in the same way as, in previous papers, has been shown to be probable with regard to the Moon and the Earth.

"The numerical data in Table II., § 7, exhibit so striking a difference between the terrestrial system and those of the other planets, that, even apart from the considerations adduced in this and previous papers, we should have grounds for believing that the modes of evolution have been considerably different."—G. H. D., *Phil. Trans.*, Part ii., 1881.

Some Types of Prominences associated with Sun-spots.

By Mrs. M. A. Evershed. (Plates 13–16.)

(*Communicated by J. Evershed.*)

The discovery of radial motion in sun-spots, made at this Observatory, reveals the fact that in the penumbra of every spot there are two opposite movements; for at the level of the reversing layer the gases are invariably flowing outwards, away from the umbra, while at the higher levels of hydrogen and calcium they are flowing inwards. It seems possible that some light may be thrown upon these remarkable movements by investigating a still higher region, that of the prominences, where moreover any indraught or outflow could be followed to a far greater distance from the spot centre, because the prominences lie above the faculæ which appear to mask the motion at its outer limits at lower levels.

Mr. Slocum has recently published some photographs of a fine prominence group * in which he detected here and there a flow towards the centre of a large spot then on the limb. This, however, hardly seems to prove that all the great masses on either side of the spot were pouring into it, as he suggests, especially as he also saw some "bright jets coming directly out of the spot." This prominence group, which was also photographed at Kodaikánal on the 8th, 9th, and 10th of October 1910, belongs to a type which I have been studying for some time. The structure always does suggest movement, usually of a violent kind, but when one tries to measure any particular streamer which looks as if it must be rushing in or out, it is usually found that it cannot be identified with certainty on a later plate, or that it has remained stationary. Where evidence of motion has been found, it is almost always outwards. The single instance, therefore, quoted by Mr. Slocum is certainly not enough to prove that sun-spots act as centres of attraction for prominences.

The type of prominence alluded to is distinguished by having a definite centre, often marked by an exceedingly brilliant point or short jet rising from the chromosphere; and from this centre streaks and streamers diverge both north and south. Spectroscopic

observations often indicate motion in the line of sight also, so that we may conceive the disturbance as radiating in every direction. The streaks are generally beaded, or carry a bright bead at the extremity. Sometimes they are straight, but often they curve, and then many of them may frequently be seen lying nearly parallel and meeting in great banks or cloudy pillars at some distance from the centre.

Sometimes, on the contrary, they stand nearly vertically above the chromosphere, and, abruptly turning, appear to fall again near the same place: then we have the arched or fountain form. The sides of the arches are often beaded, like the streaks, and there is generally a bright condensation at the top. These arch forms are usually transient or in rapid change.

There is also a rare form, in which only one arch appears, and this is remarkably stable, maintaining the same form for hours, or even days. In all the arch forms it is remarkable that they are more or less of the shape of a Moorish, not a Gothic, arch; that is, the sides converge towards the base, like a horse-shoe, instead of diverging.

The common feature of all these prominences is that they have a centre of radiation, so that we may for convenience call them radiating prominences, the commonest types being the streak, the streamer, and the arch forms, while others are quite peculiar. I measured the centres of over sixty, which were photographed here during the years 1908, 1909, and 1910, and found that with the exception of two, which were doubtful, there was always a spot or spot-group crossing the limb at the same latitude on the same day as that on which the prominence appeared. This was the more striking because, in another type of prominence which I had previously examined (massive forms united to the chromosphere by stems), not one had a spot in its neighbourhood. It may then be taken for granted that these radiating prominences are formed just above sun-spots, but by no means above all spots, nor during the whole lifetime of any single spot, for many a spot crosses the limb entirely unattended by any display of prominences.

What then is the nature of the connection between sun-spots and radiating prominences? And especially, since their forms so strongly suggest movement, what is the evidence that gases are rushing into or out of spots at this high level?

In order to present some of the evidence obtained, and also to show the strange and beautiful forms assumed, Mr. Evershed has made a set of slides enlarged directly from the original plates, which illustrate the characteristic features of eleven of these prominences.

