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PRECISION ORBITS OF 413 PHOTOGRAPHIC METEORS

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Precision Orbits of 413 Photographic Meteors

By Luigi G. Jacchia[1] and Fred L. Whipple[1]

The 413 doubly photographed meteors discussed here represent a selection of the longest and brightest trails from 3,500 such meteors obtained in the Harvard Meteor Program. The meteors were selected to give the greatest precision in derived velocity and deceleration, in order to establish with high certainty the immediate origin of meteors in the visual range and to provide exact data for studies of meteoric processes, meteoroid characteristics, and the properties of the upper atmosphere. The present paper considers orbital characteristics and associated problems of meteoritic origin, while physical problems will be discussed by L. G. Jacchia in other papers. A preliminary discussion of 308 of the present meteors was presented previously (Whipple and Jacchia, 1957a).

The observational material

The meteor orbits presented here are based on precise reductions of selected photographs taken simultaneously at two Harvard stations in New Mexico with the Baker Super-Schmidt meteor cameras. The first of these cameras was installed during the summer of 1951 at Soledad Canyon, but the double-station program did not get under way until March 1952, when a second camera started operations at Doña Ana. In July 1954 the cameras were moved to Sacramento Peak and Mayhill. All the meteors included in this paper were photographed prior to the move, between March 1952 and July 1954, with the exception of Nos. 4702 and 2961, which were photographed in September and October 1951 with a Super-Schmidt camera at Soledad and smaller meteor cameras at Doña Ana. The Super-Schmidt meteor cameras and the details of the program have been described elsewhere (Jacchia and Whipple, 1956).

In all, approximately 4,500 meteors were photographed during this period, about 3,500 of them from both stations. Of these meteors, 413 were selected for accurate reduction on the basis of trail length and quality of image.

The shutters of the Super-Schmidt cameras have two 45° openings and rotate at 1,800 rpm; the meteor trail is thus interrupted 60 times a second and presents the aspect of a row of segments separated by wider breaks. In making the selection we deliberately chose only those meteors that were likely to yield excellent decelerations. On this basis we discarded nearly all meteor trails showing fewer than 20 clearly discernible segments and those whose segments were too closely spaced, as well as trails appearing against rich star fields or too faint to be measured with accuracy. The selected meteors have an average of 40 well-measured segments on the better of the two films, and 34 on the other, and for all but 17 meteors the instant of appearance was recorded visually. A secondary criterion for selection was that comparable numbers of meteors should be chosen in the low, the medium, and the high-velocity groups, and for each month of the year. For months particularly rich in meteors the standards of acceptance were set a little higher, so that the month in question should not exert an overwhelming weight in the analysis of seasonal effects on decelerations.

As a result of this selection, the orbits presented here do not represent a random sample, and this fact should be kept in mind in evaluating the analysis. Thus, while statistical corre-

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lations between the various orbital elements are justified, frequency distributions of orbital elements should be accepted with some degree of caution. In particular, it should be remembered that by excluding meteors with closely spaced segments we have, in all likelihood, eliminated more of the low-velocity than of the high-velocity meteors. The bias introduced by our selection is added, of course, to the bias already inherent in meteor photography, allowed for in the calculated quantity, cosmic weight.

Reduction techniques

A detailed description of the reduction methods for Super-Schmidt meteors has been given by the authors (Whipple and Jacchia, 1957b). For all but five meteors the radiant was determined from the intersection of the two great circles of motion of the meteor as seen from the two stations. The five exceptions were meteors for which the angle of intersection Q of the great circles was small enough to impair the accuracy of the solution by this method. For these meteors direct triangulation was used (Whipple and Jacchia, 1957b). When a good common point is available, this method can lead to quite accurate results.

The velocity V_∞ of the meteor outside the atmosphere was computed as a by-product of the deceleration; an equation of the type

$$D=a+bt+ce^{kt} \qquad (1)$$

was fitted to the distances D on the meteor trajectory, observed in function of time t at the instants corresponding to shutter segments.

The parameter k is computed from four equidistant points on a graph, and a, b, and c are evaluated by least squares. The value of b, which represents the velocity of the meteor at $t=-\infty$, was taken as V_∞. In general, the aim was to obtain decelerations greater than their inner probable error by a factor of 20 to 40; therefore when it appeared likely that the factor would be greater if a single solution were to be computed for the whole meteor, the trajectory was divided into two, three, or more sections and separate least-squares solutions were computed for each of them. In such cases the value of b from the earliest solution was taken as V_∞. In practically all cases V_∞ was computed independently from each of the two trails, and a weighted mean taken.

Sources of error

The main sources of error in the individual solutions are briefly described as follows.

The assumed instant of the meteor.—Without a recording aid the error of a time observation can be estimated at ±2 seconds. After August 1952 the New Mexico observers used a printing chronograph, accurate to $0^{\rm m}.01$. A comparison of the records from the two stations shows that when the same meteor was observed simultaneously by both stations (as happened for approximately three-quarters of all meteors), the recorded instants agreed within $0^{\rm m}.01$ to $0^{\rm m}.02$. Very seldom did the discrepancy amount to $0^{\rm m}.03$. For average geometric conditions an error of 2 seconds in time is reflected in an error of 0.01 percent in the meteor velocity. In the reduction method based on the intersection of the circles of motion, the error varies as the inverse of sin Q. The average value of sin Q for our meteors is approximately 0.3. Only 37 meteors had sin Q less than 0.1, and, as a rule, when sin Q was found to be less than 0.03, direct triangulation was used, in which the error is independent of Q.

When no visual observations were available, the instant of the meteor had to be computed from one or more points that could be identified as common on both photographic trails. Under good conditions the error of such a determination is not more than 1 minute (0.3 percent in the velocities), but it can occasionally be as large as 6 minutes (one-half of the standard exposure time) when no definite common point can be found.

The determination of the radiant.—A source of error lies in the uncertainty with which the straight line, representing the great circle of motion of the meteor, can be determined in gnomonic projection. For a good meteor the error in the direction of motion is of the order of 10″, but 20″ is probably closer to the average. Under average conditions (center of visible trails 45° from the radiant; sin $Q=0.3$), an error of 10″ in the direction of each of the trails is reflected in a maximum error of 1′ in the radiant position and in a relative error of 0.06 percent in the velocity. This error also varies as the inverse of sin Q; it does not apply when direct triangulation is used.

The extrapolation to V_∞.—The inner probable error of V_∞, as computed by the least-squares method for a great number of meteors, appears to be of the order of 0.01 percent for a good, long meteor, and close to 0.03 percent for an average good meteor. In the worst cases on record (short, poor meteors), this type of error amounts to 0.3 percent. These errors refer to a single photographic trail. The fact that a weighted mean was taken between two values of V_∞ should reduce the error in the final value; on the other hand, uncertainty of the parameter k of equation (1) should add a little to the error. It is quite safe to assume that, when the two effects are added together, the final error is not greater than the values given above for individual trails.

Shutter flutter.—After a number of Super-Schmidt meteors had been completely reduced, there was clear evidence that a "flutter" affected the rotation of all camera shutters. Although this instrumental trouble was later eliminated by the installation of more powerful motors, it was nevertheless present during all the period of time covered by the meteors included in this paper.

The shutter flutter was semiregular in character and exhibited widely different amplitudes, ranging mostly from zero to 5°, with a fundamental period of $0^s\!.23$, but with occasional lapses into cycles half or twice that length. When two or more cycles of the flutter are covered by the photographic trail, its effect can easily be eliminated with relative confidence (Whipple and Jacchia, 1957b). For shorter trails, however, the process becomes more questionable, and a few meteors had to be rejected for this reason. The uncertainty in the correction for shutter flutter is, by a reasonable estimate, of the same order of magnitude as that arising from observational scatter; the two effects also depend in very similar manner on the duration of the meteor.

Speed of rotation of the shutters. The rotating shutters of the Super-Schmidt cameras are driven by synchronous motors fed by a 60-cycle a.c. current whose frequency is regulated by a quartz crystal. Theoretically the shutter speed should not vary more than 0.01 percent but occasional dips in speed as high as 0.1 percent have been observed. The shutter speed, always checked at the start and at the end of an observing night, and occasionally at intervals during the night, is recorded to the nearest tenth of one rpm. It is safe to assume that no error larger than 0.05 percent can come from this source.

Orbital data

Table 1 presents orbital data for the 413 photographic meteors. The column heads have the following meanings:

Trail No.: Number of trail photographed at the Doña Ana station.

Day: Day of the month in Universal Time given to $0^d\!.01$.

Yr.: Year of observation minus 1900.

Mo.: Number of the month of the observation.

Sh. No.: Identification of associated meteor shower, if any, as indicated in tables 3 and 4; the letter "Q" after the number indicates a questionable association.

a: Semimajor axis, in a.u.

e: Eccentricity.

q: Perihelion distance, in a.u.

q': Aphelion distance, in a.u.

ω: Argument of perihelion; angle from the ascending node to perihelion along direction of motion, in degrees. Equinox 1950.0.

Ω: Longitude of the ascending node along the ecliptic from the vernal equinox of 1950.0, in degrees.

i: Inclination of the orbit plane to the ecliptic 1950.0, in degrees.

π: Longitude of perihelion $\pi=\omega+\Omega$, in degrees.

True radiant: Radiant after correction for the earth's attraction in degrees and minutes: α, right ascension; δ, declination; equinox 1950.0.

V_∞: Velocity with respect to the stations, corrected for atmospheric drag, in km/sec.

V_G: Velocity with respect to the center of the earth, corrected for earth's attraction, in km/sec.

V_H: Heliocentric velocity, fully corrected, in km/sec.

TABLE 1.—*Basic orbital data*

Trail No.	Day	Yr.	Mo.	Sh. No.	a	e	q	q'	ω	☊	i	π
9880	1.31	54	1		1.665	.465	.890	2.441	45.4	100.3	38.7	145.7
9888	1.44	54	1	88	3.493	.727	.952	6.033	202.3	280.4	18.8	122.7
9900	2.27	54	1		2.900	.690	.898	4.903	218.1	281.3	29.5	139.3
9917	3.21	54	1		1.861	.533	.870	2.852	48.1	102.2	7.8	150.3
9925	3.32	54	1		6.650	.958	.281	13.020	117.4	102.4	57.5	219.7
9945	3.42	54	1	10	3.046	.682	.970	5.123	165.2	282.5	68.6	87.6
9951	3.45	54	1		11.480	.969	.361	22.600	286.6	282.5	124.6	209.1
9953	3.45	54	1	10	2.906	.664	.978	4.833	170.3	282.5	72.7	92.8
9955	3.45	54	1	10	3.119	.685	.983	5.254	180.4	282.5	72.6	102.9
9974	3.48	54	1	10	2.999	.674	.978	5.020	170.4	282.5	72.5	92.9
9983	3.49	54	1	10	3.002	.675	.977	5.027	169.6	282.5	72.4	92.1
9985	3.50	54	1	10	3.074	.683	.975	5.173	168.3	282.5	70.8	90.8
9997	3.52	54	1	10	3.274	.701	.980	5.568	172.8	282.6	73.4	95.4
10006	4.45	54	1	10	3.170	.692	.975	5.364	168.6	283.5	72.5	92.1
10012	4.53	54	1	30	18.920	.971	.556	37.280	263.2	283.6	136.4	186.8
10064	9.42	54	1		2.198	.799	.441	3.955	103.9	108.6	13.8	212.5
6062	10.13	53	1		2.037	.520	.977	3.097	11.4	109.6	13.3	120.9
10070	11.37	54	1		2.355	.770	.542	4.169	91.8	110.6	6.9	202.4
6093	13.39	53	1	100	36.467	.975	.920	72.020	150.2	292.9	67.5	83.1
6095	13.41	53	1		.839	.177	.690	.987	349.1	292.9	56.3	282.0
6105	13.46	53	1	10Q	2.361	.630	.874	3.850	135.4	293.0	75.2	68.4
6218	16.44	53	1		216.638	.995	.976	432.300	169.6	296.0	161.5	105.6
6275	20.31	53	1	31	- 49.400	1.015	.737	- 99.500	239.9	299.9	113.6	179.8
6329	23.38	53	1	32Q	2.413	.725	.664	4.162	77.0	123.1	4.2	200.0
6376	5.14	53	2	33	2.707	.858	.384	5.030	108.8	136.0	0.8	244.8
6398	10.27	53	2		16.870	.959	.697	33.050	246.4	321.2	15.8	207.6
6429	12.47	53	2		1.261	.896	.131	2.390	326.7	323.4	14.4	290.1
6433	12.49	53	2	34	9.229	.893	.986	17.470	184.7	323.4	130.5	148.1
6437	12.50	53	2		80.030	.988	.928	159.100	28.5	143.5	154.5	171.9
6491	18.40	53	2		3.064	.737	.805	5.320	235.8	329.4	19.3	205.3
6546	21.46	53	2	34	11.089	.916	.933	21.250	151.7	332.5	125.0	124.2
10173	27.16	54	2		1.889	.550	.850	2.928	233.2	338.0	2.5	211.1
10218	5.30	54	3		2.561	.799	.515	4.607	274.7	344.1	0.8	258.9
10222	5.33	54	3		32.480	.984	.533	64.420	266.2	344.2	162.1	250.3
10240	5.45	54	3		3.695	.926	.272	7.117	120.6	164.3	38.6	284.9
10273	6.37	54	3		2.867	.658	.980	4.755	194.5	345.2	60.1	179.7
10247	6.42	54	3	11Q	2.239	.888	.252	4.225	126.0	165.3	2.7	291.2
10252	6.48	54	3		88.640	.989	.966	176.300	198.7	345.3	95.5	184.0
10255	6.49	54	3		1.935	.587	.800	3.071	118.4	345.3	18.3	103.7
9815	8.29	54	3		7.816	.894	.828	14.800	229.6	347.1	111.2	216.7
10279	8.44	54	3		.987	.549	.446	1.529	123.8	167.3	1.6	291.0
10281	8.47	54	3	11Q	3.289	.822	.585	5.993	84.9	167.3	7.7	252.2
9804	9.47	54	3		-391.457	1.002	.974	-783.875	195.9	348.3	169.0	184.2
6795	12.22	53	3		2.790	.645	.993	4.590	183.2	351.3	17.7	174.5
6802	12.27	53	3		20.780	.967	.694	40.860	247.3	351.4	95.1	238.6
6811	12.30	53	3	36	10.670	.984	.175	21.160	131.4	171.4	155.9	302.8
6842	13.38	53	3	36	2.671	.941	.159	5.183	137.2	172.5	147.2	309.6
6882	14.30	53	3	37	1.528	.351	.992	2.064	187.0	353.1	7.2	180.1
6904	14.44	53	3		4.416	.913	.386	8.445	73.6	353.5	128.9	67.1
6915	18.21	53	3	38(39,40)	3.780	.786	.810	6.760	234.8	357.3	12.6	232.0
6932	18.34	53	3		5.347	.820	.963	9.731	201.9	357.4	46.2	199.3
6949	18.43	53	3	11Q	2.461	.790	.518	4.404	275.0	357.5	5.4	272.5
6959	18.47	53	3	40(38,39)	-156.200	1.004	.556	- INF	96.8	357.5	76.7	94.3
6961	19.22	53	3		2.085	.532	.976	3.194	19.6	178.1	25.9	197.7
6971	19.31	53	3	38(39,40)	2.908	.731	.783	5.033	240.4	358.4	11.5	238.8
6992	19.39	53	3		8.491	.913	.736	16.250	243.1	358.4	9.5	241.5
6998	19.43	53	3		10.280	.948	.536	20.020	87.1	178.5	9.0	265.6
7002	19.44	53	3	41(42)	.864	.880	.104	1.625	156.0	178.5	2.9	334.5
3053	20.16	52	3	44	2.913	.663	.983	4.843	14.9	179.5	12.0	194.4
7022	20.35	53	3	45	3.586	.722	.996	6.176	180.0	359.4	39.3	179.4

for double-station meteors

Trail No.	True radiant α		δ		V_∞	V_G	V_H	λ	Sin Q	C.W.	K	M_p	t	Qual.
	°	'	°	'										
9880	106	45	-45	12	25.97	23.49	35.64	82.0	.039	9.90	- .34	-0.1	1.99	2.0
9888	19	49	68	57	18.93	15.45	39.35	114.8	.171	10.10	.34	0.5	2.57G	1.0
9900	86	33	83	37	23.87	21.14	38.69	96.0	.255	11.90	.20	0.2	1.14	1.0
9917	80	2	0	4	16.44	12.07	36.42	111.1	.173	8.00	- .21	1.8	1.17	1.5
9925	126	0	- 7	33	44.57	43.08	40.85	65.0	.058	10.50	1.49	-1.2	.46	2.0
9945	234	49	49	15	41.45	39.68	38.88	65.9	.262	2.50	.21	0.4	.45	1.5
9951	166	35	28	21	60.40	59.32	41.53	41.0	.249	4.00	1.86	0.0	.29	3.0
9953	229	21	48	48	43.15	41.45	38.70	63.0	.299	2.00	.16	0.4	.42	2.5
9955	225	16	51	32	43.25	41.58	38.96	63.4	.228	1.70	.22	0.7	.36	3.0
9974	229	37	48	57	43.14	41.47	38.82	63.3	.224	2.00	.19	-1.0	.62	1.0
9983	230	5	48	48	43.07	41.40	38.82	63.4	.230	2.00	.19	-1.3	.50	1.5
9985	231	56	49	14	42.40	40.71	38.91	64.5	.167	2.20	.21	-0.4	.45	2.0
9997	228	22	49	19	43.72	42.10	39.14	63.0	.353	1.80	.27	1.1	.35	2.0
10006	231	12	48	20	43.30	41.61	39.02	63.5	.277	2.10	.24	0.4	.50	1.5
10012	175	47	23	45	64.63	63.75	41.90	33.3	.984	2.30	2.10	-1.0	.37	1.5
10064	116	52	7	9	29.01	27.05	37.40	81.2	.356	7.90	.29	-0.6	.58	1.5
6062	58	51	-35	19	15.33	10.51	36.97	122.3	.191	6.62	- .19	1.2	.58	1.0
10070	112	58	13	3	26.03	23.73	37.76	87.9	.365	4.90	.26	0.2	1.46	1.0
6093	252	10	42	51	43.50	41.78	42.16	69.5	.279	4.47	2.46	0.7	.51	2.0
6095	222	57	43	51	29.73	27.31	27.30	56.3	.322	INF	- .92	-0.3	.69	1.0
6105	243	44	35	56	43.95	42.22	37.77	60.1	.344	4.27	.02	0.7	.67	2.0
6218	210	45	- 1	3	72.78	71.67	42.40	11.2	.113	.18	3.98	-1.4	.42	1.5
6275	198	44	29	19	61.60	60.26	42.65	41.6	.297	2.80	INF	-1.1	.55	2.0
6329	117	52	14	0	22.70	20.06	37.86	95.5	.412	3.70	.18	1.7	.65	1.0
6376	147	15	12	27	31.67	29.30	38.34	80.2	.260	.39	.55	-0.1	.89	1.0
6398	142	14	38	51	27.35	24.95	41.75	97.9	.412	9.29	1.90	-2.9	1.40	1.0
6429	174	21	9	21	35.40	33.82	33.04	61.9	.652	5.24	.36	-0.1	.48	1.0
6433	236	25	9	46	66.06	64.97	41.22	28.9	.101	.39	1.21	-0.7	.40	1.5
6437	217	2	-30	1	71.07	70.20	42.23	16.8	.226	.33	3.14	-0.6	.45	3.0
6491	155	15	49	30	22.69	19.93	38.77	99.5	.157	13.01	.31	0.4	.82	1.0
6546	254	53	8	54	64.45	63.22	41.37	33.0	.207	1.06	1.40	-0.6	.40	1.5
10173	142	17	22	8	17.07	12.73	36.33	109.4	.395	2.60	- .19	1.4	.68	1.5
10218	168	8	6	4	27.44	25.09	37.95	86.6	.234	.50	.36	0.4	.65	1.5
10222	228	5	- 9	23	67.90	66.69	41.94	26.3	.108	.90	2.59	-0.3	.47	3.0
10240	176	35	-21	17	39.51	38.18	39.33	69.2	.311	10.70	.99	0.9	1.04	1.0
10273	252	23	49	14	37.10	35.17	38.43	71.8	.173	2.60	.14	-0.2	.59	3.0
10247	180	59	- 2	16	34.49	32.84	37.29	72.6	.117	1.10	.57	0.1	.47	3.0
10252	250	51	28	19	55.28	54.04	42.14	50.9	.134	1.50	3.21	-1.6	.37	2.0
10255	337	46	32	36	20.66	17.06	36.44	97.7	.259	13.60	- .13	-0.6	.91	2.0
9815	242	22	16	37	59.73	58.32	40.89	41.3	.234	2.40	1.15	-2.3	.38G	1.5
10279	182	55	- 3	41	20.56	17.55	29.79	72.3	.357	1.50	- .47	2.4	.97	1.5
10281	163	1	- 3	25	26.47	24.42	38.93	90.8	.474	5.30	.53	0.3	.90	1.5
9804	252	40	-16	2	72.78	71.80	42.27	7.7	.072	.11	INF	-3.8	.54	2.0
6795	101	53	83	11	17.39	13.42	38.29	118.9	.274	4.20	.11	-0.1	.28	2.0
6802	235	33	22	25	54.84	53.36	41.72	51.2	.238	4.50	2.09	0.9	.39	2.0
6811	217	21	-22	2	61.25	59.98	41.23	38.9	.013	2.20	2.11	0.9	.37	3.0
6842	218	40	-24	47	57.90	56.72	38.09	38.4	.111	3.10	.94	0.5	.42	2.5
6882	112	31	65	11	12.72	6.41	34.68	133.5	.346	2.24	- .50	2.2	1.12	1.0
6904	294	44	- 1	11	59.86	58.46	39.77	38.7	.176	3.60	.98	0.8	.56	1.0
6915	171	45	30	32	20.36	18.88	39.32	105.1	.566	12.90	.50	2.2	.45	1.5
6932	240	53	58	52	31.77	29.62	40.18	84.9	.248	5.14	.73	0.3	.61	1.0
6949	182	48	5	32	27.07	24.97	37.68	86.2	.442	3.60	.32	-0.5	1.30	1.0
6959	308	3	23	23	48.71	47.09	42.26	61.9	.276	7.70	INF	-0.5	.73	2.0
6961	117	4	-52	15	20.12	16.94	36.81	99.9	.282	7.20	- .17	0.8	1.90	1.0
6971	174	46	26	20	21.60	18.59	38.40	102.2	.675	9.40	.27	1.9	.38	2.0
6992	172	12	20	1	24.68	22.30	40.93	102.3	.450	6.90	1.27	2.1	.87	1.0
6998	174	15	- 8	0	30.25	28.46	41.15	89.6	.378	4.90	1.58	1.3	.97	1.0
7002	210	4	-13	39	31.40	29.52	27.46	55.1	.392	1.20	.13	1.3	.52	2.5
3053	113	35	-21	29	16.10	11.80	38.41	128.8	.608	5.53	.16	-0.5	2.02	3.0
7022	267	7	67	30	27.29	24.78	39.14	90.9	.316	2.10	.35	1.1	.74	1.0

