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ART. VII.—*The Story of Biela's Comet, a Lecture delivered by* H. A. NEWTON, *March* 9, 1874, *at the Sheffield Scientific School of Yale College.**

LADIES AND GENTLEMEN: I ask you to listen to-night to the story of Biela's comet. I will weave into the story enough of astronomy to justify its place in this course as a lecture.

The story has none of the interest which human passions give to stories of human life, and yet if it shall not be to you as interesting as a novel, it will be because I shall spoil the story in telling it to you. It is a true story. In other words, I mean to separate sharply what we know from what we guess.

One hundred and two years ago last night (March 8, 1772) a Frenchman named Montaigne, in the provincial City of Limoges, found a comet. He did what little he could with his small telescope to mark its place in the heavens, but it was not much that he could do. The comet was a faint one, not to be seen by the naked eye, and had a short tail, only one-eighth as long as across the disk of the moon. He did not dream that that little foggy speck of light was to be one day one of the most interesting comets in the solar system; in fact, that he himself was to be known to history only for having first seen it. This little comet is the hero of my story—a hero from humble life. Montaigne wrote to Paris of his discovery, and they saw it three or four times before it disappeared.

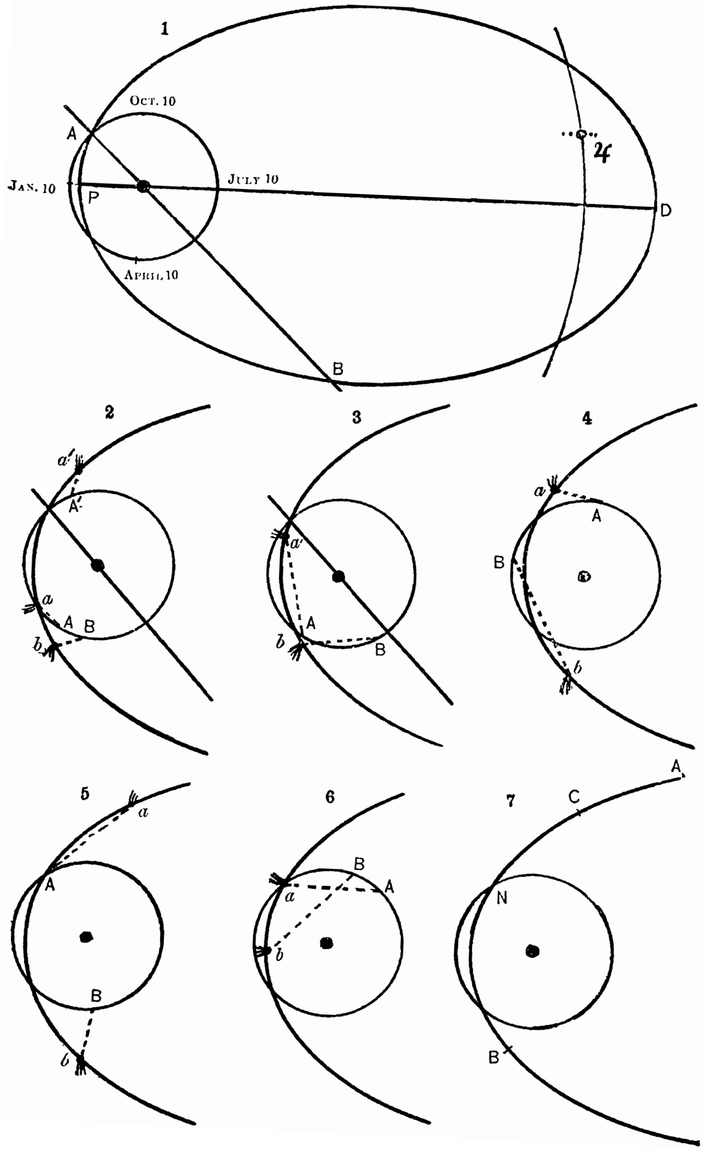
* The renewed interest in Biela's comet created by the great shower of meteors on the 27th of November last, justifies giving space for this lecture.—(EDS. JOUR. SCIENCE.)