Description of Slides. (Plates 13–16.)

On each plate the centre of radiation is marked, showing the latitude and the hour at which the photograph was taken. This is given in Indian Standard Time, which is 5½ hours in advance of Greenwich.

First Series, Nos. 1 *to* 3. East limb. February 25, 1909.

A small but highly characteristic display of beautifully beaded streaks. The fine details are best seen on the negative (No. 4,* the same as positive No. 3).

The three positives are from plates taken at $8^h\ 9^m$, $8^h\ 28^m$, and $10^h\ 34^m$, Indian Standard Time.

In the first two there is a very brilliant triple centre, occupying about 2°, with its mean position at 6° north; in the last these central jets are mere dots, but directly over them are streaks 60″ high. Unless these streaks have suddenly become visible out of nothing, so to speak, they must have rushed up in the last two hours, and it certainly looks as if the centre had blown up. Change may also be noted in the streak to the left (north), which has a bright patch at its extremity: this changes in shape in the later plates, being twisted up so that it becomes a little higher at the tip, although the part attached to the streamer is no higher than before.

This prominence was observed by Mr. Sitarama Aiyar, the first assistant at this Observatory, who saw the C line slightly displaced to the violet in the top streaks.

A stream of small and very active spots, with Greenwich number 6632, was on the meridian March 3·6, and therefore must have crossed the limb on this day, February 25: the mean position of the group was 4° north latitude.

Second Series, Nos. 5 *to* 7. East limb. September 26, 1910.

Another example of radiating streaks, but these are more nearly horizontal to the Sun's surface. The brilliant central jet at 13° south, which here is double, also obviously rises between $8^h\ 20^m$ and $8^h\ 33^m$: the rise amounts to 12,000 km., or 16 km. per sec. The first plate ($8^h\ 20^m$) shows a long streamer which is straight, but later becomes curved: very careful measurement shows that the streamer (which is tipped by a bomb) is a little longer at $8^h\ 33^m$ and is also falling slightly towards the chromosphere. It appears to be travelling out from the centre at a rate of 2·7 km. per sec., and falling at about the same speed.

The centre from which these streaks certainly appear to be shooting forth coincides with the centre of spot 6893 (Greenwich number), for its latitude was 13° south and it crossed the central meridian October 2·2. When the group went off the west limb, it was accompanied by the display photographed by Mr. Slocum.

Third Series, Nos. 8 *and* 9 (The Lady); *Nos.* 10 *to* 12 (The Lady gone). East limb. December 22 and 23, 1909.

The interesting feature on December 22 is a curved streamer with a bright condensation at its highest point. The fainter end curves very nearly down to the chromosphere, where a bright

* Not reproduced.

point nearly meets it; in the second plate (8^h 32^m) this down-curving portion has gone. Has it been sucked up and drawn into the brilliant centre, or has it fallen off? The gradually curving and dropping streamer of the last series inclines us to take the latter view. The other streamers are baffling: one grows longer, another shorter, in the 12 minutes' interval between the two plates. The streamers are exquisitely beaded, especially on the first plate, which is the best. At a little distance is a tall prominence like the figure of a lady looking on.

On the following day there are more eruptions, but the lady has vanished. At 8^h 45^m there is an extremely brilliant bomb, and if it is identical with the highest bomb seen at 10^h 42^m, it has risen 25,000 km., or at the rate of 3·7 km. per sec. In the first plate of this day (8^h 13^m) note an arch over latitude $-15°$. This marks the place of a spot which on its return was heralded by a magnificent display of arches, which we shall show presently.

Mr. Nagaraja Aiyar observed a displacement to the red in this prominence for 1·5 Å on the 22nd, and 5·0 Å on the 23rd, implying movements in the line of sight of about 70 to 200 km. per sec.

A large regular spot, with some small attendants (Greenwich No. 6791), crossed the east limb at this time with mean position 10° north. On December 24 it was observed here that C was reversed and D_3 dark in its vicinity. It crossed the central meridian on December 29·1, G.M.T.