TABLE 1.—*Basic orbital data*

Trail No.	Day	Yr.	Mo.	Sh. No.	a	e	q	q'	ω	Ω	i	π
7026	20.38	53	3		16.784	.957	.723	32.845	243.9	359.4	56.6	243.4
5688	20.39	53	3	43	4.771	.794	.985	8.558	193.1	359.4	150.0	192.5
7040	20.45	53	3	38(39,40)	2.553	.685	.804	4.302	238.4	359.5	19.3	237.9
7044	20.47	53	3		39.550	.984	.648	78.460	252.9	359.5	67.7	252.4
7046	21.35	53	3		2.847	.702	.850	4.845	50.0	180.4	5.7	230.4
7052	21.38	53	3		53.050	.983	.879	105.200	220.3	0.4	93.5	220.7
3072	21.40	52	3		1.457	.941	.086	2.829	332.3	0.7	15.6	333.0
3074	21.41	52	3		61.397	.997	.158	122.637	133.3	180.7	104.5	314.0
3076	22.41	52	3	39(38,40)	2.638	.654	.912	4.364	218.2	1.7	7.0	219.9
10342	26.27	54	3	37	1.541	.353	.997	2.084	183.0	5.0	9.3	188.0
3088	28.34	52	3	45	2.938	.663	.989	4.886	167.6	7.6	37.2	175.2
3037	30.39	52	3		219.000	.998	.475	437.500	92.9	189.6	116.6	282.5
10358	1.30	54	4	47(48)	3.078	.841	.489	5.667	276.8	11.0	9.7	287.8
3024	1.33	52	4	(43)	6.358	.851	.946	11.770	207.9	11.5	150.3	219.5
10365	1.34	54	4	46	2.716	.750	.678	4.753	75.6	191.0	17.6	266.6
10106	1.37	54	4	48(47)	3.063	.844	.479	5.647	98.0	191.0	19.8	289.0
10380	2.34	54	4		- 6.080	1.002	.103	- INF	142.4	192.0	24.9	334.4
10384	2.37	54	4	42(41)	1.740	.859	.246	3.237	129.2	192.0	8.7	321.3
10394	2.42	54	4	39(38,40)	2.835	.657	.971	4.698	201.9	12.1	5.7	214.0
7067	3.13	53	4	38(39,40)	2.862	.688	.893	4.830	222.4	13.0	9.5	235.5
7069	3.19	53	4		3.470	.744	.891	6.060	221.9	13.1	36.0	235.0
3000	3.45	52	4		- INF	1.000	.972	- INF	160.7	13.6	82.3	174.3
7073	4.17	53	4	49	2.473	.882	.291	4.656	300.9	14.1	1.7	314.9
7075	4.17	53	4	52	3.142	.690	.975	5.309	200.4	14.1	16.2	214.4
10414	5.19	54	4	44	2.620	.635	.957	4.284	27.5	194.8	13.2	222.3
10439	5.38	54	4	42(41)	2.577	.896	.267	4.886	123.4	195.0	6.0	318.4
10447	5.41	54	4	42(41)	3.251	.894	.343	6.159	113.1	195.0	15.2	308.1
10098	6.23	54	4		42.680	.990	.419	84.940	279.7	15.8	63.2	295.5
10478	6.26	54	4	46	2.804	.738	.734	4.873	68.1	195.9	16.5	263.9
10480	6.29	54	4		2.594	.671	.852	4.335	50.9	195.9	24.1	246.8
7097	7.28	53	4		1.980	.809	.378	3.580	293.0	17.1	27.4	310.1
10531	7.46	54	4	60	39.300	.976	.942	77.658	208.3	17.0	86.1	225.3
7158	9.37	53	4	50	2.669	.746	.678	4.660	75.9	199.2	0.6	275.1
7161	9.38	53	4	40(38,39)	INF	1.000	.692	INF	112.5	19.2	79.9	131.7
7169	10.14	53	4		2.800	.679	.899	4.700	138.3	19.9	12.8	158.2
7184	10.27	53	4	50	2.035	.688	.634	3.436	264.2	20.1	1.3	284.3
7188	10.33	53	4		62.340	.989	.679	124.002	249.4	20.1	51.5	269.6
7190	10.35	53	4		19.770	.963	.728	38.810	243.7	20.1	27.1	263.8
10094	10.47	54	4	40(38, 39)	167.700	.996	.677	334.700	110.5	20.0	80.4	130.4
7210	11.18	53	4	51	2.606	.618	.996	4.216	169.8	21.0	2.8	190.8
7216	11.20	53	4	48(47)	6.830	.925	.511	13.150	91.2	201.0	17.9	292.1
7240	11.34	53	4	50	2.295	.694	.703	3.887	254.3	21.1	4.2	275.4
10555	12.42	54	4	52	3.163	.683	1.003	5.323	179.4	21.9	19.0	201.3
7272	13.38	53	4	49	2.381	.831	.401	4.360	288.8	23.1	14.4	311.9
7277	13.40	53	4		15.550	.989	.164	30.940	133.0	203.1	156.8	336.2
7331	15.27	53	4		3.010	.729	.815	5.204	236.3	25.0	28.4	261.2
7333	15.28	53	4	49	2.787	.861	.388	5.186	289.0	25.0	2.3	314.0
7339	15.32	53	4		21.938	.990	.227	43.649	123.8	205.0	49.0	328.8
7367	16.13	53	4	50	4.854	.834	.806	8.902	55.5	205.8	5.2	261.3
7372	16.15	53	4	50	2.481	.695	.757	4.205	66.4	205.8	3.0	272.2
7388	16.30	53	4	50	2.157	.707	.631	3.683	264.0	26.0	3.2	290.0
7392	16.33	53	4	45	2.717	.634	.994	4.439	167.3	26.0	41.2	193.3
7454	21.44	53	4		28.233	.989	.305	56.160	66.4	31.0	68.4	97.4
3271	22.35	52	4	6	10.117	.909	.919	19.316	215.0	32.1	78.5	247.1
3217	22.43	52	4	6	31.640	.971	.915	62.360	215.2	32.2	79.1	247.4
3228	23.32	52	4		10.208	.907	.946	19.471	208.9	33.1	63.8	242.0
3234	23.36	52	4	49	1.706	.765	.401	3.011	292.8	33.1	14.9	325.9
3250	26.32	52	4	49	3.037	.841	.484	5.591	277.9	36.0	9.8	313.9
10127	28.45	54	4		2.729	.907	.254	5.204	304.9	37.6	31.7	342.4
3265	1.36	52	5		10.353	.920	.833	19.874	129.6	40.9	64.3	170.5

for double-station meteors (continued)

Trail No.	True radiant α ° ′	δ ° ′	V_∞	V_G	V_H	λ	Sin Q	C.W.	K	M_p	t	Qual.
7026	223 37	37 15	39.99	38.33	41.55	73.9	.778	9.10	1.88	0.8	.48	2.0
5688	265 37	- 6 14	68.64	67.42	39.92	17.4	.125	.24	.62	-5.7	1.16G	1.0
7040	186 27	37 13	22.15	19.42	37.84	98.0	.238	13.40	.14	0.6	.53	1.0
7044	227 47	30 22	44.95	43.64	41.91	66.5	.544	8.20	2.68	-0.9	.35	1.0
7046	154 4	- 3 37	18.72	15.39	38.31	111.5	.439	5.60	.21	1.1	.94	2.5
7052	252 12	25 59	54.40	53.03	41.98	52.2	.318	2.90	2.80	-0.3	.28	2.0
3072	209 36	- 6 43	38.90	37.34	34.21	60.0	.137	4.71	.68	-0.6	.45	3.0
3074	213 11	-31 51	55.35	54.27	42.00	50.2	.188	7.23	3.68	-0.8	.53	1.5
3076	159 27	30 30	16.82	13.00	37.98	119.4	.072	6.63	.10	0.9	1.33	3.0
10342	128 49	72 22	13.15	7.17	34.66	127.4	.612	1.70	- .49	1.3	.98	1.0
3088	288 6	68 5	25.93	23.28	38.38	91.7	.282	3.56	.16	1.2	1.01	1.0
3037	234 47	-46 27	59.92	58.84	42.07	42.6	.155	4.20	4.31	0.2	.97G	3.0
10358	197 50	3 20	29.43	27.21	38.54	84.9	.024	5.40	.55	1.1	.86	3.0
3024	272 59	- 6 36	68.85	67.58	40.42	18.4	.155	.45	.90	0.4	.70	2.0
10365	176 11	-26 35	25.04	22.64	38.04	92.0	.270	11.70	.28	1.3	1.17	1.5
10106	189 0	-24 53	30.71	28.81	38.52	82.2	.253	9.80	.56	-0.2	1.15	2.0
10380	210 28	-20 13	45.93	44.54	42.28	65.9	.030	5.70	INF	-0.2	.34	3.0
10384	206 16	-16 47	33.38	31.56	35.55	70.8	.020	3.80	.36	-0.1	1.34	3.0
10394	150 56	33 49	15.11	10.68	38.21	136.1	.004	3.90	.14	1.4	1.29	3.0
7067	176 28	28 13	18.58	14.63	38.24	114.6	.387	7.70	.19	0.5	.65	1.0
7069	222 18	49 15	27.65	25.07	38.95	90.1	.322	10.10	.37	0.7	.70	2.0
3000	288 19	37 0	49.58	48.17	42.10	60.0	.311	1.86	INF	-0.9	.42	2.0
7073	206 31	- 9 40	34.14	31.94	37.60	75.0	.170	.73	.60	1.7	.72	1.5
7075	175 48	57 23	18.04	14.10	38.60	118.9	.694	6.90	.23	1.8	.63	1.0
10414	140 15	-27 47	17.03	13.03	37.86	119.1	.234	8.20	.07	-0.9	3.84	1.0
10439	206 47	-15 12	34.71	33.01	37.78	73.8	.014	2.52	.67	-0.5	1.04	2.0
10447	200 50	-20 56	33.85	32.20	38.71	77.2	.133	6.60	.77	-0.4	.94	1.0
10098	231 35	15 53	45.71	44.01	41.83	65.8	.256	9.60	2.94	-2.9	.71G	1.0
10478	175 52	-27 58	23.71	21.00	38.14	95.9	.209	11.50	.27	-1.7	.61	1.5
10480	160 57	-43 32	22.70	19.98	37.80	97.0	.205	13.40	.12	1.9	1.22	2.0
7097	218 22	7 54	32.71	30.59	36.36	74.1	.269	11.10	.27	0.0	.65	1.0
10531	267 2	31 0	51.07	49.78	41.80	56.9	.333	2.45	2.51	-0.9	.48	1.0
7158	190 29	- 5 37	23.07	20.47	37.91	96.4	.366	.50	.26	-0.7	.46	1.0
7161	317 7	32 42	49.19	47.59	42.06	60.8	.272	6.30	8.14	-2.0	1.49	1.0
7169	33 13	49 46	18.00	14.46	38.11	114.8	.052	11.10	.17	1.2	.83	2.0
7184	196 35	- 4 51	23.12	20.23	36.51	91.9	.006	1.10	.04	0.6	.70	2.0
7188	231 59	29 38	38.93	37.21	41.88	76.6	.430	10.10	3.06	-1.3	.44	1.0
7190	208 52	27 18	29.49	27.38	41.52	93.2	.831	11.90	2.02	-1.6	.93	1.0
10094	318 21	32 13	49.31	47.77	41.99	60.4	.174	6.45	3.92	-2.6	.92	1.5
7210	97 46	36 3	13.71	8.42	37.79	161.5	.301	.80	.04	1.5	.85	1.0
7216	195 26	-25 47	31.89	29.72	40.48	85.9	.020	8.20	1.25	-1.9	1.64	1.5
7240	194 52	1 24	21.89	19.04	37.17	97.0	.409	3.70	.10	-0.6	.42	1.0
10555	166 44	78 18	18.02	14.28	38.57	118.3	.249	INF	.23	-0.2	.60	2.0
7272	215 26	- 0 44	30.92	28.99	37.35	79.0	.450	7.30	.41	-0.9	.93	1.5
7277	250 36	-28 43	60.68	59.61	41.35	39.7	.154	2.20	2.47	-0.6	.56	1.0
7331	218 18	35 6	25.65	22.99	38.36	92.6	.485	12.80	.28	0.6	.47	1.0
7333	212 12	-10 54	31.46	29.35	38.05	80.3	.267	1.20	.57	1.3	.64	1.0
7339	219 56	-37 0	44.63	43.20	41.54	66.5	.131	10.10	2.63	1.2	.38	2.0
7367	181 23	-11 39	21.94	18.68	39.79	108.6	.028	4.10	.73	1.0	.79	2.5
7372	189 49	-10 19	21.12	17.72	37.53	101.8	.224	2.60	.14	0.7	.74	1.5
7388	203 0	- 4 34	23.51	20.74	36.81	92.1	.359	2.50	.10	-0.7	.36	1.5
7392	287 12	65 53	27.56	25.07	37.94	87.3	.275	2.40	.08	-0.2	.66	1.0
7454	347 23	25 20	47.21	45.53	41.61	63.1	.307	9.90	2.72	0.1	.69G	1.5
3271	271 54	33 32	47.37	45.83	40.93	61.3	.330	3.42	1.33	-1.5	.52	1.5
3217	271 16	33 19	48.04	46.67	41.65	61.5	.451	3.44	2.33	-0.6	.30	2.0
3228	266 5	42 47	40.76	39.02	40.93	71.7	.501	3.96	1.32	1.3	.48	1.5
3234	226 55	- 3 14	28.94	26.79	35.25	77.2	.271	8.23	.11	0.4	.47	1.5
3250	221 12	- 5 22	29.37	27.22	38.33	84.7	.309	5.52	.55	1.0	.70	1.5
10127	239 38	- 2 42	37.55	36.10	37.88	76.6	.198	10.23	.75	-1.8	.29	2.0
3265	328 30	51 34	41.45	39.69	40.90	70.7	.288	6.69	1.39	0.1	.54	2.0

