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ART. XXXIX.—*The Biela Meteors of November 27th, 1885;*
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NUMEROUS notices of the brilliant meteor display of Nov. 27th (see p. 78) are given to us in the *Astr. Nachrichten*, the *Monthly Notices R. A. S.*, the *Observatory*, *Nature*, the *Comptes Rendus*, etc., by observers in various places over the Eastern hemisphere. The display in Western Europe occurred in the early evening hours, and it was reasonable to suppose that the shower would be visible over the Eastern Continent wherever the skies were clear. This seems to have been actually the case, though naturally the most valuable observations were made in Western Europe. There had been preparation for the shower by reason of anticipatory notices, especially one in a *Dun Echt* circular. Unfortunately in England, and at a few places on the continent, clouds seriously interfered with observing, though through breaks in the clouds much was seen notwithstanding.

Time of maximum.—The shower was in full activity in Europe at the close of twilight, and for a while increased in intensity. The time of the maximum was estimated.

At Pulkowa	at	8 ^h 15 ^m	P. m. t.,	that is,	6 ^h 14	Gr. m. t.
“ Upsala		7 29·8	U. m. t.,	“	6 19	“
“ Bonn (cloudy)		6 42	B. m. t.,	}		
“ “		6 37	“		6 11	“
“ “		6 40	“			

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At Moncalieri the numbers given by P. Denza are :

6 ^h	0 ^m	to 6 ^h	15 ^m	Rome m. t.	2800 meteors	by 2 obs.
6	15	"	6 30	"	3100	" 2 "
6	30	"	6 45	"	3400	" 2½ "
6	45	"	7 0	"	4500	" 3 "
7	0	"	7 15	"	6200	" 4 "

The count was continued but clouds interfered. By a table quoted below we have for the ratio of the numbers of meteors visible to 2, 3 and 4 observers, 633 : 836 : 1000. P. Denza's observations reduced by these ratios show that the display increased in brilliancy until 7^h 15^m when the sky became partly overcast. The maximum indicated by them was then later than 7^h Roman, that is, 6^h 10^m Greenwich time. Professor Zona places the maximum earlier. Professor Cacciatori at Palermo gives 7^h 45^m (that is, 6^h 52^m) as the time of maximum. But clouds are reported during the preceding half hour. Many other observers give times of the maximum display which are more or less indefinite. We shall assume 6^h 15^m Gr. m. t. as representing very well the mean of all the observations.

Duration.—From the time of maximum the intensity quite steadily diminished. The numbers counted at Upsala show the course of the shower. The weather was fine and twelve observers under the direction of Messrs. Hildebrand-Hildebrandson and Charlier, looking toward different quarters of the sky kept count by quarter hours through five hours, with the following result (Greenwich time).

5 ^h to 5½ ^h , 2545	6¾ ^h to 7 ^h , 3383	8½ ^h to 8¾ ^h , 799
5¼ " 5½, 2287	7 " 7¼, 2497	8¾ " 9, 585
5½ " 5¾, 2906	7¼ " 7½, 2072	9 " 9¼, 502
5¾ " 6, 3382	7½ " 7¾, 2295	9¼ " 9½, 375
6 " 6¼, 4213	7¾ " 8, 1999	9½ " 9¾, 307
6¼ " 6½, 4422	8 " 8¼, 1336	9¾ " 10, 268
6½ " 6¾, 3330	8¼ " 8½, 1341	

The numbers diminished so that at the end of three hours from the time of the maximum there were only one-tenth of the maximum numbers of meteors. The end of the shower was not a definite epoch. Assuming that there was an increase during the sunlight and the twilight corresponding to the later decrease we may say in general terms that the shower lasted as an extraordinary display through six hours. Some of the reports from observers in Asia give reason to believe that the increase was less rapid than the decrease. A few Andromeda meteors were seen in different places on the night of the 26th, 28th and 29th, but the number of them on each night was not large.

Hourly number of meteors at the time of maximum.—As has been noticed in other showers the meteors were not evenly distributed in time but came somewhat fitfully. There is moreover great discrepancy in the numbers counted by different observers. The numbers of persons counting, the precautions to prevent duplication, the relative directions in which they looked, and the state of the sky are in many cases not given, and this renders the comparison of numbers reported from different places difficult.

An experiment made in 1865 by the writer gave the following ratios (y) for the numbers of shooting stars seen by from one to twelve observers (x). The group of observers is presumed in each case to have the points toward which they are looking symmetrically distributed over the heavens.*

x	y	x	y	x	y
1	325	5	1106	9	1399
2	633	6	1200	10	1451
3	836	7	1282	11	1509
4	1000	8	1348	12	1560

These values of y should increase toward a limit when x increases indefinitely. The limit is evidently more than 2000, and as the differences near the end of the table decrease very slowly, I do not regard 2400 an extravagant estimate. I shall therefore use that factor in some subsequent computations.

