ticism or positive disbelief until possible causes for the fact have been examined? I have endeavoured to indicate a possible cause in the simple attraction of the Earth. The considerations I have adduced are not very thoroughly established, but they point in the right direction, and do not demand any new supposition. Further, they are not at variance with known results of more elaborate mathematical investigations; and that they are not capable of being fully confirmed by, or compared with, such results at once is due to the fact that mathematical investigations have not yet been carried far enough. The perturbations of a planet on a swarm of meteors considered as a whole have been examined, but not the selective action on different parts of the swarm, and certainly not the interaction of differently affected parts. Until this has been done, why should we deny the possibility of the facts which Mr. Denning claims as observed facts?

Observations of the Leonids made at the Cambridge Observatory on 1899 *November* 13, 14, 15. By Arthur R. Hinks, M.A.

1. The observations to be discussed were made by a number of members of the University who had volunteered to assist in securing as complete a record as possible of the expected Leonid shower. My acknowledgments are due, first, to Mr. John C. W. Herschel, B.A., Research Student in Astronomy, St. John's College, who has taken a large part in the preparations, observations, and discussion of the results; and, secondly, to the following gentlemen: Messrs. J. F. Cameron, B.A., Fellow of Caius College; L. E. H. R. Barker, B.A., A. L. Hall, B.A., and H. E. Wimperis, Caius College; R. W. H. T. Hudson, B.A., A. B. Field, and M. Walker, St. John's College; W. E. Hartley, B.A., and G. W. Walker, B.A., Trinity College; F. M. Oldham, B.A., Trinity Hall.

We attempted three things:—

I. A continuous count of all meteors seen (five observers).
II. Records of trails from visual observations (two observers and a timekeeper).
III. Records of trails photographically (three observers).

The weather was on the whole not unfavourable, though we suffered from a thick haze late on the night of the 14th, when the shower was least feeble.

I. Horary numbers of observed Leonids.

2. Four observers watched continuously on the nights of the 14th and 15th, dividing the sky among them; and a fifth recorded every five minutes the counts of the four. The numbers

of meteors recorded as Leonids are given below. It is probable that meteors from neighbouring radiants have not been entirely eliminated from the count :

1899 Nov. 13.		Nov. 14.		Nov. 15.	
		h m h m		h m h m	
Clouds with occasional breaks until 17h, then clear.		12 5 to 13	4	12 25 to 13	2
		13 „ 14	13	13 „ 14	9
		14 „ 15	17	14 „ 15	11
h h m 17 to 18	20	15 „ 16	8	15 „ 16	5
18 „ 18 25	3	16 „ 16 35	3	16 „ 17	19
		From $14\frac{1}{2}^h$ fog gradually rose, and after $15\frac{1}{2}^h$, only brighter stars visible. Clouded over at $16\frac{1}{2}^h$.		17 „ 18	21
				18 „ 18 30	5
				From $15\frac{1}{2}^h$, light clouds at times	
Totals	23		45		72

In his spare time the recorder attempted an estimate of the magnitudes of any meteors he saw :

	Nov. 13.	Nov. 14.	Nov. 15.
a. Brighter than Jupiter	0	3	3
b. Between Jupiter and α Leonis	3	9	14
c. Between α and η Leonis	6	15	16
d. Fainter than η Leonis	6	11	18

II. Radiant points deduced from the visual observations.

3. Charts for recording the trails were prepared as follows :—The coordinates of all stars down to the fourth magnitude in a field having a radius of about 65° around the radiant were calculated for a gnomonic projection on the plane tangent to the sphere at the radiant. From these a map was plotted on millimetre paper to the scale tan 45°=1=100 mm. A set of needles of graduated diameters, broken across, and with the ends ground flat, were mounted in wooden handles. Sheets of paper, dark-blue one side and white the other, were laid, half-a-dozen at a time, blue side downwards, between the map and a sheet of lead, and the stars were punched through with needles of sizes appropriate to the magnitudes. The charts were laid on a tall desk of which the top was ground glass, and were illuminated from below by electric light. The stars stood out bright on a dark-blue ground, which did not dazzle the eye ; and the trails were drawn in pencil on the white side, which was uppermost, by means of transparent celluloid rulers, of which not much more than the edge was visible on the charts. This plan was suggested to me by Mr. Herschel. It is entirely satisfactory ; and the

only modification we shall make on a future occasion will be the substitution of night-lights for electric lamps. The heat from the latter was not sufficient to keep the charts from being covered first with dew and then with ice.

