THE SPROUL OBSERVATORY ECLIPSE EXPEDITION, JUNE 8, 1918.

Coronal Arches and Streamers.

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(*Read April 25, 1919.*)

The Eclipse expedition from Sproul Observatory was located at Brandon, Colo., a station on the Missouri Pacific, approximately fifty miles from the Colorado-Kansas line.

This region is very dry, and the weather conditions are favorable. During the month preceding the eclipse the sun was either clear or only thinly clouded, at 5:26 P.M. on all but six days; and in general the afternoons were better than the forenoons. The wind was usually high, often very high, and the air many times was full of dust. It was so cloudy all day on June 5, 6 and 7, and the forenoon of June 8, that at no time could successful observations have been made. This was the longest period of cloudy weather that we had while there. At noon of June 8, however, it cleared, and at the time of totality only two small clouds were visible west of the meridian, one about twenty degree above the sun and the other near the horizon. The seeing was fairly steady.

The following instruments were mounted:

I. One lens, nine inch aperture, focal length 62½ feet. This was mounted as the Lick Observers since 1893 have mounted their long focus lenses. Exposures of two seconds, twenty seconds, forty-five seconds, and three seconds were made with this lens.

II. On a polar axis, two lenses of four inches and three and one half inches aperture, respectively, and of focal length eleven feet two inches were mounted. The exposure with each of these lenses was for eighty-two seconds.

III. In another polar axis were mounted six lenses varying in focal length from ten and one half to fifty inches; also a transmission grating.

IV. A three-prism slit spectrograph with which we hoped to determine the rotation of the corona, and a slitless spectrograph were mounted on another polar axis.

The photographs secured show a moss of coronal detail. The shorter exposures show the coronal arches that surround the great number of prominences that are found on the rim of the sun. These have been so well shown in the slides accompanying the preceding papers that it seems unnecessary to show them again and for economy of time I shall show one only, a slide from the forty-five second exposure with the sixty-two and one half feet focal length.

The problem that I had more specifically in mind was to secure if possible some data that would contribute to a knowledge of the origin of the corona, to see if we could from a study of the details of its structure get a hint of the nature of the forces that produce it and give it its shape. I shall limit myself to a brief statement of our study of two things.

1. To see if there was any indication of change of form in the corona itself during the eclipse.

2. To find if the general form of the streamers in the corona gave any indication of the way in which it is formed.

I. Change in the Corona.

Director Campbell, of the Lick Observatory, and Professor J. C. Hammond, Director of the Naval Observatory Station, most generously put at my disposal glass positives of short exposure photographs, made respectively at Goldendale, Washington, and Baker City, Oregon. The Lick plate was made with a camera whose focal length is forty feet. Totality at Goldendale lasted for one minute and fifty-seven seconds. The plate loaned me by Director Campbell was exposed from one minute fifty seconds to one minute fifty-two seconds after the beginning of totality. This plate was compared with two plates made by the Sproul Observatory expedition, one exposed for two seconds just at the beginning of totality and the other for three seconds just at the end of totality. The focal length of the camera with which these plates are made is sixty-two and one half feet, so that the pictures to be compared were of very different scales. The plates were reduced to the same scale by measuring the diameter of the moon's shadow on each plate and finding the ratio of these two measured diameters. The center of the sun for each of the three plates was found and plotted on each plate, the necessary corrections being made for different times of exposure, parallax, etc. The conspicuous prominences were as follows: Two small quiescent northern prominences, a large northwestern quiescent prominence, a large eruptive prominence in the southwest called from its shape the Skeleton prominence, and a large northeastern prominence called the Pyramid prominence.

Around the eruptive prominences there are series of arches described so well in the preceding paper by Professor Lampland that further comments are unnecessary.

Following my suggestion Miss Margaret E. Powell, a graduate student at Swarthmore College, made a study of these plates. All the measures which I shall give presently were made by Miss Powell. We selected three arches which seemed definite enough to measure.