600852 O -61 -2

TABLE 1.—*Basic orbital data*

Trail No.	Day	Yr.	Mo.	Sh. No.	a	e	q	q'	ω	☊	i	π
11816	3.15	54	5		2.481	.610	.968	3.995	26.7	222.1	22.9	248.8
11818	3.17	54	5		5.124	.808	.984	9.264	161.2	42.1	2.6	203.4
11825	3.23	54	5	57(56,58)	2.716	.743	.697	4.734	73.9	222.2	3.5	296.1
11856	3.43	54	5	57(56,58)	2.255	.675	.734	3.776	71.1	222.4	1.8	293.5
11862	3.45	54	5		13.190	.958	.560	25.820	95.2	42.4	163.5	137.6
7474	5.28	53	5	54(53,55)	2.949	.925	.220	5.679	128.8	224.4	3.2	353.3
7476	5.30	53	5	53(54,55)	1.840	.868	.242	3.438	309.4	44.5	7.9	353.9
7478	5.30	53	5	55(53,54)	2.166	.844	.338	3.993	116.9	224.5	11.6	341.3
7480	6.15	53	5	57(56,58)	2.713	.687	.850	4.576	52.2	225.3	1.4	277.5
7494	6.28	53	5	57(56,58)	2.151	.671	.707	3.596	75.3	225.4	0.5	300.6
7496	6.29	53	5		1.249	.195	1.006	1.492	168.6	45.4	13.7	214.0
11973	6.29	54	5		6.131	.884	.711	11.550	248.3	45.2	71.9	293.4
7499	6.29	53	5	58(56,57)	1.907	.766	.446	3.368	286.7	45.4	10.3	332.1
7520	7.27	53	5	56(57,58)	2.800	.687	.876	4.724	227.5	46.4	3.4	273.9
7522	7.27	53	5	52	2.339	.569	1.009	3.670	182.5	46.4	28.1	228.8
7524	7.28	53	5	59	9.613	.896	1.002	18.220	190.0	46.4	55.2	236.3
7534	7.31	53	5	53(54,55)	2.781	.901	.276	5.286	302.2	46.4	12.0	348.6
7560	8.26	53	5		21.550	.967	.718	42.370	245.7	47.3	50.4	293.0
7562	8.27	53	5		3.591	.827	.620	6.563	261.5	47.3	9.8	308.8
7592	9.33	53	5	51	2.402	.580	1.009	3.796	176.3	48.4	1.8	224.6
7607	9.37	53	5		5.207	.815	.966	9.449	154.5	48.4	46.6	202.9
7635	12.24	53	5	58(56,57)	2.875	.838	.466	5.285	280.5	51.2	9.5	331.6
7637	12.24	53	5	55(53,54)	2.489	.850	.372	4.606	112.0	231.2	4.1	343.1
7664	13.16	53	5	56(57,58)	2.697	.676	.873	4.521	228.5	52.1	3.1	280.5
7666	13.18	53	5		.870	.162	.733	1.020	14.3	52.1	17.8	66.4
3344	21.21	52	5	52	2.981	.661	1.010	4.952	173.6	60.1	22.5	233.7
3340	21.30	52	5		16.561	.947	.884	32.238	222.4	60.1	121.1	282.5
3342	21.31	52	5	60	2.321	.648	.818	3.825	59.2	240.2	9.7	299.4
3334	21.32	52	5		- 20.761	1.027	.556	- 42.080	263.6	60.2	91.5	323.8
3332	21.34	52	5		2.713	.737	.713	4.713	252.3	60.2	19.5	312.5
3327	21.36	52	5	54(53,55)	2.622	.915	.223	5.020	129.2	240.2	4.5	9.4
3312	22.25	52	5	52	2.768	.635	1.011	4.524	174.3	61.1	15.8	235.4
3307	22.27	52	5	52	2.892	.650	1.012	4.772	182.8	61.1	22.7	243.9
3303	22.28	52	5	56(57,58)	2.040	.581	.855	3.226	234.8	61.1	2.2	295.9
3299	23.35	52	5		2.180	.797	.442	3.919	285.7	62.1	13.3	347.8
3295	23.40	52	5	53(54,55)	1.792	.826	.311	3.272	302.1	62.2	21.7	4.3
3288	24.28	52	5	60	1.932	.619	.737	3.128	73.3	243.0	12.2	316.3
3286	25.22	52	5		1.875	.948	.098	3.652	148.9	243.9	38.1	32.8
3277	31.33	52	5		75.118	.987	1.006	149.230	190.1	69.8	85.9	259.8
12342	31.35	54	5	66	2.844	.759	.686	5.001	255.5	69.3	1.3	324.8
12361	1.18	54	6		4.512	.821	.806	8.218	57.0	250.1	12.8	307.1
12363	1.18	54	6		2.980	.715	.850	5.111	127.7	70.1	8.2	197.8
4103	1.37	52	6	62(61)	2.322	.580	.976	3.669	206.3	70.8	21.8	277.0
12399	2.23	54	6	61(62)	2.867	.667	.954	4.779	211.5	71.1	21.2	282.6
7726	4.20	53	6		2.343	.838	.379	4.307	112.0	253.2	3.0	5.2
7734	4.24	53	6	63	2.460	.610	.959	3.960	31.2	253.2	0.8	284.4
10587	4.39	54	6	59	89.970	.989	1.008	178.900	170.7	73.2	55.5	243.8
10583	4.39	54	6		42.820	.984	.686	84.960	290.3	253.2	178.1	183.4
7742	5.17	53	6	64	3.464	.717	.979	5.949	203.7	74.2	71.6	277.9
7744	5.17	53	6	66	2.372	.665	.795	3.949	242.7	74.2	1.1	316.9
7750	5.21	53	6	63	2.367	.620	.900	3.833	45.2	254.2	1.2	299.4
7754	5.25	53	6	66	2.059	.667	.686	3.432	259.0	74.2	7.0	333.2
12504	5.26	54	6		3.008	.703	.894	5.122	135.3	74.0	14.9	209.3
7758	5.28	53	6	65	10.666	.953	.505	20.830	271.7	74.3	130.9	346.0
7787	8.28	53	6	64	3.778	.745	.964	6.592	208.1	77.1	78.8	285.3
7820	9.23	53	6	62(61)	2.806	.645	.995	4.616	198.5	78.0	20.8	276.5
7838	9.34	53	6		1.921	.491	.978	2.864	207.1	78.2	15.7	285.3
7841	9.38	53	6		7.747	.874	.972	14.521	24.6	258.2	177.5	282.8
12577	11.41	54	6	67	2.163	.816	.398	3.929	290.7	79.9	10.3	10.6
7871	13.35	53	6		1.691	.725	.464	2.917	106.9	262.0	6.6	8.9

for double-station meteors (continued)

Trail No.	True α °	'	radiant δ °	'	V_∞	V_G	V_H	λ	Sin Q	C.W.	K	M_p	t	Qual.
11816	151	23	-56	4	19.87	16.56	37.43	105.0	.156	8.20	.01	1.1	2.16	2.0
11818	105	40	31	57	15.58	11.33	39.81	150.7	.175	1.40	.68	-0.1	2.19	1.5
11825	209	26	-18	1	22.96	20.03	37.83	97.7	.004	2.80	.27	0.3	1.03	2.5
11856	208	47	-15	20	20.73	17.88	36.94	99.4	.474	1.80	.06	1.0	1.32	1.0
11862	335	34	- 1	53	66.76	65.49	41.12	26.2	.127	.85	1.78	-0.7	.58	2.5
7474	239	7	-22	13	36.83	34.99	38.16	72.0	.160	1.20	.88	0.8	.65	1.0
7476	241	28	-15	51	33.77	31.80	35.71	71.1	.171	3.40	.42	0.2	.94	1.0
7478	232	54	-28	23	31.95	29.93	36.71	76.3	.195	5.50	.41	1.4	.75	1.0
7480	199	41	-11	46	18.91	15.11	37.81	111.8	.064	1.30	.16	0.8	.94	1.0
7494	214	42	-14	51	21.45	18.39	36.67	97.2	.151	.50	.04	1.4	.60	1.0
7496	236	44	77	39	13.67	7.94	32.36	104.0	.331	INF	- .73	0.7	.33	1.5
11973	267	24	25	9	44.93	43.29	40.15	63.7	.266	7.10	1.00	-0.8	.67	1.0
7499	234	10	- 8	33	28.11	25.76	35.94	80.8	.132	6.10	.16	0.8	.78	1.5
7520	201	49	- 0	9	18.13	14.45	37.94	115.0	.593	3.20	.18	1.5	.93	1.0
7522	241	20	69	8	21.03	17.79	37.11	100.5	.390	INF	- .07	0.0	.69	1.0
7524	275	38	54	28	36.11	34.17	40.79	79.3	.305	INF	1.24	-1.8	.87	1.0
7534	241	2	-12	57	35.05	33.19	37.91	74.2	.164	4.83	.73	1.1	.46	1.0
7560	251	50	26	58	37.75	35.87	41.41	77.9	.401	10.00	2.10	0.2	.48	1.0
7562	225	8	- 3	43	26.43	23.94	38.84	92.7	.114	6.40	.58	1.1	.87	1.0
7592	140	2	24	30	13.25	7.82	37.23	171.1	.155	INF	- .04	1.5	.	3.0
7607	311	50	69	13	31.58	29.44	39.81	85.0	.293	5.10	.71	0.2	.44	1.0
7635	236	32	-10	14	29.70	27.38	38.02	83.9	.108	5.20	.51	0.4	.69	1.0
7637	238	18	-23	47	31.36	29.17	37.38	79.2	.009	2.10	.49	-1.7	1.10	2.0
7664	207	25	- 3	7	18.28	14.35	37.75	114.5	.113	2.80	.15	1.1	.89	1.5
7666	305	55	50	41	14.55	9.09	27.22	66.9	.410	4.40	- .92	0.3	.62	1.0
3344	205	43	72	15	19.25	15.74	38.12	111.6	.392	INF	.16	2.3	.54	2.0
3340	306	43	14	37	62.80	61.18	41.20	36.0	.299	1.58	1.78	-0.9	.46	2.0
3342	214	3	-35	43	19.54	16.27	37.00	104.5	.388	8.90	.04	-0.7	1.56	1.5
3334	283	28	14	3	53.57	52.19	42.35	54.2	.174	6.05	INF	-0.6	.49	4.0
3332	240	23	9	40	24.60	22.07	37.74	93.2	.617	12.61	.25	0.4	.82	1.0
3327	256	22	-25	24	35.96	34.25	37.58	71.9	.222	1.76	.77	1.3	.38	2.0
3312	180	54	63	33	16.57	12.45	37.82	124.1	.090	INF	.09	2.1	.92	1.5
3307	217	36	64	9	19.24	15.76	38.00	110.9	.140	INF	.13	1.2	.81	1.5
3303	219	36	- 9	40	17.33	13.42	36.28	110.1	.390	2.27	- .11	2.2	.65	2.0
3299	250	56	- 9	14	29.05	26.93	36.65	81.0	.431	7.53	.29	1.0	.61	2.0
3295	259	58	- 7	29	32.27	30.45	35.43	72.6	.333	9.71	.28	1.1	.52	1.5
3288	227	7	-40	48	21.02	17.92	35.93	95.8	.281	10.44	- .09	1.5	1.20	3.0
3286	274	27	-34	57	41.37	39.58	35.73	60.3	.031	9.42	.84	1.1	.94	4.0
3277	309	44	41	54	50.70	49.26	41.66	57.5	.348	INF	3.05	-0.9	.42	2.5
12342	239	29	-18	27	23.04	20.39	37.90	97.6	.264	1.10	.32	1.1	.85	2.0
12361	222	44	-41	8	22.62	19.63	39.38	105.3	.088	9.20	.66	0.5	1.44	1.0
12363	93	33	42	11	18.93	15.65	38.08	111.9	.044	7.90	.25	0.2	2.34	2.0
4103	236	24	42	41	18.98	15.62	36.96	106.5	.266	7.45	- .06	2.3	.43	2.0
12399	235	41	35	52	20.07	16.68	37.92	107.7	.449	9.10	.16	0.4	.84	1.5
7726	262	22	-25	53	30.76	28.44	36.99	79.6	.071	1.60	.43	1.2	.70	1.5
7734	207	49	-14	14	15.19	10.57	37.23	131.8	.411	.60	.01	1.9	.71	1.0
10587	297	37	66	18	36.63	34.88	41.68	80.4	.419	INF	3.20	-2.0	.67	1.5
10583	3	26	0	26	68.98	67.70	41.55	20.6	.161	.08	2.72	-1.2	1.00	1.5
7742	300	53	44	45	42.39	40.63	38.61	64.6	.298	2.07	.32	0.9	.78	1.0
7744	236	34	-17	35	19.76	16.16	37.05	105.4	.110	1.01	.07	1.4	1.02	1.0
7750	221	58	-19	38	16.83	12.66	37.04	118.2	.183	1.10	.00	1.7	.80	1.0
7754	248	45	-10	14	22.01	18.94	36.28	95.0	.432	6.00	.01	0.1	.77	1.0
12504	105	11	58	35	19.32	15.98	38.10	111.0	.121	11.30	.24	-0.5	2.95	1.0
7758	310	0	3	44	61.82	60.48	40.78	36.4	.141	3.00	1.64	-0.3	.55	2.5
7787	306	12	41	16	45.68	44.07	38.87	60.0	.370	2.30	.41	1.0	.53	1.5
7820	232	34	44	35	18.92	15.34	37.81	111.8	.255	3.50	.11	-0.4	1.17	1.0
7838	234	1	34	52	16.25	12.12	35.84	113.0	.212	6.80	- .25	0.5	.79	1.0
7841	343	22	- 8	37	70.57	69.38	40.39	6.6	.106	.03	1.06	-0.2	.49	1.0
12577	269	58	-14	14	29.65	27.70	36.55	79.7	.152	5.80	.33	-0.6	1.06	1.0
7871	269	57	-30	46	26.06	23.67	34.94	81.8	.274	4.60	.03	0.6	1.14	1.0

Table 1.—*Basic orbital data*

Trail No.	Day	Yr.	Mo.	Sh. No.	a	e	q	q'	ω	☊	i	π
7873	13.36	53	6	65	9.277	.925	.695	17.858	249.9	82.0	131.0	331.9
7882	13.41	53	6	61(62)	3.371	.721	.940	5.801	214.6	82.0	18.7	296.6
4111	14.19	52	6	63	2.461	.630	.911	4.011	42.8	263.0	4.3	305.8
7902	16.35	53	6		5.778	.957	.251	11.300	302.7	84.8	147.3	27.5
4125	19.30	52	6	61(62)	2.838	.660	.966	4.710	209.0	87.9	17.5	296.9
7929	20.39	53	6		191.000	.996	.732	381.300	243.9	88.7	174.4	332.6
4136	21.41	52	6		17.310	.947	.911	33.700	218.2	89.9	94.4	308.1
4138	21.42	52	6	68	18.010	.951	.886	35.130	137.4	89.9	153.6	227.3
4141	22.18	52	6	52	2.502	.603	.994	4.010	160.4	90.7	16.3	251.0
4143	22.19	52	6	67	2.937	.839	.473	5.401	279.9	90.7	14.4	10.6
4147	22.22	52	6	66	2.229	.702	.665	3.792	260.7	90.7	3.6	351.4
4151	22.38	52	6	68	78.887	.988	.968	156.807	154.6	90.8	163.1	245.5
4153	23.28	52	6	66	2.773	.720	.778	4.769	244.0	91.7	3.0	335.7
4181	25.22	52	6	67	3.923	.878	.480	7.366	277.4	93.6	13.0	11.0
12714	25.26	54	6		2.009	.717	.568	3.449	273.2	93.1	16.9	6.3
4199	29.43	52	6	3	1.502	.852	.223	2.780	314.2	97.6	7.4	51.8
10566	30.25	54	6		55.990	.982	1.009	110.960	189.7	97.9	33.6	287.6
7944	6.30	53	7	69	3.092	.761	.738	5.446	248.5	103.9	7.2	352.4
7946	6.31	53	7	72(73)	2.491	.621	.945	4.038	215.4	103.9	18.1	319.3
8012	15.25	53	7		3.898	.862	.537	7.258	271.1	112.4	21.8	23.5
8017	15.26	53	7	69	3.042	.756	.741	5.343	68.2	292.4	2.5	0.7
8054	16.28	53	7		26.200	.967	.859	51.530	133.3	113.4	95.5	246.7
8068	16.38	53	7		26.230	.978	.588	51.860	278.5	293.5	147.8	212.0
8075	16.41	53	7	20	1.553	.925	.117	2.988	327.4	113.5	26.5	80.9
8083	16.43	53	7		7.045	.919	.571	13.519	265.2	113.5	166.9	18.7
3355	19.41	52	7	3	2.489	.901	.248	4.730	126.6	296.6	0.9	63.2
8089	20.36	53	7		- 80.920	1.012	.973	-162.800	203.7	117.3	43.6	321.0
3360	21.35	52	7	5	2.795	.983	.047	5.542	157.5	298.5	33.1	95.9
8106	21.39	53	7		1.285	.812	.242	2.328	134.5	298.3	6.3	72.7
8108	21.40	53	7		12.150	.916	1.015	23.290	177.1	118.3	72.9	295.4
8110	21.41	53	7	3	2.559	.860	.358	4.760	293.7	118.3	5.4	52.0
8113	23.42	53	7	68	22.880	.957	.986	44.770	160.1	120.2	164.3	280.3
3377	24.34	52	7		34.060	.971	.994	67.130	197.1	121.3	129.8	318.4
3379	24.36	52	7	1	2.528	.765	.594	4.461	267.6	121.3	7.7	28.9
3386	25.27	52	7	1	2.134	.732	.573	3.694	271.9	122.2	7.6	34.1
3393	25.42	52	7	70	6.208	.912	.545	11.870	268.4	122.4	44.1	30.7
3399	25.44	52	7	5	2.848	.978	.063	5.632	153.8	302.4	27.3	96.2
3405	26.22	52	7	1	2.447	.775	.551	4.344	272.8	123.1	7.6	35.9
3407	26.25	52	7	3	3.337	.920	.266	6.408	122.7	303.2	1.9	65.9
3411	26.27	52	7	1	2.069	.725	.568	3.569	272.7	123.2	5.3	35.9
3416	26.35	52	7	1	2.536	.774	.574	4.499	269.9	123.3	7.2	33.1
3424	27.27	52	7	5	3.001	.977	.069	5.933	152.4	304.1	26.1	96.5
3450	28.31	52	7	5	2.358	.973	.064	4.652	154.2	305.1	30.1	99.3
3463	28.31	52	7	5	3.084	.979	.064	6.105	153.3	305.1	25.6	98.4
3487	29.42	52	7	5	2.179	.969	.067	4.291	153.8	306.2	28.5	100.0
8127	3.19	53	8		2.305	.725	.635	3.970	263.7	130.5	25.3	34.2
8143	4.21	53	8	73(72)	3.582	.737	.942	6.222	213.7	131.5	29.4	345.1
8147	4.22	53	8	1	2.482	.801	.495	4.469	278.7	131.5	6.7	50.2
8149	4.25	53	8	1	2.588	.768	.601	4.575	266.5	131.5	7.0	38.0
8153	4.29	53	8	7	22.370	.958	.942	43.790	148.6	131.6	112.4	280.1
3497	4.46	52	8		2.751	.635	1.005	4.496	167.4	132.0	43.1	299.4
8168	5.24	53	8	50	2.751	.976	.065	5.437	333.4	132.5	23.8	105.8
8187	5.33	53	8	5	2.950	.967	.098	5.801	146.9	312.6	24.1	99.4
8189	5.34	53	8		3.126	.750	.781	5.470	242.4	132.6	13.0	15.0
8192	5.35	53	8	71	.947	.723	.263	1.631	140.1	312.6	10.2	92.6
8215	5.43	53	8		19.527	.954	.908	38.147	141.7	132.6	69.8	274.4
8224	5.45	53	8	7	23.080	.958	.960	45.200	152.8	132.7	111.2	285.5
8238	6.21	53	8	5	2.779	.961	.109	5.450	145.2	313.4	25.4	98.6
8240	6.22	53	8		5.844	.854	.854	10.830	229.0	133.4	36.2	2.4
8244	6.24	53	8	74(75)	2.950	.662	.995	4.900	197.8	133.4	13.9	331.2

for double-station meteors (continued)