Thirty-three years later, November, 1805, another Frenchman named Pons, saw the comet. It passed rapidly from the northern heavens, and in a month went below our horizon. It came this time very close to the earth, and I shall in a moment tell you how it appeared. It was visible to the naked eye, even in strong moonlight. Twenty years later, February 1826, an Austrian officer, Von Biela, again found the comet. So soon as an orbit could be computed, it was seen that the three comets of 1772, 1805 and 1826 were the same body. This has since been known as Biela's comet. Its exact path around the sun could now be told. Let me show it to you.

Let us look down upon the solar system from a point several hundreds of millions of miles north of it. Looking southward we should see the sun in the center. The earth, with its moon, would travel around the sun in a path or orbit denoted by the circle in the figure (fig. 1).

It goes about the sun once a year, being, on the 10th days of January, April, July and October, at the points so marked on the diagram. The motion is opposite to that of the hands of a watch. Outside, five times as far from the sun as is the earth, will be the huge planet Jupiter, a part of whose path you see. It goes about the sun once in twelve years. The paths of the other planets are not in the figure, as I have nothing to say about them to-night. In the figures which I show you the earth's orbit is twenty inches in diameter, or one inch to nine million miles. An express railway train traveling all the time for a fortnight would pass over about the thousandth of an inch in this figure. The comet's path is the ellipse. Around this ellipse it traveled three times in twenty years, or once each $6\frac{2}{3}$ years. When nearest to the sun, or at perihelion, it went within the earth's orbit, and when most distant it passed beyond Jupiter.

The comet's motion is very unequal. At D it moves very slowly. As it falls toward the sun the sun's attraction makes it move faster and faster, so that it whisks rapidly by P. As it then rises from the sun on the other side of the orbit, the sun not only turns it ever out of the straight path it would move in, but it stops its upward momentum, so that when it reaches D again it has only its old velocity with which to repeat its circuit. At P its velocity is twenty-eight miles, at D four miles, a second. In fact, to pass over the part lying apparently outside of Jupiter's orbit, just half of the whole $6\frac{2}{3}$ years is required. I said *apparently* outside, for another fact must be noticed: while Jupiter and the earth may be said to move in the same plane, that of the figure, the comet's orbit, lies at an angle. Suppose the ellipse to be a metal ring, and let it turn about the line AB as a hinge, the part ADB ris-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ing toward you, and the part APD retreating from you. The parts near D must rise about the half-diameter of the earth's orbit to give the true position of the two planes. Notice that the comet's and the earth's orbits cut each other at the node on the line AB. The importance of this fact will by and by appear. The two orbits seem to cut each other at another point (below P), it is true, but because of the angle of the planes the cutting is only apparent.

Like all other comets, this one was visible only when near the earth and near the sun. Through the outer part of its path it was never seen, even with a telescope. The comet was seen in 1826 for the third time.

Positions in 1772 *and* 1805.—In March, 1772, it was first seen from A in the direction A*a* (fig. 2). It was last seen four weeks later from B in the direction B*b*. In November, 1805, Pons found it when the earth was at A′ and the comet at *a*′ (fig. 2). Both the earth and the comet were going to the node, the comet going faster than the earth. The earth passed the node just ahead of the comet. I have told you that the comet was then visible to the naked eye even in moonlight, and well it might be. On the 8th of December, with the scale of the figures before you, it was only $\frac{5}{8}$th of an inch from the earth at the node. On the same scale the moon is $\frac{1}{40}$ of an inch from the earth. The comet passed $\frac{1}{16}$ of an inch outside the earth's orbit, but the earth was already past that point.

Dr. Schröter describes the comet: To the naked eye it was (Dec. 8) a large round cloud of light nearly as large as the moon. In a 13-foot telescope it had the same appearance, though it was much smaller, and it had a bright, star-like nucleus. This nucleus had not sharp edges, not even a definitely round form, but was like a light shining through a fog. Its diameter was about 112 miles, or, if we take only the central light, 70 miles; speaking roughly, as large as the State of Connecticut. The whole cloud, as seen in the telescope, was some 6,000 miles in diameter; to the naked eye perhaps 30,000 miles. How much smaller than 70 miles was the hard part of the nucleus, we cannot say.

Position in 1826.—In 1826 it was first seen from A in the line A*a* (fig. 3). Astronomers followed it with care, as they had come to know that it was a comet of short period, and not many such were then known. Its path then crossed just inside the earth's orbit at the node, but only $\frac{1}{500}$ of an inch in the diagram, or 20,000 miles, in fact, from it.