A copy of the chart, with a catalogue of the positions of the stars on the gnomonic projection, is placed in the Library.

4. The number of trails plotted was :

November	13	15.
"	14	11.
"	15	33.

Of these there were many that came from the general direction of *Leo*, but were clearly not true Leonids, and it was necessary to decide which should be included in the determination of the radiant point. Denning has given in the *Observatory* (1897, xx. 306), and in his General Catalogue (*Memoirs R.A.S.* vol. liii.) the positions of a number of radiants near *Leo*, all of which furnish in November swift streak-leaving meteors indistinguishable in appearance from Leonids. These were afterwards plotted on the map. They are clustered so thickly round *Leo* that it is somewhat difficult to pick out a trail which cannot be assigned with some probability to one or more of them. Even the small number of observations which we obtained gave, however, some evidence confirming the existence of definite radiation from two of these points ; and this will be considered later.

We eventually decided to reckon as true Leonids seven trails on the 13th, eight on the 14th, and eleven on the 15th.

In two or three cases the same meteor was plotted on two maps. These have been reduced as if they were observations of separate meteors, which is a convenient method of weighting the doubly observed meteor if the radiant is assumed to be strictly a point, but is perhaps not quite justifiable if it is an area of which we wish to determine the mean centre.

5. The displacement of the position of the apparent radiant point due to the attraction of the Earth on the meteors was calculated according to the theory of Schiaparelli. Tables for facilitating the computation are given in his treatise, "Entwurf einer astronomischen Theorie der Sternschnuppen," pages 65 and 109 ; and are reprinted in Valentiner's "Handwörterbuch der Astronomie," vol. ii. pp. 167, 168.

I assumed that the apparent radiant on November 14, 15^h was in R.A. 149° Decl. +23° (Clark, *Monthly Notices*, 1899 December, vol. lx. p. 169). The elongation ψ of the apparent radiant from the apex of the Earth's way was then 9°·8.

Assuming for the major axis of the meteor orbit 10·34 we have for the velocity of the meteors at their node on the Earth's orbit $v = \sqrt{1 \cdot 90}$, the velocity of the Earth being taken as unity.

The undisturbed velocity of the meteors relative to the

Earth comes out $u_0=2\cdot353$; the velocity is increased by the Earth's attraction to $u=2\cdot383$; and the apparent radiant when on the horizon is displaced towards the zenith by an amount $\Phi=0^\circ\ 43'\cdot8$.

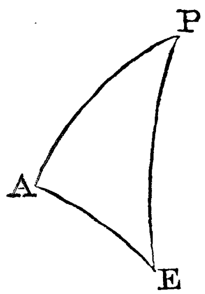
The displacement η for a given zenith distance ζ is then

$$\tan\tfrac{1}{2}\,\eta=\tan\tfrac{1}{2}\,\Phi\,.\,\tan\tfrac{1}{2}\,\zeta.$$

If q is the parallactic angle the displacements in R.A. and Decl. are $\eta\sin q$, $\eta\cos q$ respectively. Their values are given in the table :

Hour-angle.	18h.	19h.	20h.	21h.	22h.	23h.	24h.
$\eta\sin q$	−20′·6	−17′·9	−14′·6	−11′·2	−7′·5	−3′·4	0′·0
$\eta\cos q$	+24·4	+20·1	+16·8	+14·4	+12·7	+11·8	+11·4

6. The displacement of the position of the apparent radiant due to the rotation of the Earth was calculated as follows :— Let P be the pole ; A the apparent radiant ; E the apex of the



diurnal motion of the observer ; that is, the eastern point of the celestial horizon.

