

APPENDIX No. 16a.

REPORT ON THE ECLIPSE OF THE SUN ON THE 22^d OF DECEMBER, 1870, BY BENJAMIN PEIRCE, LL.D.,
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[From the Coast Survey Report for 1871.]

Certain astronomical phenomena of rare occurrence and high importance for the advancement of human knowledge have, in all civilized countries since modern science has been cultivated, been deemed matters of national importance. Among these are total eclipses of the sun; and for many years it has been customary for the great nations to organize expeditions for the observation of them.

The first total eclipse visible in this country since the formation of the Government was that of June, 1806. This was accurately observed at several points, and a valuable painting was made of it. We were not favored with another until November 30, 1834, when the moon's shadow passed over the continent from northwest to southeast. This eclipse was observed by R. T. Paine, esq., of Boston, at Beaufort, South Carolina. A third eclipse did not visit our country until 1860; hence at that time this wonderful phenomenon was for most American astronomers a matter of hearsay.*

The path of the eclipse of July 18, 1860, was from Washington Territory to the northern shore of Labrador, and thence across the ocean to Spain. This eclipse was observed by expeditions organized under the Superintendent of the Coast Survey, and the results are published in the report for that year. It was also observed by the astronomers of several governments abroad, and was the first total eclipse which was photographed. In 1868 British, French, and German expeditions were fitted out for the observation of a total eclipse in India. On this occasion brilliant discoveries were made in regard to the spectrum of certain rose-colored prominences seen about the sun at such times; and these discoveries have been increasing in interest ever since. In 1869 another total eclipse was visible in the United States. It was observed by parties organized by the Coast Survey and other Government bureaus. The results were of high importance. Photographs of the whole corona were taken for the first time; the first observations were made upon the spectrum of the corona; the radial polarization of the corona was first observed with care, while the former knowledge of the subject was advanced in every direction. The results of these two eclipses were of such importance in regard to one of the chief scientific problems of our time—the constitution of the sun—as to excite the profoundest interest throughout the world. It was felt by everybody even casually interested in science that the eclipse of 1870 afforded an opportunity for removing the last obscurity from the subject of the corona, such as ought not to be let slip, the more so as no other eclipse was expected to be observed during this century.† In accordance with these views, the Hon. John A. Bingham, of Ohio, introduced a joint resolution, which was approved by Congress and the Executive, authorizing the fitting out of an American expedition, such as were to be sent out by Germany, by France, by Great Britain, by Italy, and by Spain, to study the phenomena of this eclipse. The late unhappy war prevented the first two nations from sparing any of their energy for this peaceful emulation, but extensive preparations were made by all the others. The American and English parties were in co-operation, and afforded each other mutual aid. It is hoped that the good feeling thus engendered was not without influence beyond the circle of science. The observations of this eclipse had for their general result the triumphant vindication of the American observations of the year before, the novelty of which had made them somewhat suspected in Europe, as well as the establishment of the superior accuracy of the American lunar predictions. Some new features were observed in the corona and in the chromosphere, and other

* Mr. G. P. Bond had observed the eclipse of 1851 in Sweden.

† Nevertheless, the British government has sent out parties to another eclipse in 1871 in India and Australia; and three American astronomers have been invited, through the Superintendent of the Coast Survey, to join the expedition.

observations were multiplied. This is, however, not the place for entering upon the details of scientific proceedings, which will be given with all desirable fullness in the Appendix.

With a view of selecting localities where astronomical conditions, as well as those of the weather, might be expected to be favorable for observation, Mr. Charles S. Peirce proceeded to Europe in advance, under my direction, and, after visiting Italy, Spain, and European Turkey, recommended the occupation of stations in Southern Spain and in Sicily. The country east of Italy over which the track of the totality passed, had the sun too low for photographic purposes. Considering the probable distribution along the line of totality of the European astronomers, I decided finally to dispatch two parties, one to be stationed in the vicinity of Jerez, in Spain, the other, under my immediate personal direction, to occupy positions on the Island of Sicily, in the neighborhood of Catania. In selecting observers I availed myself of such as had previous experience, which, in matters pertaining to solar eclipses, is of much importance, and whose former services in the special lines of duty assigned gave full assurance that no fact that could possibly be noted under the circumstances would be lost.