Position in 1832.—Six and two-thirds years brings us to 1832, and you can readily imagine with what interest this first predicted return was watched for. Some of you also remember the wide-spread, though groundless, fears at that time of a collision of the earth and the comet. The comet was first seen by Sir John Herschel in September. In his 20-foot reflecting telescope he saw it pass centrally over a group of small stars of the 16th or 17th magnitude. The slightest bit of fog would have at once blotted out the stars. Through the comet, however, they looked like a nebula, resolvable, or partly resolvable, into stars. How thick the cometic matter was we do not know. Its extent, laterally, was not less than 50,000 miles. Again M. Struve saw it pass centrally over a star of the ninth magnitude. A like star was seen in the telescope at the same time, so that he was able to say that the comet did not dim in the least the one which it covered. The comet, as the figure (fig. 4) shows, was in 1832 always at a great distance from the earth.

Another six and two-thirds years brings us to 1839. The comet came to perihelion, at P, in July. The earth and comet were on opposite sides of the sun both before and after July, and of course the comet was not seen.

Position in 1845.—Another circuit was finished in 1845–6. The comet was visible then during five months, from *a* to *b* (fig. 5), or as viewed from the sun through nearly half its circuit. At this time it was that the comet became all at once famous.

On the 29th of December Mr. Herrick (then Librarian of Yale College) and Mr. Francis Bradley (then in the City Bank) were watching the comet through the Clark telescope in the Atheneum tower yonder. They saw a small companion comet beside the larger one! What did it mean? Had the comet a satellite like the earth's moon? Or had the comet been split by some convulsion? Two weeks later the companion comet was seen by Lieut. Maury and Professor Hubbard at Washington, and two days after that, it was seen by two or three European astronomers.

Changes were seen in the larger telescopes that increased the mystery. The faint companion grew in size and brilliancy. Each comet threw out a tail. Then the smaller one had two tails. Then the larger one had a pointed, or diamond-shaped, rather than a round head. Two nuclei were seen in the larger one, and it also had two tails. An arch of light was thrown over from one to the other. For some days in February the companion was the brighter of the two. Presently three tails were seen running from the primary, and three cometary fragments (one observer says five) around its nucleus. What could it all mean? Do you wonder that astronomers were excited by these wizard changes?

The companion comet was seen in Washington by Maury and Hubbard two weeks after it was seen here by Herrick and Bradley. Professor Joseph Hubbard was the son of a resident of New Haven, well-known to many of you from his connection with the New Haven Bank. Professor Hubbard was graduated two years before (in 1843) at this college, and was now Professor in the Naval Observatory at Washington. He took up the study of the motions of the two Biela comets as special work, outside of his hours on duty. How faithfully he worked, four thick manuscript volumes of figures might tell. I cannot show you those books. They form, since Professor Hubbard's death, a cherished memento in the possession of a friend. But I have brought another of Hubbard's volumes from the College Library, one of three upon the comet of 1843, in order to show you by what patient labor some of the results of astronomy must be wrought out. In your school days you called it a wondrously long sum that covered both sides of the slate. On the leaves of this book there are as you see one, two, three, and in some cases, I think, even four thousand figures upon the page. You will, I am sure, excuse me from telling in detail to-night, how we learn about the sizes, distances, and motions of the comets. Eight or ten such volumes of figures, to be increased in time, we hope, by the four Biela volumes, form a monument to a true, devoted, gentle scholar of science. You will not wonder when I tell you that he hated shams.

Positions in 1852.—In 1852 the comet was always at a great distance from the earth (fig. 6), and only to be seen through the largest telescopes. The changes of size and brightness of the two comets were remarkable, and as they could but just be seen, sometimes one and sometimes the other alone was visible; which one it was that a person saw at any time was only told by computation afterward.

The two comets were now eight or ten times as far apart as they had been seven years before. They were at the point P, 1,250,000 miles apart. Professor Hubbard found that he could not tell which comet of 1852 was preceding and which following, in 1845. One supposition agreed as well with the observations as the other.

Perhaps the knowing ones among you have noticed that the arc from the node to the point marked Jan. 10, in the first diagram is too large for one month, for in 1772 the earth passed the node Dec. 9. But you will notice that when the comet is at D, and the large planet Jupiter is near by, he draws the comet toward the plane of the figure. The result is to bring the comet down to meet the earth's orbit farther from P. The node thus went back from Dec. 9 to Nov. 27, a distance of 12 days, or 12 degrees in the circle. The figure represents this last orbit. By the same cause the inclination was reduced one-fourth, or from 17° to 12°.