Of the shower of Nov. 27th no published set of observations show more completely the course and intensity of the shower than those above cited made at Upsala. They imply at the maximum an hourly number of $4 \times 4422 \times 2400 \div 1560$ (that is about 27000) for the total number visible at Upsala. They also give for the quarter-hour number for one observer at their maximum $4422 \times 325 \div 1560$ (that is, about 60 per minute.)

At Marseilles three observers (Stephan, Borrelly and Coggia) in several trials counted over 600 per minute, which represents 233 per minute, for one observer and a *total* hourly number of over 100,000. At moonrise ($10\frac{1}{2}^h$) there were 50 to 60 a minute counted.

At Palermo the maximum number per minute reported was 214 for two observers from $7^h 43^m$ to $7^h 48^m$.

At Geneva 55 to 60 a minute were reported. The sky was partly clouded.

* Dr. Kleiber (*Astr. Nachr.*, No. 2621) has given a similar table from some observations made by him in 1884 at St. Petersburg. As he has in his discussion, however, taken every possible combination of his eight observers instead of considering such combinations as contain observers looking to different parts of the heavens, Dr. Kleiber's numbers and mine represent different quantities, and are not properly comparable. His method of reduction seems to me faulty, and to have vitiated his results for practical use.

At Glasgow one observer counted 74 in a minute at 6^h 10^m, and another counted 100 in a minute at 6^h 24^m.

At Greenwich there were 30 to 40 a minute for one observer between 6^h and 7^h.

From Beyrout, Professor Robert H. West of the Syrian Protestant College reports in *Nature* (vol. xxxiii, p. 152): "The maximum appears to have been between 8 and 9 o'clock. At 6^h 3^m two observers watching opposite parts of the sky counted 850 meteors in five minutes. At 7^h 50^m (5^h 30^m Greenwich mean time) seven observers divided the heavens among them and together counted 525 in one minute. We all agreed that we had not been able to count all that we saw, so that this number is probably too small. At any rate I do not think the number of meteors visible between 7 and 9 P. M. was at any time less than 500 per minute. At 10^h I alone counted 210 in two minutes, facing the north, which was then partially clouded."

The number 525 for seven observers corresponds to $525 \times 325 \div 1282 = 133$ per minute for one observer, and to a total hourly number (computed as before) of 59,000. The count of 850 in 5^m for two observers represents 87 per minute for one observer.

At Moncalieri the 6200 for 4 observers in a quarter hour in like manner represents about 60,000 per hour for the total number visible.

In many other places larger or smaller numbers were reported. Over 100 in individual minutes were counted by a single observer in several places. It can hardly be doubted that there was a purer sky and so a larger number of meteors visible at Beyrout, Moncalieri and Marseilles than at Upsala and Greenwich.* In computing the hourly number of meteors visible we should choose the clearer rather than the hazy skies. Probably it will not be considered unreasonable to assume from these observations, that the density of the meteor stream in its central and densest portions may be fairly expressed by 75,000 meteors per hour visible at one place in a very pure clear sky by a very great number of observers.

By an extended examination of meteor paths it was shown in 1864 (this *Journal*, II, xxxix, p. 196) that *about one in fifty* (one in 50.35) of *all shooting stars visible at a place should have the middle points of their apparent paths within 10° of the zenith*. The hourly number of meteors within 10° of the zenith at the time of the maximum, Nov. 27th, was then 75,000/50, or 1500.

* It is not reasonable to suppose that the product of the number of meteoroids that entered the air near the several places multiplied by the cosine of the zenith distant of the radiant greatly differed. Can a different constitution of the upper strata of the atmosphere, by reason of which paths become more brilliant in one place than in another be admitted as possible?

Following a similar process of reasoning to that of the article referred to, we may compare the number N of meteor tracks which are visible during a given time at one place whose middle points are within 10° of the zenith, with the number N' of tracks visible during the same time (not necessarily visible all at one place) whose middle points are in a right cylinder of circular base whose radius is r , and whose axis proceeds from the observer in the direction of the radiant. The following proportion is readily formed :

$$N:N'::\int_a^b \pi \rho x^2 \tan^2 10^\circ dx : \int_a^b \pi \rho r^2 \sec z dx :: \tan^2 10^\circ \int_a^b \rho x^2 dx : r^2 \sec z \int_a^b \rho dx,$$

in which x expresses the height from the ground of middle points of meteor tracks, a and b the limiting values of x , z the zenith distance of the radiant, and ρ a factor proportional to the mean density of the meteor tracks at different altitudes, which is assumed to be a function of x only.