The party organized for service in Sicily had the threefold duty assigned of making measures of precision, including the determination of the geographical position and local time of contact, of getting photographic impressions of the various phases of the eclipse and of the corona, and of analyzing the corona by means of the polariscope and spectroscope. Accompanying phenomena were also to be recorded. To improve as much as possible the chances of the weather, the party was spread over as large an area as could conveniently be included, a precaution which proved of great value, as may be gathered from the account of the labors of the party.

A most cordial co-operation with the party of British observers, several members of which took position at Catania, was maintained throughout our stay. While in England and on the Continent, on my way to the place of observation, the opportunity was taken to procure additional instruments required for our purpose.

The party is indebted to Mr. Wilding, our vice-consul at Liverpool, and to Signor Cattaneo, Italian consul at that port, for affording facilities to pass our instruments through the Messina custom-house. Our thanks are especially due, for most effective assistance rendered in receiving, storing, and forwarding our instruments and reshipping them to New York, to our consul, Mr. F. W. Behn, at Messina, and the vice-consul, Mr. Augustus Peratoner, at Catania. We were indebted, also, to Professor Lorenzo Madden and Professor Oratio Silvestri, of Catania, for assistance, and to the municipal authorities for permission to use the grounds occupied by the observers.

The distribution of the party in the vicinity of Catania, and the nature of the results secured, will be briefly mentioned.

Our principal station was in the garden of the Benedictine Convent of St. Nicola, in the western part of the city, a position selected by Assistant Charles A. Schott, who determined, early in December, the latitude and longitude, and also the local time. L. M. Rutherford, esq., of New York, provided photographic apparatus for use, by Mr. H. G. Fitz, optician, who was sent in charge of the equatorial, and was assisted by Mr. D. C. Chapman and Mr. Burgess, photographers. For determining time and latitude Mr. Schott used the portable meridian-telescope, C. S. No. 9, and sidereal chronometer, Kessels, 1287, which was rated at Washington, and checked at London, Berlin, Munich, and Naples. For local-time comparisons the party is indebted to Dr. Förster, director of the Berlin observatory; to Dr. Lamont, director of the Munich observatory; and to Professor de Gasparis, director, and Mr. Fergola, assistant, of the observatory at Cape di Monte at Naples.

Transits were recorded on five nights, and thirteen pairs of stars were observed for latitude; the longitude depends upon that of Naples and Munich. In order to secure accuracy, Mr. H. H. D. Peirce compared chronometer-times at Syracuse with the party of observers from the United States Naval Observatory, thus verifying the determination for longitude of the respective stations. A number of chronometers were in advance rated for the use of observers, and a small triangulation was made, uniting the eclipse-stations in the garden with the triangulation by Dr. Peters and Baron Waltershausen, who surveyed that vicinity previous to the year 1841. It is gratifying to note the very close accordance between the earlier astronomical determinations and those taken thirty years afterward. Time-signals by heliotropes were sent and received by the observers at Catania, and at the Monte-Rossi station. Mr. Schott included, in his series of geographical posi-