Since September, 1852 (with one doubted exception to be spoken of), neither of the two Biela comets has been seen. In 1859 their path was to us behind the sun. In 1866 they should have been at the point P on the 26th of January. A better chance of seeing them could hardly be. They were at all times to be away from the sun's light, and when nearest to the earth not more than one-fifth the sun's distance. The paths were carefully computed, and the action of all the planets, notably that of Jupiter, allowed for. A dozen observers for months swept the heavens with their telescopes, but not the slightest trace of the comets was seen.

Again, they should have come to perihelion a year ago last Autumn (Oct. 6, 1872), but, as I suppose, neither of them was seen. With the loss of its hero, our story would seem to come to an end. I must ask your indulgence, however, for another chapter.

I suppose that each one of you has often seen a shooting star. On a clear night you have seen a bright point of light travel quickly across the sky, as though a star had been shot from its place in the firmament. It may, if it was a large one, have broken into sparks as it disappeared, or have left a cloudy train along part of its path for an instant; or perhaps it was so faint even that you could not be quite sure that you saw anything. Some of you have seen those shooting-stars by hundreds in star showers.

Until near the close of the last century, poets dreamed, and other men guessed, about these objects, but knew nothing. Two German students, Brandes and Benzenberg, found out, and told us, that these bright flights were in the upper parts of the atmosphere. From the two ends of the city a track always appeared to be in the same part of the heavens. But when one went to a village many miles away, a track was seen by the two persons (at A and B, figure 8), in different parts of the sky. Hence they were able to measure the height of the shooting stars from the ground.

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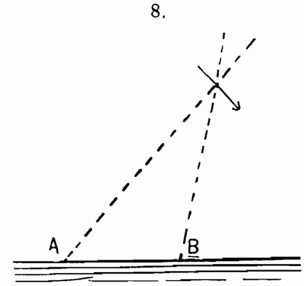

We now know that these luminous paths are rarely less than 40 miles or more than 90 miles from the earth. We also know that any shooting-star was a small body, of unknown size, perhaps not larger than a pebble or a grain of coarse sand even, undoubtedly solid, which has been traveling around the sun in its own independent orbit, like any planet or comet. Its path came within 4,000 miles of the earth's center, and so the small body struck into the earth's atmosphere. Its velocity was so great—fifty or a hundred times that of a cannon ball—that even in our rare upper atmosphere an intense light and heat was developed by the resistance, and the body was scattered in powder or smoke. These bodies before they come into the air, I call meteoroids. It is only when they have reached our atmosphere and begin to burn that we ever see them. They are then within 90 miles of the ground.

Brandes, one of the two German students spoken of, was riding in an open post-wagon on the night of Dec. 6, 1798, and saw and counted hundreds of these shooting stars or meteors. At times they came as fast as six or seven a minute. These meteors which Brandes saw that night we know now were bits from Biela's comet. In November, 1833, occurred the famous star shower, which some of you saw. The facts of that shower gave to two New Haven men, Professor Twining and Professor Olmsted, the clue to the true theory of the shooting stars. From that date shooting stars have belonged to astronomy. The November meteors were admitted a new constituent of the solar system. Three years later, M. Quetelet, of Brussels, found that shooting stars are to be seen in unusual numbers about the 10th of August of each year. A few months afterwards Mr. Herrick made independently the same discovery; but he also told us of star showers in April and January. What Brandes had seen in December, 1798, led Mr. Herrick, moreover, to expect a like shower in other Decembers, and he asked that shooting stars be looked for on the 6th and 7th of December, 1838. This shrewd guess was justified, for on the evenings of those days hundreds of these meteors were seen in America, in Europe, and in Asia by persons thus induced to look for them. These shooting stars also had once been parts of Biela's comet, though this fact was not dreamed of at that time.

In the course of time we came to know more about the meteoroids; that in general they moved in long orbits like comets, rather than round ones like planets; that some of them were grouped in long, thin streams, many hundreds of millions of miles long, and that it was by the earth's plunging through these that we have star showers; that the space traveled over by the earth has in it everywhere some of these small bodies, probably the outlying members of hundreds of meteoroid streams.

