

# THE TOTAL SOLAR ECLIPSES OF 1889.

## CONTRIBUTIONS FROM THE LICK OBSERVATORY.



VERY year there must be two eclipses of the sun, and there may be five. These are partial eclipses, however, except in the comparatively rare case in which the moon passes nearly centrally over the sun's disk and produces a total obscuration of his light. Since the invention of the spectroscope, in 1860, there has been barely a score of total eclipses, and a number of these could not be observed because the belt of totality fell at the earth's polar regions or upon the oceans. The belt of totality is a narrow strip—never more than one hundred and seventy miles wide—where the point of the moon's shadow falls upon the earth. Total eclipses

flames which are seen at the sun's border during an eclipse are solar and not lunar appendages. They are shown *dark* in figures 3 and 4. The moon covered them up progressively as she advanced in her orbit. In 1868 Messrs. Janssen and Lockyer established the fact that these rose-colored prominences were, in truth, huge flames and spires of hydrogen gas extending thousands of miles above the solar globe, but truly belonging to it, as our atmosphere belongs to the earth. A method was then invented by which the flames can be observed with the spectroscope on any clear day, even without the intervention of an eclipse, and there are several observatories the chief work of which is the accurate mapping of the solar prominences day by day. Thus the few moments of totality are now left free for other

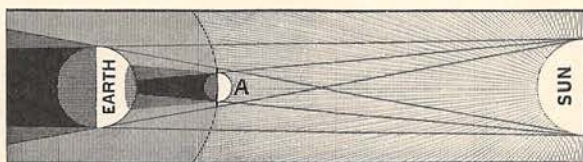


FIG. 1. THEORY OF A TOTAL ECLIPSE OF THE SUN.

The moon is at A. The eclipse is total to a spectator within the black interior shadow, and partial to a spectator anywhere within the penumbra.

rarely recur, therefore, at the same point of the earth. At London, for example, there has been no total eclipse since the year 1140 except that of 1715, and there will be none during the next century.

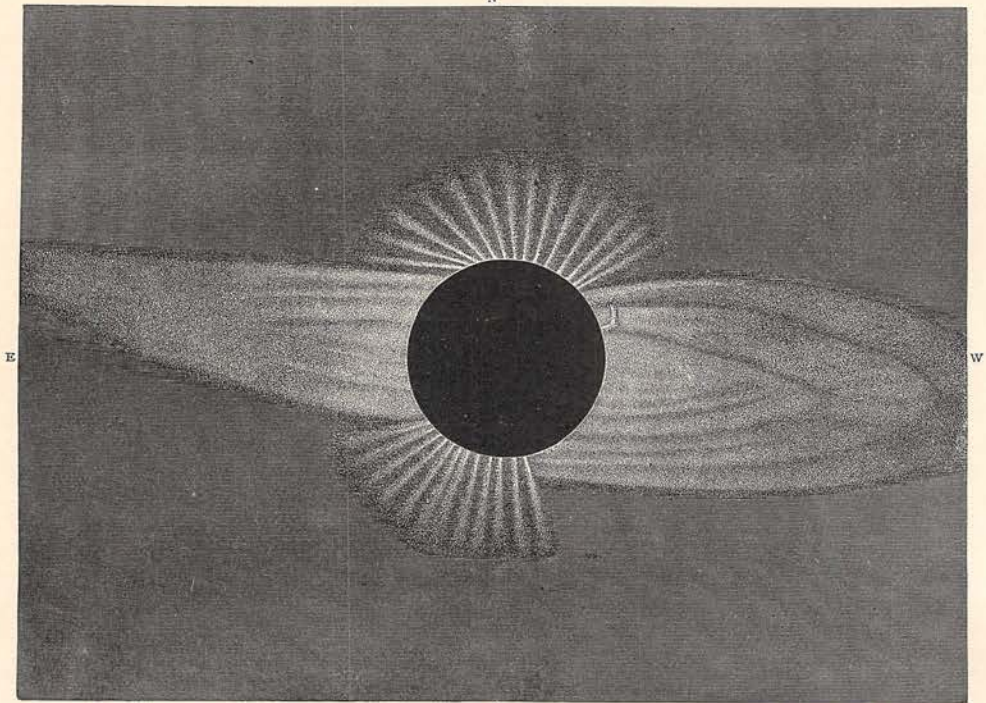
Figure 1 gives an idea of the cause of a total eclipse, but the dimensions of the moon's shadow are enormously exaggerated. As the moon moves rapidly along its orbit, the duration of an eclipse to any one spectator is never more than eight minutes, and ordinarily it is not so much as four.