Fourth Series, Nos. 13 *to* 15. East limb. April 28, 1910.
(The Cauliflower.)

It is only necessary to glance at this series of three to see that the bundle of bombs was rising, and Mr. Sitarama Aiyar's notes show that there was also movement in the line of sight, for he saw displacements over almost the whole prominence in both directions, C and D_3 appearing double in several places. As the interval between the last two plates is much greater than between the first two, the motion is more striking to the eye, but it was really diminishing in velocity. Measurements of the photographs show that the small bright spot just above the cauliflower-like mass moved upward at first at a rate of 12 km. per sec., and later at 3·6 km. per sec. The main mass was not moving quite so fast as the spot at first (8·2 km. per sec.), but caught it up and is seen touching it, because the spot grew larger; afterwards both were moving at nearly the same velocity (the spot 3·6, the main mass 3·2 km. per sec.).

A new group of sun-spots was visible close to the east limb on the day following this extraordinary outburst, and the main spot was on the parallel of latitude 2° north. It was very active on the 30th of April. When going off west, it was accompanied by a number of large irregular arches, 90″ high. The Greenwich number was 6842: it did not reappear.

Fifth Series, Nos. 16 *and* 17. West limb. January 9 and 10, 1909. (The Telegraph Post.)

We now come to examples of curving streamers radiating from a centre and merging at their other extremity in banks or columns. This group is specially well developed on the south side, for there is often a lack of symmetry of this kind. The centre (at 9° north) is very brilliant, and was higher on a plate taken an hour later (not shown), so that here again we have a plain instance of gas welling up from the spot-centre. On the following day the single broad jet has vanished, but there are two bright points at 9° and 11½°. The rather small mass seen to the south at $8^h\ 20^m$ on the 9th was higher and thicker at $9^h\ 19^m$, and streamers extended from it in both directions. On January 10, $8^h\ 32^m$, it will be observed that it has greatly developed; it is now leaning away from the centre, and the top is drawn out into a horn pointing away south; a great number of fine streamers run between it and the centre, like wires from a telegraph post. Is this tall post pouring its matter into the spot along the "wires," or is matter shooting out from the spot, and building up the post? There is nothing on the plates which helps us to determine the question, except that gas has undoubtedly been rising from the centre, and the post has not diminished but greatly grown both in height and thickness. Is not this merely a later stage of something like what we saw in our series 2 (September 26, 1910), where one streamer at least was shooting outwards and carrying its bomb gradually downwards towards the chromosphere?

The spot with which this prominence was connected was a very large one, followed by numerous small companions: its mean position was 9° north. It crossed the central meridian January 3.3 (G.M.T.), and had Greenwich No. 6591.

Sixth Series, Nos. 18 *and* 19. West limb. October 9, 1910. (Mr. Slocum's Spot.)

A splendid confusion of beaded streaks and streamers, short and long, straight and curved, with masses and filaments, mingled together on both sides, the whole extending for quite 45°, with its centre at 12° south. We have examined the plates very carefully for motion, but can find none. One long, nearly horizontal streamer (seen on the left) is 8000 km. shorter towards the spot in the second plate, rather suggesting motion outwards than inwards. Mr. Slocum found motion in both directions on his photographs, which were taken about twelve hours earlier than ours of the 9th, and twelve hours later than ours of the 8th.

The spot was a double group forming a splendid stream visible to the naked eye. It is the same group which was accompanied by the curving and dropping streamer of our second series when it crossed the east limb on September 26, 1910. This was its third apparition, when it received the Greenwich numbers 6893 and 6894. The mean latitudes of the double group were 13° and 15° south.

Seventh Series, No. 20. West limb. September 22, 1909. (The Wing.)