The velocity of an observer in the latitude of Cambridge is 0·285 km. per second ; and the velocity of the meteors, corresponding to $u=2\cdot38$ is 70·4 km. per second. If then $k=\frac{0\cdot285}{70\cdot4}$ ($\log k=\bar{3}\cdot6072$) the displacement of A towards E is very nearly $k\sin\mathrm{AE}$. And if h is the hour angle west of A

$$\text{displacement in R.A.}=k\sin\mathrm{AE}\sin\mathrm{PAE}$$
$$=k\cos h.$$
$$\text{displacement in decl.}=k\sin\mathrm{AE}\cos\mathrm{PAE}$$
$$=k\cos\mathrm{AP}\sin h.$$

The values of these displacements for the Leonid radiant are given in the table :

Hour-angle.	18h.	19h.	20h.	21h.	22h.	23h.	24h.
$\Delta\alpha$	0′·0	+3′·6	+7′·0	+9′·8	+12′·0	+13′·5	+13′·9
$\Delta\delta$	−5·4	−5·3	−4·7	−3·8	−2·7	−1·4	0·0

7. The Leonid shower extends over so few days that it does not seem possible at present to decide whether (1) the *true* radiant is stationary, and consequently the motion of the *apparent* radiant in latitude and longitude variable; or (2), as in the case of the Perseids, the motion of the *apparent* radiant is uniform in longitude and zero in latitude, in which case the *true* radiant is not stationary.

I have therefore not attempted to include in the reduction the effect of the orbital motion of the Earth, but have reduced each day's results separately.

8. The diagram exhibits the motions of the apparent radiant due to the separate effects of the attraction of the Earth and its rotation, and also the resulting motion due to the combination of the two.

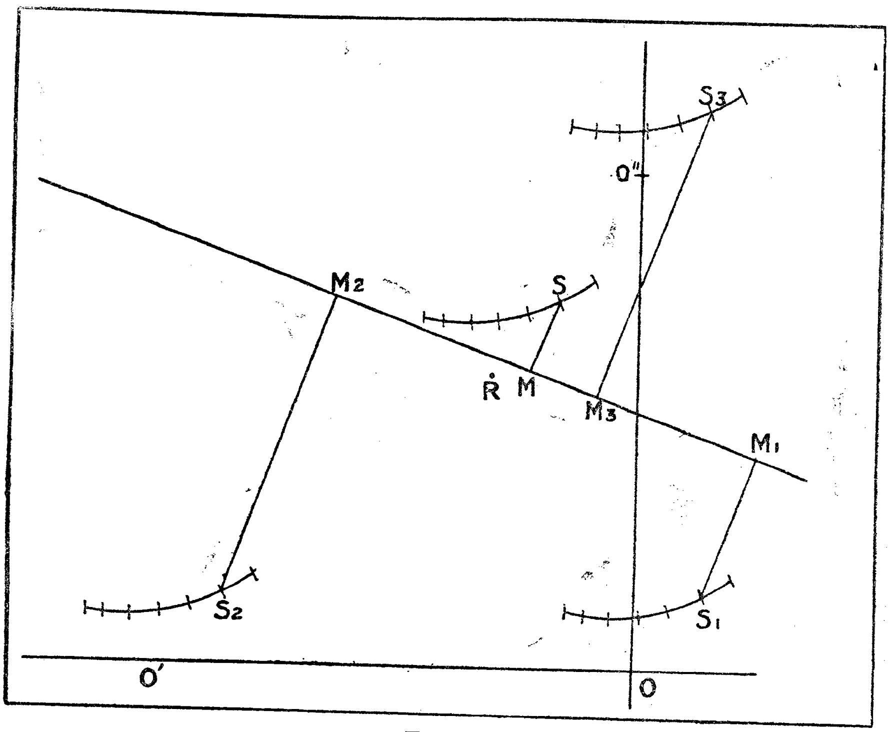


FIG. 1.