Trail No.	True radiant α °	'	δ °	'	V_∞	V_G	V_H	λ	Sin Q	C.W.	K	M_p	t	Qual.
7873	322	9	10	56	63.03	61.81	40.61	33.2	.238	2.20	1.38	-0.4	.42	1.5
7882	240	23	26	43	19.62	16.54	38.50	111.1	.125	10.40	.32	1.0	1.10	4.0
4111	226	18	-30	0	16.82	12.64	37.21	119.7	.414	3.85	.03	-0.8	1.34	1.0
7902	317	33	- 4	57	60.17	58.93	39.89	37.5	.004	2.80	1.41	-0.2	.38	3.0
4125	240	33	29	27	18.37	14.82	37.84	114.0	.427	8.29	.14	1.3	.56	1.5
7929	340	14	- 5	15	69.42	68.30	41.70	18.9	.015	.20	4.00	-1.8	.51	2.5
4136	319	27	35	35	53.45	52.25	41.14	51.7	.147	2.52	1.81	-1.2	.37	2.0
4138	5	42	18	28	68.79	67.60	38.67	19.5	.327	.63	1.85	-0.6	.38	2.0
4141	179	5	61	9	16.92	12.94	37.28	118.7	.099	3.70	.00	0.3	.70	2.5
4143	276	40	- 8	59	29.90	27.49	37.97	83.9	.198	7.60	.53	1.4	.79	1.5
4147	265	13	-17	35	22.70	19.65	36.69	95.1	.086	3.05	.10	-1.9	1.08	2.0
4151	3	45	12	15	70.97	69.76	41.62	12.4	.229	.20	3.11	-0.7	.47	2.0
4153	256	0	-17	2	20.58	17.42	37.74	104.9	.393	2.75	.23	0.1	.81	1.5
4181	278	5	-10	22	30.45	28.15	38.95	85.4	.058	6.77	.78	-1.6	.79	3.0
12714	276	53	- 2	4	25.92	23.31	36.09	85.9	.211	10.90	.09	0.1	.81	1.5
4199	299	18	-16	4	32.12	30.32	33.96	69.4	.466	3.51	.27	1.5	.67	3.0
10566	250	11	54	32	26.18	23.77	41.56	102.6	.337	INF	2.79	-3.2	1.30	2.0
7944	272	8	-11	0	22.20	19.34	38.16	101.5	.414	6.09	.36	0.5	1.21	1.5
7946	257	33	25	23	18.49	15.08	37.25	110.0	.798	10.40	.03	-0.7	2.55	1.0
8012	294	48	1	51	30.09	27.86	38.94	85.9	.087	10.90	.72	-0.6	.97	1.0
8017	281	1	-27	35	21.77	18.74	38.11	102.8	.186	2.20	.34	1.6	.94	1.0
8054	23	59	60	25	54.13	52.79	41.35	51.3	.198	3.20	2.20	-1.5	.60	1.0
8068	50	42	2	51	65.67	64.33	41.35	29.3	.218	1.60	2.36	0.5	.81G	2.0
8075	321	4	- 4	50	37.57	35.99	34.25	62.3	.399	8.60	.60	-0.3	.59	1.0
8083	357	25	5	34	65.99	64.95	40.22	24.6	.103	.70	1.22	-0.9	.35	2.0
3355	315	41	-17	27	34.28	32.58	37.25	73.8	.504	.41	.68	0.9	.40	3.0
8089	280	58	50	43	31.38	29.53	41.89	90.8	.099	4.90	INF	-0.9	.88	3.0
3360	333	49	-17	52	44.34	42.85	37.78	59.7	.291	7.54	1.52	-0.8	.22	2.0
8106	323	15	-19	10	29.91	27.84	32.47	69.2	.321	3.38	.09	1.5	.72	1.0
8108	334	1	67	34	44.11	42.70	40.88	66.2	.350	INF	1.45	-0.4	.55	1.0
8110	310	25	-13	44	31.05	29.22	37.39	79.4	.325	2.90	.53	1.4	.76	1.0
8113	30	36	22	8	70.85	69.72	41.30	10.7	.401	.10	2.02	-2.2	.43	2.0
3377	10	28	36	46	65.33	64.14	41.46	30.0	.552	.30	2.36	-0.8	.38	1.5
3379	300	13	-10	0	24.84	22.42	37.34	91.4	.385	5.88	.28	1.0	.51	2.0
3386	303	11	- 9	39	24.72	22.02	36.46	89.3	.147	5.71	.14	1.0	.45	2.0
3393	309	48	20	10	36.05	34.54	40.03	77.2	.309	12.68	1.13	0.6	.45	1.5
3399	335	53	-17	4	43.05	41.73	37.86	61.5	.517	6.89	1.41	0.1	.44	2.0
3405	304	39	-10	1	26.10	23.44	37.19	88.9	.036	5.21	.29	-1.7	.95	2.0
3407	320	38	-16	40	35.16	33.16	38.46	75.7	.082	.80	.91	-0.9	.25	2.5
3411	304	54	-12	22	24.47	21.75	36.29	89.3	.035	4.07	.11	1.5	.35	2.5
3416	303	20	-10	24	25.34	22.95	37.36	90.4	.339	5.35	.30	1.0	.54	2.0
3424	336	56	-16	43	43.23	41.54	38.08	62.2	.008	6.48	1.41	-1.4	.62	2.0
3450	339	39	-16	28	42.71	41.06	37.01	60.8	.068	7.45	1.23	-0.7	.29	2.5
3463	337	57	-15	55	43.42	41.83	38.18	62.0	.118	6.33	1.47	-0.8	.52	2.0
3487	340	33	-16	2	41.82	40.41	36.59	60.9	.466	7.48	1.14	0.1	.37	2.0
8127	307	57	15	5	26.80	24.18	36.91	86.6	.228	13.77	.16	1.8	.50	1.5
8143	282	58	39	24	23.67	20.91	38.72	99.4	.726	9.50	.37	-0.4	.70	1.0
8147	315	57	- 9	4	27.52	24.99	37.28	86.3	.150	4.20	.35	1.7	.30	2.0
8149	309	39	- 8	35	24.91	22.23	37.48	92.2	.223	5.20	.29	1.1	.65	2.0
8153	37	50	56	9	60.10	58.85	41.32	40.7	.280	1.40	2.02	-1.3	.52	2.0
3497	262	9	74	52	28.17	25.99	37.75	85.8	.072	INF	.09	0.5	.38	2.5
8168	340	21	- 1	55	42.99	41.26	37.75	62.0	.232	5.98	1.36	-1.1	.62	2.5
8187	343	25	-15	14	41.61	40.00	38.04	64.4	.036	6.60	1.24	0.3	.48	3.0
8189	296	8	3	15	21.65	18.82	38.26	103.0	.542	10.80	.34	2.2	.71	1.0
8192	343	40	-16	28	25.48	22.86	28.48	64.7	.169	6.70	- .23	1.0	.41	2.0
8215	59	33	83	10	43.62	42.15	41.25	67.8	.277	4.60	1.91	1.3	.58	2.0
8224	36	26	56	57	59.70	58.57	41.34	41.3	.411	1.20	2.04	-0.2	.28	3.0
8238	344	18	-15	54	41.26	39.41	37.80	64.8	.088	7.00	1.14	0.5	.95	2.0
8240	297	48	36	1	28.77	26.48	39.95	91.2	.670	11.30	.87	-0.8	.75	1.5
8244	258	39	24	1	16.50	12.46	38.04	125.9	.061	3.30	.16	1.8	1.17	2.0

TABLE 1.—*Basic orbital data*

Trail No.	Day	Yr.	Mo.	Sh. No.	a	e	q	q'	ω	☊	i	π
8254	6.29	53	8	5	3.814	.972	.109	7.520	144.3	313.5	19.2	97.8
8294	7.39	53	8	74(75)	2.063	.515	1.000	3.125	196.2	134.5	7.7	330.7
8307	8.19	53	8	3	3.316	.927	.243	6.390	125.5	315.3	7.5	80.8
8344	8.39	53	8	5	2.458	.963	.092	4.820	148.7	315.5	26.9	104.2
8368	9.21	53	8	10	2.525	.804	.496	4.554	278.5	136.3	11.8	54.7
8394	10.22	53	8	75(74)	2.362	.587	.976	3.747	205.8	137.2	4.3	343.1
8401	10.24	53	8	7	51.492	.982	.949	102.034	150.6	137.3	110.9	287.9
8413	10.30	53	8	120	2.870	.647	1.012	4.728	184.8	137.3	39.2	322.1
8415	10.30	53	8	75(74)	2.477	.603	.984	3.970	202.9	137.3	1.2	340.2
8417	10.32	53	8	71	1.168	.787	.249	2.088	315.5	137.3	14.4	92.9
8658	10.44	53	8	7	25.750	.964	.935	50.560	147.3	137.4	113.5	284.7
8668	10.45	53	8	1	2.672	.748	.673	4.671	257.6	137.5	7.2	35.1
8447	11.42	53	8	72(73)	4.175	.774	.944	7.407	212.5	138.4	22.1	350.9
8679	11.46	53	8	7	135.595	.993	.951	270.239	151.3	138.4	113.6	289.7
8469	13.24	53	8	7	28.250	.967	.939	55.560	148.3	140.1	113.5	288.4
8476	13.28	53	8	12073(72)	3.171	.688	.990	5.352	199.2	140.2	28.9	339.4
8510	13.42	53	8	72(73)	2.495	.617	.955	4.034	211.8	140.3	17.3	352.1
8463	13.45	53	8	7	17.738	.946	.958	34.517	152.7	140.3	113.8	293.0
8719	14.19	53	8	7	10.189	.908	.937	19.442	147.4	141.0	114.0	288.5
8726	14.29	53	8	7	18.598	.948	.960	36.240	153.1	141.1	115.5	294.2
8546	14.29	53	8		2.793	.701	.834	4.753	55.1	321.1	3.6	16.3
8572	14.43	53	8		10.720	.960	.425	21.010	100.7	321.3	159.7	62.0
8576	14.43	53	8		- 10.272	1.075	.770	- 21.314	57.5	321.3	89.1	18.8
3567	15.32	52	8	1	3.105	.827	.538	5.672	272.1	142.4	0.4	54.4
3573	15.37	52	8		1.358	.925	.102	2.614	330.6	142.4	22.1	113.0
8609	17.32	53	8	70	6.134	.840	.982	11.287	200.9	144.1	121.6	345.0
3604	18.25	52	8		20.917	.952	1.011	40.823	183.4	145.2	44.7	328.6
3610	18.34	52	8	5	2.487	.970	.075	4.898	331.7	145.3	16.9	117.0
3612	18.35	52	8	7	10.171	.906	.961	19.381	153.3	145.3	109.2	298.6
3629	18.46	52	8	20	2.183	.897	.225	4.142	310.2	145.4	5.3	95.6
3633	20.21	52	8	12073(72)	2.880	.651	1.008	4.755	188.1	147.1	33.8	335.2
3636	20.24	52	8	1	2.610	.753	.645	4.575	261.0	147.1	0.1	48.1
3640	20.27	52	8	74(75)	3.359	.704	.994	5.724	196.7	147.1	9.6	343.8
3643	21.19	52	8	1	2.735	.808	.525	4.945	274.4	148.0	4.3	62.4
3651	21.29	52	8	10	2.746	.787	.586	4.906	267.5	148.1	1.2	55.6
3655	21.30	52	8	10	6.313	.902	.621	12.010	259.3	148.1	8.0	47.4
3657	21.40	52	8		16.815	.946	.905	32.720	141.5	148.2	100.2	289.7
3663	21.46	52	8	71	1.431	.824	.252	2.610	311.5	148.3	6.8	99.8
3784	22.24	52	8	3	2.580	.931	.178	4.982	135.2	329.0	13.8	104.2
3786	22.27	52	8		1.675	.624	.630	2.719	88.9	329.1	3.8	58.0
4216	25.26	52	8	70	56.500	.982	1.010	112.000	182.1	152.0	111.8	334.0
3813	25.44	52	8	12073(72)	2.758	.634	1.011	4.507	178.6	152.1	32.4	330.7
3847	30.36	52	8	70	43.673	.977	1.009	86.337	178.9	156.9	107.6	335.7
3861	30.46	52	8		6.879	.868	.909	12.849	218.2	157.0	93.2	15.2
3877	31.47	52	8	71	.958	.752	.237	1.678	321.3	158.0	4.5	119.3
3886	1.47	52	9	?	1.640	.806	.318	2.962	302.3	158.9	1.9	101.2
4289	10.15	52	9	76(77)	3.780	.769	.874	6.687	225.9	167.3	5.8	33.2
4311	13.27	52	9		2.590	.690	.804	4.377	59.5	350.4	11.4	49.9
4313	13.32	52	9	77(76)	2.694	.643	.961	4.426	207.6	170.4	7.9	18.0
4328	14.21	52	9	79(80)	3.800	.834	.633	6.969	259.3	171.3	13.6	70.6
4330	14.23	52	9		59.005	.985	.903	117.107	217.5	171.3	125.4	28.8
4340	14.31	52	9	80(79)	2.374	.724	.654	4.093	80.3	351.4	6.1	71.7
4351	14.37	52	9	80(79)	1.931	.720	.541	3.321	96.0	351.4	12.0	87.4
4360	16.15	52	9	78	3.970	.884	.462	7.479	278.7	173.2	73.1	91.9
4369	16.33	52	9	79(80)	2.961	.818	.537	5.383	271.9	173.4	7.2	85.2
4388	17.27	52	9	77(76)	3.326	.717	.940	5.711	212.2	174.3	3.5	26.5
4394	17.31	52	9	20	2.470	.894	.263	4.678	124.4	354.3	4.5	118.7
4229	19.20	52	9		3.385	.718	.956	5.815	152.1	176.2	53.6	328.2
4454	19.36	52	9	81	23.080	.957	.997	45.170	170.3	176.3	144.6	346.6
4464	19.43	52	9	79(80)	2.307	.707	.675	3.938	257.9	176.4	7.5	74.3

for double-station meteors (continued)

Trail No.	True	radiant	V_∞	V_G	V_H	λ	Sin Q	C.W.	K	M_p	t	Qual.
	α ° '	δ ° '										
8254	342 7	-14 30	41.72	40.06	38.92	66.1	.087	5.30	1.42	1.6	.42	3.0
8294	253 58	11 34	13.73	8.68	36.31	138.3	.183	INF	- .19	0.5	.64	2.5
8307	335 7	-15 6	36.06	33.99	38.48	74.4	.093	2.91	.94	0.8	1.02	1.0
8344	347 41	-14 9	41.23	39.73	37.25	63.2	.407	7.40	1.11	0.7	.46	1.0
8368	319 38	- 2 13	27.99	25.48	37.38	85.6	.004	7.10	.37	0.5	.70	2.0
8394	266 52	- 6 35	14.52	9.57	37.06	138.1	.497	2.70	- .04	1.0	1.03	1.0
8401	44 11	58 47	59.93	58.70	41.61	41.6	.266	1.30	2.74	-1.6	.90	1.0
8413	273 54	64 53	26.29	23.97	37.94	90.1	.082	INF	.13	1.6	.82	2.0
8415	262 5	-18 30	14.12	9.19	37.29	145.1	.403	.70	.00	1.5	.85	1.0
8417	338 5	2 2	29.18	26.92	31.46	67.8	.207	7.72	- .01	-1.1	.28	2.5
8658	46 46	57 16	60.46	59.31	41.40	40.1	.560	1.40	2.14	-0.9	.40	2.0
8668	310 23	- 6 30	22.78	20.29	37.64	96.8	.260	6.40	.27	1.2	.97	1.0
8447	281 17	29 43	20.83	18.02	39.20	109.2	.095	10.60	.52	1.2	1.50	1.0
8679	45 53	57 33	60.80	59.69	41.74	40.1	.501	1.25	3.59	-2.5	.72	3.0
8469	49 56	58 0	60.59	59.37	41.45	40.1	.269	1.40	2.22	-2.6	1.33	1.5
8476	275 42	48 3	22.19	19.40	38.34	101.6	.069	4.51	.23	-0.1	.85	2.0
8510	280 8	26 33	17.74	14.26	37.34	112.9	.138	10.00	.02	-1.5	.93	1.0
8463	47 13	57 38	60.52	59.34	41.22	39.6	.219	1.14	1.80	-0.1	.65	1.5
8719	51 5	57 39	60.13	58.93	40.78	39.5	.270	1.39	1.33	-2.0	.40G	2.0
8726	48 28	56 54	61.10	59.87	41.25	38.7	.223	1.07	1.85	-3.6	.96	1.5
8546	303 46	-28 22	18.79	15.28	37.85	111.9	.385	3.70	.20	0.8	1.89	1.0
8572	23 34	0 45	64.21	63.16	40.83	30.9	.255	1.30	1.72	-0.4	.32	3.0
8576	34 7	-36 8	52.79	51.50	42.85	56.3	.041	4.69	INF	0.5	.60	4.0
3567	325 10	-13 24	26.85	24.50	38.27	90.0	.427	.28	.52	0.3	.74	1.0
3573	349 46	4 20	36.80	35.11	33.13	61.0	.462	7.45	.54	-1.6	.60	1.0
8609	30 39	48 38	61.91	60.70	40.08	34.5	.310	.60	.85	-1.2	.37	2.0
3604	273 28	65 37	31.01	29.06	41.34	89.9	.309	INF	1.93	-0.3	.44	2.0
3610	351 48	1 36	41.56	40.00	37.35	62.9	.134	4.70	1.21	0.2	.46	2.0
3612	52 59	61 26	58.71	57.48	40.79	42.2	.322	1.22	1.31	-0.3	.43	2.0
3629	343 54	- 3 31	34.20	32.63	36.68	72.3	.329	2.33	.61	1.4	.55	2.0
3633	271 46	59 10	23.91	21.27	38.00	95.8	.255	INF	.13	0.8	.83	1.0
3636	324 16	-14 2	23.46	20.55	37.58	95.8	.121	.08	.27	0.1	1.42	1.0
3640	265 10	11 4	15.59	11.34	38.57	137.6	.355	2.88	.29	-2.0	2.06G	1.0
3643	330 19	- 6 46	27.00	24.36	37.79	88.7	.083	2.84	.41	1.6	.62	3.0
3651	328 9	-11 15	25.12	22.53	37.81	92.4	.439	.90	.36	0.8	.65	1.5
3655	321 43	- 3 59	26.74	24.42	40.14	95.9	.543	5.42	1.09	0.3	.88	1.0
3657	68 49	67 22	55.84	54.59	41.22	48.1	.280	2.30	1.78	-0.1	.29	2.0
3663	347 13	- 0 21	30.35	28.53	33.65	71.0	.408	3.65	.17	0.5	.89	1.5
3784	353 31	-10 1	37.50	35.56	37.54	69.8	.055	4.83	.86	-0.6	.37	2.0
3786	332 40	-17 59	21.28	18.09	34.98	91.6	.278	3.62	- .14	-0.3	.64	1.0
4216	44 9	59 45	60.51	59.29	41.69	40.8	.332	INF	2.80	0.2	.48	2.0
3813	259 25	60 54	23.11	20.44	37.85	97.0	.107	INF	.09	1.6	1.18	1.5
3847	51 45	63 54	59.03	57.85	41.66	43.3	.283	INF	2.57	-0.2	.17	2.5
3861	17 11	61 32	52.24	51.12	40.33	52.0	.241	2.72	.99	-2.4	.52	2.0
3877	2 29	4 58	25.95	23.73	28.84	64.6	.314	3.02	- .17	1.2	.83	1.0
3886	353 57	- 0 54	29.16	27.29	34.87	75.7	.292	1.14	.18	0.7	1.16	1.0
4289	316 37	- 1 33	18.82	15.04	39.06	118.6	.114	5.29	.46	0.5	1.00	1.0
4311	346 20	-31 59	20.13	16.77	37.68	105.3	.167	10.23	.15	-1.1	.43	2.0
4313	298 57	7 22	15.37	11.07	37.85	131.5	.363	6.01	.09	1.6	1.14	1.0
4328	341 7	12 23	25.81	23.18	39.10	94.9	.423	9.35	.62	-0.3	.73	1.0
4330	57 58	51 48	64.16	63.00	41.80	33.8	.253	1.33	2.88	-2.5	.60	1.5
4340	351 26	-14 10	22.74	19.90	37.27	95.7	.553	5.30	.17	0.0	1.10	1.0
4351	2 30	-15 41	24.98	22.51	36.10	86.6	.570	8.96	.07	0.3	.72	1.5
4360	11 41	45 59	45.40	43.77	39.24	61.1	.326	9.25	.81	0.1	.34	2.0
4369	351 41	5 49	26.73	24.43	38.26	89.6	.430	4.96	.47	1.1	.77	1.0
4388	310 36	- 6 40	16.02	11.85	38.69	132.9	.530	3.17	.31	1.6	1.08	1.0
4394	10 39	1 24	33.85	31.93	37.48	74.9	.174	2.00	.64	0.8	.48	1.5
4229	213 28	73 16	34.18	32.44	38.76	77.1	.123	4.86	.31	1.0	.76	1.0
4454	89 48	44 8	69.05	67.90	41.55	20.8	.250	.21	2.01	0.0	.25	3.0
4464	346 25	7 44	21.89	19.25	37.15	96.6	.355	7.03	.13	-0.9	2.27	1.0

