(*Am. Museum Nat. Hist. Anthropol. Paper No. 32* (1930), pt. 1.
55. E. M. Shook, in *The Civilizations of Ancient America* (vol. 1 of selected papers of the 29th Intern. Congr. of Americanists), S. Tax. Ed. (Univ. of Chicago Press, 1951), pp. 93-100.
56. M. D. Coe, thesis, Harvard University, 1959.
57. For Mamom phase, see A. L. Smith, "Uaxactun, Guatemala: Excavations of 1931–1937," *Carnegie Inst. Wash. Publ. No. 588* (1950).
58. The early ceramic phases, Yarumela I, Yohoa Monochrome, and Pavon, from Honduras and northern Veracruz, may represent village-farming cultures, or they may be coincident with incipient cultivation. For these phases see J. S. Canby, in *The Civilizations of Ancient America,* S. Tax, Ed. (Univ. of Chicago Press, 1951), pp. 79-85; W. D. Strong, A. Kidder II, A. J. D. Paul, *Smithsonian Inst. Publs. Misc. Collections* **97**, 111 (1938); R. S. MacNeish, *Trans. Am. Phil. Soc.* **44** No. 5 (1954).
59. J. B. Bird, in "Radiocarbon Dating," *Soc. Am. Archaeology Mem. No. 8* (1951), pp. 37–49, sample 75.
60. C. Evans and B. J. Meggers, *Am. Antiquity* **22**, 235 (1957); personal communication (1958).
61. H. M. Wormington, "A Reappraisal of the Fremont Culture," *Proceedings, Denver Museum of Natural History* (1955), No. 1.
62. A. R. Gonzalez, "Contextos culturales y cronologia relativa en el Area Central del Noroeste Argentino," *Anales arqueol. y etnol.* **11** (1955).
63. J. R. Caldwell, "Trend and Tradition in the Prehistory of the Eastern United States," *Am. Anthropol. Assoc. Mem. No. 88* (1958).
64. See J. B. Griffin, *"The Chronological Position of the Hopewellian Culture in the Eastern United States," Univ. of Michigan Museum of Anthropol., Anthropol. Paper No. 12* (1958), for a résumé and analysis of Adena and Hopewell radiocarbon dates.
65. J. A. Ford and C. H. Webb, "Poverty Point: A Late Archaic site in Louisiana," *Am. Museum Nat. Hist., Anthropol. Paper No. 46* (1956), pt. 1.
66. R. Wauchope [*Middle American Research Records* (Tulane University, New Orleans, La., 1950), vol. 1, No. 14] states the case for an early village-farming level without ceremonial mounds or constructions. While it is true that in some regions of Middle America the temple mound is absent in the earlier part of the "Formative" or "Preclassic" period, it is not clear that such a horizon prevails throughout all of Middle America. In fact, recent data [see M. D. Coe (*56*)] suggest that temple mounds were present in southern Middle America at the very beginnings of village farming.
67. See R. K. Beardsley, B. J. Meggers *et al.*, in "Seminars in Archaeology: 1955," *Soc. Am. Archaeol. Mem. No. 11* (1956), pp. 143-145, for discussion of an "advanced nuclear centered community."
68. It is possible that such a ceremonial center as San Agustín, in southern Colombia, was, in effect, a town with concentrated ceremonial components and, probably, scattered hamlet-sustaining populations. San Agustín has not been satisfactorily dated, but estimates have been made which would place it as comparable in age to town-temple centers in Middle America and Peru. See W. C. Bennett, "Archaeological Regions of Colombia: A Ceramic Survey," *Yale Univ. Publs. in Anthropol.* **30**, 109 (1944).
69. The town life of the Caribbean regions of Colombia and Venezuela at the period of the Spanish conquest is described by J. H. Steward in "Handbook of South American Indians," *Bur. Am. Ethnol., Smithsonian Inst. Publ.* (1949), vol. 5, pp. 718 ff.
70. See W. C. Bennett, E. F. Bleiler, F. H. Sommer, "Northwest Argentine Archaeology," *Yale Univ. Publs. in Anthropol.* **38**, 31 (1948).
71. See H. M. Wormington, "Prehistoric Indians of the Southwest," *Denver Museum Nat. Hist., Popular Ser. No. 7* (1947), pp. 76-102, 107-147.
72. J. B. Griffin [*Archaeology of Eastern United States* (Univ. of Chicago Press, 1952), Fig. 205] estimates these events at about A.D. 900 to 1000. There are indications from some parts of the southeastern United States that temple mounds are much older. For example, see H. P. Newell and A. D. Krieger, "The George C. Davis Site Cherokee County, Texas," *Soc. Am. Archaeol. Mem. No. 5* (1949), and R. P. Bullen, *Florida Anthropologist* **9**, 931 (1956), for a radiocarbon date (about A.D. 350) on the Kolomoki culture.
73. See W. R. Wedel, in P. Drucker, "La Venta, Tabasco, A Study of Olmec Ceramics and Art," *Bur. Am. Ethnol. Smithsonian Inst. Bull. No. 153* (1952), pp. 61-65, for a description of a stone-columned tomb within an earth mound at La Venta. In this connection, the stone tombs covered by earth mounds at San Agustín, Colombia, as described by K. T. Preuss, *Arte monumental prehistoric* (Escuelas Salesianas de Tipografia y Fotograbado, Bogotá 1931), may be pertinent.
74. See V. G. Childe's criteria of city life in *Town Planning Rev.* **21**, 3 (1950).
75. Such centers, although serving as foci for the achievements of civilization, continue more in the form and in the homogeneous traditions of the Beardsley, Meggers *et al.*, "advanced nuclear centered community" (*67*).
76. This kind of city, a "true" city in a modern western European sense, corresponds more closely to what Beardsley, Meggers *et al.* call "supra-nuclear integrated" communities (*67*, pp. 145-146).
77. See G. R. Willey, *Am. Anthropologist* **57**, 571 (1955), and in *New Interpretations of Aboriginal American Culture History* (Anthropological Society of Washington, Washington, D.C., 1955), pp. 28-45; see also, S. F. de Borhegyi, *Middle American Research Records* (Tulane University, New Orleans, La., 1959), vol. 2, No. 6.
78. Such features as Middle America-derived ballcourts and the casting of copper ornaments are well known in Hohokam archeology [see Wormington (*71*)].