Less than three quarters of an hour of actual observing time has been available to astronomers since the spectroscope was invented, or since photography was first fruitfully used in recording the features of a total eclipse. We are apt to be impatient with the slow progress of science, but, when we consider what advances have been made in these few years, we must admit that each one of the brief and precious moments has been well utilized.

The eclipses of 1842, 1851, and especially that of 1860, proved that the rose-colored

observations, and the discovery of Janssen and Lockyer has virtually doubled our opportunities for the study of the corona itself, which has never been seen except at totality. Dr. Huggins has spent the last few years in experiments in photography, with the object of studying the corona in full sunshine, but so far without success. It is the next great step required.

In 1869 a very favorable total solar eclipse occurred in the United States (the first since 1834), and its opportunities were fully utilized to the permanent fame of American astronomers. The observations of Professor Young of Princeton, and of Professor Harkness of Washington, decided the question as to the general nature of the corona. It certainly consisted of a glowing gas, the composition of which, however, is still unknown. It was a solar appendage, and was not an appearance produced by the earth's atmosphere. The eclipse of 1870 (in Spain) confirmed the results of 1869. In 1871 another eclipse allowed Janssen to observe beside the bright line (1474) in the spectrum of the corona, the presence of which proved



ENGRAVED BY FELIX LE BLANC,

S

FROM A DRAWING BY M. TROUVELOT.

FIG. 2. THE CORONA OF JULY, 1878.

It is to be remarked that the corona consists of polar rays and of two faint wings.

it to consist partly of incandescent gas, the dark Fraunhofer lines, which showed that some, at least, of its light must be due to sunlight reflected from solid particles near the solar body. Polariscopic observations confirm this also.

The photographs of the 1871 eclipse yielded a marvelous account of the complex details of the inner coronal forms. We began to see, with this eclipse, that the corona was of much more complex nature than the hydrogen flames, for example. Not only was its light derived both from reflected sunshine and from native brilliancy, but it appeared that the inner and brighter corona might even be of a different quality from the long wisps and streamers which form its outer portions. The eclipses of 1874 and 1875, owing to bad weather, etc., added little to previously known facts.

The American eclipse of 1878 was fully observed from Wyoming to Texas. Among its most important results was the observation that the characteristic spectrum line of the corona (1474) certainly extended nearly a radius of the sun (400,000 miles) from the edge, and that when this line vanished no other spectrum was visible. From this the conclusion was drawn that the gas corresponding to the 1474 line (coronium) extended at least to this height above the sun. The observations of Langley and Newcomb showed that coronal matter of some sort extended much further than this, even

out to nine millions of miles. The photographs taken by the parties of the United States Naval Observatory were very satisfactory, and showed the shape and structure of the corona of 1878 to be essentially different from that of 1871. The year of 1878 was a year of few sun-spots; 1871 was a year of many sun-spots. It was suggested that the corona varies periodically in shape and in appearance as the sun varies in frequency of sun-spots, and an examination of the few trustworthy records lent considerable force to the suggestion.

The observations and drawings of the corona which we possess were collected into a splendid volume by Mr. Ranyard of London. A careful examination of the drawings seemed to show that among the thousand apparently accidental and capricious coronal forms two types, characteristic forms, could be traced.

During a period of maximum sun-spot frequency the corona appeared to be fully developed and of great brilliancy. Its typical form was that of a bright quadrilateral filled with rays, which have been likened to those on the card of a mariner's compass.

