

ward and 2° southward in the constellation *Virgo*, and at the end of August it will be about 6° north and 2° west of *Spica*, α *Virginis*, and its brightness will be about the same as that of the star. The Moon approaches very close to *Saturn* on the evening of July 19, and may occult the planet as seen from some parts of the Earth. There is another close approach on August 16, but this occurs during daylight in the United States.

Uranus rises at about 11 P. M. on July 1 and at about 7 P. M. on August 31. On account of its faintness it can not be seen until more than an hour after rising. It is retrograding slowly along the border line of *Aquarius* and *Pisces*, the whole motion during the two months being about $1^\circ.5$, a little south of east. The nearest bright star is the fourth magnitude ϕ *Aquarii*. On August 24 the planet is only $17'$, about half of the Moon's apparent diameter, north of the star, and during the entire two months the planet and star are quite close together.

Neptune passes conjunction with the Sun on August 11 and becomes a morning star. It is on the border line of the constellation *Cancer* and *Leo*.

NOTES FROM PACIFIC COAST OBSERVATORIES

OBSERVATIONS ON THE DEFLECTION OF LIGHT IN PASSING THROUGH THE SUN'S GRAVITATIONAL FIELD, MADE DURING THE TOTAL SOLAR ECLIPSE OF SEPTEMBER 21, 1923

By W. W. CAMPBELL and R. TRUMPLER

The W. H. Crocker Eclipse Expedition to Wallal, Western Australia, (see report by W. W. Campbell in the February number of these *Publications*) included in its program observations on the eclipse test of Einstein's Generalized Theory of Relativity. According to this theory light rays, when passing near the Sun are bent in such a way that a star seen at the edge of the Sun appears displaced from its normal position by $1''.745$, while for other stars the displacements are inversely proportional to their angular distances from the Sun's center.

Two twin cameras of fifteen feet and five feet focal length respectively, were used in connection with this problem. As far as the photographs obtained with the larger instrument are concerned, the measures and reductions have just been completed and will form the subject of a Lick Observatory Bulletin, now in press.

The problem of observing the predicted light deflections is solved by photographing during the eclipse the stars surrounding the eclipsed Sun and comparing these photographs, by accurate measures, with other photographs of the same stars taken at night several months before or after the eclipse, when the Sun is in another part of the sky and has no disturbing influence on the positions of these stars. Such comparison photographs were secured by Trumpler in May 1922, on the island of Tahiti, as nearly as possible under the same conditions (hour-angle, zenith-distance, temperature) as were expected to prevail during the eclipse. As a check on any instrumental sources of error that might affect such delicate measures an auxiliary star group was selected, following the eclipse star field by $6^{\text{h}}15^{\text{m}}$ in right ascension but at the same declination. At both observing stations these check stars were photographed on the same plates and at the same hour angle as the eclipse stars, and at both observing dates this check field was over 90° distant from the Sun and therefore unaffected by any light deflections.

At Tahiti the comparison plates were given an exposure of 3 minutes on the eclipse field at about ten o'clock in the evening; the two plateholders were then left undisturbed in the telescope (closing only the slides) until about 4:15 in the morning, when the same plates were exposed on the check field. In a similar way the procedure at Wallal was to make an exposure on the check field at about 7:45 on the evening preceding the eclipse, to leave the two plates in the telescope, and to use them again the following day for the first pair of eclipse photographs, with a 2 minute exposure, started 10 seconds after the beginning of totality. The plate holders were then changed (the operation taking 50 seconds), and another pair of eclipse plates exposed for 2 minutes 5 seconds, the exposure being stopped

10 seconds before the end of totality. This pair of plates received the impression of the check field on the evening following the eclipse. A visual guiding telescope was attached to the camera, and during all the exposures the observer (Trumpler) corrected the irregularities of the clock work by means of the right ascension slow motion so as to keep the guiding star (β *Virginis* for the eclipse field, 70 *Ophiuchi* for the check field) exactly on the cross wire.