The measures were made in this way. A point is selected which can be certainly identified on each of the three plates. Choosing a line through this point and the center of the sun as an initial line and the center of the sun as origin, we may locate any point in the streamer by its polar coördinates θ and ρ. The arches were about equally well defined in the Lick plates and each of the two Sproul plates. The polar coördinates of a series of points on an arch were measured on the Lick plate, then setting off the same series of vectorial angles on a Sproul plate and measuring the radii vectors, we obtained the polar coördinates of the corresponding points on the Sproul plate. If these radii vectors are the same the arch is unchanged, but if they are different (assuming the measures are exact) the shape or the position of the arch has changed.

Miss Powell measured three arches in this way. The accompanying tables give the details of the measures. The vectorial angle is given by θ. The quantities ρ and ρ' are the radii vectors in inches measured on the Sproul and Lick plates respectively and reduced to the scale of the Sproul plate.

The eclipse at Brandon occurred twenty-five minutes after it occurred at Goldendale; $\rho-\rho'$ is therefore the amount the arch has changed. If $\rho-\rho'$ is positive for a given point, that point is farther from the center of the sun, when the sun was eclipsed at Brandon than when it was eclipsed at Goldendale twenty-five minutes before.

After the first set of measures was made, the zero line was redetermined and all angles and distances remeasured, so that each set of measures was independent of the others except the same size of each vectorial angle was retained. The different series of measures were made on different days, the last series being made about six weeks after the first were made, so that I believe little, if any, prejudice originating in the earlier measures was carried into the last set.

Measures of the Arch Around the Southeastern Prominence.—This prominence is a few degrees east of the South Pole. There are five well defined arches on the equator side of this prominence, the inner one of which is measured. The table shows the results.

1. AN ARCH AROUND THE SOUTHEASTERN PROMINENCE.

	First Measures.				Second Measures.			Third Measures.			
	ρ	ρ'	$\rho-\rho'$	θ	ρ	ρ'	$\rho-\rho'$	ρ	ρ'	$\rho-\rho'$	θ
1.	3.81	3.71	+0.10	+1° 48′	3.84	3.76	+0.08	3.84	3.76	+0.08	+1° 48′
2.	3.88	3.71	.17	1 18	3.91	3.76	.15	3.91	3.80	.11	1 18
3.	3.91	3.76	.15	0 48	3.94	3.84	.10	3.94	3.84	.10	0 48
4.	3.94	3.84	.10	0 24	3.97	3.88	.09	3.97	3.88	.09	0 24
5.	3.97	3.88	.09	−0 18	3.97	3.93	.04	4.00	3.93	.07	−0 18
6.	3.97	3.88	.09	−0 36	4.00	3.93	.07	4.00	3.93	.07	−0 36

The quantities ρ and ρ' in the "first measures" of this arch are from center of the sun to the inner boundary of the arch; the other measures from this arch and all the others are to the middle of the stream forming the arch. The first measure in each series is always for a point near the limb of the sun, and is in consequence very indefinite.

2. AN ARCH AROUND THE PYRAMID PROMINENCE.

Toward the Pole side of this prominence there are four well-defined arches; one of these was measured. The arches on the Brandon plates seem to curve more than those on the Goldendale plates. The results are shown of four sets of measures on three different days.