If we further assume that the values of ρ in the present shower are equal to those used in the memoir cited, and which were obtained from all the measured altitudes of shooting stars then available, we shall have for ρ at elevations of 45, 75, 105, 135 and 165 kilometers the several values 114, 243, 277, 106 and 57.

Using finite summation for integration we have,

$$\Sigma \rho \Delta x = 797 \Delta x, \text{ and } \tan^2 10^\circ \Sigma x^2 \rho \Delta x = 252930 \Delta x;$$

hence the above proportion gives $N' = .00315 N r^2 \sec z$ where r is to be expressed in kilometers.

The radiant at the time of the maximum of the shower was vertical over the Caucasus, and the value of $\sec z$ for the several stations varied from 1.02 to 1.15. I shall use the value 1.08 for $\sec z$, and 1500 for N for an hour. This gives $N' = 5.1 r^2$ for one hour, in other words, at the maximum of the shower there were 5.1 meteors per hour, the middle points of whose visible paths were in a fixed right cylinder whose axis was parallel to the relative motion of the meteoroids, and whose radius was one kilometer. But such a cylinder evidently received all the meteoroids of a cylinder of nearly equal radius located in the meteoroid group, and whose length was the hourly motion of the meteoroids relative to the earth before the earth began sensibly to attract them.

The velocity of the Biela meteoroids relative to the earth (using the orbit of 1852), is found by Weiss to be .53484. (*Beiträge zur Kenntniss der Sternschnuppen* I, p. 11.) The earth's velocity being 29.8 kilometers per second, we get

57,300 k. for the meteoroid's relative velocity per hour. *The space in the meteoroid group corresponding to each single visible meteor was therefore, in the densest portion of the group, a cube whose edge in kilometers is the cube root of $57,300\pi/5\cdot1$, that is, 32·8 kilometers, or 20·4 miles.*

Thickness of the stream of meteors.—As the earth has a velocity of 18·5 miles a second and its orbit has an inclination to the stream of $12^{\circ} 33'$, the earth's motion perpendicularly to the stream is 14,500 miles per hour, or 87,000 miles in six hours. The really dense portion of the stream was then less than 100,000 in breadth and nearly all of it was included in a belt 200,000 miles in thickness. One hundred thousand miles subtends at the sun an angle of $3'\cdot7$.

Radiant of the meteors.—Nearly every observer paid special attention to the radiant, so that perhaps at no previous time has there been so generally an effort to determine its position accurately as in the present shower. The result is correspondingly instructive. I have collected in the following table a considerable number of places assigned for the radiant, applying in a few cases a correction for precession to reduce from the date of the chart to the equinox of 1885·0. With some of these there is given the hour of the evening to which the radiant belongs, but the larger part are without such an indication. Five of them reported by Mr. Denning, at Bristol, are for preceding and following evenings. About seven-eighths of these tabular places are represented in the accompanying figure, p. 417, the remaining places being beyond its limit. The Pulkowa observations are plotted with R. A. $25^{\circ}\cdot5$.

Place.	Observer.	R. A.	Dec.
Agra,	Strahan,	$26^{\circ}\cdot2$	46°
Mauritius,		near	γ Andr.
Beyrout,	West,	25·5	43·5
Athens,	Lephay,	21	32
Pulkowa,	Romberg,	24–27	44
“	Backlund, etc.,	24–27	46
“	H. Struve,	24–27	48
“	O. Struve, etc.,	24–27	50
“	L. Struve, etc.,	22	53
“	“	24	44
Upsala,	Gyllenskiöld,	23·7	44·4
“	“	22·3	44·2
“	“	21·0	44·2
“	“	25·6	45·9
“	Fineman,	22·6	41·5
“	“	22·15	44·9
“	“	21·65	45·4
“	Charlier,	23·4	45·0
“	“	24·6	45·5

