The Orbit

From the coördinates of the earth, the heliocentric radiant and the heliocentric velocity, the orbit of the meteor about the sun was computed, using the method given in *Contribution of the University of Iowa Observatory,* No. 9. The following are the elements:

$$a = 1.78$$
$$e = 0.45$$
$$\omega = 159°9$$
$$\Omega = 310°3$$
$$i = 0°8$$
$$P = 2.37 \text{ years}$$

It will be noticed that the orbit is very similar to those which have been determined previously at Iowa for spectacular fireballs, detonating fireballs, and fireballs dropping meteorites. The eccentricity, period, and inclination are all less than for the average short-period comet. For this meteor the inclination is exceedingly small. The drawing shows the orbit of the meteor projected on the plane of the orbit of the earth.



THE ORBIT OF THE PULTUSK METEOR
(JANUARY 30, 1868)

Summary

The available information indicates that with one exception Galle's figures for the Pultusk meteor should be close to the truth. The exception is the height of appearance which is much too high. Since there is little variation in the height of appearance for fireballs varying greatly in size and brightness, a height based on modern measures was adopted for the Pultusk meteor.

Using this adopted height of appearance the velocity was determined, and following this the elements of the orbit about the sun. It was found that, instead of being hyperbolic, the Pultusk meteor was a quite regular member of our solar system, the orbit having a relatively small period, eccentricity, and inclination.

The calculations in this paper have been checked by J. W. Kitchens, former Research Assistant, and J. F. Foster, Jr., present Research Assistant.

University of Iowa Observatory, April 18, 1940