	First Measures.				Second Measures.			Third Measures.			
	ρ	ρ'	$\rho-\rho'$	θ	ρ	ρ'	$\rho-\rho'$	ρ	ρ'	$\rho-\rho'$	θ
1.	4.06	4.14	−0.08	+1° 36′	4.09	4.01	+0.07	4.09	4.05	+0.04	+1° 36′
2.	4.28	4.27	+ .01	2 12	4.28	4.23	.05	4.28	4.18	.10	2 12
3.	4.38	4.31	.07	2 36	4.38	4.23	.15	4.38	4.23	.15	2 36
4.	4.41	4.35	.06	3 30	4.47	4.27	.20	4.47	4.31	.16	3 30
5.	4.47	4.40	.07	4 18	4.47	4.31	.16	4.47	4.35	.12	4 18
6.	4.47	4.44	.03	4 54	4.50	4.35	.15	4.50	4.35	.15	4 54
7.	4.50	4.48	.02	6 06	4.50	4.40	.10	4.50	4.40	.10	6 06

	Fourth Measures.			Fifth Measures.			
	ρ	ρ'	$\rho-\rho'$	ρ	ρ'	$\rho-\rho'$	θ
1.	4.00	4.10	+0.10	4.06	4.05	+0.01	+1° 36′
2.	4.25	4.18	.07	4.22	4.18	.04	2 12
3.	4.31	4.23	.08	4.28	4.23	.05	2 36
4.	4.34	4.27	.07	4.34	4.27	.07	3 30
5.	4.38	4.35	.03	4.38	4.35	.03	4 18
6.	4.41	4.40	.01	4.47	4.40	.07	4 54
7.	4.41	4.40	.01	4.47	4.40	.07	6 06

3. An Arch of the Skeleton Prominence.

This prominence has five distinct arches on the equatorial side. On the Pole side they are much less distinct, due perhaps to the presence of another prominence beyond the edge of the sun. The measures of the fourth arch from the prominence on the equatorial side are shown in Table 3.

	First Measures.				Second Measures.			Third Measures.			
	ρ	ρ'	$\rho-\rho'$	θ	ρ	ρ'	$\rho-\rho'$	ρ	ρ'	$\rho-\rho'$	θ
1.	4.09	4.01	+0.08	+ 9° 30′	4.09	4.01	+0.08	4.00	4.01	−0.01	9° 30′
2.	4.15	4.10	+ .05	10 24	4.16	4.10	.01	4.09	4.10	+ .01	10 24
3.	4.19	4.18	+ .06	11 30	4.19	4.18	.01	4.19	4.14	.05	11 30
4.	4.22	4.23	− .01	13 06	4.25	4.23	.02	4.25	4.18	.07	13 06
5.	4.22	4.27	− .05	13 42	4.28	4.27	.01	4.28	4.27	.01	13 42
6.	4.28	4.31	− .03	14 42	4.31	4.31	.00	4.31	4.27	.04	14 42
7.	4.34	4.35	− .01	16 00	4.34	4.31	.03	4.37	4.31	.07	16 00
8.	4.38	4.35	+ .02	17 06	4.38	4.35	.02	4.38	4.35	.03	17 06
9.	4.41	4.40	+ .01	17 48	4.41	4.40	.01	4.40	4.40	.01	17 48
10.	4.44	4.44	− .00	18 48	4.44	4.40	.04	4.44	4.40	.04	18 48

Miss Powell found that on the average the recession of the arch around the Southeastern Prominence is (assuming these measures are correct) ninety miles a second; that the recession of the arch around the Pyramid is sixty miles per second and that the Skeleton is receding fifteen miles per second.

The Skeleton Prominence and its arches cover 37.5° along the margin of the sun, the highest arch is 108,000 miles; this means that if these arches are a mechanical effect that a volume of gas of more than 2,540,470,000 millions of cubic miles has been affected.

There are other things suggesting changes of form, but hardly such things as one could measure. It is not unusual for streamers to issue from small projections on the prominences. From each of three tips of the Southeastern Prominence there issues streams each of which assume the approximate form of the arches above them.