Place.	Observer.	R. A.	Dec.
Upsala,	Charlier,	23·9	47·3
“	Schultz—Steinheil,	25·2	42·5
“	Meyer,	22·05	46·4
Helsingfors,	Donner,	22·5	53
Vienna,	Weiss,	near	γ Andr.
Prague,	Weinek, etc.,	“	“
“	Safarik,	21·5	42
Breslau,	Galle,	27·1	43·9
“	“	27·7	43·5
Tuschkau,	Kaschka,	30·8	49·4
Königsberg,	Rahts,	23·1	43·8
“	Franz,	24·4	44·3
Berlin,	Förster,	25·7	43·2
“	v. Sichart,	25	45
Bremen,	Meinardus,	17	45
Leipzig,	Bruns,	22·6	48
Munich,	Oertel,	near	γ Andr.
Patenkirchen,	Ward,	“	χ “
Bonn,	Schönfeld,	24·7	44·2
“	Deichmüller,	16·4	44·9
Cologne,	Klein,	near	γ Andr.
Arnsberg,	Busch,	22	39
Essen,	v. Heyden,	30	50
Osterath,	Meller,	24	42
Malta,	Scoles,	21	46
“	v. Tucher,	27·7	42·5
Palermo,	Zona,	22·4	42·6
“	“	22·9	41·9
“	“	24·4	40·9
“	“	23·4	41·8
“	Ricco,	25·4	41·1
Milan,	Schiaparelli,	15	45
“	“	18·5	44
“	“	23	42
Moncalieri,	Denza,	22	44
“	“	26	43
“	“	28	42
Geneva,	Kammermann,	24	41
Deventer,	Sirks,	23	42
Sneek,	Nyland,	21	42
Enscheele,	v. Deinse,	22	43
Dongen,	v. Boxel,	25	39
Ongrée,	DeBall,	22	42
Nice,	Perrotin,	24·2	43·1
Marseilles,	Stephan, etc.,	22·5	49·2
Grignon,	Jehl,	23	42
Bordeaux,	Rayet,	28·5	46
Alton,	Howlett,	near	γ Andr.
Chepstow,	Lowe,	“	“
Bristol,	Denning (26)	26	44

Place.	Observer.	R. A.	Dec.
Bristol,	Denning (26)	27	43
"	" "	26	43·5
"	" (27)	24	43·5
"	" "	23	45
"	" (28)	22	43·5
"	" (30)	21	42·5
Harrow,	Tupman,	27	44
"	"	22·5	45·5
Greenwich,	Nash,	20	49
Stonyhurst,	Perry,	24	41
Oxford.	Stone,	22·5	42
"	Wickham,	10·3	52
"	Plummer,	21	45
"	Jenkins,	23	46
Dun Echt,	Copeland,	25·9	46·4
Dundee,	Smieton,	21	44
Glasgow,	Grant,	24	45·5
Cape Town,	Gill,	39	27
New Haven,	Newton,	near	γ Andr.
Cambridgeport,	Sawyer,	22·5	42·5
Princeton,	Young,	27·5	43·5

The object of forming this table is not to obtain the best possible observed place of the radiant. If this had been intended, there are many indications that some observations are entitled to considerable confidence and that some are not much to be relied on. The object is rather to bring out distinctly the fact that the radiant was not a mathematical point nor even a very small area. A considerable number of the observers distinctly stated that the tracks did not radiate from a point. Some thought there were two or more centers of dispersion. The same want of strict radiation from a center has been noticed in nearly every star-shower since 1833, the time when radiation was first noticed, and is shown equally when the tracks near the radiant are charted, and when the observer watches the stars near the radiant for the very purpose of deciding this question. Of course tracks beginning at a great distance from the radiant are of little use in determining the size and shape of the radiant area.

There are two corrections that should in strictness be applied to all these assigned positions, one for the zenithal attraction, and one for the observer's motion with the earth's rotation. The Biela meteors have a slow initial velocity relative to the earth, equal to 9·9 miles a second, and the same is increased before the earth's surface is reached to about 12 miles a second. Not a little deviation from the original direction is by reason of this slow velocity caused by the earth's attraction. The deviation is in the vertical plane, and is a function of the zenith distance very much like refraction.

The observed radiant is nearer the zenith than the original direction with which meteors approach the earth.

An approximate correction for this cause can be easily computed. For this we may disregard the height of the air, and assume that the meteors come to the ground. Also, the meteors may be regarded as coming in a hyperbolic orbit from an infinite distance instead of being only for a finite distance within the dominant influence of the earth's attraction.

Chart showing the places assigned to the radiant. The cluster is at γ Andromedæ. The large star is the place of the radiant corresponding to the Biela orbit of 1852.

Let us consider a single meteor that comes to the earth's surface, at the observer's place. The tangent to its path would then be directed to the observed radiant of a group that moved parallel to this single meteor. Let z be the angle which this path makes with the vertical line of the observer and α be the

quantity sought, namely, the angle through which the direction of path has been changed. The asymptote of the hyperbola makes then an angle $z+x$ with the vertical. Let the velocities at infinity, at the earth's surface, and what should be attained, at the perigee of the hyperbolic orbit, be respectively v , v_1 and v_0 ; let p , p_1 and p_0 be the perpendiculars upon the corresponding tangents; let g , a , b , and e , be the force of gravity, the semi-axes and the eccentricity of the hyperbola; let θ be the angle at the earth's center between the lines to the observer and to the center of the hyperbola, α the angle between the original direction of the meteor and the conjugate axis of the hyperbola, and r the earth's radius.