At a period of minimum sun-spots (as in 1878) the corona, on the other hand, seemed to be far fainter and of smaller dimensions, except for faint wing-like projections which extend sometimes for prodigious distances on each side of the sun. A rough idea of the scale of

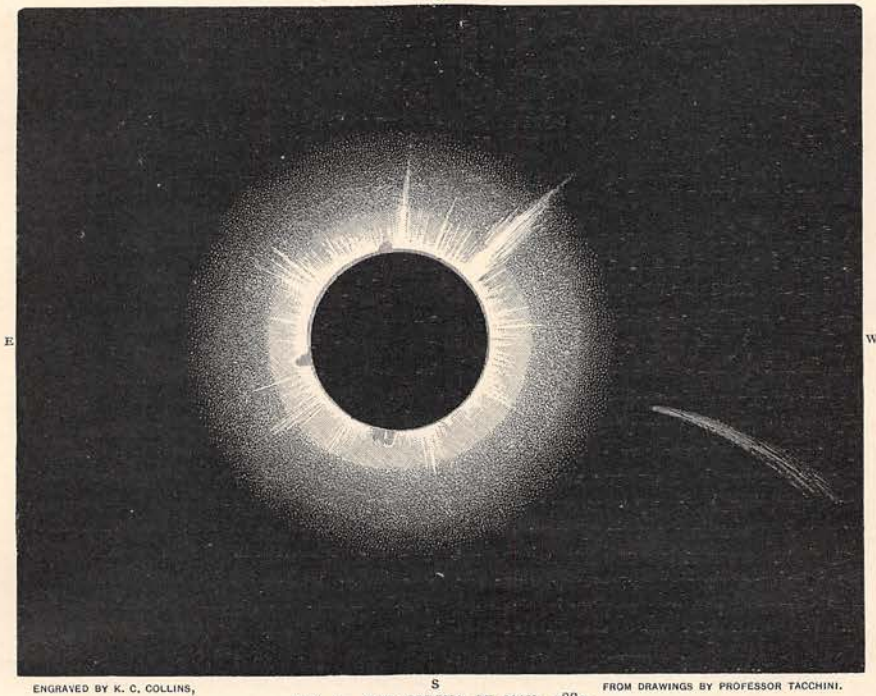


FIG. 3. THE CORONA OF MAY, 1882.

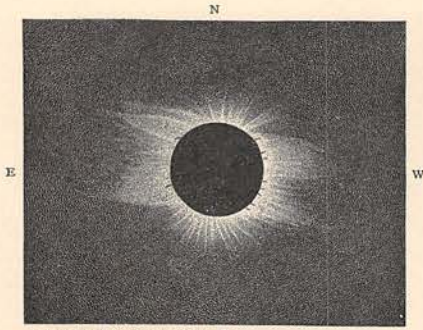
the various drawings in this paper may be had by recollecting that the diameter of the sun is about 850,000 miles.

A striking event of the eclipse of 1882 was the revelation, during the darkness of totality, of a noble comet near the sun (see figure 3). This eclipse, which lasted only seventy seconds, is also memorable for the new and bright spectral lines which were added to the 1474 line, and which indicated that the corona was composed not only of coronium gas, but of other gases as well. The dark lines due to reflected sunshine were once more visible. The spectroscopic observations of 1883 and 1886 made by Professor Tacchini seem to show the existence not only of the rosy prominences long known, but also that certain other *white* prominences exist, which are due probably to relatively cool products. Moreover, a comparison of the red prominences observed during totality with the same objects seen before and after the eclipse indicates that the ordinary spectroscopic methods give only a part, and not the whole, of the phenomenon. The reason of this is not yet fully understood, and these observations should be repeated at the next eclipse. While we are far from understanding the phenomena of the sun's envelope as revealed by the spectroscope, the foundations for a proper interpretation are laid, and the appropriate methods are already invented. But the corona still remained the mystery of mysteries. Why did it exist at all? Why did it change in

shape and character? How could the same object appear so different at different times? Was it in fact the same object? It was even suggested that the corona had no objective existence at all, but was a pure diffraction phenomenon, like the alternate light and dark interference bands which one can see by holding the edge of a razor up against the bright daylight.