The Great Fireball of 26 July 1938

A strongly hyperbolic orbit is derived for this body, indicating an origin outside the solar system.

Charles P. Olivier

At 9:02 P.M., E.S.T., on 26 July 1938, a great bolide or exploded fireball started over eastern Pennsylvania and, moving in a general northeast direction, ended over southern Vermont. It passed to the west of New York City, and its greatest brilliance, due to several explosions or flares, occurred to the north of that city; hence, comparatively few persons much to the south had their attention called to it. Further, few stars were readily visible, due both to the early hour and to scattered clouds or haze over some regions. Three persons at once began to gather data; C. A. Federer, then at the Hayden Planetarium, New York City; C. H. Smith at Waterloo, N.Y., who was the regional director for the American Meteor Society, and F. G. Watson at Harvard Observatory, Cambridge, Mass. All three began solutions based upon the data in their hands, and in fact Smith actually computed a preliminary atmospheric path, but after some time, as the number of reports was so great, all three men decided to send what was in their hands to me for a final solution. At an estimate, about 800 reports came in—far the largest number ever received by me on one fireball. Work was started, then delayed, and the same thing happened several times, but at last I have taken time to make as complete a solution as seems possible, and the results appear in this article.

Finding the Path

The solution of paths and orbits of fireballs is of course of scientific interest and furnishes important data about our atmosphere and also enables one to form hypotheses dealing with their place and manner of origin. I have computed and published about 100 of them in the past, but for reasons to be

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set forth, the fireball of 1938 has special significance because it appears quite certain that the body had a hyperbolic velocity and hence must have originated outside our solar system. As many of the greatest authorities in meteoric astronomy have expressed serious doubts about the possibility of fireballs coming from outer space, a full discussion of this case is justified. A parabolic orbit was also computed as a check, and every care was taken in deriving the apparent velocity.

From the immense number of reports, I had hoped that a very accurate path and orbit could be computed. But in computing the path of a fireball one is always handicapped by the fact that the object appears without warning; that most observers are untrained in estimating directions, angles, and time intervals; that many are in unfavorable locations and see but part of the path; and that a few are actually terrified. Also, many, despite carefully prepared questionnaires, are unable to fill them out intelligently, and a large percentage write pages without giving one useful fact. But all reports must be read by the computer and listed, and the useful data must be sifted from the useless. Hence, the task of dealing with some 800 reports is truly a very great one.