Then we have,

$$\text{by conservation of areas, } vp = v_1 p_1 = v_0 p_0; \quad (1)$$

$$\text{by conservation of energy, } v_1^2 - v^2 = 2gr, \text{ and } p_0(v_0^2 - v^2) = 2gr^2; \quad (2)$$

$$\text{by nature of the hyperbola, } \begin{cases} a = b \tan \alpha, p = b, e = \operatorname{cosec} \alpha, \\ r(1 + e \cos \theta) = a(e^2 - 1), \\ p = p_0(\tan \alpha + \sec \alpha), \end{cases} \quad (3)$$

Also

$$p_1 = r \sin z. \quad (4)$$

From (4)

$$\frac{p}{p_0} - \frac{p_0}{p} = 2 \tan \alpha,$$

and from (1) and (2)

$$\frac{p}{p_0} - \frac{p_0}{p} = \frac{2gr^2}{pv^2},$$

hence

$$\frac{gr^2}{v^2} = p \tan \alpha = b \tan \alpha = a. \quad (5)$$

Again from (1) and (2)

$$\frac{v_1}{v} = \left(1 + \frac{2gr}{v^2}\right)^{\frac{1}{2}} = \frac{p}{p_1},$$

hence

$$b = p = r \sin z \left(1 + \frac{2gr}{v^2}\right)^{\frac{1}{2}} = \sin z (r^2 + 2ar)^{\frac{1}{2}} \quad (6)$$

and from (3)

$$\cos \theta = \frac{a}{r} \frac{(e^2 - 1)}{e} - \frac{1}{e} = \frac{a}{r} \cos \alpha - \sin \alpha. \quad (7)$$

But evidently

$$\theta + z + x = \frac{\pi}{2} + \alpha, \quad (8)$$

since each member is equal to the angle between the transverse axis of the hyperbola and the asymptote. The equations (5), (6), (7) and (8) enable us to compute a , b , α , θ , and x for given values of z . Taking $g = 32.12$ feet, $r = 3956$ miles, $v = 9.9$ miles, we obtain this table of values of x with argument z .

z	x	z	x	z	x
10°	$1^\circ 0'$	40°	$4^\circ 9'$	70°	$8^\circ 0'$
20	2 1	50	5 19	80	9 35
30	3 3	60	6 36	90	11 22

Hence we may say that *the earth's attraction changes the radiant of the Biela meteors toward the vertical of the observer,*

one-tenth of the observed zenith distance of the radiant. When the radiant is near the horizon the change is somewhat greater than one-tenth of the zenith distance.

The radiant was to the east of the greater number of observers until the shower had nearly ceased, and the correction would be generally under 2° , though in some cases exceeding that amount.

A second correction to the observed place of the radiant is required by reason of the motion of the observer due to the rotation of the earth on its axis. This correction must be applied before the observed places can be compared with each other, or with a radiant deduced from the orbit of a comet. For the Biela meteors this may be easily shown to be about $1^\circ 0' \times \text{sine of the arc from the east point of the heavens to the radiant}$ and is to be applied to increase that arc. It is nearly constant for the European observations in the table.

These two corrections do not appear, however, to bring the scattered radiant positions any nearer together. We cannot, therefore, regard the earth's attraction and rotation as having much to do with their wide distribution over the constellation from which the meteors proceed.*

The luminous portions of meteor tracks are usually to the eye arcs of great circles. It is only in rare cases that the path appears curved. The luminous paths of the meteors were therefore straight lines, but were not parallel lines, for had they been parallel, the radiant should be a mere point, and not an area. How much they deviated from parallelism it is not easy to determine with exactness. That their directions differed from the average direction of the group by angles which for a considerable fraction of the whole number of meteors amounted to several degrees, seems a proper and necessary inference from the wide scattering of the radiant points as described by the observers and represented in the figure on page 417. Mr. Denning says (*Mon. Not. R. A. S.*, xlv, p. 69), "The area of radiation must have been fully 7° in diameter to accommodate the discordances in the flights. The center was at 24° , $+44^\circ$, but I saw several very short paths from a point south of γ Andromedæ. I noted many of the meteors with the utmost care in order to assure myself of the diffuseness of radiation, and it was found impossible to get a sharply defined position.

* Since writing the above, Professor Fœrster's paper, in No. 2720 of the *Astr. Nachr.* containing a discussion of thirty-two assigned positions of the radiant in this shower has been received. He applied the above two corrections to the observed places, and gives the reduced R. A. and declination of each assigned radiant. If the means of the observed R. A.'s or declinations be taken, and their deviations from the observed added together (neglecting sign), the sum is $97^\circ 7'$. But if the corresponding sum of differences be taken for his reduced places, the sum is $98^\circ 8'$. In other words, the radiants are equally scattered before and after correction.

The contrary effect was indeed so obvious as to arrest the eye whenever simultaneous bursts of about six or seven meteors took place near the radiant. It was then seen that the collective flights were not symmetrical emanations from a central point. They rather appeared to be discharged in a loose, disjointed fashion from a comparatively large space on the N.W. region of γ Andromedæ, and just perhaps enveloping that star within its limits." Similar testimony is given by other observers.