#### THE ECLIPSES OF 1889.

THE eclipse of New Year's day of 1889 was to be total in California, and the Lick Observatory, then newly established, made preparations to observe it. It was also well observed by other parties, whose reports are not published at the time of writing this account. It was decided to attempt both spectroscopic and photographic observations. The former were directed to the question just spoken of; namely, Is or is not the solar corona mainly a diffraction phenomenon? The observations of Mr. Keeler show that it really has an objective existence, and that the diffraction phenomenon previously observed must have been mainly due to atmospheric glare. Some of the photographs obtained, notably those of Mr. Woods, show the moon projected upon the corona *before the eclipse began*, and therefore before a diffraction effect was possible. The spectroscopic observations made by Mr. Keeler also establish the important fact that the length of a coronal line in the spectrum is no index of the



ENGRAVED BY FELIX LE BLANC. S

FIG. 4. THE CORONA OF JANUARY, 1889.

depth of the corresponding gas in the solar atmosphere. This relieves us of amazing theoretical difficulties. We may now consider the sun to be surrounded by a comparatively shallow atmosphere, and have no longer to tax our ingenuity to explain how it is that a comet passing close to the sun is not in the least retarded by a solar atmosphere. Another main object of the expedition was to obtain the best possible photographs of the corona, and for this purpose Mr. Barnard of the observatory utilized our very incomplete photographic apparatus, and supplemented it by turning one of our small visual telescopes into a camera. We were also extremely fortunate in securing the fullest coöperation of the Amateur Photographic Association of San Francisco, which organized a party of seventeen observers, working according to a program which had been prepared in consultation with the astronomers at Mount Hamilton. The vital point of the program was the selection of the proper times of exposure, and here we had the benefit of the advice of Mr. Burnham of the observatory, who showed by experiments in photographing light, fleecy clouds, while the sun was obscured by heavier and darker ones, that the proper exposure times must be very short. It all seems extremely simple now, but this principle had not been well understood at previous eclipses. At the eclipse of 1883 some of the negatives were exposed for more than five minutes! The main object is to register the extremely small contrast between the outlying faint corona and the sky, which is by no means totally dark. This can be done by giving relatively short exposures, and only in this way.

The coöperation of the amateur photographers enabled us to make a series of exposures of varying length, and to test the question in an experimental way. Thanks to their aid and skill, we secured a great number of negatives, and these, together with the exquisite plates made by Mr. Barnard, give an account of the eclipse of January, 1889, which is complete and highly satisfactory. Figure 4 is a copy of one

of Mr. Barnard's negatives. It is on a small scale, because his photographic apparatus was not powerful; but the work was so well done that the original shows a vast amount of detail—more, I think, than has been shown at any other eclipse.

Fig. 6 gives a diagram on an enlarged scale made from Mr. Barnard's photographs by studying them under the microscope. There are very many features shown in these photographs, but I will stop to mention only two of the more important. At previous eclipses the polar rays had been photographed, but it had never been noticed that these polar rays extended all round the solar disk (see fig. 6, rays 2, 4, 6 . . . 18, 21, 24, 26, 30, 32 . . . 37, 50, 64 . . . 71, 75 . . . 84, 86, 98, 100, etc.). They had always been evident at the poles, but at the sun's equator they had been lost in the brightness of the great "wings." It had therefore been too hastily supposed that the polar rays were in fact confined to the region of the poles. The photographs of the January eclipse proved clearly that such rays extended all around the sun. Again, the photographs showed that the corona, instead of growing narrower as we go further from the sun

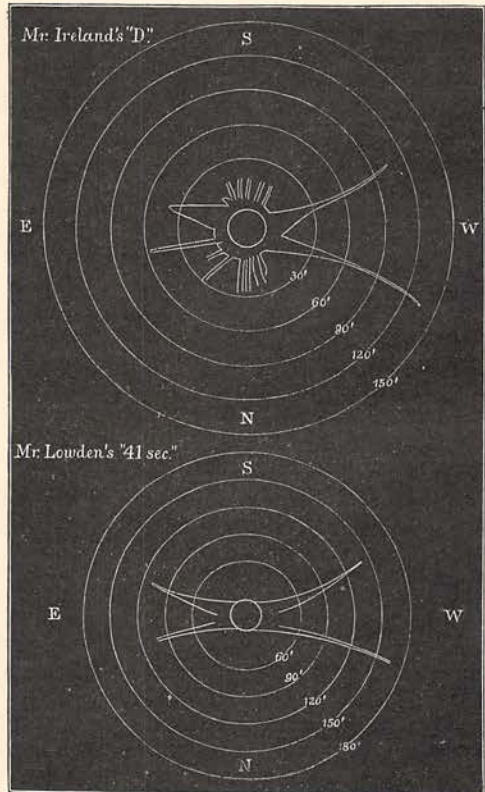


FIG. 5. EXTENSION OF THE CORONA OF JANUARY, 1889. THE OUTLINES ARE FROM NEGATIVES BY MESSRS. IRELAND AND LOWDEN.