To compute the atmospheric path, the angular coordinates of both beginning and end points are needed. Altitudes and azimuths are usually given and can be directly employed; if positions among the stars are given (these are far more accurate if the person knows the constellations), it is necessary to turn the declinations and right ascensions into altitudes and azimuths before proceeding. Of course, the position of the observer and the time must be given. To obtain the velocity in the atmosphere, the duration must be estimated in seconds or fractions. Here the probable error will always be large. The physical aspects are also important: the color of the fireball, its stellar magnitude, whether it had flares or explosions along the path, and whether it had a train such as is sometimes left. This last is of special importance, for the drift of the train furnishes information about the winds in the upper atmosphere, mostly in the 104- to 80-kilometer level. These limits are for night trains; twilight and daylight trains are lower. However, most fireballs do not leave long-enduring trains.

For a solution, a map of the region is prepared on coordinate paper; the most convenient unit is 1 millimeter to 1 minute of latitude. It is necessary to compute the corresponding distances that the circles of longitude must be placed apart, but this is easy; simply multiply your unit by the cosine of the latitude. Then your map shows latitude circles as parallel straight lines; the longitude circles also straight but slightly converging. The positions of observers who have furnished angular coordinates must then be plotted. It is obvious that this is a tedious matter, but it is necessary for the best solution. If all stations are within one state, an automobile map serves almost as well, but when the area is larger, distortions of azimuth lines will probably occur. Upon the map, the observed azimuth lines are then plotted; however, the longitude circles are used for the protractor, not the latitude circles, as on such a map, except for the central meridian, the circles do not intersect exactly at right angles, though the difference is very small.

Were the observations perfect, all azimuth lines for the sub-beginning point B_1 would intersect in a point; the same would be true for the sub-end point, E_1. In practice, we find the wildest deviations, due both to poor estimates and to the observers' not seeing the real ends of the path but intermediate points.

The computer then has to decide where within this area is the point in question. Each case has to be settled on its merits, so no rigid rule can be given. But it is obvious that more weight must be given to reports which indicate that the observer has some knowledge of the heavens and to those from observers who use a compass or other mechanical aids, to determine directions. But even here we often run into a difficulty as to the compass directions, for many forget to tell whether the local deviation has been allowed for. Since the deviation is often greater than 10°, this is serious.

Path through the Atmosphere

The azimuth of the path of the 1938 fireball could be found with considerable certainty because, to ten observers in New Jersey or west of New York City, the path appeared vertical; this meant they were in its plane. This permitted a much better selection of the subpoints B_1 and E_1 than could have been made otherwise. These two points having been chosen, the heights, as determined by each observer, could be determined by measuring his distance from the two points and multiplying by the tangent of the altitude, with curvature correction added to the observed altitude. This correction is nearly one half the

Table 1. Data on the atmospheric path and orbit (American Meteor Society No. 2279). The calculations were carried out with four-place logarithms to minutes of arc.

Date	1938, July 26.88 G.M.T. (26 July, 9:02 P.M., E.S.T.)	
Sidereal time at *B*	261° 54′	
Began over B_1	$\lambda = 75° 44'$; $\phi = 40° 0'$ at 69 km	
Point over C_1	$\lambda = 74° 34'$; $\phi = 41° 20'$ at 60 km	
End over E_1	$\lambda = 72° 42'$; $\phi = 43° 18'$ at 45 km	
Projected length of B_1E_1	441 km	
Projected length of C_1E_1	258 km	
Length of *BE*	443 km	
Length of *CE*	260 km	
Duration for *CE*	9.71 sec	
Velocity over *CE*, observed (*W*)	26.8 km/sec	
Velocity over *CE*, geocentric (*u*)	24.5 km/sec	
Orbital velocity, parabolic (*v*)	41.4 km/sec	
Orbital velocity, hyperbolic (*v*)	52.7 km/sec	
Radiant uncorrected	$a = 34.5°$; $h = 3.3°$	
Curvature correction	+ 1.2°	
Atmospheric path		
Zenith correction, parabolic	15.6°	
Zenith correction, hyperbolic	−5.0°	
Radiant *P* (parabolic)	$a = 34.5°$; $h = -11.2°$	
Radiant *H* (hyperbolic)	$a = 34.5°$; $h = -0.6°$	
Radiant *P*	$\alpha = 208.6°$; $\delta = -46.2°$	
Radiant *H*	$\alpha = 216.5°$; $\delta = -37.3°$	
Radiant *P*	$\lambda = 224.2°$; $\beta = -32.0°$	
Radiant *H*	$\lambda = 226.6°$; $\beta = -21.6°$	
Heliocentric orbit		
	Parabolic	*Hyperbolic*
Semimajor axis	∞	0.86 A.U.
Eccentricity	1.00	2.17
Perihelion distance	1.012 A.U.	1.007 A.U.
Longitude ascending node	303.5°	303.5°
Longitude perihelion	310.5°	311.5°
Inclination	10.5°	10°