Table 1.—*Basic orbital data*

Trail No.	Day	Yr.	Mo.	Sh. No.	a	e	q	q'	ω	☊	i	π
4472	20.25	52	9	12Q	3.580	.720	1.001	6.150	186.7	177.2	32.0	3.8
4505	20.37	52	9	80(79)	3.121	.817	.572	5.669	87.6	357.3	1.1	84.9
4507	20.38	52	9	2Q	1.521	.792	.317	2.726	123.3	357.3	8.5	120.6
4513	20.39	52	9	9Q	2.356	.575	1.002	3.710	174.4	177.3	24.3	351.7
4702	24.14	51	9	82	3.012	.680	.965	5.059	205.0	180.3	49.0	25.2
4534	25.28	52	9	82	4.431	.777	.988	7.875	195.0	182.1	48.4	17.1
4542	25.33	52	9	80(79)	1.983	.713	.568	3.398	92.3	2.2	5.8	94.5
4574	26.22	52	9	2	1.154	.782	.252	2.056	134.9	3.0	5.3	138.0
4596	26.36	52	9		2.139	.573	.913	3.366	220.9	183.2	29.6	44.0
4618	27.28	52	9		2.220	.677	.719	3.730	72.5	4.1	1.9	76.6
4622	27.29	52	9	81	78.830	.988	.949	156.700	153.2	184.1	137.9	337.3
4624	27.30	52	9	76(77)	2.986	.721	.833	5.139	233.3	184.1	1.6	57.4
4645	27.40	52	9		51.248	.991	.463	102.000	94.7	4.2	115.4	98.9
4659	27.46	52	9		1.311	.497	.659	1.963	91.8	4.2	6.2	96.0
4657	27.46	52	9	80(79)	3.004	.788	.638	5.371	79.9	4.2	5.7	84.1
4677	28.38	52	9		35.480	.972	1.002	69.960	181.7	185.2	64.9	6.8
4679	28.39	52	9	76(77)	3.527	.749	.884	6.169	223.4	185.2	3.1	48.6
4683	28.41	52	9	81	75.109	.987	.945	149.273	152.4	185.2	134.9	337.6
8766	30.19	53	9	80(79)	2.311	.737	.607	4.016	85.9	6.7	5.5	92.5
4701	30.48	52	9	2	1.670	.820	.300	3.030	123.7	7.2	6.3	130.9
2961	2.22	51	10	2Q	2.701	.864	.366	5.036	291.6	188.2	2.7	119.8
8793	2.28	53	10		5.242	.854	.767	9.717	240.5	188.7	27.0	69.3
8817	2.35	53	10		15.730	.948	.825	30.630	129.7	188.8	151.1	318.5
8819	2.35	53	10	78	13.990	.973	.373	27.600	285.8	188.8	66.1	114.6
8881	6.24	53	10	9Q	3.356	.705	.990	5.722	167.5	192.6	15.4	0.1
8891	6.29	53	10		8.554	.886	.971	16.140	200.0	192.7	48.4	32.7
8917	7.39	53	10		1.919	.649	.673	3.166	80.2	13.8	1.9	93.9
8943	9.19	53	10	9	3.371	.704	.998	5.743	177.0	195.5	24.6	12.5
8945	9.19	53	10	2	1.539	.826	.268	2.811	128.1	15.6	5.8	143.7
8951	9.23	53	10	9	3.293	.697	.998	5.587	176.9	195.6	24.6	12.5
8976	9.31	53	10		19.447	.949	.998	37.896	177.0	195.7	104.0	12.7
8974	9.31	53	10	85	2.029	.744	.520	3.539	97.1	15.7	9.7	112.8
8990	9.47	53	10	2Q	1.109	.755	.271	1.947	133.8	15.8	4.1	149.6
9015	10.29	53	10	2	1.747	.829	.299	3.195	123.1	16.6	7.0	139.7
9030	10.39	53	10		1.898	.715	.540	3.255	275.7	196.7	3.6	112.5
9062	12.44	53	10		5.385	.940	.324	10.447	246.8	18.8	146.0	265.6
9087	16.46	53	10		1.671	.548	.756	2.585	71.5	22.7	16.9	94.3
4952	19.44	52	10		.948	.127	.827	1.069	119.9	26.0	2.8	145.9
9104	20.47	53	10	2	1.740	.825	.304	3.176	122.4	26.7	6.1	149.1
4962	21.20	52	10	83	3.693	.756	.902	6.484	218.5	207.7	22.8	66.2
4964	21.20	52	10	84	3.237	.693	.994	5.479	176.4	207.7	13.0	24.1
4966	21.22	52	10	85	2.118	.762	.504	3.733	98.1	27.7	6.4	125.9
4974	21.27	52	10	8Q	57.176	.988	.664	113.688	70.7	27.8	145.1	98.5
5006	21.34	52	10	8	14.983	.959	.614	29.352	77.4	27.8	164.8	105.2
5022	21.40	52	10	2	2.055	.830	.349	3.760	115.6	27.9	5.8	143.5
5045	21.48	52	10		3.514	.729	.952	6.075	206.2	208.0	71.2	54.1
5047	22.13	52	10		1.583	.479	.825	2.342	61.8	28.6	4.0	90.5
5063	22.26	52	10	8Q	26.773	.971	.773	52.774	236.8	208.8	173.0	85.6
5073	22.29	52	10	83	3.016	.686	.946	5.087	208.5	208.8	23.1	57.2
5079	22.31	52	10	8	12.667	.953	.592	24.743	80.2	28.8	164.3	109.0
5083	22.33	52	10	8	18.935	.972	.533	37.337	86.7	28.8	163.8	115.5
5101	22.37	52	10	8	11.178	.949	.574	21.781	82.5	28.9	163.8	111.3
5112	22.43	52	10	8	29.377	.981	.546	58.209	84.9	28.9	165.5	113.8
5124	22.47	52	10	2Q	2.760	.829	.473	5.048	99.1	29.0	5.3	128.1
5176	23.42	52	10	2	2.022	.836	.333	3.712	117.5	29.9	5.5	147.4
5180	23.44	52	10	17	2.258	.865	.305	4.211	299.7	209.9	3.9	149.6
5195	23.48	52	10	2	2.046	.813	.383	3.710	111.8	30.0	5.0	141.8
5231	24.27	52	10	8Q	22.758	.973	.609	44.908	257.6	210.8	158.0	108.4
5237	24.30	52	10	86	16.244	.962	.620	31.868	76.6	30.8	15.6	107.4
5257	24.38	52	10	17	2.153	.875	.269	4.036	304.2	210.9	3.2	155.1

for double-station meteors (continued)

Trail No.	True radiant α	δ	V_∞	V_G	V_H	λ	Sin Q	C.W.	K	M_p	t	Qual.
	° '	° '										
4472	276 15	57 1	23.50	20.93	38.95	99.2	.016	INF	.34	0.8	.91	2.0
4505	356 51	- 2 58	25.66	23.36	38.48	92.3	.525	.83	.49	1.9	.82	1.0
4507	15 20	- 1 3	29.03	26.95	34.39	74.6	.636	4.94	.12	2.0	.55	3.0
4513	258 33	50 36	19.30	16.00	37.27	105.5	.083	INF	- .06	-0.3	.84	2.0
4702	312 17	71 49	31.62	29.60	38.37	80.7	.288	4.84	.20	-2.1	.78	2.0
4534	295 6	72 10	31.78	29.90	39.59	83.3	.156	2.98	.55	-1.8	1.00	1.0
4542	6 33	- 5 56	23.86	21.22	36.34	89.5	.307	4.77	.07	1.2	.60	1.0
4574	24 58	6 3	28.62	26.09	31.63	68.7	.177	2.97	- .03	1.9	.80	1.0
4596	319 2	53 27	22.41	19.71	36.80	94.1	.005	12.00	- .10	2.0	.92	3.0
4618	356 19	- 5 36	20.50	17.28	37.02	100.6	.298	2.00	.06	1.9	.80	1.0
4622	108 22	46 46	67.87	66.69	41.92	25.6	.203	.67	3.11	0.3	.37	1.5
4624	341 6	- 3 48	18.57	15.09	38.36	113.9	.529	1.70	.27	0.9	.88	1.0
4645	61 57	- 6 6	58.85	57.69	41.85	44.1	.114	4.48	3.05	-1.1	.45	2.0
4659	10 31	- 9 16	18.16	14.75	33.06	89.5	.387	7.32	- .41	0.4	.88	1.0
4657	2 41	- 8 8	23.79	21.43	38.39	96.0	.317	4.90	.40	0.8	2.11	1.0
4677	256 27	83 54	41.15	39.65	41.76	72.4	.149	1.41	2.39	-0.5	.87	1.0
4679	332 44	- 2 21	17.50	13.99	38.96	121.9	.274	3.36	.39	-0.2	1.89	1.0
4683	110 54	48 16	67.16	66.01	41.92	27.4	.433	.76	3.07	-1.2	.40	1.5
8766	7 36	- 5 22	24.01	21.05	37.24	92.7	.224	4.30	.18	-0.4	1.30	1.0
4701	23 33	4 36	30.01	28.21	35.19	74.7	.414	3.50	.23	1.5	.92	2.0
2961	16 14	9 24	31.22	28.96	37.98	80.6	.205	1.40	.57	-2.2	.68	2.0
8793	342 58	38 36	26.59	24.28	40.02	95.0	.028	13.80	.82	1.2	.73	2.0
8817	119 47	36 33	68.89	67.68	41.41	21.3	.287	.83	1.77	0.7	.49	1.5
8819	24 4	44 35	45.45	44.11	41.32	64.7	.202	10.30	2.02	0.3	.38	1.0
8881	258 58	27 30	17.02	13.34	38.84	123.9	.132	5.10	.29	0.0	3.48G	1.0
8891	303 45	71 45	32.72	30.90	40.86	84.6	.152	4.60	1.15	-0.2	.85	1.0
8917	9 18	0 18	20.63	17.68	36.22	96.0	.424	2.00	- .04	0.6	.78	1.0
8943	270 56	47 14	20.20	17.16	38.88	108.7	.087	2.20	.29	0.1	1.10	2.0
8945	33 13	8 54	31.06	28.69	34.62	72.5	.206	2.90	.21	1.7	.90	1.0
8951	270 50	47 18	20.11	17.08	38.80	108.6	.063	2.20	.27	0.1	1.33	1.5
8976	123 8	66 42	57.96	56.74	41.58	45.3	.245	.30	1.87	0.6	.38	2.0
8974	23 15	- 3 8	25.66	23.15	36.58	86.4	.326	7.00	.14	-1.9	.42	1.5
8990	36 35	10 55	26.95	24.85	31.24	69.0	.221	2.70	- .10	1.6	.90	1.0
9015	32 24	7 23	30.88	28.71	35.61	74.9	.084	3.60	.27	-0.1	1.05	1.0
9030	16 29	12 10	24.07	21.61	36.17	87.9	.349	3.00	.06	1.2	1.09	1.0
9062	140 44	2 10	62.23	60.87	40.14	34.8	.186	2.50	1.24	0.2	.52	1.5
9087	30 36	-24 21	19.80	16.73	35.32	94.4	.328	15.30	- .24	0.2	.61	1.5
4952	50 31	- 6 42	11.49	3.41	29.07	72.5	.564	1.10	- .92	1.4	.79	2.0
9104	41 33	11 3	30.30	28.51	35.65	75.2	.225	3.40	.26	-0.1	.96	1.0
4962	336 9	47 3	21.65	18.69	39.25	105.4	.058	12.58	.42	0.0	.82	2.0
4964	282 41	24 34	15.92	11.84	38.82	131.7	.246	3.62	.25	1.7	1.00	1.0
4966	32 52	5 6	26.29	23.64	36.91	86.3	.121	4.43	.20	1.4	.72	1.5
4974	95 22	5 56	67.05	65.75	42.01	28.6	.199	1.52	2.99	-0.5	.77	1.0
5006	96 1	15 57	68.17	66.98	41.49	24.1	.185	.69	1.85	-0.3	.37	2.5
5022	39 42	10 17	30.13	28.20	36.74	78.3	.442	3.30	.35	-0.6	.90	1.0
5045	126 59	85 11	42.42	40.93	39.10	64.8	.197	3.14	.35	-1.2	.44	2.0
5047	16 30	- 5 32	16.26	11.55	34.95	106.2	.321	4.47	- .35	0.3	.73	1.0
5063	104 16	26 32	70.64	69.41	41.81	17.3	.252	.22	2.26	0.1	.55	2.0
5073	322 40	50 46	20.26	17.20	38.57	106.7	.102	10.85	.21	-1.0	1.82	1.0
5079	96 16	15 49	67.83	66.60	41.37	24.8	.205	.74	1.72	-1.1	.38	1.5
5083	93 57	15 57	67.27	66.07	41.65	26.9	.278	.85	2.12	-2.4	.46	1.5
5101	95 45	15 40	67.40	66.26	41.25	25.3	.317	.80	1.63	-1.3	.34	2.0
5112	94 30	16 38	67.51	66.50	41.85	26.3	.739	.75	2.50	-2.3	.39	1.5
5124	33 37	7 26	27.88	25.94	38.21	86.0	.304	3.50	.47	0.4	1.50	1.0
5176	42 20	11 35	30.47	28.62	36.66	77.5	.370	3.01	.35	-0.8	.90	1.0
5180	40 50	18 55	31.88	30.15	37.27	76.7	.149	1.99	.49	-0.6	.60	1.0
5195	39 55	10 43	28.92	27.05	36.73	80.1	.306	3.05	.30	0.9	.95	1.0
5231	99 30	33 49	67.83	66.60	41.75	25.8	.230	1.02	2.22	-0.6	.52	1.5
5237	31 39	- 8 6	28.61	26.39	41.56	94.9	.636	9.00	1.92	0.8	.77	1.0
5257	44 2	19 4	32.87	31.08	37.02	74.7	.360	1.52	.51	-1.7	.78	1.0

TABLE 1.—*Basic orbital data*

Trail No.	Day	Yr.	Mo.	Sh. No.	a	e	q	q'	ω	☊	i	π
5273	24.42	52	10		58.588	.989	.635	116.542	105.8	210.9	124.0	316.7
5289	24.49	52	10		327.815	.999	.204	655.426	233.9	31.0	177.2	264.8
9130	2.12	53	11	84	4.017	.755	.983	7.050	168.4	219.3	17.2	27.8
9147	2.29	53	11		10.660	.971	.314	21.000	292.8	219.5	121.1	152.3
9149	2.30	53	11		15.909	.981	.307	31.511	293.3	219.5	74.1	152.8
9170	3.20	53	11		6.507	.903	.633	12.381	76.3	40.4	39.4	116.7
9172	3.21	53	11		14.540	.951	.713	28.370	245.0	220.4	8.0	105.4
5332	7.09	52	11	18Q	2.790	.732	.749	4.830	245.0	224.6	17.4	109.6
9238	7.37	53	11	2	1.970	.793	.405	3.530	109.6	44.6	6.0	154.2
9240	7.37	53	11	2	1.881	.751	.469	3.293	103.2	44.6	5.2	147.8
9246	7.43	53	11	2	2.191	.823	.387	3.994	110.4	44.7	4.9	155.1
9252	7.46	53	11	18Q	2.292	.679	.735	3.849	248.8	224.7	0.0	113.5
9257	7.48	53	11	17	2.257	.844	.353	4.161	294.0	224.7	2.5	158.7
9265	9.25	53	11	17	2.326	.841	.369	4.283	291.9	226.5	3.5	158.4
9284	10.36	53	11		2.434	.722	.676	4.191	75.9	47.6	27.0	123.5
5346	11.21	52	11	2	2.000	.796	.409	3.600	109.0	48.7	5.8	157.7
5370	12.18	52	11		3.860	.748	.974	6.750	195.7	229.7	8.1	65.4
9331	13.35	53	11	17	2.073	.838	.336	3.810	296.7	230.6	3.1	167.3
9335	13.35	53	11		17.860	.978	.394	35.320	102.5	50.6	114.4	153.1
5450	15.48	52	11	13	12.557	.922	.983	24.131	171.0	233.0	161.8	44.0
5472	19.50	52	11		4.209	.770	.968	7.451	197.5	237.1	79.4	74.6
5511	21.44	52	11	17	3.540	.887	.400	6.670	105.4	59.1	0.4	164.5
9375	26.17	53	11		2.240	.697	.679	3.801	76.1	63.6	3.8	139.7
9379	1.13	53	12		3.501	.748	.882	6.121	221.2	248.6	14.7	109.8
9411	4.44	53	12	16	56.660	.995	.279	113.050	116.0	72.0	128.7	187.9
9416	7.39	53	12	20	2.167	.756	.529	3.805	94.3	74.9	6.5	169.2
9418	7.40	53	12	4	1.383	.903	.134	2.631	325.1	254.9	21.4	220.1
5551	9.25	52	12		34.874	.994	.220	69.527	303.9	257.1	135.2	201.0
5557	9.27	52	12		3.452	.773	.782	6.122	58.1	77.1	16.9	135.2
9451	9.37	53	12	4	1.244	.885	.143	2.345	325.1	256.9	23.4	222.0
5572	10.21	52	12	88	3.170	.696	.964	5.376	198.5	258.1	15.3	96.6
5601	11.19	52	12	4	1.379	.898	.141	2.617	324.2	259.1	24.3	223.3
5605	11.21	52	12	4	1.310	.894	.139	2.480	325.0	259.1	23.5	224.1
9507	11.39	53	12	4	1.263	.886	.144	2.381	35.2	259.0	24.1	223.8
5640	12.21	52	12	4	1.472	.904	.141	2.802	323.6	260.1	23.8	223.6
5644	12.22	52	12	4	1.275	.887	.144	2.405	324.7	260.1	21.7	224.8
5648	12.23	52	12	4	1.335	.893	.143	2.527	324.3	260.1	23.8	224.4
9547	12.35	53	12	4	1.376	.897	.142	2.610	324.0	260.0	23.6	224.0
5759	13.14	52	12	4	1.348	.894	.142	2.554	324.3	261.0	23.9	225.3
9611	13.31	53	12	4	1.471	.904	.141	2.801	323.5	261.0	23.5	224.5
8645	13.34	53	12	4	1.355	.896	.141	2.570	324.4	261.0	23.4	225.4
9627	13.36	53	12	4	1.412	.903	.137	2.687	324.5	261.0	22.8	225.5
9631	13.36	53	12	4	1.380	.897	.142	2.617	324.0	261.0	23.5	225.0
9656	13.43	53	12	4	1.362	.896	.141	2.582	324.3	261.1	23.2	225.4
9660	13.43	53	12	16	11.178	.980	.225	22.130	124.0	81.1	125.0	205.1
9709	13.52	53	12	4	1.361	.896	.142	2.580	324.3	261.2	23.6	225.4
9719	14.34	53	12	4	1.403	.899	.141	2.664	324.0	262.0	22.8	226.0
9725	14.37	53	12	4	1.353	.895	.142	2.564	324.3	262.0	23.5	226.3
9742	14.40	53	12	4	1.463	.904	.140	2.787	323.7	262.1	23.4	225.8
9749	14.40	53	12	4	1.394	.897	.143	2.644	323.8	262.1	23.5	225.9
8640	14.43	53	12		22.731	.957	.980	44.481	352.6	82.1	96.7	74.7
8648	15.48	53	12	16	11.870	.981	.225	23.520	123.9	83.2	124.9	207.0
9833	29.24	53	12		2.596	.740	.675	4.518	74.8	97.2	18.6	172.0
	:				:	:	:	:	:	:	:	:
	:				:	:	:	:	:	:	:	:

for double-station meteors (continued)