9. The radiant points were derived by an elegant graphical process given by Schiaparelli on p. 254 of his treatise (German edition).

The prolongation of the trails near the radiant point were transferred to millimetre paper on a scale ten times the original maps.

Let O be the origin of coordinates; R the position of the undisturbed apparent radiant to be derived from our observations; S the point on the curve of position of the displaced radiant corresponding to the time of appearance of a meteor; SM the perpendicular upon the observed trail. Schiaparelli shows that if R is the most probable radiant given by the observations the sums of the projections upon the coordinate axes of all the perpendiculars such as SM are each zero.

We can therefore determine R as follows :—Take two points O′ O″ on the axes. Draw about O, O′, O″ as origins the curves of displacement of the apparent radiant. From the points on these corresponding to the time of appearance of meteor draw the perpendiculars on its trail. (In practice find by a square the feet of the perpendiculars, and read off their coordinates directly.)

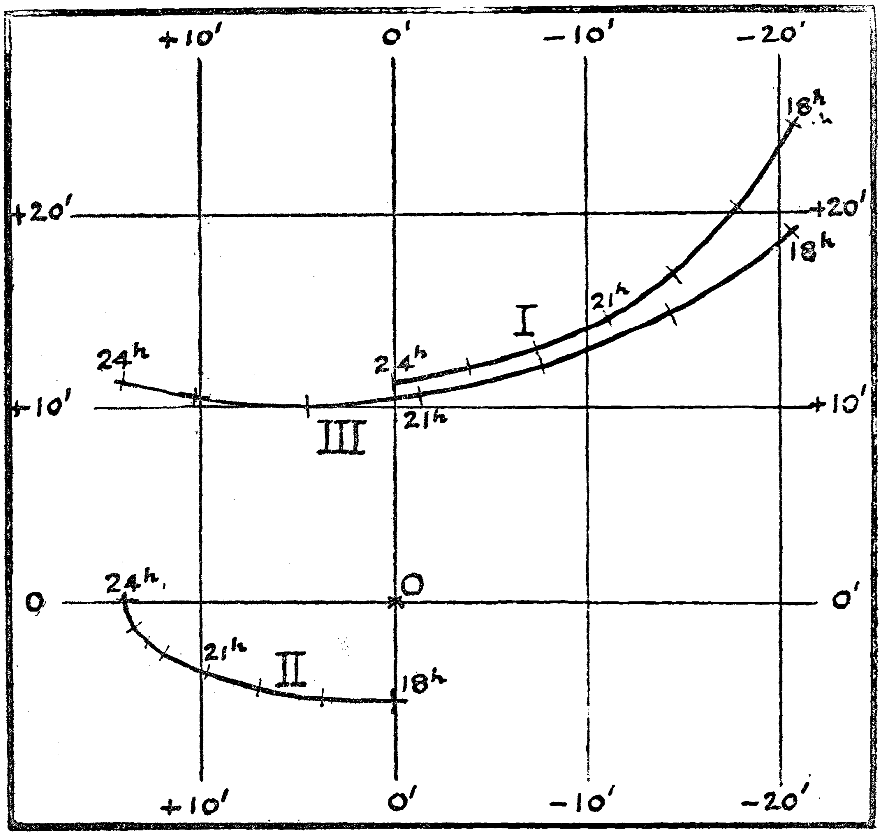


Fig. 2. O is the undisturbed radiant.
I ,, Zenith Attraction curve.
II ,, Diurnal Aberration curve.
III ,, combination of I and II.