Also the periodic time and the path of the stream of November meteoroids were found out. Then came the interesting discovery that in this stream, and in that of the August meteoroids, lay the paths of two comets. Then Dr. Weiss of Vienna showed that the meteors seen by Brandes in 1798, and by Herrick in 1838, as well as many meteors seen near December 1 of other years, and the Biela comets, all belonged to each other.

It is then properly a part of my story to show you the behavior of one of the streams of meteoroids. Standing several hundreds of miles away, see them enter the upper atmosphere. They are entirely unseen until they strike the air. They then

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come down like drops of fiery rain a few miles, in parallel lines, burning up long before they reach the ground (see fig. 9). The air is in fact a shield, protecting the men below from a furious bombardment. The region of the luminous tracks is many miles above that of the highest mountains.

Go farther away. Parallel lines may show the paths of the meteoroids, though the bodies themselves are too small to be seen. They strike a little way into the air, to some persons coming from the zenith, to some coming obliquely, to some skimming through the upper air—and unseen by all upon one whole hemisphere. I need hardly remind you that sunlight, and twilight, and clouds often come in to prevent the seeing of the star-flights by persons below.

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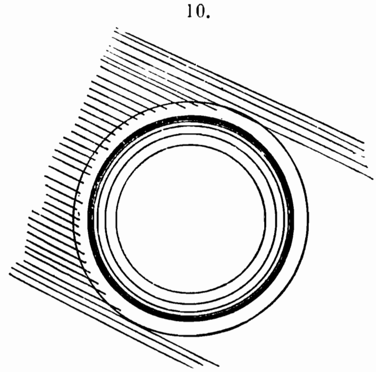

Go still farther away. From outside look in toward the sun upon the earth and meteoroid stream. The meteoroids in fact are not to be seen. The stream is of unknown depth, perhaps millions of miles deep. Its density increases in general toward the center. We cross the densest part of the November stream in two or three hours, and the whole of it in 10 or 15 hours, while the passage of the August stream requires three or four days. The Biela stream is crossed obliquely, the meteoroids overtaking the earth. The August stream is nearly perpendicular, and the November stream meets the earth.

Again go still farther away, out to the point from which we first looked down upon the earth and comet. We then see (by the mind's eye) the meteoroids strewn along the elliptic orbit of the comet for hundreds of millions of miles, forming a stream of unknown breadth, but in the scale of the first figure shown you, about $\frac{1}{50}$ of an inch in thickness.

Come back now and stand inside the stream, at its densest part. You in fact see nothing; but the meteoroids are all about you scattered quite evenly, and distant each from its nearest neighbors 20 or 30 miles. They all travel the same way and with a common motion.

Once more change your place and look up from the earth's surface. The meteoroids can now be seen, for when they strike the air they burn with intense light, becoming shooting stars. As it is from this position only that we ever see them, note their behavior with more care. A shooting star coming toward you appears only as a bright stationary point in the sky. That point is a marked one in every star shower, and is called the radiant. The meteors to the right and left of the stationary one are, in fact, moving in the common direction, but they seem to move in the sky away from the radiant (fig. 11).

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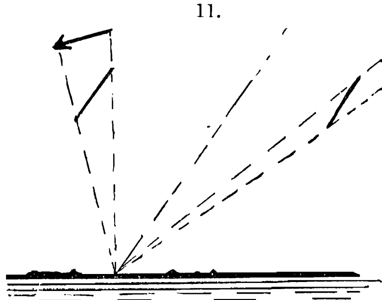

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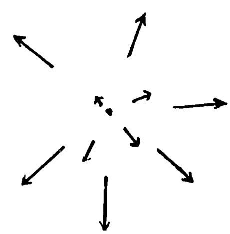

In other words, the tracks produced backward will all meet in one point in the sky (fig. 12). This radiant point may be in the horizon, or in the zenith, or at any place between. It will in general rise in the east and set in the west, like the sun or a star, keeping always its fixed place among the stars.

Need I tell you how much we would like to have some of these bits from the meteoroid streams to handle, to try with the blowpipe and under the microscrope, perhaps thus to learn something of their history? We do have something like this. At times large meteor masses come crashing into the air. They burn with a light bright enough to be seen over several States. Coming down usually a little lower than the shooting stars, most frequently to a height of 25 or 30 miles, they break up with a noise like the firing of heavy artillery, to be heard over several counties. Fragments scattered in every direction fall to the ground over a region ten or twenty miles in extent. I can show you several such fragments. There are over a hundred of them in our college cabinet, one of which weighs nearly a ton.