Trail No.	True radiant α	δ	V_∞	V_G	V_H	λ	Sin Q	C.W.	K	M_p	t	Qual.
	° ′	° ′										
5273	162 10	36 46	63.05	61.75	42.04	37.3	.239	2.75	3.03	-0.8	.34	3.0
5289	160 6	7 28	63.40	62.10	42.18	36.9	.223	.24	5.02	0.2	.35	2.0
9130	278 34	30 40	17.98	14.48	39.57	121.6	.258	6.50	.46	1.4	.88	1.0
9147	91 30	44 1	58.79	57.51	41.27	43.5	.321	4.70	1.85	-0.1	.47	2.0
9149	67 55	50 47	48.46	47.07	41.60	60.6	.516	9.50	2.21	-1.9	.39	2.0
9170	59 43	-21 48	33.83	31.66	40.63	82.3	.095	12.30	1.10	1.3	.86	1.0
9172	20 21	22 13	25.10	22.46	41.54	103.7	.265	5.80	1.76	-1.7	1.07	1.0
5332	20 13	42 9	23.04	19.96	38.36	98.2	.375	12.50	.26	1.1	.85	1.0
9238	53 48	13 18	28.35	26.23	36.58	80.8	.472	3.70	.23	0.2	.72	1.0
9240	50 52	12 31	26.20	23.90	36.30	83.7	.460	3.70	.12	0.3	.79	1.5
9246	53 45	14 41	29.34	27.43	37.20	80.5	.568	2.90	.35	1.1	.81	1.5
9252	31 4	12 40	19.84	16.87	37.44	102.2	.357	.02	.08	1.7	.81	1.0
9257	53 39	21 24	30.40	28.63	37.36	79.0	.289	1.40	.42	-1.2	1.51	1.0
9265	54 19	22 33	30.53	28.31	37.53	80.0	.387	1.90	.43	1.0	.57	1.5
9284	58 29	-18 34	26.34	23.99	37.76	87.8	.003	14.70	.18	-1.2	1.05	2.5
5346	57 33	14 18	28.75	26.28	36.72	81.0	.274	3.40	.25	0.7	.83	1.0
5370	334 50	21 26	15.58	11.20	39.51	142.0	.409	5.40	.43	1.3	.65	1.0
9331	61 8	23 24	30.75	28.75	36.93	77.7	.097	1.70	.37	-1.9	.92	1.0
9335	101 40	- 2 4	58.52	57.28	41.73	44.8	.149	4.80	2.20	-1.5	.50	1.0
5450	152 0	22 46	71.73	70.69	41.49	10.7	.435	.15	1.49	-3.3	.64	2.5
5472	180 47	68 33	46.75	45.30	39.79	59.7	.394	2.06	.51	-1.2	.60	1.0
5511	65 4	21 7	31.00	29.23	39.29	82.9	.287	.20	.77	-0.2	1.05	1.0
9375	56 13	13 0	21.96	18.72	37.42	97.1	.230	3.40	.10	1.0	.81	2.0
9379	22 22	48 39	19.63	16.14	39.30	112.4	.429	11.50	.39	-0.3	.93	1.0
9411	121 38	2 39	60.39	59.40	42.22	42.2	.066	4.20	3.36	-0.9	.50	2.0
9416	77 49	14 52	25.61	23.30	37.28	87.3	.085	4.80	.19	-0.4	1.05	1.5
9418	105 3	32 3	36.30	34.61	34.03	62.9	.205	7.40	.43	-0.9	.58	1.0
5551	133 53	31 39	60.76	59.42	42.12	42.0	.261	3.80	3.04	0.6	.40	2.0
5557	67 40	-10 12	22.67	19.78	39.28	101.5	.192	12.41	.43	-0.6	1.22	1.0
9451	108 33	33 11	35.23	33.41	32.98	62.2	.234	8.30	.31	0.0	.56	1.5
5572	353 9	53 19	17.19	13.35	38.99	122.0	.146	9.03	.25	1.4	1.15	1.0
5601	110 9	32 58	36.66	34.63	34.02	62.8	.301	7.92	.41	0.4	.58	1.0
5605	110 36	32 39	36.18	34.14	33.52	62.4	.366	7.84	.37	-2.7	1.14	1.0
9507	110 55	33 12	35.39	33.63	33.14	62.2	.293	8.50	.32	-0.4	.48	1.5
5640	110 33	32 35	37.13	35.14	34.61	63.4	.318	7.66	.47	0.9	.44	2.0
5644	111 24	32 8	35.56	33.51	33.24	62.6	.390	7.53	.33	-0.4	.60	1.0
5648	111 28	32 49	36.21	34.20	33.71	62.7	.438	7.96	.37	-0.7	.74	1.0
9547	110 58	32 40	36.26	34.46	34.00	63.0	.189	8.00	.40	-1.0	.55	1.0
5759	112 29	32 38	36.41	34.34	33.81	62.8	.273	7.86	.38	1.0	.67	1.0
9611	111 28	32 23	36.92	35.08	34.61	63.5	.351	7.70	.46	-0.8	.55	1.0
8645	112 20	32 23	36.20	34.39	33.86	62.8	.148	7.95	.39	-3.5	1.10	1.0
9627	111 57	31 56	36.61	34.85	34.25	63.0	.171	7.60	.44	-0.8	.48	2.0
9631	112 6	32 29	36.27	34.49	34.03	63.0	.232	8.00	.40	-0.2	.51	1.0
9656	112 18	32 18	36.04	34.40	33.90	62.9	.315	8.00	.40	-1.3	.63	1.0
9660	128 19	1 35	58.66	57.63	41.49	43.8	.036	4.80	2.04	-0.5	.45	2.5
9709	112 29	32 27	35.89	34.41	33.90	62.9	.154	8.30	.39	-0.2	.58	1.0
9719	112 56	31 59	36.43	34.63	34.19	63.2	.355	7.70	.42	0.9	.50	2.0
9725	113 31	32 20	36.10	34.34	33.85	62.8	.336	8.00	.39	-2.4	.95G	1.0
9742	112 48	32 6	36.76	35.09	34.57	63.4	.405	7.80	.46	-1.0	.54	1.0
9749	113 9	32 20	36.23	34.55	34.13	63.2	.271	8.00	.41	-2.5	.84	1.0
8640	152 22	-43 15	55.74	54.52	41.97	49.9	.086	1.09	2.01	-1.6	1.18G	1.0
8648	130 9	1 3	58.59	57.67	41.55	43.9	.061	4.90	2.09	-0.8	.43	2.0
9833	94 14	- 4 40	24.94	22.22	38.22	92.2	.176	12.10	.24	-0.2	.50	1.0

λ: Elongation of the true radiant from the apex of the earth's motion, in degrees.

sin Q: Q is the angle between the apparent great circles of motion as seen from the two stations.

C.W.: Cosmic weight, a weighting factor intended to be inversely proportional to the probability that meteoroids of constant mass in their observed orbits will, in one revolution, collide with the earth and produce photographable meteors. C.W. is calculated from the expression,

$$\text{C.W.}=\frac{V_G \sin i}{V_\infty^4}\left(2-\frac{1}{a}-p\right)^{1/2},$$

where $p=a(1-e^2)$; p and a are expressed in a.u. and the velocities in units of 100 km/sec (see Whipple, 1954).

K: A criterion designed to distinguish statistically between cometary and asteroidal orbits. The K criterion is defined by the expression $\log_{10}\left(\frac{q'}{1-e}\right)-1$, where the aphelion distance is measured in a.u. The term $q'/(1-e)$ is proportional to the inverse square of the aphelion velocity. In most cases $K>0$ for comets and $K<0$ for asteroids, but the values of K are not well known for asteroids of $q<1$.

M_p: Photographic absolute magnitude.

t: Duration of longer photographed trails in seconds of time. Trails both limited by the edge of film are designated by G.

Qual.: Quality class of velocity and orbit determination, defined in table 2 and in text (below).

Classification on the basis of quality

When all sources of possible error are added, the velocities of good meteors turn out to be correct to approximately 0.1 percent, those of fair meteors to some 0.4 percent, and those of poor meteors (comprising less than 10 percent of the total) to approximately 1 or 2 percent.

We have tried to assign to each meteor a grade of reliability by which it is classified. Table 2 gives for each quality class in table 1 the most probable value of the relative error and the maximum error to be expected if all causes of error were working in the same direction.

TABLE 2.—*Errors for meteors of various quality classes in table 1*

Quality class	Most probable error (%)	Maximum error (%)	No. of such meteors in table 1
1	0.1	0.13	173
1.5	0.2	0.3	78
2	0.4	0.7	103
2.5	0.7	1.5	23
3	1.0	3	32
3.5	2	6	0
4	3	10	4

Frequency distributions of orbital elements

On page 97 ff. we discuss certain minor selection factors operating in the choice of the meteoric trails reduced in the present program. A number of strong selection factors, however, enter into the statistical distributions of the orbital elements and, indeed, into the correlations among them. Certain of these factors are included in the quantity, cosmic weight (C.W.). Thus meteors of small orbital inclination or with apsides near the earth's orbit are distinctly favored. Also, the photographic technique appears to favor meteors of higher velocity, exclusive of the geometric factors involved. On the other hand, the effect of the cross-sectional area of the earth is to favor the slow meteors.

Perturbational effects, especially of Jupiter, play important roles in determining the distribution of orbital elements. A selective effect probably operates in the case of meteoric streams, resulting from the fact that the earth moves on a line through the stream. This effect is not well understood and deserves major consideration. Because of the complexity of this problem, however, no attempt will be made here to discuss it. A few of the statistical interrelationships among the observed orbital elements will be treated in the following sections and some of the major selectional factors will be discussed briefly.

Perihelion distance versus argument of perihelion.—Figure 1 is a plot of the perihelion distance against the argument of perihelion ω for the observed meteors. A rather amazing correlation results from the fact that meteors must, by definition, be observed at the nodes of their orbits at heliocentric distances near 1 a.u. The effect of this requirement is peculiarly conspicuous in the figure because the eccentricities of

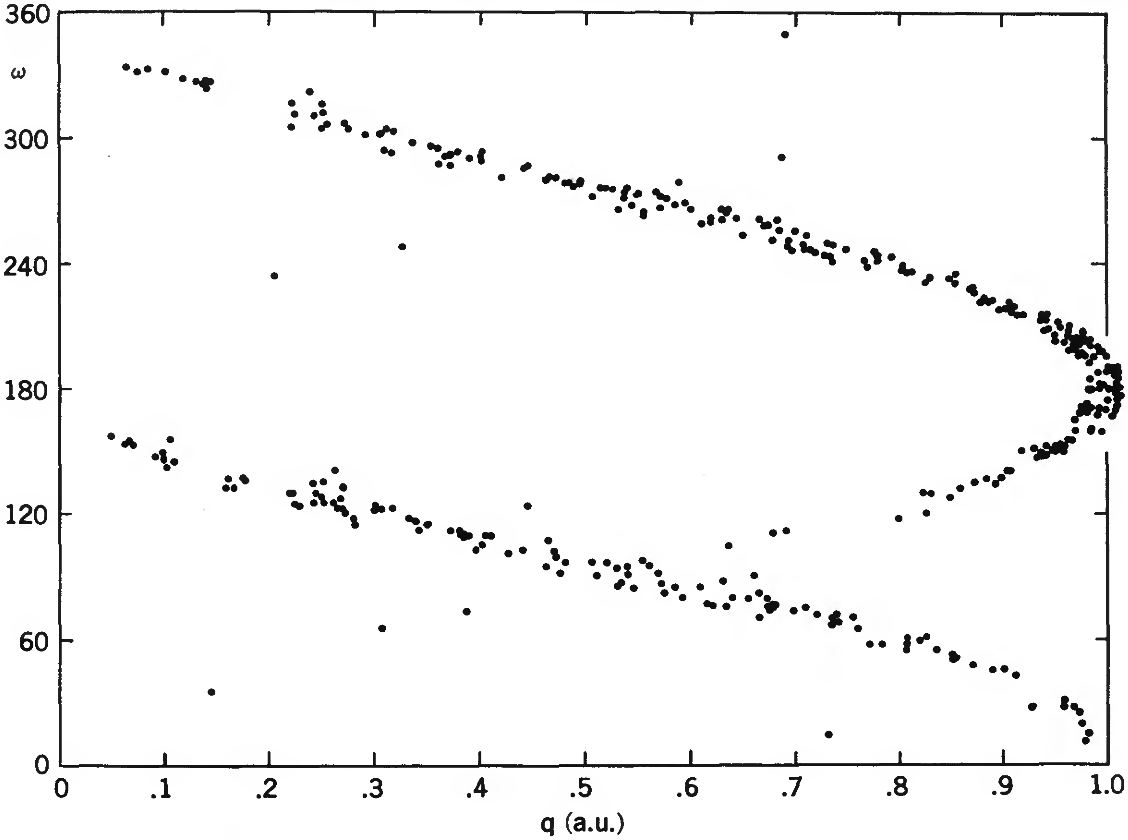

FIGURE 1.—Argument of perihelion ω plotted against perihelion distance q (all meteors).

the orbits are generally large and the aphelion distance much greater than 1 a.u. The concentration near the two parabola-like curves in figure 1 would be even more complete were meteoric observations from a point near the equator possible on a 24-hour basis. A complete discussion would involve the detailed effects resulting from night versus day, northern versus southern hemisphere, and ascending versus descending node. We merely show the diagram as a warning that correlations among orbital elements of meteors as well as among distribution functions must be evaluated carefully in terms of selection effects.

Inclinations of orbits having aphelia within Jupiter's orbit.—One of the authors (Whipple, 1940) investigated the perturbations in the angular elements of meteors derived from Comet Encke and showed that the Taurid meteor shower is associated with this comet. Some of the conclusions apply broadly to all meteors in orbits with aphelion distances less than the perihelion distance of Jupiter. With the secular perturbations in node, for Comet Encke the inclination varies over the range from 4° to 16° (with respect to the plane of Jupiter's orbit, not far from that of the earth). For similar orbits of small perihelion distance, the condition heliocentric distance $r=1$ a.u. at the node permits encounters with the earth only when the inclination is relatively low, approximately 4.6°.

On the other hand, the rate of change of the node at this orientation is a maximum and strongly influences the chance of encounter with the earth. Hence, any theory dealing with the distribution of inclinations or with the dependence of inclination upon perihelion distance, for orbits with aphelia lying within Jupiter's orbit, must be carefully studied if the observed distribution or correlation is to be of significance. The ramifications of these perturbational relationships are too involved for the present paper. They are mentioned only to indicate that the mean inclinations of the very short-period meteor orbits in space may be seriously underestimated because of the peculiarities of the perturbations of Jupiter.

Inclination versus perihelion distance.—Figure 2 depicts the observed distribution of meteors with respect to perihelion distance and inclination. As is to be expected from geometrical selection effects, a high concentration of observed meteors occurs near $q=1$ a.u. and near $i=0$. No conspicuous gaps occur in the diagram except in the neighborhood of $q=0$, and possibly near $i=90°$ for small q.

Although there is no dearth of comets with small perihelion distances, the meteoric distribution cuts off sharply at $q=.05$ a.u. with only 3 sporadic meteors having $q<0.1$ a.u. The remarkable δ-Aquarid shower shows a high concentration near $q=0.06$ a.u. with a minimum value of 0.047 a.u. Six of the 7 sporadic meteors with $q<0.15$ a.u. are of short period with aphelion distance <5 a.u. The inclinations are all moderate, $<40°$.

We conclude that the sun's energy, possibly heat or corpuscular radiation, eliminates mete-

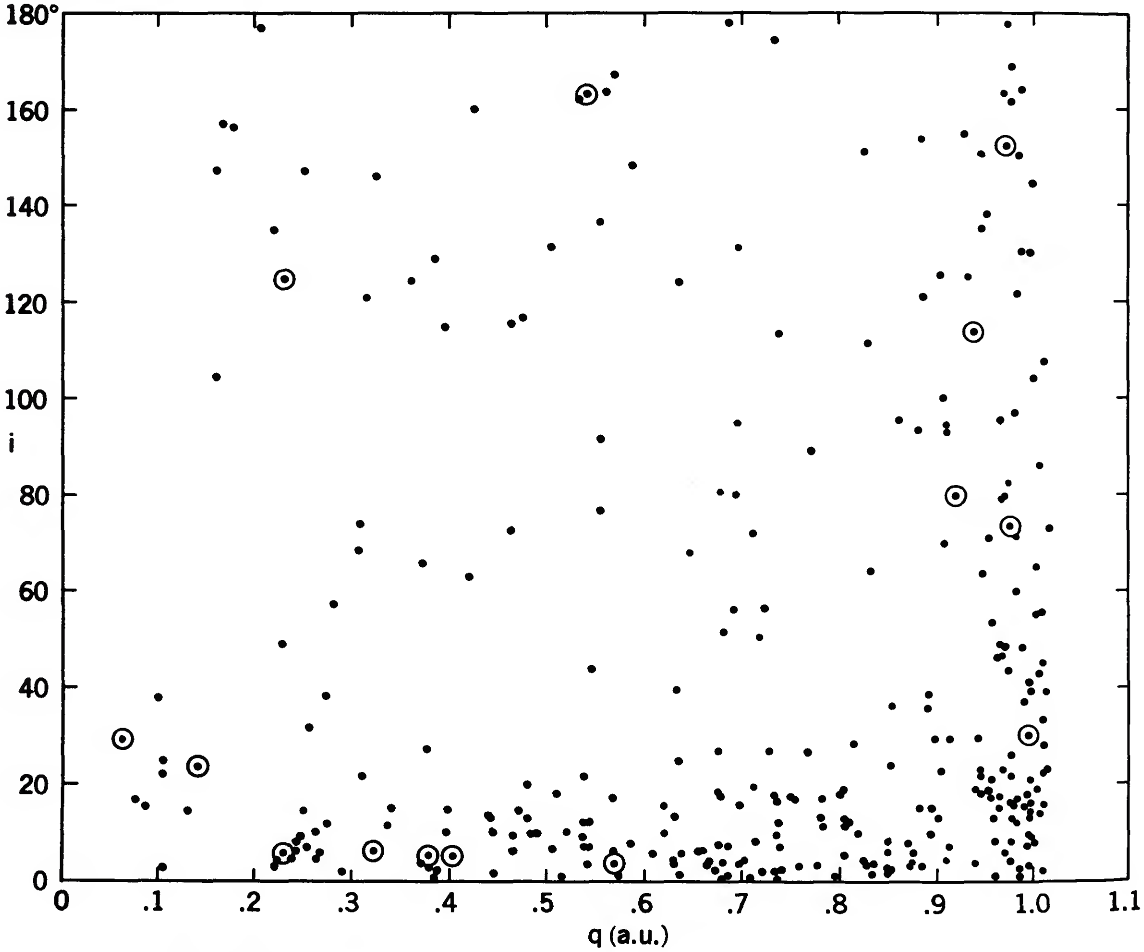

FIGURE 2.—Orbital inclination i plotted against perihelion distance q. Major showers (mean values) are indicated by circled dots.

ors rapidly within a distance of .05 a.u. and effectively reduces the numbers with $q<0.1$ a.u. The existence of the dense δ-Aquarid stream, however, with $q<0.1$ a.u. suggests strongly that these effects do not arise from direct melting or destruction but from some slow process such as etching by corpuscular radiation or by sublimation in the range $0.05<q<0.10$ a.u.

A possibly significant scarcity of meteors, both shower and sporadic, near inclination 90° may be associated with the minimum of comet frequencies in this same range. The effect may well be of a perturbational character and deserves more thorough study.

Inclination versus aphelion distance.—In figure 3 orbital inclinations are plotted against $q'^{-1/2}$, where q' is the aphelion distance ex-

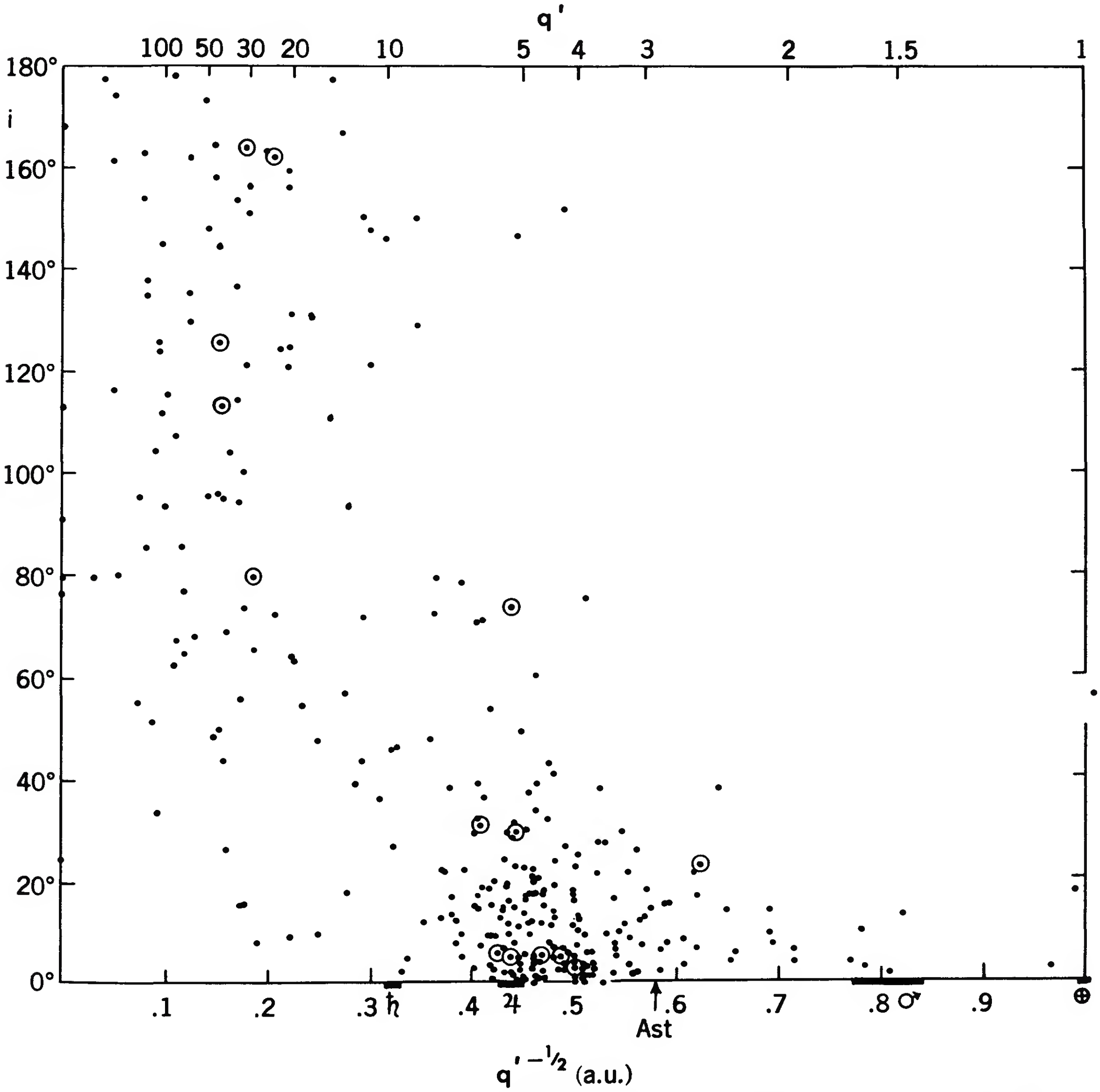

FIGURE 3.—Orbital inclination i plotted against aphelion distance q'. The variable in abscissa is $q'^{-1/2}$; heliocentric distances of the major planets are marked at the bottom. Major showers (mean values) are indicated by circled dots.

pressed in a.u. This parameter was chosen in preference to q' or q'^{-1} to avoid the crowding of points at one end of the diagram.