(as, for example, in M. Trouvelot's picture, fig. 2), really terminated in branching forms. The beginning of this trumpet-shaped extension is shown in fig. 6, but is more plainly displayed in fig. 5, where I have traced only the outlines of the corona, as shown on the negatives of two amateur photographers, Messrs. Ireland and Lowden. These negatives are confirmed by others, especially by the admirable pictures of P. Charroppin, and also by a naked-eye sketch made by an artist. They show an extension to the corona which had never before been photographed. It had been seen in 1878 by Professors Langley and Newcomb, but its true shape had not been suspected by them.

I consider, then, that the main photographic

Messrs. Burnham and Schaeberle of the observatory, aided by a volunteer observer, Mr. Rockwell of Tarrytown, made the journey to Cayenne, and under somewhat unfavorable conditions secured excellent results. No engravings from their pictures are given here, as they do not differ greatly from fig. 4, and as they are to be printed elsewhere. It suffices to say that the records of the December eclipse were comparable with those obtained in January. Other expeditions were sent by the National Academy of Sciences of Washington and the Royal Astronomical Society of London to Africa, and by the latter body, and also by the Paris Academy of Sciences, to South America. The day was cloudy in Africa, and no results

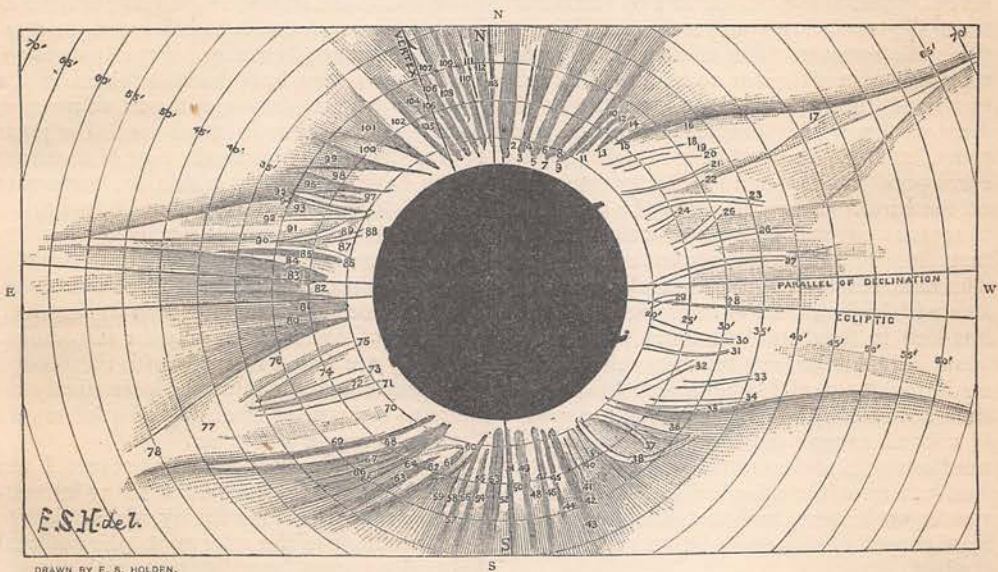


FIG. 6. INDEX DIAGRAM MADE FROM THE LICK OBSERVATORY PHOTOGRAPHS OF JANUARY, 1889.

results of the January eclipse were two—that the polar rays extended all round the disk, and that the corona was extended in a trumpet-shaped form. These results were merely the records of fact, and however important the facts might be, we seemed to be no nearer to the solution of the questions: What is the corona? Why has it such a shape? Why does it vary in form, and according to what laws does it vary?

The excellent photographs of the January eclipse made it highly desirable that the eclipse of December, 1889, which was total in Guiana and on the west coast of Africa, should be observed on the same principles. The small income of the Lick Observatory did not allow us to send out a party, and the plan had been reluctantly abandoned, when Mr. Crocker, one of the regents of the University of California, generously offered to bear the whole cost of an expedition to South America. Accordingly

were obtained. The results secured by the English and the French parties in South America add nothing to our own. The two eclipses of 1889 were thoroughly well observed, and the records of the appearances and structure of the corona were plain; but the vexed questions still remained: What is the corona? What are the laws of its variation of shape?