Between these stone-producing meteors and the faintest shooting star I cannot find any clear line of division. We have meteors that break with a loud detonation, but no fragments are seen to fall. One such was seen in 1860 from Pittsburgh to New Orleans, and from Charleston to St. Louis. It exploded over the boundary line of Tennessee and Kentucky. We have others which are only seen to break into pieces, no noise being heard. Then we have those which quietly burn out. Like the larger ones, these may leave smoky trains that last for minutes. One such I have seen for 45 minutes as it slowly floated away in the currents of the upper air.

Thus through the whole range, from the meteors that give us these stones and irons for our museums, down to the faintest shooting star hardly seen by a person watching for it, we pass by the smallest differences. They differ in size, in color of flame, in direction, in train, in velocity. But in astronomical character all seem to be alike. They move in long orbits like comets, and like comets at all angles to the earth's orbit. In fact, a meteoroid is a small comet, not having, however, the comet's tail.

Let us turn from this long digression again to the story of Biela and tell you what we saw of it in November, 1872. We of course looked for a few fragments from the comet the last week in November, but not quite as early as the 24th. But on that evening they came, in small numbers it is true. Before midnight we saw in New Haven about 250 shooting stars, three-fourths of them from Biela. Very few of them were to be seen the next morning and evening. Then for a day or two it was cloudy. But in the early part of the evening of the 27th they came upon us in crowds. Over 1,000 were counted in an hour. By 9 o'clock the display was over. But we saw only the last few drops of a heavy shower. Before the sun had set with us the shooting stars were seen throughout all Europe, coming too fast to be counted. At least 50,000, perhaps 100,000, could have been seen then by a single party of observers.

Notice what was really seen. Here is a chart of the paths of the shooting stars as actually seen on that evening, and drawn with care at the time upon maps of the stars. You see a few stray flights cutting wildly across the others. These are strangers to the system.

You see also that the paths do not, as we had reason to expect, all meet in one point. This is not due to errors of observing, for we see it in every star-shower. It is probably because the small bodies glance as they strike the air, just as a stone skips on the water. In fact, we often see the meteors glance in the air—the paths being crooked.

The meteors came from the northern sky. A German astronomer, Professor Klinkerfues, at once thought that if this

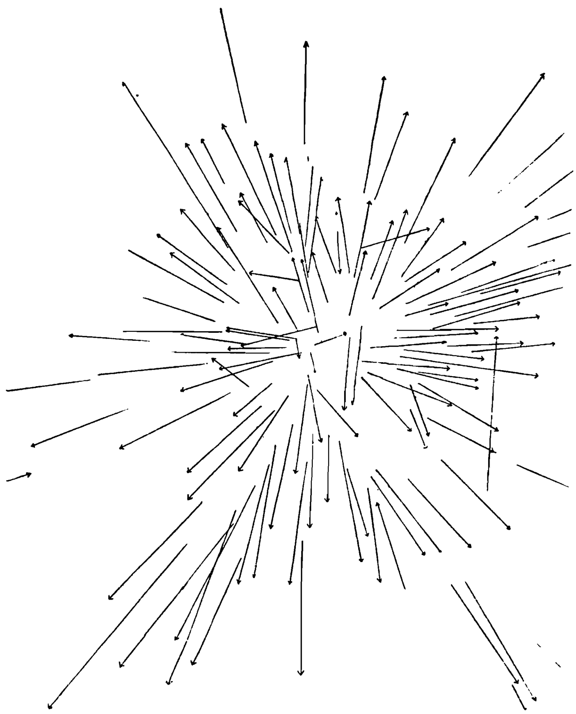

FIG. 13.—METEORS SEEN IN ITALY, NOV. 27, 1872.

was the main body of the comet it ought to be visible as it went off from us. For this, however, we must see the southern sky. He telegraphed to Mr. Pogson at Madras in India: "Biela touched earth Nov. 27. Search near Theta Centauri." Mr. Pogson looked for the comet and found it. On two mornings he saw a round comet with decided nucleus, and having on the second morning a tail eight minutes long. But clouds and rain returned the next day. This is the last that has been seen of Biela's comet.