We must then accept one of two propositions: either the luminous paths are not true continuations, unchanged in direction, of the orbital paths of the meteoroids as they approach the earth; or else these orbital paths make angles of several degrees with their mean direction. The first alternative seems the more probable.

The meteoroid is probably a fragmentary body of irregular form. The meteorites which come to the ground are fragments, and nothing in their structure suggests a spherical or otherwise regular form upon entering the air. A small irregular body could not traverse with great velocity a fluid, even a fluid of extreme rarity, without there being developed such unsymmetrical resistance as would cause a curvature of path or glancing of the stone. This unsymmetrical resistance would continue so long as the stone retained its original irregularity. But in time the condensed air in front of the stone becomes hot enough to melt or burn off the stone. The thin angles in front must of course burn first. The melted matter being wiped off by the atmosphere, the anterior surface is rounded in such manner that the resistance of the air upon the stone becomes symmetrical. Thenceforth the path, now a luminous trail, is in general a right line. Curvature of path is an exceptional instead of an ordinary occurrence.

This rounding of one or more sides of the body is very clearly shown in many meteorites. Thus the Emmet Co. meteor broke into a very great number of large and small irregular fragments, and the small fragments retained enough velocity to burn after leaving the parent mass. Rounded surfaces evidently produced by the melting and wiping off of the material by the air are characteristic of these smaller pieces, several thousands of which have been collected.

The alternative proposition is that each luminous path is a portion continuous in direction, of the meteoroid's orbit about the sun and earth. Upon this hypothesis the orbits of different members of the group are not parallel, but the motions relative to the earth differ in direction by angles which amount in some cases to many degrees. The mean of the deviations from a common direction would be measured by degrees and not by minutes.

Suppose the directions of the luminous paths regarded as right lines to be first corrected for the earth's attraction and rotation as heretofore indicated, and the corrected lines to be produced indefinitely. They will intersect the celestial sphere in and near the constellation Andromeda. The most of the points will lie in an area comparable in size with the area dotted over by the assigned radiants, as shown in the figure on p. 417. Probably the points would be somewhat more widely distributed than the assigned radiants, since these latter are *centers* of radiation deduced each from many observed paths. Let an area R be taken on the celestial sphere that shall contain the principal part of the points so determined, an area that for convenience may be taken of an oval form. To this area R corresponds a second area R' , such that R' bears the same relation to the motion of the meteoroids relative to the sun as R does to the undisturbed motions relative to the earth. The area R' may be thus constructed. Let P be the point of the celestial sphere from which the earth is moving. To any point in R will correspond a point in R' co-planar with P and conversely. Hence great circles from P touching R will be tangent to R' . If u be the earth's velocity, and v the meteoroids' velocity relative to the sun (which may be assumed to be the same for all the meteoroids), then by the law of composition of velocities, $v:u::\sin PR:\sin RR'$. The dimensions of R' for the Biela meteors will be easily found to be in one direction about $\frac{4}{5}$, and in the other about $\frac{2}{3}$ of the dimensions of R . Therefore for the shower of Nov. 27th, R' is measured by degrees rather than minutes.

If the orbits of the Biela meteoroids were nearly (or quite) co-planar the area R' would be a narrow oval (or a mere line). And if S be the earth's place as seen from the sun at the time of the shower the major axis of the oval (or the line) would be co-planar with S .

But to each point in R' corresponds a point in R , and if R' is a narrow oval (or line), R will also be a narrow oval (or line, which would be in fact, a portion of a sphero-conic). The lengths of lines in R will be to the lengths of corresponding lines in R' in ratios not much greater than $9:4$, nor much less than $3:2$.

Now the thickness of the dense part of the stream subtends at the sun as was seen, an angle of about $3'.7$. Therefore, either there is something like a nodal point of the meteoroid orbits near where the earth's orbit cuts them, or else the deviation of the planes of the orbits from their mean plane is generally not greater than one-half of $3'.7$. Because a large group of orbits whose planes intersect the mean plane at angles

near 90° distant from where the shower happened would give a stream of meteors nearly equal in thickness to the radius of the earth's orbit into twice the limiting angle of the inclinations of the individual orbits to the mean orbit.

Unless therefore there is a nodal region for the several orbits near the ecliptic the area R' must have a breadth not much greater than $3'7$, and consequently R a breadth not much greater than $6'$ or $8'$ in a northerly and southerly direction.