This is rather a rare type, showing only a slight development to the north, from a centre at 10° north, but a massive form south, spreading over the equator like a great bird's wing from 10° north to 10° south. It is joined to the centre by two slender filaments. The exceedingly definite edge of the mass southwards is a peculiar feature, but by no means unknown in other types. An earlier plate at $8^h\ 33^m$, and several later ones, show so little difference that we have not reproduced them: the mass shows no upward or downward movement, but there is slight outward movement between $8^h\ 33^m$ and $8^h\ 55^m$, amounting to about 2 km. per sec. This was found by measuring the distance in each plate between the central point and the distinct edge of the southern mass.

This prominence seems to have been connected with quite a new spot, which was seen at Kodaikánal to be forming in this region on September 20 (two days before the prominence appeared): it returned to the visible disc as a large regular spot at latitude 10° north, followed by small companions, and crossed the central meridian October 13·1 as Greenwich No. 6741. Its earlier appearance near the west limb does not seem to have been noted at Greenwich.

Eighth Series, Nos. 22 *to* 26. West limb. December 6 and 7, 1909. (The Cockroach.)

Another peculiar form. The negative (No. 21),* enlarged from a photograph taken at $9^h\ 16^m$ December 6, shows all the delicate detail of this curious prominence, which has the appearance of a gigantic insect with many legs. In the series of positives (three for December 6) the insect seems to be trying to fly away, but is so firmly held by threads to the bright low mass at 15° south that it does not move, either upwards or outwards, towards the south. The chief changes on this day consist in the legs becoming thicker and more numerous.

Next day it is much smaller, and seems to have succeeded at last in soaring upwards, having almost completely broken its connection with the bright prominence at 15° south, though it is still guyed down to the chromosphere vertically below it by filaments. New threads are put out towards the bright prominence at $10^h\ 19^m$.

It is curious that this soaring and diminishing prominence should be the last farewell of a large spot, which had appeared no less than four times. Its Greenwich number on this occasion was 6772, and it had crossed the central meridian on November 28, its mean position being 13° south. When it went off the west limb for the first time, on September 14, it was accompanied by a few prominences; and when it came on to the east limb for the

* Not reproduced.

second time there was a typical display of streamers and bombs (September 27 and 28). There were no displays in October and November, but it was monsoon time and the plates were often poor.

Ninth Series, Nos. 27 to 30. West limb. November 19, 1908. (The Arch.)

We now come to the arched forms, which are fairly frequent, though not so common as the streamers, streaks, and bombs. This particular prominence remained at a constant height, though it changed in shape, and at $9^h\ 29^m$ almost vanished (though the definition was still good), to return at $10^h\ 19^m$. Another faint arch was meanwhile taking form beside it. The curious disappearance may have been due to a displacement of the K line from the second slit, owing to motion in the line of sight.

Here, as often, there is change of intensity but no evidence of motion. In another case, however, an arch distinctly rises, and at the same time a low jet rushes up into one of its sides. (This was photographed on January 22, 1909: the forms are too delicate to show well on the screen.)

On the previous day there were streamers and a bank with a bright centre at 12° north at this place.

This is the first of the series of prominences which accompanied spot-group 6564 (position 13° north) in some of its seven apparitions; it was first seen, as a pair of small spots, on November 7, but quickly developed into a splendid group visible to the naked eye.

Tenth Series, Nos. 31 to 36. West limb. January 7, 1910. (Fountains.)

An ascending movement is clearly shown in a magnificent series of arches photographed fifteen times on January 7, 1910. This display accompanied the spot which was marked at its crossing of the east limb by the feeble arch shown on a plate of our third series (December 23, 1909, $8^h\ 13^m$, No. 10). In the first plate, at $8^h\ 5^m$, there is only one group of arches, and the form is scarcely distinguishable: they might be mere streamers with bright heads, but later they appear distinctly as arches, seen edgewise, and the bright tops rise with diminishing velocity.

Between $8^h\ 5^m$ and $8^h\ 53^m$ the rate of ascent is 3 km. per sec.

Between $8^h\ 53^m$ and $10^h\ 10^m$ the rate of ascent is 1·9 km. per sec.

At $10^h\ 31^m$ and $11^h\ 6^m$ the height remains the same.