In interpreting these measures, one must not be unmindful of the difficulties of these measures and the consequent uncertainty. The streamers themselves are somewhat indefinite objects to measure. An error in plotting the center of the sun on the plates might cause the differences of ρ and ρ'. On the other hand, the measures have been very conscientiously made. No one could have been more painstaking than Miss Powell has been. The center of the sun was plotted separately on the plate for the first and for the second measures. Any two series are reasonably consistent, and in one thing they are very consistent—$\rho - \rho'$, though small, is almost always positive. Moreover, the three prominences are so distributed about the sun's limb that an error in plotting the center should have affected $\rho - \rho'$ in different ways for different arches. In my judgment these measures make it probable that these arches of the corona changed in the twenty-five minutes between the eclipse at Goldendale and that at Brandon, and that they are going outward from the sun.

The other study is of quite a different nature. There are in every corona a number of streamers, those around the poles of the sun being most conspicuous, but streamers are by no means confined to these regions. In 1911 I published a paper[1] in which I assumed that what we see or photograph as the streamers of the corona are projections on a plane perpendicular to the line of sight, of streams of particles the motion of which is produced by ejection, by the rotation of the sun, by the attraction of the sun and by radiant pressure from the sun. At that time Director Campbell generously placed at my disposal the most excellent series of long focus photographs that had been made by eclipse expeditions from Lick Observatory.

[1] *Astrophysical Journal,* XXXIII., 4, page 303.

I was able to show that if these streamers were thus mechanically produced that there would result in each corona a few streamers of such a shape that one could draw a radius vector from the center of the sun which would be tangent to the streamer and that one could find for streamers of this shape the following things:[2] the point on the sun from which the streamer issued, the velocity with which the particles in it were ejected, the velocity of the particles at any time, the paths described by the particles and if we assume the law of the repulsive force, we can find its magnitude. Theoretically, there should be very few streamers of this shape. In an examination of the Lick plates made at six eclipses between 1893 and 1908, I found sixteen streamers of this type; and on the plate made by Father Cortie at a time of minimum sun-spots in 1914, Miss Caroline Smedley, an assistant at the Sproul Observatory, found and measured two streamers of this type, and in the corona of 1918 there is unmistakably one and probably two streamers of this form. These also Miss Smedley measured and reduced. There always exists the possibility that the form of the streamer has been affected by local causes and the arches which I have just discussed makes it apparent that at least near the surface of the sun at this eclipse local forces were very effective, but the streamers that we found in this corona and which we measured stand out separated from these disturbed regions and away from the prominences.

This theory works admirably with one exception which I shall now discuss. Since the solution gives the form of the paths in which the particles in the streamer are traveling, one should be able to compute an ephemeris for each particle and using the constants determined in the solution compute a streamer that exactly reproduces the streamer from which the constants were found. It turns out that with these constants the streamer on the sunward side of the tangential point P and for some distance on the other side of the P the streamer can be perfectly represented, but that when we compute the position of the particles at a distance of two or three radii from the sun, that the streamer thus plotted turns back much more abruptly than those do that are shown in the photograph. We have plotted with the constants obtained by the solution several

[2] See Fig. 4, *loc. cit.*

streamers and they all possess this property. This may be interpreted to mean that this mechanical theory of the corona is wrong or that there are other forces acting on these particles than the attractive forces of the sun, and of a repulsive pressure that varies inversely as the square of the distance from the sun's center. It is easy to conceive of many forces such as resistance to motion by gases or that the particles at greatest extension of the streamer were lighter than those forming the part of the streamer measured.

We attempted also to apply Bigelow's earlier theory to the formation of these streamers. Miss Smedley was able to show that if this (Bigelow) theory is true that these magnetic forces alone could produce no streamer of the form described in Figure 4; that is, that the vectorial angle of the radius vector from the center of the sun to any point P on the streamer either constantly decreases or constantly increases as P is moved along the streamer away from the sun.