tions, the three places occupied in the garden of the convent, two by the English party in charge of Mr. J. Norman Lockyer, and the other by Mr. J. H. Lane, of the Office of United States Weights and Measures, who, though fully prepared for spectroscopic observations, was prevented by unfavorable weather from recording special results. The photographic party secured forty-five negatives of the sun, seventeen during the eclipse and before totality, and fourteen after it, at irregular intervals, taking advantage of breaks in the clouds. The direction of a parallel of declination was indicated by the image of a thread, so adjusted before the eclipse that a solar spot might be seen as moving along the thread during the transit. Mr. Fitz operated the equatorial and timed the pictures. An attempt was made by means of an ordinary camera to secure an impression during the momentary appearance of a portion of the corona. The time of the first contact was noted by Mr. Schott, who was apprised by a pistol fired by a member of the English party, (the report by preconcert,) indicating that Mr. Lockyer had already spectroscopically noted the approach of the moon's limb over the solar chromosphere. The dense clouds which came from the direction of Mount Etna, and to the west of it, defeated all attempts at observing the times of the inner contacts and of the last contact. Mr. Schott, however, saw, through a rift in the clouds, a part of the corona, to the northward and eastward of the sun's center, for about three seconds. It appeared in sharp outline, nearly concentric with the moon's limb, of white silvery light, extending, by estimation, to about one-third of the moon's radius. The light tint of orange-yellow usually accompanying total eclipses was seen about the southern and eastern horizon. The first contact or beginning of the eclipse, as predicted from data in the American Ephemeris, was only 3.9 seconds earlier than the time actually noted in observing at Catania.

My own station was about three miles north of Catania, at the villa of the Marquis di San Giuliano, whose obliging courtesy is a subject of grateful remembrance. There the weather was more favorable than at the city, and afforded a full view of the corona, the study of which was made a special object. Mr. C. S. Peirce observed with a polariscope and obtained good results. Mrs. C. S. Peirce was successful in drawing the corona, and distinctly recognized the dark rifts which have become a subject of discussion, and which were photographed by Mr. Brothers, of the British party, at another station. Farther north were stationed Brevet Brigadier-General H. L. Abbot, United States Engineers, Professor Roscoe, of England, and Signor Amerigo da Schio, Dr. Vogel, of Berlin, and others. Their object was to observe the phenomena of the eclipse at the greatest possible height on the southern slope of Mount Etna, for comparison with similar observations taken at stations near the sea-level. It is much to be regretted that this party was overtaken by a snow-storm, which obscured the sky, and obliged them to descend during the time of the eclipse.

A few miles to the westward and northward of Catania, at one of the trigonometrical signals on the western peak of Monte Rossi, Dr. C. H. F. Peters, of Hamilton College, Clinton, New York, and Sub-Assistant W. Eimbeck, selected a position for observing the eclipse. Dr. Peters had a spectroscope-apparatus, and Mr. Eimbeck a comet-seeker. This party also had unfavorable weather, but succeeded in noting the times of the first contact and of the last contact; the last through thick haze. The interior contacts were lost on account of a passing hail-storm. Mr. Eimbeck also assisted Mr. Schott in recording transits and other observations at Catania.

Professor J. C. Watson, of Ann Arbor, Michigan, occupied a station on the high ground near Carlentini. The weather there was favorable during the time of totality. Professor Watson made observations, which resulted in two colored drawings of the corona, of unrivaled fullness of detail and accuracy. Dr. T. W. Parsons, at Syracuse, also made an elaborate colored representation of the eclipse.

It will thus be seen that my party in Sicily were distributed to the north of the track of total eclipse, while stations to the south of it were occupied by the party from the United States Naval Observatory. Stations on the central line were occupied by the Italian astronomers, including the Padre Secchi, Professor Cacciatores, and others.

A detailed account of the results of observations will be found in the Appendix No 16 of the Report of 1870.

I take this opportunity to mention the kindness of Henry Suter, esq., Her Britannic Majesty's vice-consul at Larissa and Volò, who, when it was contemplated to send a party to Larissa, afforded every facility for the prosecution of inquiries, and was in readiness to assist further if it had been expedient to occupy a station near that city.

The general charge of the observations to be made in Spain was assigned to Professor Joseph Winlock, director of Harvard College observatory, Cambridge, Mass., with Assistant George W. Dean, of the Coast Survey, as executive officer.

The party of eleven persons from the United States was organized early in October, 1870. Nearly all were scientific observers, and had been so engaged during the total eclipse in August, 1869.

Two English and one Spanish observer joined the expedition at Jerez; and it is highly gratifying that, notwithstanding the unfavorable weather on the day of the eclipse, most of the observers were quite successful.