Between $11^h\ 6^m$ and $12^h\ 44^m$ the rate of rise is 1·5 per sec. At this time they seem to have floated free from their base, but part of the K line may have been thrown off the slit, through change of temperature in the spectroheliograph, combined with distortion of the K line due to motion.

This is the only group of arches at $8^h\ 5^m$, but at $8^h\ 53^m$ we see some streaks beside it, and at $10^h\ 10^m$ there is a second group.

fully formed, interlacing and beautifully beaded, wide open, so that we look through them. As they rose to their full height in the space of two hours and five minutes the average rate of ascent would be 12 km. per sec.

Mr. Subrahmanya Aiyar noted that at $9^h\ 10^m$ the C line was displaced to the red at the top and to the violet at the base of the arches, while eight minutes later it was displaced to the red at the base for 2 Å, and to the violet over the rest of the prominence.

The spot with which these arches and the single arch of December 23 were associated was No. 6793, with position 15° south. It was a large active spot, with a few small companions.

Eleventh Series, Nos. 37 to 42. East limb. July 31, 1908. (Ring.)

An extremely brilliant and stable prominence, which had the same form on the previous day, when it was photographed on an excessively poor flocculus plate through thick cirrus. No plate could be taken on August 1 or 2, because of cloudy weather.

It is here shown on two fast-exposure disc plates, and its shape is quite clear, even though the first photograph was taken (at 8 a.m.) through thin cloud. These plates show how it rose directly out of a large flocculus, and they show plainly the usual bright condensation at the top of the arch, which is not so clear on the longer-exposed prominence plates. This arch has a horse-shoe shape, and its appearance almost suggests that it was continued on the chromosphere as a complete ring. The four selected prominence plates show that though the ring did not alter in height during the time it was observed here, it changed in width, being rounded and thick in two plates, and in the two alternate plates elliptical and thinner. We have tried to deduce motion from the two small jets which stand out on each side, like two little ears; the one on the left (north) side certainly seems to be descending between $8^h\ 47^m$ and $9^h\ 25^m$.

It is gratifying to find confirmation of this in the very interesting observations of Father Chevalier at Zô-zè.* He was fortunate enough to see this remarkable prominence well, and his observations of July 31, which began two hours earlier than ours, showed it to him at first as a much lower arch with the northern side incomplete, not reaching the chromosphere; in an hour's time it was higher and a perfect horse-shoe arch. Riccò adds a note that he saw it as a curved jet on the 29th, and, persisting as an arch on the 30th and 31st, disappearing on the 1st of August.† Both observers were struck with its extraordinary brilliancy, and note that the brightest part was the summit. Father Chevalier found that this part gave a continuous spectrum on the 30th.

Putting all these observations together, it seems clear that this arch originated in an uprush of intensely hot gas which curved

* *Memorie della Società degli Spettroscopisti Italiani*, vol. xxxviii. p. 17.

† "Il 10 agosto" is, I presume, a misprint for "il 1".

and fell northwards, and that a stream continued to ascend and follow nearly the same course for three days. The bright condensation at the summit, so characteristic of these arched forms, remains unexplained, for Father Chevalier's suggestion does not commend itself to us as satisfactory.

The spot over which this ring stood was oval, crossed by bright bridges, and was large enough to be seen by the naked eye. This was its second apparition. When it went off the west limb on August 14, it was entirely unaccompanied, though there were some insignificant prominences in the place the day before.

In conclusion, our investigation suggests more problems than it solves, yet some preliminary conclusions may be drawn.

1. The movements observed in these prominences, which are situated directly above sun-spot groups, are of quite a different kind from those discovered in the penumbræ of spots; for, instead of being uniform and constant, they are intermittent, and vary both in direction and amount.

2. In the greater number of radiating prominences we have been unable to find direct evidence of motion, but where found the motion is outward from the centre.

3. The visible movements are slower than one would expect both from the appearance of the prominences and from the movements observed in the line of sight, which are occasionally of the order of a hundred km. per sec. The gas has several times been observed to rise from the centre at a rate of about 12 km. per sec., but this velocity diminishes; at a distance from the centre it is of the order of 2 or 3 km. per sec.