At great aphelion distances the distribution is rather uniform with inclination although there is some scarcity of low inclination orbits. The effect of Jupiter's perturbations shows strikingly for aphelia between Jupiter and the asteroids, where retrograde orbits are absent and the mean inclination falls rapidly as the aphelion distance decreases. The apparent concentration near the orbit of Mars does not seem to be real (see data of Hawkins and Southworth, 1958).

No concentration at all is evident in the region of the asteroid belt. This fact is a powerful argument against an asteroidal origin of an appreciable number of the meteors in this collection. The concentrations of major showers near the ranges 0.1 to 0.2 and 0.4 to 0.6 in $q'^{-1/2}$ are of some interest. The former concentration may, of course, be fortuitous. The latter indicates a strong dependence of shower comets on Jupiter's perturbations, with some longevity in orbital characteristics attained by those showers with aphelia inside of Jupiter's orbit. It appears to be very difficult for comet aphelia to be reduced much below 2 a.u.; the Geminids represent an extreme case. Figure 3 is very similar to a corresponding figure for comets except for the dearth of comets with very small aphelion distance. Such comets, of course, would be very short lived and it is difficult to see how they could develop. Meteors, on the other hand, subject to physical forces, can theoretically attain quite small aphelion distances.

Aphelion distance versus longitude of aphelion.—We have already seen that aphelia for meteors are highly concentrated near Jupiter's orbit. In figure 4 the aphelion distance is plotted as a function of longitude of aphelion with the corresponding radius-vector of Jupiter indicated as a curve. There is a slight tendency for the distribution of meteoric aphelia to fall off just beyond Jupiter's orbit. It is not clear, however, that this effect is statistically significant.

Among the asteroids the concentration of aphelia in the direction of Jupiter's aphelion is extremely marked. The effect exists because the perturbations of Jupiter are greater when the asteroidal aphelion is closer to the orbit of Jupiter and the consequent forward motion of the line of apsides is more rapid. Thus, the aphelia tend to concentrate in the direction of Jupiter's aphelion. We should expect such an effect for meteor orbits that lie entirely within Jupiter's orbit. No such tendency is indicated in figure 4. Apparent concentrations appear to be possibly significant some 90° from Jupiter's line of apsides. Three possible explanations for this lack of a well-explained perturbational effect are as follows:

(1) Physical forces change the lines of apsides for meteors more rapidly than do Jupiter's perturbations.

(2) Meteors of small aphelion distance may be contributed by a relatively small number of comets (or other bodies) and show a random distribution because of the small statistical selection of sources.

(3) The lifetimes of meteoroids may be extremely short, appreciably smaller than the revolution period of apsides.

Explanation (1) is purely hypothetical insofar as physical perturbations of meteoroids are concerned. The major physical forces that have been considered are the Poynting-Robertson effect, corpuscular radiation from the sun, and encounters with meteoritic dust. There is no evidence that electromagnetic forces act appreciably on meteoroids while the forces listed above should not generally shift the lines of apsides appreciably. In other words, if physical forces are responsible for the lack of concentration of lines of apsides, these forces must be of a character not yet considered seriously.

The number of recognized meteor streams is relatively small and a few major sources, such as extraordinarily large comets, may indeed play a significant role in providing the observed meteors. Nevertheless, if meteoroids had long lifetimes we should expect the Jupiter effect to be manifest in the distribution of the lines of apsides.

Hence, it seems necessary to conclude that meteors are injected into their orbits without a significant correlation with the lines of apsides of Jupiter's orbit, and that their lifetimes are relatively short. For Comet Encke, with an aphelion distance of 4.1 a.u., the line of apsides revolves in some 13,000 revolutions. The Taurid meteors can be traced back in history by their association with Encke's comet through

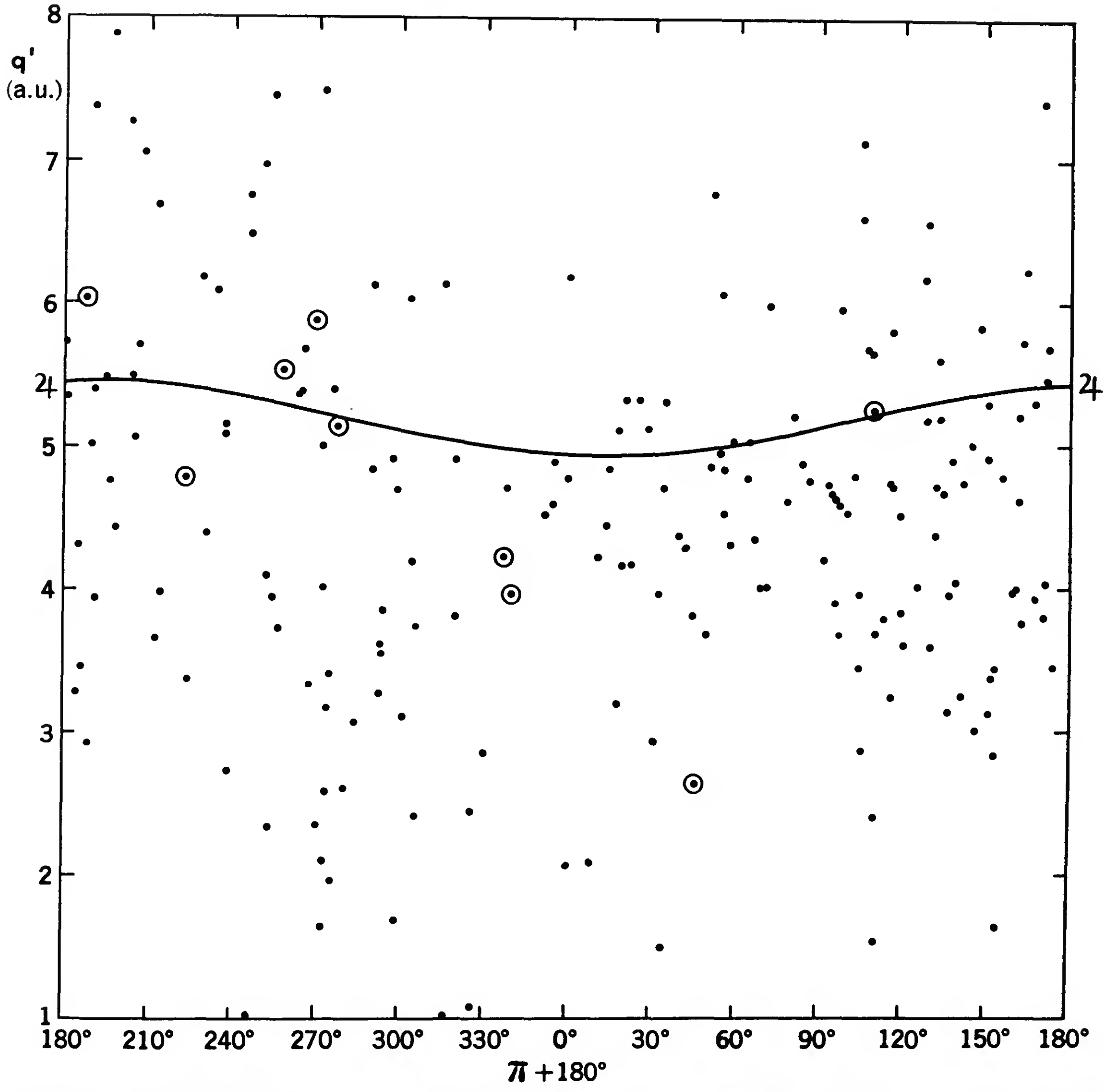

FIGURE 4.—Aphelion distances q' plotted against the longitude of aphelion $\pi+180°$. Only meteors with $q'<8$ a.u. are shown in the diagram. The curve represents Jupiter's heliocentric distance. Major showers (mean values) are indicated by circled dots.

some 1,500 revolutions, not much more than 10 percent of a complete revolution in the line of apsides. Although aphelia near Jupiter will move somewhat more rapidly than that of Comet Encke, nevertheless we clearly should expect no concentration of the lines of apsides for meteors if the ordinary meteor lifetime averages less than perhaps 2,000 to 3,000 revolutions.

Since meteors (see p. 125) originate almost entirely from comets, and since the lines of apsides of comets with aphelia near Jupiter or within its orbit appear not to be concentrated by perturbations by Jupiter, we appear to have a satisfactory explanation of figure 4 in terms of short lifetimes for meteors. The fact that some 60 percent of the meteors exist in identifiable streams or associations is added evidence for their short lifetimes because a number of forces, both physical and gravitational, tend to disturb the stream motions and hide the evidence for comet origin.

Geocentric velocity versus elongation of the radiant.—For certain types of meteoritic orbits our only reliable information is the elongation of the radiant. Hence we present the meteor data in figure 5, where the ordinate is geocentric velocity, V_G (corrected for earth's attraction), and the abscissa is the elongation, λ, of the corrected radiant from the apex of the earth's motion about the sun. Small values of λ correspond to the high-velocity meteors that make head-on encounters with the earth, while large values correspond to relatively slow meteors that "catch up" with the earth. The continuous curve in figure 5 indicates the parabolic limit in V_G. For elongations up to about 60° the observed values describe a curve parallel to the parabolic one, with a rather narrow scatter. Above about 60° in λ the effect of short-period orbits occurs and extends the range of velocities over an area much below the parabolic limit in geocentric velocity. The asteroids with perihelia inside the earth's orbit would occur near the lower edge of the distribution in figure 5, with a concentration near elongation 90°.

Sources of meteors

With the precise material presented in the previous pages, we may now consider possible sources of these photographic meteors.

Interstellar meteors.—Meteoroids of immediate interstellar origin should travel in hyperbolic orbits about the sun. Table 1 lists 7 meteors with hyperbolic velocities and 2 with parabolic velocities. Among the 7 hyperbolic meteors none is of quality as high as 1.5, while the one parabolic case is of quality 1. Hence, among the 251 meteors of highest quality, there are no hyperbolic and only one parabolic velocities measured. Four of the 7 hyperbolic cases lie among the 36 meteors of poorest quality.

All meteors with nearly hyperbolic velocities have been carefully restudied to search for errors in the calculations and to determine whether uncertainties in the instant of the meteor might lead to a spurious determination of a hyperbolic velocity. In all cases an elliptical solution can be obtained by use of an instant within the common interval of exposure.

No evidence exists that the velocities of identified shower meteors differ significantly from those of the comets with which they are associated. This fact can be used to indicate that the systematic errors in meteoric velocities are small, not exceeding the errors indicated on page 114.

Any hypothesis that hyperbolic meteors are selectively avoided in the photographic meteor program because of their greater apparent velocities appears to be unfounded. Strong evidence indicates that a given body moving at high velocity through the atmosphere produces more light than a similar body at a lower velocity, and that the luminosity dependence is more than linear with the velocity. For meteors of the same intrinsic brightness the camera's ability to register the meteor varies roughly as the inverse product of distance and velocity. Since faster meteors occur at somewhat higher altitudes than slower meteors, the product is the inverse velocity raised to a power slightly less than unity. Hence the luminosity and the geometric factors combine to favor the photography of more rapidly moving meteors in preference to slower moving ones.

The criteria of selection used here for meteor trails favored the slower meteors because those of highest angular velocity tend to produce fewer shutter breaks; this effect was partially compensated by the inclusion of more of the faster meteors than would have been allowable by strict application of the selection criteria. Hyperbolic meteors, moreover, need not enter the atmosphere with high velocities. The fact that observed borderline cases occur almost entirely in the high-velocity range casts further doubt on the existence of hyperbolic meteors.

The observing program ran continuously through the hours of darkness for more than 2 years; hence any selection factor stemming from a lack of observations in the late night hours versus the early evening hours appears not to be serious.

We conclude, therefore, that hyperbolic meteors constitute, at most, less than 1 percent of our sample—the most precise photographic material yet available—and that there is no strong evidence for the existence of any hyperbolic meteors. This conclusion agrees with that obtained by radio techniques in the researches of

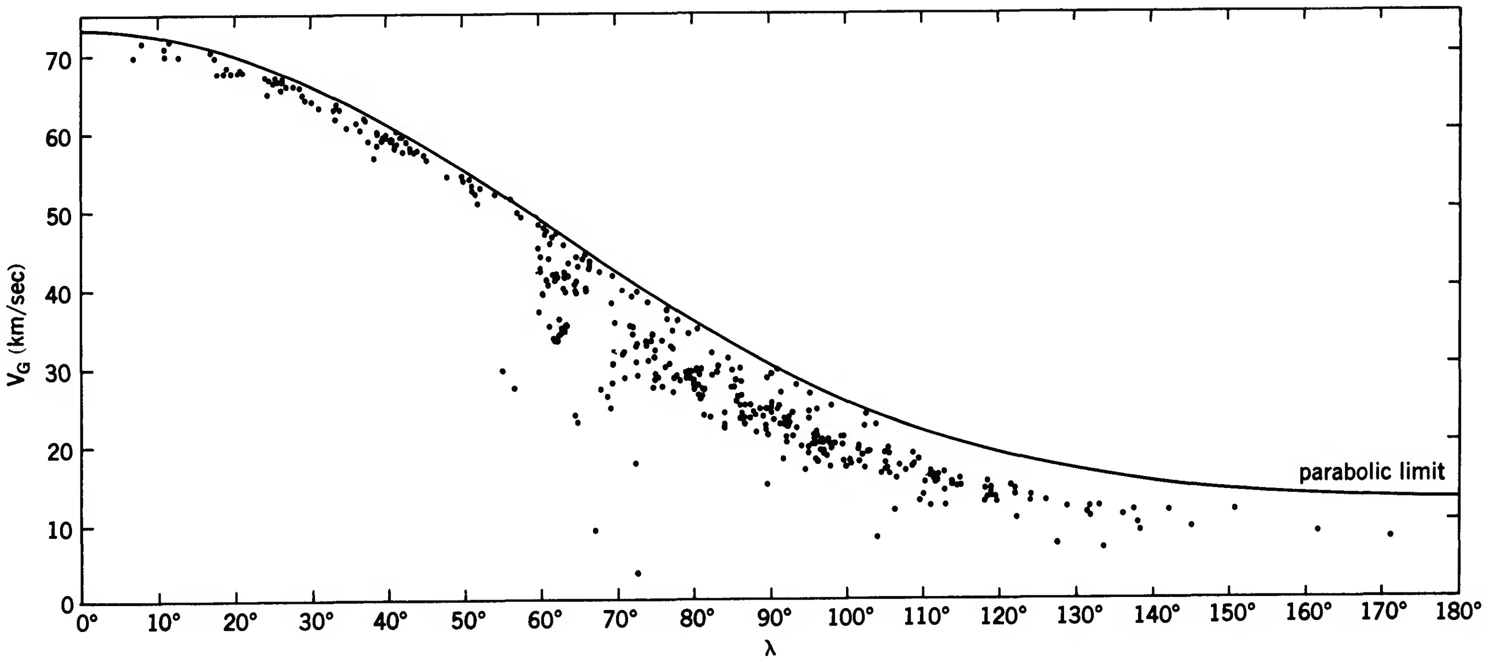

FIGURE 5.—Geocentric velocity V_G against the elongation λ of the corrected radiant from the apex of the earth's motion (all meteors). The curve represents the parabolic velocity at earth's perihelion.

McKinley (1951) in Canada, and of Lovell (1949) and associates (see Almond, Davies, and Lovell, 1953) in England.

The occurrence of hyperbolic meteors remains to be demonstrated.

Lunar meteoroids.—It has been suggested recently by Urey (1960) that the encounter between large meteorites and the moon might produce an appreciable number of secondary meteorites from lunar material, which subsequently would have a moderate probability of falling on the earth. In the present collection of 413 meteor orbits only one has a geocentric velocity (V_G, corrected for earth attraction) below 9 km/sec. This is meteor No. 4952, which fell on October 19, 1952, with $V_G=3.41$ km/sec. Its hypothetical velocity of ejection from the moon would have been increased by the effect of the earth potential at the moon (1.0 km/sec) and the lunar velocity of escape (2.38 km/sec), so that it would have required a lunar ejection velocity of 4.4 km/sec. The study by Hawkins and Southworth (1958) of randomly selected fainter meteors indicates 6 meteors with velocities of ejection from the moon less than 9 km/sec.

Further criteria are not available for any of these meteors except one. For number 4952, Jacchia (unpublished) finds that its behavior in the upper atmosphere is normal as compared with the average of the other slow meteors.

Of the few meteors that have aphelion distances less than 1.4 a.u.—only 3 out of the 413—all have aphelia less than 1.1 a.u. This fact strongly suggests that the earth, in some manner or other, is responsible for this concentration. This concept is strengthened by the data of Hawkins and Southworth, which indicate that of 12 meteors with aphelia less than 1.3 a.u., 7 have aphelia less than 1.1 a.u. About half the meteors of small q' have geocentric velocities much too great to ascribe to lunar ejection—2 out of 3 among the 413 presented here and 6 out of 12 from the data of Hawkins and Southworth. These ratios suggest that the earth perturbs meteor orbits, possibly by "capture" phenomena as has happened for comets and meteors with aphelia near Jupiter. The capture phenomenon and the concomitant encounter phenomenon are both favored by low orbital inclinations and apsides near the earth's orbit. Hence the few data available do not answer the question as to whether lunar ejection is likely or not for the very few possible examples.

The lunar ejection theory for meteorites is greatly weakened by the fact that the collisional cross-section of the earth is much greater than that of the moon, by approximately a factor of 16, if we neglect the additional gravitational factors at low relative velocities. Unless the process of formation and ejection of secondary meteorites by encounters between primary meteorites and the moon is extremely efficient, one would expect only a small fraction of the total number of meteorites found on the earth to be of lunar origin. The low velocity of encounter with the atmosphere, required by a lunar ejection mechanism, is not a great compensating factor.

In summary, we find little or no evidence to support the hypothesis of meteoric ejection from the moon, although for photographic meteors the hypothesis is not excluded at approximately the 1 percent level.

Comets and asteroids.—In earlier sections we have shown that no appreciable fraction of the meteors discussed here could have come from sources outside the gravitational control of the sun, or from encounters between larger meteoritic bodies with the moon. Observationally, each of these sources is within the 1 percent level of probability and no evidence proves the existence of either source.

There remain two obvious sources of meteors: comets and asteroids. The only proven source of meteors is cometary. Whipple and Hawkins (1959) identify 12 meteor streams with 9 comets, the association of the η Aquarids and Orionids with Halley's comet being somewhat uncertain. Tentative identifications of other meteor streams with as many as 20 comets have been made and are fairly probable; the list grows continuously with increasing orbital information on meteors. Incidentally, the present orbital information on meteors now exceeds both in quantity and quality that on comets.