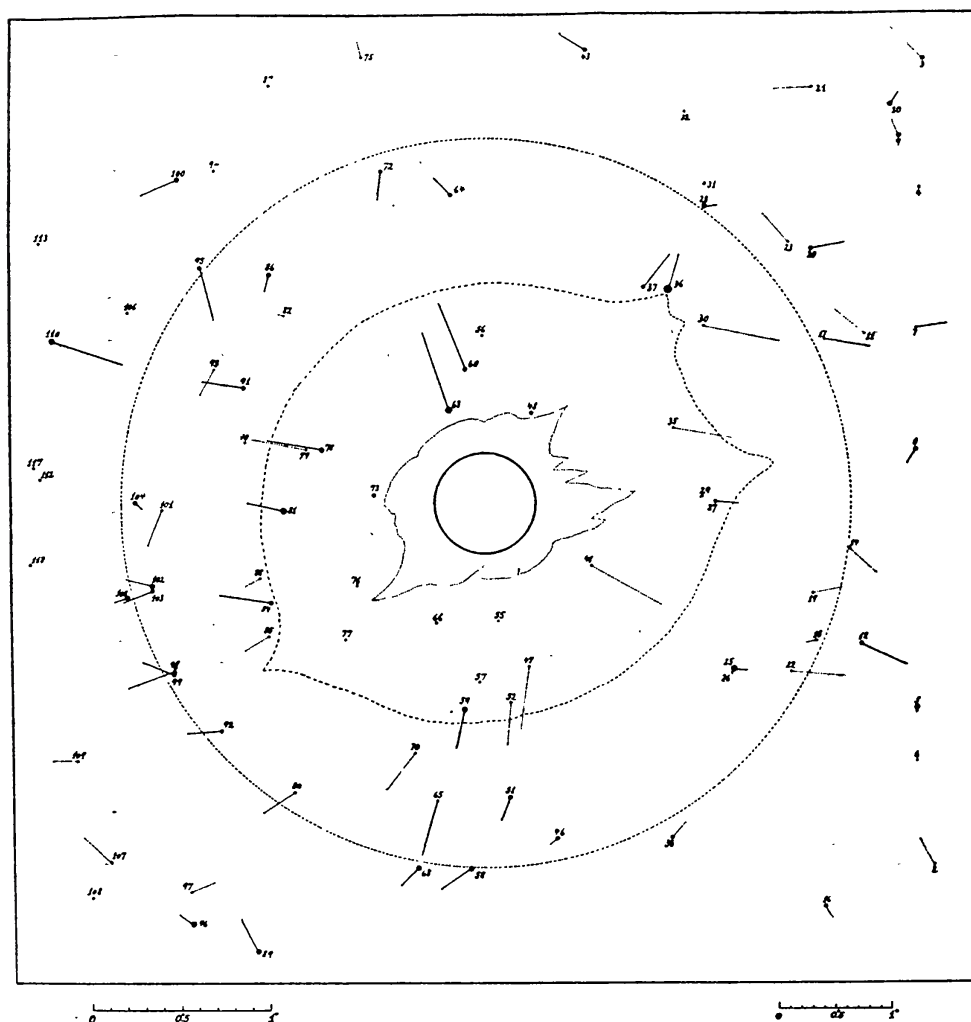


Fig. 1. Star chart of the total solar eclipse of Sept. 21, 1922, containing the 92 stars actually measured. The observed relative displacements with weights 2.0 to 3.9 are marked by a full line; those with weights 1.0 to 2.0 by a dotted line; displacements of smaller weight are omitted. The dotted circle is of 2° radius and gives the inner limit of the reference stars. The outlines of the brighter parts of the corona as well as those of the farthest traces of coronal light are drawn in. The border line represents the edge of the plate.

ASTRONOMICAL SOCIETY OF THE PACIFIC 161

The eclipse photographs show the corona strongly with traces reaching as far as $1\frac{1}{4}^\circ$ from the Sun's center (see outline in Fig. 1). The sky background also is considerably blackened. Nevertheless, thanks to the excellence of the objectives and to the precautions taken with the development, stars as faint as 10.8 photographic magnitude are visible and 92 stars altogether were measured on one or another of the plates. This is probably the first time that such faint stars have been photographed or observed during a solar eclipse. The star images on the eclipse photographs are somewhat fuzzy and diffuse (probably an effect of the fogging of the background) especially for the fainter stars, and different weights were assigned to the measures according to the quality of each star image.

Following the example of the British expeditions of 1919 an intermediate plate was taken at Tahiti with the glass side turned toward the objective. This intermediate plate, having right and left reversed, could be placed film to film with any of the eclipse photographs or the night comparison plates so that corresponding star images on the two plates fell close together. The distance between the two images was then measured with the micrometer of the measuring microscopic. Each of the eclipse plates was combined with one of the Tahiti comparison plates, and three of these pairs of plates were measured independently by both observers, the last pair by one observer only.