These questions have now been answered by Professor Schaeberle of the Lick Observatory, in his "Mechanical Theory of the Solar Corona," just completed. It is possible by this theory to account for the general form and characteristics of all past coronas and to predict the general form of future ones. A solar eclipse will take place in 1893 on the coast of Brazil, and Professor Schaeberle is able to give a drawing of the general features of the corona as they will appear at that time. It may be said that the fundamental law is now established.

There are minor matters to be studied, but the explanation of the long-standing mystery of the corona is now in our hands. Like all great things, it is extremely simple, and in its principal points it is easily understood. I shall speak only of the main points in this place, leaving the particularities to be treated in more technical publications.

To understand Professor Schaeberle's explanation, let us recall a few facts of observation. We know that the sun turns on its axis once in about twenty-five days. Its equator remains always in one plane. The earth revolves about the sun in a plane which is inclined to the plane of the sun's equator by about seven degrees; that is, the earth is sometimes seven degrees above (in September), sometimes seven degrees below (in March), the plane of the sun's equator. The effect is that sometimes one pole of the sun, sometimes the other, is turned toward a spectator on the earth. Now we know that the sun is covered with spots, confined to two belts which roughly correspond in situation to the temperate zones on the earth. These belts may be compared to regions covered by geysers which are perpetually sending out matter from their interiors. This matter is shot out perpendicular to the surface with high velocity — something like three hundred to four hundred miles per second. Now, if the sun did not revolve on its axis, we could make a model to represent this state of things by sticking straight needles into a sphere of cork all around the temperate zones. The needles would represent the streams of matter shot out from the solar surface. But the sun rotates on its axis, and therefore the needles in a proper model must be curved and not straight.

Professor Schaeberle has calculated the true curvature, and it is quite possible from his figures to construct a model of the sun with its outgoing streams of matter. We have simply to take a globe of cork, and to insert many wires of the proper curvature at something like equal distances from one another all over the surface of the temperate zones, where we know that the solar activity is manifested. It is a very curious fact of observation that sun-spots are never

seen near the solar poles, and very seldom indeed in high latitudes. Such a model will represent the sun and the solar corona as they really are — but not as we see them. For a spectator on the earth is sometimes above, sometimes below, the plane of the sun's equator; or, to put it in another way, the sun sometimes turns its north pole, sometimes its south pole, to him. If, then, we place our model on a stand, and place the eye where the earth should be in its orbit at the time of an eclipse (according to the month of the year, etc.), we shall actually see the curved needles overlapping and interlacing by projection and by perspective exactly as the streams of matter overlap and interlace. If we go far enough away from the model to lose the view of the individual streamers, we shall see the outlines of the corona, with its polar rays, its interlacing streamers, its trumpet-shaped extension, precisely as they have been depicted in the photographs and drawings of past eclipses, or as they will be shown in future ones. The polar rays are caused by the overlapping of streamers which have their bases within the temperate zones, but which are long enough to project *beyond* the sun's disk above or below it.

The records of all past eclipses have actually been examined according to these principles, but in a more accurate way than by a model, which is, of course, used only for illustration, and they are found to agree with the theory. The predictions for future eclipses simply require us to know at what day of what month the phenomenon will occur.

In a general paper like the present I am obliged to omit any account of many interesting consequences of this theory, which relate to the periodicity of the solar spots, the zodiacal light, the aurora borealis, terrestrial magnetism, etc., and to confine myself to a simple relation of how the external appearances and the characteristic forms of the corona are explained in an extremely simple and beautiful manner. The corona is no longer a mystery. Its characteristic forms have been accurately recorded on the negatives taken in 1889, and the explanation of Professor Schaeberle accounts for the occurrence of these forms in the past, and enables one to predict them in the future.

*Edward S. Holden.*

### "THE SHADOWS FOLD."

THE shadows fold; come back as of old,  
Shine, Helen, girl with the head of gold.  
As the moon from the sky overcast  
Bursts into the open blue,  
Out of the cloudy past  
Push your bright body through.

The shadows fold; come back as of old,  
Once more glow over me, head of gold.  
Burn back to your place on high,  
Flame there, for my heart to see:  
O Helen, my youth's blue sky,  
The heavens you made for me!

*John Vance Cheney.*