These positive and tentative identifications leave a major fraction of the observed meteors without a known source. In the search for possible asteroidal sources, we must consider the character of asteroid orbits.

If an asteroid is to contribute meteors, its perihelion must lie near or within the earth's orbit. Only 7 asteroids have been observed to pass within the earth's orbit; hence our sample for comparison is extremely small. The mean aphelion distance of these asteroids is 2.2 a.u. and the inclinations are generally small. Since we know of only 1 asteroid, Hidalgo, that passes beyond Jupiter's orbit (neglecting, of course, the Trojans), it seems to be a proper assumption that meteors of asteroidal origin should have aphelia well within Jupiter's orbit, perhaps concentrated in the major portion of the asteroid belt or its inner reaches. No asteroidal aphelion is known to lie within the orbit of Mars.

No meteor orbit in the present collection appears to be sufficiently like that of any individual asteroid to suggest a specific genetic association. If, then, we eliminate as of asteroidal origin all meteors with aphelia very close to the orbit of Jupiter and beyond, as well as those definitely associated with known comets, we will have reduced the asteroidal source to less than approximately 40 percent. If we choose aphelion distance near and beyond the environment of Jupiter as a criterion for cometary origin, and if we assume in addition that all meteors in streams or associations are of cometary origin, then we reduce the potential asteroidal contribution to less than 11 percent. Since the percentage of the meteors identifiable with streams will increase as a larger number of accurate meteor orbits becomes available, it seems quite safe to conclude, on the basis of these assumptions, that the asteroidal contribution to the present collection of photographed meteors cannot possibly exceed 10 percent. Let us now seek evidence that any of the remaining 10 percent are actually of asteroidal origin.

A somewhat more vivid picture of the distribution of aphelion distances is shown in figure 6, where the meteoric data have been divided into two groups: sporadic, and showers plus associations. The frequency distributions have been compared with the total number of comet passages in the list by Baldet and De Obaldia (1952), except that the orbits listed as parabolic have been excluded because of the generally poor orbital determinations (comparison is properly made between the distribution of *all* cometary passages and the observed meteoric distribution).[2] The histogram is in terms of the argument $(q')^{-1/2}$ and the meteor groups reduced to a common basis of 1000. The three sets of curves are very similar in general character, and suggest that the meteoric orbits are shifted towards somewhat smaller values of q' than the comet orbits. In particular, there is a marked absence of very great aphelion distances among the meteors, while the comets show the well-known heavy concentration near the parabolic limit.

The influence of Jupiter's perturbations is markedly shown in all three curves, the most striking feature of the distribution function. One has the impression that meteoric orbits are pressing against the Jupiter barrier (Whipple, 1951, 1955; Öpik, 1951). The sporadic meteors include a considerable number of longer period, in comparison to the shower meteors, but otherwise the two distributions are so nearly identical in form that it is difficult to draw any other conclusion than that the two classes of orbits are similar, and that the bodies are probably of the same origin.

A number of other orbital data are available for a comparison among the three groups of elements, for sporadic meteors, showers plus associations, and comets. The distributions of inclinations are similar in character, as noted earlier, and the lines of apsides appear not to give any clues of importance. The *K* criterion, used earlier by one of the authors (Whipple, 1954) apparently will not be particularly valuable until we have far greater information concerning the asteroids that cross the earth's orbit. Furthermore, it is not certain that the *K* criterion is more significant than the distribution of aphelion distances. So many selection factors enter into the cometary statistics as well as the meteor statistics that an exact equality of distributions is hardly to be expected. Other elements than those discussed seem not to add appreciably to a solution of the problem but are entirely consistent with a cometary origin for photographic meteors.

A comparison of the present collection of meteor orbits with those of comets indicates a

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[2] More precisely, the frequencies could be properly corrected for the cosmic weight. This has been done but has not been presented here since the histograms are not markedly changed by this weighting factor.

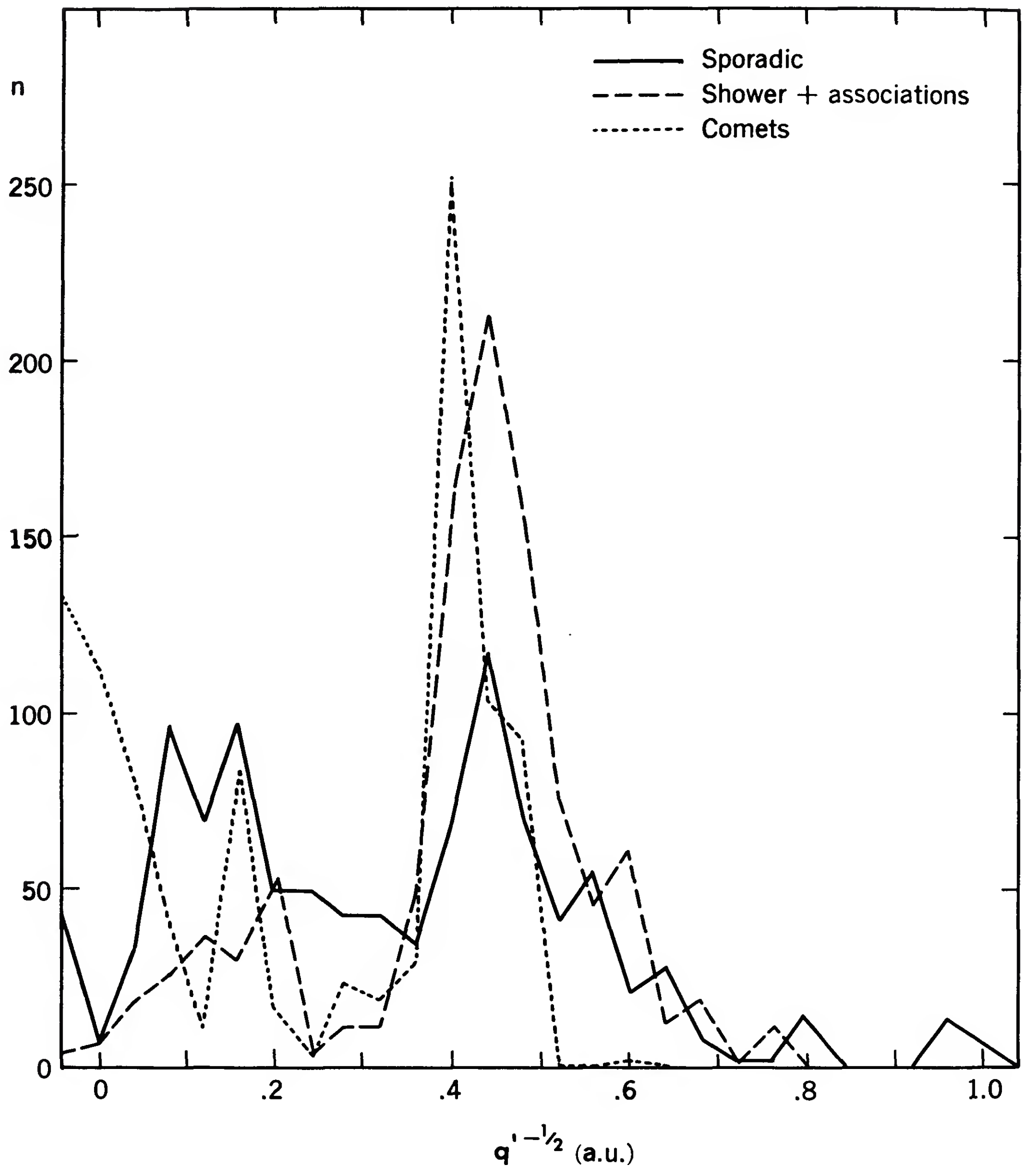

FIGURE 6.—Distribution of aphelion distances for comets, shower meteors, and sporadic meteors. Ordinates are numbers of objects reduced to a standard population of 1,000 in intervals of 0.04 of $q'^{-1/2}$. Comets for which only parabolic orbits had been computed were eliminated from the comet distribution.

cometary origin for at least 90 percent of the meteors. If we assume that meteors in streams and associations are of cometary origin, the general similarity of their distribution functions with those of the sporadic meteors would indicate no significant difference in origin; therefore, a cometary origin appears likely for practically all meteors. One of the authors (Jacchia, unpublished) can find no significant difference in physical characteristics among meteors with very small orbits of low inclination, among typical stream meteors, or among meteors with distinctly cometary orbits. Striking evidence exists that photographic meteors are produced by extremely fragile objects (Jacchia, 1955; McCrosky, 1955), and the forward motions in meteoric trains (Cook and Whipple, unpublished) provide strong indications that photographic meteors may be of extremely low density. Such evidence makes it doubtful that the photographic meteoroid is comparable to the iron or stony meteorites that fall on the earth.

The writers are of the opinion that the asteroidal contribution to the photographic meteors probably does not exceed 1 percent of the total and may well be less.

Meteor streams and associations

The selection of meteor streams and associations given in tables 3 and 4 is not intended to be definitive. The dividing line between the terms "stream" and "association" is not rigidly defined. The intent here is to indicate the nature of the streams and associations to be found by intercomparison of a limited amount of rather precise data, the 413 orbits of the meteors listed in table 1, and the 144 brighter orbits previously published (Whipple, 1954). Other investigators might apply more rigid rules or might be constrained to include even more members in the associations.

TABLE 3.—*Code for identifying known meteor showers listed in table 1*

Shower No.	Shower
None	Sporadic meteor
1	α Capricornids
2	Southern Taurids
3	ι Aquarids (So.)
4	Geminids
5	δ Aquarids
6	Lyrids
7	Perseids
8	Orionids
9	Draconids
10	Quadrantids
11	Virginids
12	κ Cygnids
13	Leonids
14	χ Orionids
15	Ursids
16	σ Hydrids
17	Northern Taurids
18	Andromedids
19	η Aquarids
20	ι Aquarids (No.)

The large variations that occur in the orbits of certain comets, such as Lexell or Brooks II, must also certainly occur among the orbits of meteors both before and after their ejection from comets. Refined analysis in many cases will undoubtedly indicate widespread variations in the orbital elements of meteors originally produced by the same comets.

We find a number of low inclination streams with components in which the line of nodes is shifted by 180°. This phenomenon was first observed for the Taurid meteors in association with Comet Encke (Whipple, 1940).

TABLE 4.—*Identification of tentative meteor associations listed in table 1*

[EXPLANATION: (N), northern branch of the stream; (S), southern branch of the stream; parentheses, small camera meteors not included in table 1 but listed in Whipple (1954).]

Associated Shower No.	Trail No.	Date	Remarks
30	10012	1- 4-54	
	(1918)	(1-20-50)	
31	(2889)	(1-15-51)	
	6275	1-20-53	
32	(1257)	(1-22-44)	
	(1988)	(1-23-50)	
	6329	1-23-53	
33	6376	2- 5-53	
	(1243)	(2- 6-45)	
34	6433	2-12-53	
	6546	2-21-53	
35?	6802	3-12-53	
	7052	3-21-53	
36	6811	3-12-53	
	6842	3-13-53	
37	6882	3-14-53	Same as Association Whipple II, originally composed of meteors 1920 and 2031. It now seems very doubtful that 2031 belongs to this group.
	10342?	3-26-54	
	(1920)?	(4-21-50)	

Table 4.—*Identification of tentative meteor associations listed in table 1*—Continued

Associated Shower No.	Trail No.	Date	Remarks
38	6915	3-18-53	
	6971	3-19-53	
	7040	3-20-53	
	(1068)	(3-23-41)	
	7067	4- 3-53	
39	3076	3-22-52	Possibly related to No. 38.
	10394	4- 2-54	
40	6959?	3-18-53	
	7161	4- 9-53	
	10094	4-10-54	
41	7002	3-19-53	
	(1937)	(3-23-50)	
42	10384	4- 2-54	Possibly related to No. 41.
	10439	4- 5-54	
	10447	4- 5-54	
43	5688	3-20-53	
	3024	4- 1-52	
44	3053	3-20-52	
	10414	4- 5-54	
45	7022	3-20-53	
	3088	3-28-52	
	7392	4-16-53	
46	10365	4- 1-54	
	10478	4- 6-54	
47(N)	10358	4- 1-54	
	(2918)	(4- 4-51)	
	(3454)	(4-12-51)	
48(S)	10106	4- 1-54	Related to No. 47.
	7216	4-11-53	
49	7073	4- 4-53	
	7272	4-13-53	
	7333	4-15-53	
	3234	4-23-52	
	3250	4-26-52	
50	7158	4- 9-53	
	7184	4-10-53	
	7240	4-11-53	
	7367?	4-16-53	
	7372	4-16-53	
	7388?	4-16-53	
	(1954)?	(4-17-50)	

Table 4.—*Identification of tentative meteor associations listed in table 1*—Continued

Associated Shower No.	Trail No.	Date	Remarks
51	7210	4-11-53	
	7592	5- 9-53	
52	7075	4- 4-53	
	10555	4-12-54	
	7522?	5- 7-53	
	3344	5-21-52	
	3312	5-22-52	
	3307	5-22-52	
	4141	6-22-52	
53(N)	7476	5- 5-53	
	7534	5- 7-53	
	3295	5-23-52	
	(1205)	(5-25-43)	
54(S)	7474	5- 5-53	
	3327	5-21-53	
55	7478	5- 5-53	Probably related to Nos. 53, 54.
	7637	5-12-53	
56(N)	7520	5- 7-53	
	7664	5-13-53	
	3303	5-22-52	
57(S)	11825	5- 3-54	
	11856	5- 3-54	
	7480	5- 6-53	
	7494	5- 6-53	
58	7499	5- 6-53	Probably related to Nos. 56, 57.
	7635	5-12-53	
59	7524	5- 7-53	
	10587	6- 4-54	
60	3342	5-21-52	
	3288	5-24-52	
61	(2862)	(5-20-50)	Nos. 61, 62 very probably are one single, diffuse stream; could be related to No. 52.
	12399	6- 2-54	
	(2024)	(6- 9-50)	
	7882	6-13-53	
	4125	6-19-52	
62	4103	6- 1-52	
	7820	6- 9-53	
63	7734	6- 4-53	
	7750	6- 5-53	
	4111	6-14-52	
64	7742	6- 5-53	
	7787	6- 8-53	

TABLE 4.—*Identification of tentative meteor associations listed in table 1*—Continued

TABLE 4.—*Identification of tentative meteor associations listed in table 1*—Continued

Associated Shower No.	Trail No.	Date	Remarks
65	7758	6– 5–53	
	7873	6–13–53	
66	(2863)	(5–23–50)	
	12342	5–31–54	
	7744	6– 5–53	
	7754	6– 5–53	
	4147	6–22–52	
	4153	6–23–52	
67	12577?	6–11–54	
	4143	6–22–52	
	4181	6–25–52	
68	4138?	6–21–52	
	4151	6–22–52	
	8113	7–23–53	
69	7944	7– 6–53	Could be related to No. 66.
	8017	7–15–53	
70	3393	7–25–52	
	(2073)	(8–10–50)	
71	8192	8– 5–53	
	8417	8–10–53	
	3663	8–21–52	
	3877	8–31–52	
72	7946?	7– 6–53	
	8447	8–11–53	
	8510	8–13–53	
73	8143	8– 4–53	Nos. 72, 73 possibly are related streams; associated with κ Cygnids?
	(2185)	(8– 9–50)	
	8476	8–13–53	
	3633	8–20–52	
	3813	8–25–52	
74	8244	8– 6–53	
	8294	8– 7–53	
	3640	8–20–52	
75	8394	8–10–53	Nos. 74, 75 are related streams.
	8415	8–10–53	
76	4289	9–10–52	
	4624	9–27–52	
	4679	9–28–52	
	(1514)?	(10–12–47)	
77	4313	9–13–52	Nos. 76, 77 possibly are related streams.
	4388	9–17–52	
78?	4360	9–16–52	
	8819	10– 2–53	
79(N)	4328	9–14–52	
	4369	9–16–52	
	4464	9–19–52	
80(S)	4340	9–14–52	Nos. 79, 80 are related.
	4351	9–14–52	
	4505	9–20–52	
	4542	9–25–52	
	4657	9–27–52	
	8766	9–30–53	
81	4454	9–19–52	
	4622	9–27–52	
	4683	9–28–52	
82	4702	9–24–51	
	4534	9–25–52	
83	(1180)?	(10– 4–42)	Same as Association Whipple V.
	(2463)?	(10– 9–50)	
	4962	10–21–52	
	5073	10–22–52	
84	8881	10– 6–53	May be related to the Draconids (Giacobinids).
	4964	10–21–52	
	9130	11– 2–53	
85	8974	10– 9–53	
	4966	10–21–52	
86	5237	10–24–52	
	(3134)	(11– 6–51)	
87	(2624)	(11– 6–50)	Same as Association Whipple VI.
	(2622)	(11– 7–50)	
	9252	11– 7–53	
88	5572	12–10–52	
	(2292)	(12–12–50)	
	9888?	1– 1–54	

The fact that 268 out of 413 meteors can be placed in associations—even though the criterion may be somewhat loose—is proof that streaming is a major phenomenon among meteors. This is not surprising when we consider that, on astronomical time scales, the lifetimes of small bodies must be quite finite. On the other hand, the orbital evidences of origin for meteors crossing the orbit of Jupiter would be lost long before an appreciable percentage of the bodies would be eliminated by encounter or major perturbational effects. For orbits lying entirely within that of Jupiter the expectations are not so clearcut. Asteroidal families have long been recognized by their orbital characteristics and presumably must persist over periods of time measured possibly in hundreds of millions of years. The Poynting-Robertson effect alone would destroy such associations, in terms of possible identification, in much shorter times for meteors in the photographic range with masses measured in grams. More research along these lines is urgently needed in order to clarify the time scales applicable to the lifetimes of meteors. We can see that these are measured in terms of a very few thousand revolutions, but other approaches to the problem are highly desirable.

Table 5 gives some tentative identifications of known comets with the meteor associations indicated in table 4. Five of these cometary associations appear quite valid and six others fairly probable. Three are in the extremely doubtful category. As a larger number of precise meteor orbits become available, the number of such identifications will undoubtedly increase. A more definitive identification of meteor streams and cometary associations can be made from a combination of the other photographic evidence available, particularly the concurrent publications by Hawkins and Southworth (1961) and by McCrosky and Posen (1961).

TABLE 5.—*Possible associations between comets and meteor associations of table 4*

Associated Shower No.	Comet
33	1833 ?
34	1947 c
36	1826 III ??
40	1886 I ?
44	1858 III (Tuttle-Giacobini)
47, 48	1834
51	1945 c ?
52	1930 VI
61, 62	1930 VI ?
66	1770 I (Lexell)
68	1864 II ?
81	1790 I ???
84	P Giacobini-Zinner?
86	1779 ??

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Abstract

Orbital results are presented for 413 long-trail meteors doubly photographed with the Baker Super-Schmidt cameras in New Mexico and reduced by precise methods. The error in velocity probably does not exceed 0.1 percent for 173 meteors, or 0.4 percent for 181 others.

With such exact material it is now possible to determine definitively the source of meteors in the visual range. The obvious possibilities are interstellar, cometary, asteroidal, and secondary lunar sources.

Meteors of interstellar origin would move in hyperbolic orbits about the sun. The 251 orbits of precision 0.2 percent in velocity include no hyperbolic cases; for 7 hyperbolic orbits among the less precise cases, a long-period solution exists within the possible range of each. Hence more than 99 percent, if not all, must have been gravitational members of the solar system. The orbital data alone indicate that more than 90 percent of these, probably more than 99 percent, must be cometary in origin, while the physical data from decelerations and light curves show no unusual characteristics for the remainder. The number of meteoroids produced by the encounter of meteorites with the moon cannot exceed the 1 percent level of probability among the current selection. Thus comets seem to supply essentially all the visual meteors and probably also smaller meteoroids.

A number of statistical correlations among meteor orbital elements are shown and commented on. Also a preliminary study of meteor streams and associations is made. Several new cometary associations with meteor streams are suggested.

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