It being desirable to obtain as far as practicable, in advance, information in regard to the meteorological conditions of the winter-climate of Southern Spain, Assistant Dean, before leaving England, collected statistics, which proved of much value in selecting the locality in Spain for observing the eclipse. Mr. Dean was cordially assisted in his inquiries by the astronomer-royal, and by several members of the Royal Astronomical Society.

Professor Winlock, Capt. O. H. Ernst, of the United States Engineers, Professor C. A. Young, Professor S. P. Langley, Professor Edward C. Pickering, and several other members of the expedition, sailed from New York for Liverpool early in November, and reached London about the middle of that month. Most of the instruments and equipments were reshipped at Liverpool for Gibraltar, arriving at the latter port near the close of November, and from thence were forwarded by steamer to Cadiz.

The information obtained from commanders and chief officers of steamers plying between England and Mediterranean ports, in regard to probabilities of weather, was confirmed by the observations of other gentlemen, who had long resided in Southern Spain. Comparison of statements showed that the prospect for fair weather on the day of the eclipse might be hoped for at points on or near the Atlantic coast.

The geographical position of Jerez being favorable, with good facilities for transportation by railroad from Cadiz, Professor Winlock decided to make the necessary arrangements for observing the eclipse near that place.

The principal station was located about a mile northeasterly from the city, in an olive-grove belonging to Messrs. Richard H. Davies and brother. These gentlemen placed their grounds and buildings at the disposal of the expedition, and their constant aid and generous hospitality to all the observers during their stay at Jerez is gratefully acknowledged.

Some delay was experienced in obtaining lumber and other materials, but all difficulties were readily met. On the 16th of December the instruments were in position, and good observations for time and latitude were made by Assistant Dean and Captain Ernst, assisted by Mr. Henry Gannett, of Harvard College observatory.

These observations were repeated on several favorable nights immediately preceding the day of the eclipse, at which date the latitude and local time at the eclipse-station had been well determined, completing the necessary arrangements for observing the phenomena.

The day preceding the eclipse was unusually pleasant; but about midnight clouds began to cover the sky, and in a few hours the rain fell rapidly, with a strong wind from the southwest. The prospects for success on the morning of the 22d of December were exceedingly doubtful; nevertheless, each observer continued to perfect his arrangements, hoping that before the beginning of the eclipse the clouds would open, and give an opportunity to all to complete the observations so earnestly desired. These hopes were in the main realized. The time of the "first contact" was successfully recorded by Assistant Dean, and a few seconds later the photographer of the expedition, Mr. O. H. Willard, of Philadelphia, obtained a good photograph of the sun. During the progress of the eclipse, Mr. Willard, with the assistance of Mr. J. Mahoney, took fourteen photographs of the eclipse, one of them exhibiting very satisfactorily the coronal structure during totality. The equatorial telescope used by the photographer has a focal length of about seven feet, with an aperture of six and a half inches, corrected for actinic rays. This instrument and several others for the service were furnished by Professor Winlock. The photographic telescope used by Mr. Gannett had a focal length of about thirty-five feet, with an aperture of four inches. This telescope was firmly adjusted in a horizontal position, receiving the solar rays from a movable

heliostat near the objective. Mr. Gannett obtained five photographs in the course of the eclipse, but owing to partial obscuration by clouds they were not entirely satisfactory.

The time at which each photograph was taken was recorded by the chronograph.

Spectroscopic observations upon the sun were made by Professor Winlock with two prisms, attached to a five and a half inch achromatic telescope. Professor Winlock had devised a very complete apparatus for recording the positions of the lines seen in the spectroscope as rapidly as the observer could point upon them, and with a precision equal to measurements with a micrometer. Before leaving America, each spectroscope for use in Spain was provided with this apparatus, which consisted essentially of a steel point or graver, movable by a micrometer-screw, so that in pointing upon any line seen in the spectroscope the exact position of the line would be recorded upon a small silver plate when the observer pressed the graver-key. Professor Winlock observed a faint continuous spectrum, without dark lines. Of the bright lines, the most conspicuous was Kirchhoff, 1474, which was seen in all the spectroscopes.