Subtracting the measures of a comparison plate from those of the corresponding eclipse photograph, the intermediate plate is completely eliminated, and we obtain directly the differences between the two plates to be compared. In these differences the light deflections are mixed up with the effects of the plate constants. Using the stars in the outer portions of the plate (outside of the dotted circle in Fig. 1) as reference stars, the effects of the plate constants were determined and applied without any priori assumptions as to the nature of the light deflections, since, for these stars, the deflections would be very small under any assumption. The resulting star displacements in the mean of the four plates are plotted, 2250 times magnified, in Fig. 1. They are the *relative* displacements of the stars near

the Sun as compared with the reference stars near the edge of the plate. For the latter the average displacements were made zero by the way in which the plate constants were determined. Fig. 1 gives a striking illustration of the existence of light deflections near the Sun as predicted by Einstein's theory. If these deflections are not always pointed exactly away from the Sun's center, this is (according to the theory of errors) entirely accounted for by the accidental errors of observation.

Our observations are in good agreement with the prediction of the theory that the deflections are inversely proportional to the star's angular distance from the Sun's center, and on the basis of this law we can calculate from all the stars measured on a plate, what the light deflection of a star at the Sun's limb would be. The results of the least squares solutions made separately for the two observers and the four plates are given, together with their probable errors, in the following table:

LIGHT DEFLECTION AT THE SUN'S LIMB

Plates	Campbell	No. of Stars	Trumpler	No. of Stars	Plate Mean
CD22—CD15	*1".72±".32	62	*1".88±".27	69	1".80
CD23—CD17	1 .35±.22	77	*1 .62±.22	81	1 .48
AB18—AB12	*1 .78±.22	80	*1 .91±.19	84	1 .85
AB17—AB10/9 . .			1 .76±.22	85	1 .76 (weight .9)
Mean for each observer	1 .60±.14		1 .78±.11		
Mean from four plates					1 .745
Einstein's predicted value					1".72±".11

Our observations agree very closely with Einstein's prediction.

A test was also made to determine whether or not the stars near the Sun's poles show as much deflection as those near the Sun's equator:

Two quadrants near Sun's equator 1".63±".15 (53 stars)

Two quadrants near Sun's poles 1 .76±.18 (39 stars)

The small difference between the two values is within the

*These five values, very slightly modified, were the only ones available when the preliminary announcement of our results for the Einstein eclipse problem was made through the press associations and otherwise, on April 11, 1923. At that date we had also determined, from measures of the check region star images, that any corrections suggested or demanded by existing small plate errors could not operate to diminish any of the five values of the Einstein coefficient.

ASTRONOMICAL SOCIETY OF THE PACIFIC 163

limits of the errors of observation, and the deflections seem to be essentially the same all around the Sun.

A selected list of 37 stars of the check field was measured intermingled with the eclipse stars. After applying the plate corrections in a similar way as for the eclipse field, the check stars near the center of the plate do not show any displacements away from the plate center; on the contrary they seem, on the average, rather to be displaced a trifle toward it. This proves that any instrumental errors that might have affected our measures could not have produced the observed light deflections of the stars of the eclipse field; they could only have had the tendency to make our results too small. If corrections based on the residuals of the check stars are applied to the observations of the eclipse stars the light deflection at the Sun's limb derived from the corrected values is $2''.05$. It is, however, not the stars nearest to the Sun that differ from the theory; it is only the stars between 1° and 2° from the Sun's center that show, with these corrections, somewhat too large deflections. Perhaps the application of such corrections is not quite justified, or perhaps an effect additional to that of Einstein's theory (like Courvoisier's "yearly refraction"¹) enters for the stars mentioned. The plates of the five foot camera, to be measured shortly, may throw some light upon this question.

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THE AXIS OF SYMMETRY OF THE POLAR STREAMERS IN THE
SOLAR CORONA

It is frequently remarked that the polar streamers in the Sun's corona which accompany sun-spot inactivity resemble magnetic lines of force. If the resemblance is more than accidental, then the axis of symmetry of these streamers should define the position of the Sun's magnetic axis. To obtain data on this matter we have measured the position angles of the axis of symmetry on photographs of the corona which have been

¹A. N. 211, 305, 1920.