Another phenomena which seems very exceptional in the case of this eclipse occurs in connection with the polar rays. In almost no case are the polar rays arranged exactly symmetrical with regard to the axis of rotation of the sun. But in most coronas the vectorial angle of a point ρ decreases as it moves out along a streamer on the west side of the axis of rotation; while for those on the east side the vectorial angles increase; that is, these rays are gently curved away from the axis, but, as I have said, not exactly in a symmetrical way. All these things can be produced under the assumption of the mechanical theory; but in this eclipse the vectorial angle decreases as P moves out along the streamer whether it is on the east or on the west side of the axis of rotation, and this is true not only of the rays around the north, but also around the south poles. I have not had time to investigate whether or not this is possible under the mechanical theory.

It seems probable to me that the long graceful streamers of the corona, at least the part of them that is at some distance from the sun are largely the product of mechanical influences. The suggestions made by Mr. Lampland in the preceding paper that of certain prominences the inner arches seem to circle around the prominence while the outer arches were pointed, is in my opinion very significant and seems to me to exhibit the general tendency of coronal streamers to straighten themselves out at some distance from the sun.

We examined the long streamers on the forty-five second exposure with the 62½-foot focal-length camera to see if one would guess from the shapes of the streamers that there was a violently disturbed region immediately below them. Our conclusions were in the negative, that is, that no one would guess from the shape of the outlying streamer that there was any violent agitation at the solar surface. There are many phenomena that lead one to believe that the corona is a magnetic or electric product and it is possible that it results from a combination of these things. At any rate there seem to be abundant reasons to believe that the problem is not beyond solution.

Dr. L. A. Bauer had consented to give a summary of the magnetic work done during the eclipse of 1918 at stations under his direction. He was prevented from doing this because of his departure to establish stations in Africa and Brazil to make magnetic and electric observations during the eclipse May 29. Before leaving he sent a summary of the chief conclusions that he reached from the observations of the eclipse of June 8, 1918. I shall read this summary.

The following conclusions are drawn covering the chief results of the magnetic observations made in connection with the solar eclipse of June 8, 1918:

(*a*) Appreciable magnetic effects were observed during the solar eclipse of June 8, 1918, at stations distributed over the entire zone of visibility and immediately outside. (How much further some of the effects may have extended must be left for future study.) The chief characteristics of the effects took place generally in accordance with the local eclipse circumstances and in general accord with effects observed during previous eclipses. The evidences of a direct relation between the magnetic effects and the solar eclipse are so numerous as to warrant drawing the definite conclusion that an appreciable variation in the Earth's magnetic field occurs during a solar eclipse. This particular variation is termed here the "solar-eclipse magnetic variation."

(*b*) The range of the solar-eclipse magnetic variation, according to the particular magnetic element, is about 0.1 to 0.2 that caused by the solar-diurnal variation on undisturbed days. The effects are of a more or less complicated character, according to location of observation-station in the zone of visibility. The effects caused during the local eclipse-interval are superposed upon those caused by the continued disturbance of the Earth's magnetic field in the region over which the shadow-cone has already passed. It is thus possible to discern effects having a period approaching that of the local eclipse-interval and others having a period approximately that of the entire or terrestrial eclipse-interval.

(*c*) The general character of the system causing the solar-eclipse magnetic variation is the reverse of that causing the daylight portion of the solar-diurnal magnetic variation. The range of the eclipse variation is comparable with that of the lunar-diurnal variation, and, like the latter, the variation usually consists of a double oscillation during its period of development.

(*d*) The range of the apparent effect on the intensity of magnetization of the Earth during the solar-eclipse magnetic variation, is about equal to that found associated with a 10 per cent. change in the solar radiation as shown by changes in the solar-constant values.

(*e*) The results at the high mountain-station, Corona, Colorado, indicate that the magnetic effects during a solar eclipse may be modified and even intensified by altitude of station, topography and meteorological conditions. In view of the bearing of these results upon the theory of the solar eclipse magnetic variation and possibly upon the theory of other variations of the Earth's magnetic field as well, it will be highly desirable in the planning of future eclipse work to include as many mountain-summit stations as conveniently possible.—*Terrestrial Magnetism,* March, 1919, Vol. XXIV., No. 1.