Professor Young, of Hanover, N. H., used a new spectroscope, recently designed by him, and constructed by Messrs. Alvan Clark & Sons, of Cambridgeport, Mass. It has a train of six prisms of heavy flint-glass, each two and one-fourth inches high, and having a refracting-angle of fifty-five degrees. A seventh *half-prism* follows, on the back of which is cemented a right-angled prism, by which, after two total reflections, the light is sent back through the upper part of the same train of prisms until it reaches the observing-telescope. A description of this instrument has been published by Professor Young in our scientific journals.

With this spectroscope attached to the Dartmouth College equatorial, having a focal length of nine feet, and aperture of six and a half inches, Professor Young was enabled to watch the occultations of the protuberances, and announce the approach of the moon several seconds before the "*first contact*." With the slit of the spectroscope placed tangentially at the moment of obscuration, the field of the instrument was *filled with bright lines*.

Mr. Pye, a young gentleman who assisted Professor Young, saw this with a spectroscope of one prism.

Mr. Abbey, of Wadham College, Oxford, also observed with a spectroscope, and his results were soon after published in the English journals.

Professor Langley, of Allegheny, Pa., observed the structure of the corona with a grand achromatic of four inches aperture, and a power of about one hundred and fifty. He reports that, on the closest scrutiny of the part nearest the sun, nothing was seen but a nearly uniform diffused light, except that one dark ray in the field was noticed to be absolutely straight, and nearly radial. The outline of the corona was roughly quadrangular, the larger diagonal making an angle of nearly forty-five degrees with the vertical. Professor Langley also used a Savart's polariscope, which was attached to a small telescope of one and a half inches aperture. During totality the bands were distinctly seen on the corona, and were brightest where normal and tangent to it. As the polariscope was slowly rotated, no marked change of their brightness was seen during the whole revolution, and they presented the appearance and characteristics of radial polarization.

Captain Ernst occupied an elevated station about half a mile northwest of the principal eclipse-station. His observations were upon the general appearance of the corona and landscape during totality. Mr. Gordon, who resides in the vicinity, was at the same station, and made an excellent sketch of the corona.

Professor Pickering, of Boston, also occupied the station last mentioned, and successively used an Arago polariscope, one of the Proymowski form, and a Savart, and obtained similar results with each, which indicated the radial polarization of the corona.

The light covering the moon's disk was observed to be polarized throughout in the same plane, and the observations showed that the Arago and other polariscopes dependent on color were sufficiently delicate to determine the plane with accuracy.

Mr. Ross, at the same station, used a modification of the Bunsen photometer, and obtained several accordant measurements, showing that the light was about equal to that of a candle burning at a distance of two feet.

While the preliminary observations at the Olivar Station at Jerez, were in progress, a meridian-line, one hundred and forty-six metres in length, was established and carefully marked with stone posts by Assistant Dean.

With the friendly co-operation of Captain Pujazon, director of the San Fernando observatory, arrangements were also made for exchanging clock-signals by telegraph, for the purpose of determining the longitude of the Olivar Station, but the continual stormy weather prevented the execution of this work. Assistant Dean acknowledges the valuable assistance rendered by Capt. José S. Montop, chief of the Spanish coast-survey, who, in addition to other data furnished, kindly offered to connect the American eclipse-station by triangulation with the Spanish survey.

Captain Montop's observations place the longitude of our eclipse-station at Jerez $4^{\circ} 55' .3$, or $19^{\circ} .7$, east of the observatory at San Fernando, which would give for the Olivar Station approximately $4^{\circ} 43' 42^{\circ} .1$ east of Washington.

The expedition was successful, and results of great value have been obtained. In the Appendix (No. 16 of the Report of 1870) will be found the details noted by the several observers.