4. The outward-moving gas seems to have a tendency to fall back upon the chromosphere. Sometimes it apparently accumulates there, and forms massive banks, but sometimes it seems to rise and fall again continuously like a fountain. Occasionally it rises very high and disintegrates.

There can be no doubt that other forces are at work on the Sun's surface besides an eruptive force and gravity. Prominences of very varied forms are seen falling, rising, expanding horizontally, being checked and driven back, stretching out long filaments towards the chromosphere or towards each other.* Light pressure, electric forces acting on ionised gases, and the magnetic force which we know from the discoveries of Professor Hale must exist in the vicinity of sun-spots, all must produce their own effects, and they must mask the upward and outward movements, which nevertheless do seem to be traceable to the intermittent action of certain sun-spots upon the gases immediately above them.

* The rising prominences in some cases observed at Kodaikánal move with an *accelerating* velocity and appear to be driven entirely away into space by a force opposed to gravity (see *Astrophysical Journal*, vol. xxviii. p. 79).

The Observatory,
Kodaikanal, South India:
1913 *March.*

1. E.L. 1909 Feb. 25. $8^h\ 9^m$.

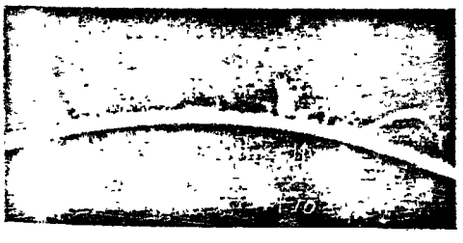
2. E.L. 1909 Feb. 25, $8^h\ 28^m$.

3. E.L. 1909 Feb. 25, $10^h\ 34^m$.

5. E.L. 1910 Sept. 26, $8^h\ 20^m$.

6. E.L. 1910 Sept. 26, $8^h\ 33^m$.

7. E.L. 1910 Sept. 26, $9^h\ 13^m$.

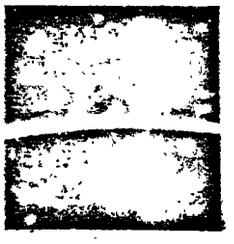


8. E.L. 1909 Dec. 22, $8^h\ 20^m$

9. E.L. 1909 Dec. 22, $8^h\ 32^m$.

10. E.L. 1909 Dec. 23, $8^h\ 13^m$.

11. E.L. 1909 Dec. 23, $8^h\ 45^m$.



12. E.L. 1909 Dec. 23, $10^h\ 42^m$.

TYPES OF PROMINENCES. MRS. EVERSHED.

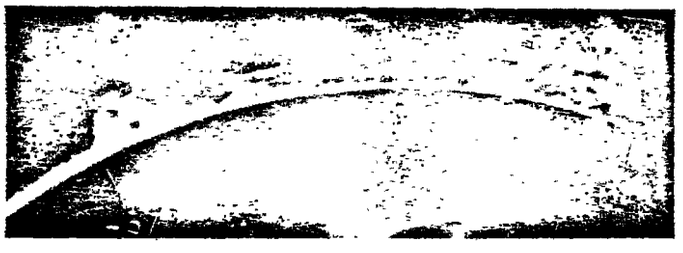
13. E.L. 1910 April 28, $8^h\ 58^m$.

14. E.L. 1910 April 28. $9^h\ 19^m$.

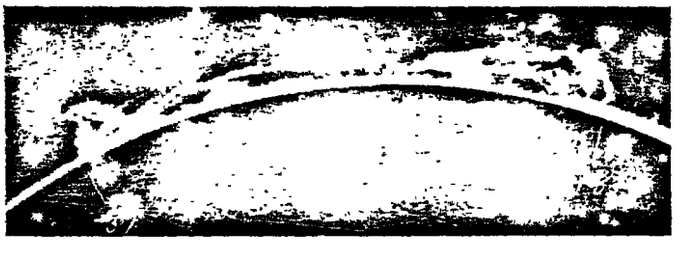
15. E.L. 1910 April 28, $10^h\ 27^m$.