Again if the meteoroid orbits are nearly co-planar, and we compare two orbits corresponding to two points at the extremities of the narrow area R' , it is easily seen that the tangents to these two orbits make an angle with each other equal to the length of R' . Now if two equal elliptic orbits of great eccentricity and a common focus cut each other at a small angle near perihelion the lines of apsides of the two orbits make an angle with each other, nearly twice that made by the orbits themselves at their intersection. Hence the major axes of the two orbits corresponding to the two extremities of R' make an angle with each other nearly double the length of R' , that is, nearly the length of R . That is, if R is several degrees long E. and W., the lines of apsides of the meteoroid orbits are distributed over several degrees. The group itself therefore must have enormous extent nearly in the mean plane, especially at aphelion. This would be true even if we suppose that the orbits have a nodal point at the place where they cut the ecliptic. Such scattering seems inconsistent with present compactness of the group, and a common history.

That there should be nodal points, either of inclination of planes or of intersection of orbits, where the earth cuts the meteoroid stream might be supposed possible if we had but one meteor-swarm to consider. But the same hypotheses must be for like reasons extended to the Leonids, and Lyraids, and perhaps to the Perseids. Unless the earth has been the controlling body in the history of all these swarms such hypotheses are violently improbable.

The more reasonable explanation therefore of the large area of radiation of the meteors of the Biela and other star-showers is the glancing of meteors on entering the air. The burning off of the angles of the solid fragments as soon as burning begins makes them move in straight lines thereafter. The curvature of path otherwise should continue through the whole length of the luminous tracks.

This glancing is not confined to the Biela meteors. It was true of the Leonids and still more of the Perseids. It is reasonable to assume that it is true of all shooting stars. It is not therefore as simple a matter as some have supposed to separate meteors into groups, allotting them to different radiant points, or to establish the persistency or change of such points.

To the uncertainty of the observation of a path, which with the very best observers amounts to two or three degrees, is to be combined this uncertainty of the amount and direction of its early glancing, which amounts also to several degrees. Besides all this there is the uncertainty due to the fact that any point above the horizon in a meteor path produced backward may have been its radiant. Any radiant that has been determined from a small number of paths must be very unreliable, and if the observations of the paths themselves have not been published the value of such determination as a contribution to astronomy is still farther diminished.

Movement of the nodes of the comet's orbit, and corresponding change of date of the shower.—The longitudes of the nodes of the orbit of the comet were greatly changed between its discovery in 1772 and its last appearance in 1852. The earth at first passed the node in the second week in December, but a change of ten or twelve days had brought it down to Nov. 27th before 1852.

The following table contains the longitudes of the nodes of the orbit reduced to the equinox of 1885.0, together with the inclination of the orbit to the ecliptic, for the successive appearances of the comet. The corresponding quantities for 1859 and 1866 are added from the orbits computed by Michez, the computation having taken account of the changes of these quantities in the interval from 1852. Since 1866 the perturbations of these quantities have been small, since Jupiter has not been at any time very near to the comet.

Longitudes of the nodes and inclinations of the orbit of Biela's comet at its successive appearances.

Year.	Ω	i	Year.	Ω	i	Year.	Ω	i
1772	258 $^{\circ}$ 7'	17 $^{\circ}$ 1'	1833	249 $^{\circ}$ 0'	13 $^{\circ}$ 2'	1859	246 $^{\circ}$ 1'	12 $^{\circ}$ 4'
1806	252 $^{\circ}$ 4'	13 $^{\circ}$ 6'	1846	246 $^{\circ}$ 5'	12 $^{\circ}$ 6'	1866	246 $^{\circ}$ 0'	12 $^{\circ}$ 4'
1826	251 $^{\circ}$ 2'	13 $^{\circ}$ 6'	1852	246 $^{\circ}$ 3'	12 $^{\circ}$ 6'			

With the progression of the node corresponds a progression of the star-shower, and with the change of inclination corresponds a change of radiant to the south. In 1798, on the evening of December 6th, Brandes counted for about four hours as many as 400 shooting stars. They diminished rapidly after 10 o'clock. In 1838 Mr. Herrick, on the evening of December 7th, with an assistant, counted 93 meteors in an hour radiating "from a spot not far from Cassiopeia; or perhaps, more nearly, from the vicinity of the cluster in the sword of Perseus. The radiant, however, could not well be fixed within three or four degrees." Observations at New Haven and elsewhere show that the maximum was on that evening. In 1847 Professor Heis at Aix la Chapelle observed on the evenings of December 8th

and 10th and recorded 226 meteors, a portion of which he has classified as radiating from R. A. 22° , Dec. $+55^{\circ}$. If from the meteors recorded by him on those two nights we select all those whose paths produced backward would pass near Cassiopeia or Andromeda, and at the same time make a considerable angle with the meridian, we have about 27 which cross the 20° hour circle north of 50° declination, and 9 south of 50° declination. The large north declination of 55° assigned by Heis for the radiant is, therefore, required by the paths as recorded. There is no indication of the time of maximum. In 1867, Zezioli on the evening of November 30th, saw seven meteors, which Schiaparelli assigns to the radiant, R. A. 17° , Dec. $+48^{\circ}$.