Was this Pogson comet one of the two parts of Biela seen in 1845 and 1852? This is yet an open question among astronomers. It may have been, but I think it was not. The Biela comets should have been nearly 200,000,000 miles away.

Their orbits had been computed with care. The comets, as single or double, had been observed for 80 years, that is 12 revolutions, and we knew well their orbits. All known disturbing forces had been allowed for. It could hardly be that they should have gone so large a distance out of the way. It is much more probable that this was a third large fragment, thrown off centuries ago. The two observations made by Mr. Pogson were not enough to compute an orbit from, but they do show that his comet was very near us, and were such as one traveling in the Biela stream might give. But they also show that the earth did not pass through the Pogson comet centrally.

Orbit of the Biela Meteors.—In 1798, when the earth was at N, and Brandes saw the fragments from Biela, the comet was at C (fig. 7). In 1838 Mr. Herrick and others saw such fragments of the comet at N, 300,000,000 miles ahead of the main body at A, and in 1872 we met like fragments at N, 200,000,000 miles behind the main body, which should have been at B. Thus the fragments are strewn along the comet's orbit, probably in clusters, for at least 500,000,000 miles.

My story of Biela's comet and of its fragments has covered 100 years. Do we get any glimpses of its earlier life, and can we guess how it grew into its present shape? Yes, we may make our hypothesis. But we must not forget that to tell others how God must have made the world is bewitching to many minds, and that of the thousands of trials at world-building almost all have been grievous failures. With this caution let me give you a plausible form of this early story of Biela.

Once upon a time, hundreds of thousands of years ago, this comet was traveling in outer space, among the fixed stars, too far away to be attracted by the sun. What I mean by this outer starry space may be told by the help of the pictures I have shown you. In them the earth's distance from the sun is 10 inches, and the comet's longest range about five feet. Upon the scale of these figures only a few of the nearest fixed stars, perhaps two or three only, would be in the State of Connecticut. In this starry space the comet was traveling. What had happened before I do not try to guess. How, when, by what changes, its matter came together, and had become solid, I do not know, nor whether, in fact, it had not always been solid.

In the course of time its path and the sun's path through space lay alongside of each other, and the sun drew the comet down toward itself. If the comet had met no resistance as it ran around the sun, whether from the ether that fills space, or from the sun's atmosphere, and if it had not come near any of the planets, it would have gone off again into outer space whence it came. Some such cause robbed it of a little of its momentum, and it could not quite rise out of the sun's controlling force, but it came around again in an elliptic orbit to remain thenceforth a member of the solar system. It may or it may not then have been a great comet, like Donati's (in 1858). It was probably a small one. It may have made its circuit of the sun in tens of years or in tens of thousands.

At some time, probably in the early historic ages, it came near the huge planet Jupiter. When it had gone out of his reach it had just momentum enough left to go around the sun in its present orbit of 6⅗ years. It went away from Jupiter an entire and single comet. As it came near the sun, his burning heat acting upon the cold rocky body of the comet cracked off and scattered in every direction small angular bits. At the same time a very thin vapor, shining by its own light, was set free. To this vapor both comet and sun had an unaccountable repulsion. It was driven off first by the comet every way. But soon that which was sent toward the sun was driven back again, and it went streaming off into space to form the comet's tail, a process ably set forth by Professor Norton.

This matter which made the tail of the comet never got back. It had, moreover, nothing whatever to do with the meteoroid stream. The meteoroids are solid fragments. To them the sun, at least, had little repulsion. The comet was so small that perhaps the force with which a boy can throw a stone would have sent the bits of stone entirely off the comet, never to come back. Those which were shot forward from the comet near P (first figure) went up along the orbit with greater velocity and rose higher from the sun than the comet did near D. Having a longer road to travel, they took a longer time to come around to P in each circuit. On the other hand, those bits which were shot backward followed the comet with less velocity and could not quite rise to D, and so having a shorter road to go over came sooner back to P, gaining on the comet at each circuit. Thus the stream grew longer slowly, and new fragments being thrown off at each circuit, the meteoroid stream grew in length to its hundreds of millions of miles. At times, the main comet has broken into two or more parts, giving us the double comets of 1845 and 1852, the Pogson comet of 1872, and the double meteor stream of November, 1872.