16. W.L. 1909 Jan. 9, $8^h\ 20^m$.

17. W.L. 1909 Jan. 10, $8^h\ 32^m$.



18. W.L. 1910 Oct. 9, $9^h\ 56^m$.



19. W.L. 1910 Oct. 9, $10^h\ 11^m$.

20. W.L. 1909 Sept. 22, $8^h\ 55^m$.

TYPES OF PROMINENCES. MRS. EVERSHED.

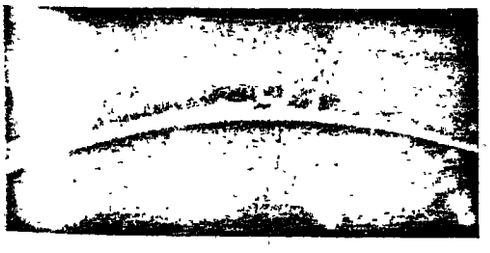
22. W.L. 1909 Dec. 6, $8^h\ 23^m$.

23. W.L. 1909 Dec. 6, $9^h\ 16^m$.

24. W.L. 1909 Dec. 6, $10^h\ 19^m$.

25. W.L. 1909 Dec. 7, $8^h\ 51^m$.

26. W.L. 1909 Dec. 7, $10^h\ 19^m$.



27. W.L. 1908 Nov. 19, $8^h\ 25^m$

28. W.L. 1908 Nov. 19, $8^h\ 33^m$.

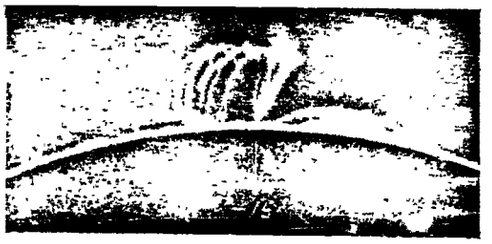
29. W.L. 1908 Nov. 19, $9^h\ 29^m$.

30. W.L. 1908 Nov. 19, $10^h\ 19^m$.

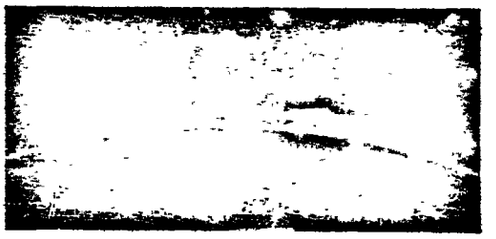
TYPES OF PROMINENCES. MRS. EVERSHED.

31. W.L. 1910 Jan. 7, $8^h\ 5^m$.

32. W.L. 1910 Jan. 7, $8^h\ 53^m$.



33. W.L. 1910 Jan. 7, $10^h\ 10^m$



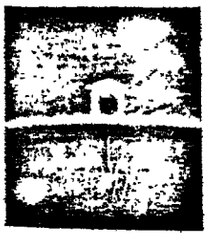
34. W.L. 1910 Jan. 7, $10^h\ 31^m$.

35. W.L. 1910 Jan. 7, $11^h\ 6^m$.

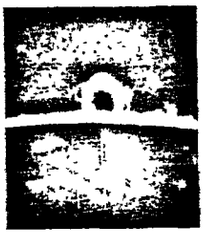
36. W.L. 1910 Jan. 7, $12^h\ 44^m$

37. E.L. 1908 July 31, $8^h\ 0^m$.

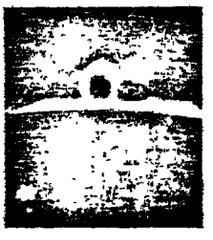
38. E.L. 1908 July 31, $8^h\ 18^m$.



39. E.L. 1908 July 31, $8^h\ 47^m$



40. E.L. 1908 July 31, $5^h\ 7^m$.



41. E.L. 1908 July 31, $9^h\ 25^m$

42. E.L. 1908 July 31, $9^h\ 34^m$.

TYPES OF PROMINENCES. MRS. EVERSHED.