The great shower of 1872 had its maximum at Nov. 27³⁴, Gr. m. t. The mean of 90 assigned radiants considered as single points was given by Professor A. S. Herschel as R. A. $24^{\circ}54'$ Dec. $+44^{\circ}74'$ (Monthly Notices R. A. S., xxxiii, p. 504).

The longitude of the earth at the times of these several dates is given in the following table (equinox 1885.0):

Table of sun's longitudes at the dates of meteor displays.

Year.	Long. $\odot$	Year.	Long. $\odot$	Year.	Long. $\odot$
1798....	$256^{\circ}2'$	1847....	$257^{\circ}7'$	1872....	$246^{\circ}1'$
1838....	$256^{\circ}1'$	1867....	$248^{\circ}4'$	1885....	$245^{\circ}8'$

Since the Biela meteoroids are encountered at the *descending* node of the comet's orbit, the longitude of the ascending node and the longitude of the sun are quantities to be compared. It will be seen at once that on the first three of the six dates, viz: 1798, 1838, and 1847, the sun's longitude was about that of the node of the comet's orbit in 1772, differing from it by an amount easily explained by the action of Jupiter at some distance. On the contrary, the few meteors seen by Zezioli and the two grand meteor showers of 1872 and 1885 are related to the orbit of the comet since its near approach to Jupiter in 1841-42.

The change of declination of the radiant shows the same fact. Professor Weiss gives the radiants for the Biela orbits as follows (eq. 1850) [Beitrage, etc., p. 15]:

Year	1772	R. A.	$18^{\circ}7'$	Dec.	$+58^{\circ}1'$
"	1826	"	$22^{\circ}8'$	"	$+47^{\circ}7'$
"	1852	"	$23^{\circ}4'$	"	$+43^{\circ}0'$

The meteors of the years 1838 and 1847 have a radiant corresponding very well with that of the 1772 orbit, while the radiants of 1867, 1872 and 1885 are well represented by that belonging to the orbit of 1852.

The comet approached Jupiter and was greatly perturbed in 1794, 1831, and 1841-42. It is very difficult to conceive of

any way in which the meteors of 1872 and 1885 could be sent around in such a thin stream as we encountered, and one so near to the plane of the comet's orbit, unless they were a very compact group, and were also very near to the comet, as late as its near approach to Jupiter in 1841-42. If they left the comet before that time the effect of Jupiter would not be the same on the meteoroids as on the comet, and if they at that time formed an extended group, such disturbance as the comet suffered would have scattered the group, and we should have had a much less brilliant star-shower in 1872 and 1885.

Assuming, then, that the comet and the meteoroids were very near each other, if not united, at the date 1841.5 it seems possible to compute the disturbing forces and the resulting orbit along which some of these bodies traveled from that date until they met the earth in 1872, and also the orbit along which others traveled to meet the earth, Nov. 27, 1885. The observed orbits of the double comets in 1845-46 and in 1852 furnish the basis of such a computation. Possibly the result will give evidence for or against a resisting medium in the solar system.

We are moreover entitled to conclude that the process of disintegration of the comet is quite rapid. The non-appearance of the comet in recent years has like significance.

The following is a summary statement of conclusions:

1. The maximum of the shower was near 6^h 15^m Gr. m. t.
2. Three hours after the maximum the numbers of meteors had diminished to one-tenth the maximum number, and it is not unreasonable to assume six hours as containing the principal part of the shower.
3. The total hourly number of meteors visible at one place in a very clear sky, to some one or other of a very large group of observers may at maximum be regarded as 75,000.
4. In the densest part of the meteor stream where and when the earth encountered it, the space that corresponded to each meteoroid was equal to a cube whose edge was about 20 English miles.
5. The dense part of the stream was not over 100,000 miles in thickness.
6. The *zenithal attraction* of the Biela meteors was about one-tenth of the observed zenith distance of the radiant.
7. The radiant was an area several degrees across.
8. It is reasonable to suppose that the meteoroids while in the upper part of the atmosphere, before the paths become luminous, change direction by a glancing, due to irregularity of form. After the resistance has developed heat enough to melt or burn off projecting angles of the stones, and the tracks

become luminous, the forms of the bodies become rounded in front, and the paths described are straight lines.

9. The meteoroids encountered by the earth on the 27th of November, in 1872, and in 1885, did not leave the immediate neighborhood of the Biela comet earlier than 1841·5, and may be treated as having at that time orbits osculating that of the comet. The determination of the paths of these meteoroids through their five and seven last revolutions about the sun seems to be a problem capable of complete solution.