distance measured in minutes of arc—one good reason why that was chosen as the unit for our chart. However, many reports indicated that the first and last point seen by the observer were far from the true ends. Hence, a vertical diagram was drawn, with the projected path horizontal, and points where the separate azimuth lines cut this path were determined, and then the heights of the points on the path were calculated in same manner. In this way, not only are the end points B and E shown on the diagram, but many intermediate points are shown as well. The computer draws a line which will best satisfy all these points, as a wide scatter from a straight line must be expected.

There was an added fact which helped greatly in determining the slope of the true path: 28 observers in New England saw the path parallel to the horizon or with a very small slope. By knowing the distance of these observers from the sub-points, or knowing where their azimuth lines cut the projected path, it is quite possible to calculate the true slope, once we have calculated the end height E_1E, which is almost always more readily determined. These determinations were added to the chart, and the atmospheric path arrived at was based upon all the data mentioned. As a result, much confidence can be had in the calculated direction of motion of the fireball, and, when this is corrected for curvature it gives at once the position of the apparent radiant in the sky. From the paucity of observations of the exact beginning point B, this point is known with far less certainty, and hence knowledge of the length of the path also suffers. Again, however, we were fortunate in that most observers near New York City did not see the fireball until it was past the west point, and under or near Ursa Major. Since they used stars in this constellation as references, we were able to determine an intermediate point C_1, which is much better known than B_1, the true sub-beginning point. In fact, the distance C_1E_1 is the projection of the path as seen by the majority of the observers, particularly of those who gave estimates of duration. Hence, it seems wise to use CE instead of BE in determining the observed velocity. This, incidentally, gives a minimum value for the latter, a point of great importance as will be seen later. The adopted C_1C is based upon 39 reports, E_1E upon 41.

There were 183 duration estimates in all. As those under 4.0 seconds were obviously too small and the six over 43 seconds were much too long, we used 145, which gave the mean as 9.71 seconds. This gives an observed velocity of 26.8 km/sec. When corrected for the earth's attraction, this value drops to 24.5 km/sec, the true geocentric velocity.

The fireball did not leave an enduring train, but it did flare up or burst at least four times. Doubtless many of the discrepancies in the reports arose from observers' taking the last bursting point as the true end point. There is no doubt but that the fireball showed a definite disk to observers who were anywhere near the path; estimates of the diameter ran from 3 to 30 minutes of arc, or the diameter of the moon. It was also very brilliant, growing in brightness at each flare, though it is almost impossible to give a definite figure in stellar magnitudes. The color was reported by several hundred observers; it was probably blue-white for most of its path, reddish near the end, but this latter observation may be due to most observers' having seen it then at a greater distance and a lower altitude. Some report a slight curving after the last explosion, but it is impossible to allow for this in computing. Fragments or sparks certainly fell near the end. Its considerable height and rather large velocity make it improbable that it furnished any meteorites. Data on path and orbit are given in Table 1.

In further considering the observed velocity, which helps so greatly in determining the true heliocentric velocity, we find that the approximate deviation from the 9.71 seconds adopted for the duration is $\pm$ 4.4 seconds. A rough approximation for u, the geocentric velocity, when parabolic velocity is assumed, gives about 10 km/sec. This is two and one-half times smaller than the derived value. Even were we to add the 4.4 to the 9.71 seconds, this would make w, the observed velocity we use, still 18 + km/sec, and u about 2 km/sec less. As for the duration, 33 of the reported values are within less than 1.0 second of the 9.71 seconds adopted, and of all the 145, 3 to 2 are smaller than 9.71. Also, if it were assumed that the whole path BE was observed by all 145 observers, this would give us a far greater velocity; hence, the assumption that CE was the part of the path observed by the average observer tends to lessen the velocity, though it is known that some saw more—and of course some must have seen less.

In conclusion, there seems no reasonable doubt that in this case we had a fireball with a large hyperbolic velocity. While I have computed other orbits with the same implications, never before have the data been so numerous and so decisive (*1*).

Note

1. This work would have been impossible but for the time and trouble spent by the three workers mentioned in the opening paragraph, who collected and partly digested the data. I am most grateful to them and also to the many hundreds of observers who reported.