If now the sums of the projections on the axes of all the perpendiculars of the three sets O, O′, O″ be S, T ; S+ΔS, T+ΔT ; S+Δ′S, T+Δ′T ; the coordinates x, y of R are given by

$$0=S+\frac{x}{OO'}\cdot\Delta S+\frac{y}{OO''}\cdot\Delta' S.$$

$$0=T+\frac{x}{OO'}\cdot\Delta T+\frac{y}{OO''}\cdot\Delta' T.$$

The observations for the three nights were treated in this manner, and the rectangular coordinates of the apparent radiants referred to an origin in R.A. 150°; Decl. +22° (the centre of our projection) were

Date.	x	y	Mean Deviation.
	m	m	m
Nov. 13	−0·043	−0·017	0·025
14	−0·044	+0·003	0·017
15	−0·008	+0·001	0·022

The unit is tan 45°=1=1 metre; and the corresponding positions of the radiant are

	R.A.	Decl.	Mean Deviation.
	°	°	°
Nov. 13	147·4	+21·0	1·4
14	147·3	+22·2	1·0
15	149·5	+22·1	1·3

Note.—The R.A. of the radiant on November 14 has extremely little weight: it depends practically on three trails, two of which are observations of the same meteor, which may well have belonged to the subsidiary shower B. (See below.)

When the coordinates of the apparent radiants had been found, the curve of position of the displaced radiant was drawn for each night, and the perpendiculars from the proper points on these curves to the respective trails were measured. The mean value of the perpendicular is given under the heading "mean deviation," and affords a criterion of the accuracy of the selected observations.

10. *Subsidiary Showers.*—We obtained four meteors on the 13th and four on the 15th, which might be ascribed to a subsidiary radiant A. Of these one was very probably a true Leonid, and has been included in the previous discussion. It is of course impossible to correct for zenith attraction &c. in the absence of knowledge of the true orbit. A graphical determination, similar to the above, of the most probable radiant from the eight paths gave

R.A. 153°·5, Decl. +37°·0.

Denning gives in his General Catalogue several determinations of a radiant which agree with this:

CXVIII. *μ Ursids.*

No. 15	155°+35°,	Nov. 13–15,	1879,	Perry.
16	154+41,	14–17,	1885,	Denning.
17	154+37,	15,	1875,	A. S. Herschel.
18	155+35,	15,	1896,	A. S. Herschel and Corder.

There were also five meteors on the 15th which might be ascribed to a radiant B. Of these, one was very likely a true

Leonid. The trails were not well situated for an accurate determination of the radiant point. It is approximately

R.A. 146°·7, Decl. + 7°·4,

which is quite near the radiant given in the General Catalogue as

CXII. *o Leonids.*

No. 13 146° + 8°, 1891 Nov., Corder.

11. An attempt was made to photograph the trails with a 5-inch portrait lens on the Northumberland Equatorial. Only one trail was secured, on November 15, of a bright meteor nearly end on. Measurement of this trail is deferred until the arrival of our new measuring machine.

12. The method of Schiaparelli used here was adopted after a trial of several, because it seemed to combine quite admirably simplicity with rigour; and this note must be regarded as the account of an attempt to prepare and gain experience for the future, rather than as the presentation of results of observation of much weight in themselves.

Cambridge Observatory:
1900 *March* 26.

The Equatorial Current of Jupiter in 1898.
By A. Stanley Williams.

The very striking appearance of the great Red Spot in the year 1879 gave an immense impetus to the study of the planet *Jupiter*, particularly as regards the investigation of the motions of the various spots and markings; and as a result of this impetus we have available at the present time the results of researches extending over a period of more than twenty years. We are consequently now in a position to commence the discussion of certain questions having an important connection with the physical condition of the planet in a more satisfactory and intelligent manner than was before possible.

One of the most important of these questions is that connected with the changes which have been found to occur from time to time in the motions or velocities of certain spots and surface currents on the planet. Valuable papers on the changes in the motion of the Red Spot have already been published recently by Mr. W. F. Denning and Dr. O. Lohse,* and the changes which have happened, and are happening, in the velocity of the great equatorial current form a subject of perhaps not inferior importance. With regard to this latter subject, the

* See *Astr. Nach.* No. 3490, and *M. N.*, vol. lix. p. 574.

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