PRELIMINARY RESULTS OF ANALYSIS OF LIGHT DEFLECTIONS OBSERVED DURING SOLAR ECLIPSE OF MAY 29, 1919[1]

1. TABLE 1 summarizes the available observational data for deriving the amount of deflection of a light ray grazing the sun's limb as observed on the earth. The sources of the data are given in the remarks below the table. No. 2 has been rejected by the British astronomers because of the diffuseness of the star-images on the photographic plates obtained with the astrographic object glass of the Greenwich Observatory used in conjunction with a 16-inch cœlostat, the figure of which apparently changed appreciably during the plate-exposures. It will be observed that the indiscriminate mean results, I. and II., would indicate a value about midway between that (0″.87) computed on the basis of the Newtonian Mechanics and that (1″.74) computed according to Einstein's law of gravitation. If on the other hand the observational results are weighted inversely as the squares of the probable errors, than the weighted mean results, especially IV. (1″.76), are found to be in close agreement with Einstein's value, though the probable error (± 0″.2) is still somewhat large.

TABLE I

Summary of All Observations Concerning Deflection of Light at Sun's Limb

No.	Eclipse	Station	Observers	Deflection at Sun's Limb	Probable Error	Approximate Weight
1	June 8, 1918	Goldendale. U. S. A.	Campbell-Curtis	0″.58	—	1
2	May 29, 1919	Sobral, Brazil	Davidson	0.93	±0″.3	1
3	May 29, 1919	Sobral, Brazil	Crommelin	1.98	±0.12	6
4	May 29, 1919	Île of Principe	Eddington	1.61	±0.3	1
	General results	I. Indiscriminate mean of all		1.28	±0.21	
		II. Indiscriminate mean without No. 2		1.39	±0.28	
		III. Weighted mean of all		1.67	±0.20	
		IV. Weighted mean without No. 2		1.76	±0.22	

Remarks: No. 1 was derived from Dr. Campbell's statement (see SCIENCE, March 26, 1920, page 310) that the mean of their results "came out at 0″.08 or 0″.15, according to which of Einstein's hypotheses was adopted"; the probable error of one star position is given as 0″.5, but the probable error of the mean result is not stated. Nos. 2, 3 and 4 are given in *Monthly Notices, R.A.S.*, Vol. LXX., p. 415, February, 1920. (See SCIENCE, March 26, 1920, p. 308.)

2. The weighted mean value IV. depends chiefly upon Crommelin's result (No. 3), obtained at Sobral, Brazil, during the solar eclipse of May 29, 1919, from 7 photographic plates, using a 4-inch lens of 19-foot focus and an 8-inch cœlostat, and from similar check-plates obtained at the same station before sunrise between July 12 to 18, 1919. These observations appear to be the best ones for undertaking a critical analysis of the results with the view to ascertaining, if possible, whether any other effect has been measured than that accredited to the sun's gravitational action. The following results of a preliminary analysis, as made by the Department of Terrestrial Magnetism at Washington, are based partly upon data already published in the British journals and partly upon those very courteously supplied by the Astronomer Royal, Sir Frank Dyson, to whom we desire to return our appreciative thanks. The chief purpose of our investigation was to ascertain the possible bearing of the geophysical observations, made by the two chief

[1] Résumé of papers presented before the American Philosophical Society at Philadelphia (February 6 and April 24), the American Physical Society (February 28 and April 24), and Bureau of Standards at Washington (May 7, 1920). For a general account of observations concerning the solar eclipse of May 29, 1919, and the Einstein effect, the reader may be referred to the author's "Résumé," published in SCIENCE, March 26, 1920, pp. 301–312.

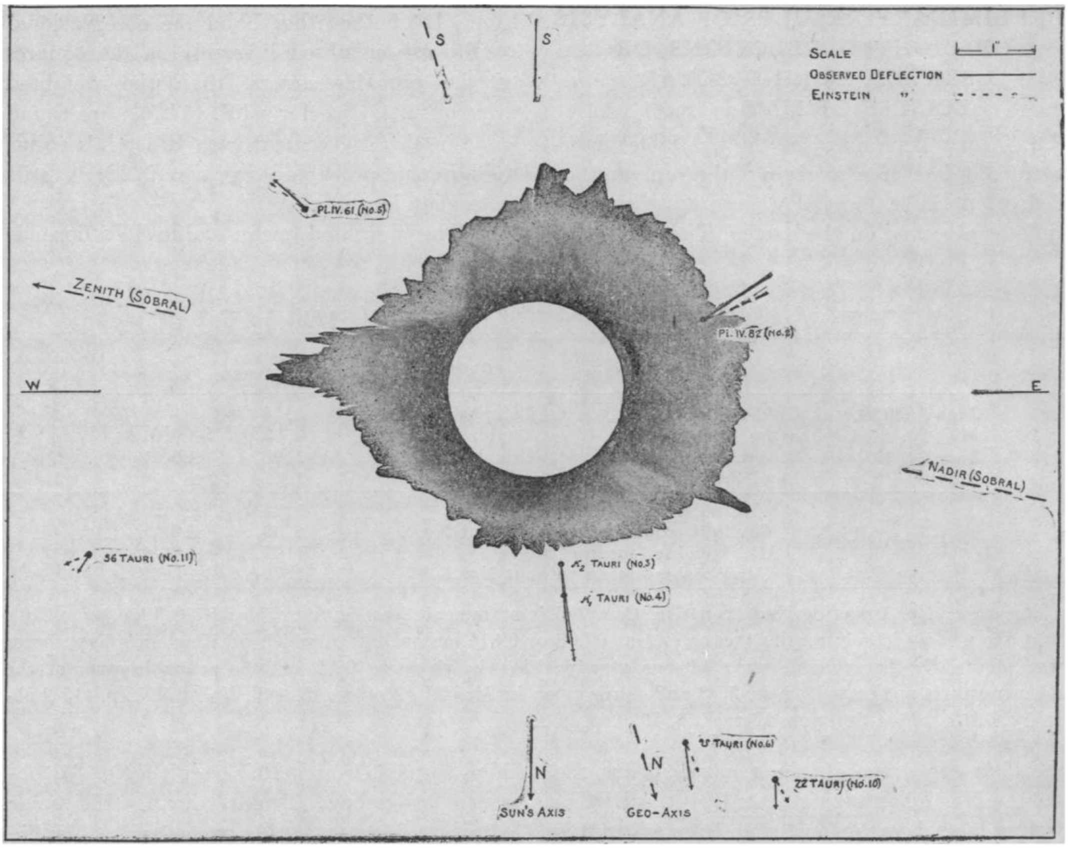

FIG. 1. Dr. Crommelin's observed light deflections at Sobral, Brazil, plotted for each star according to direction and a relative scale of magnitude.

(Full line is observed vector; broken line is the Einstein vector. It will be observed that, in general the observed vector departs from the Einstein vector in a direction *away* from a diameter of the sun passing through the zenith for Sobral as projected on the photographic plate; about this diameter, furthermore, the angular departures, or non-radical effects, are found to be symmetrical.)

expeditions of the Department of Terrestrial Magnetism during the solar eclipse of May 29, 1919, at Sobral (D. M. Wise, in charge) and at Cape Palmas, Liberia (L. A. Bauer, in charge) upon the complete interpretation of results of the astronomical observations. We also received from Dr. H. Morize, director of the Rio de Janeiro Observatory, meteorological data pertaining to his eclipse station, which was likewise Sobral, and desire to acknowledge our indebtedness to him. It may be recalled that the rays of light whose deflections were measured during the solar eclipse were subject chiefly: *a* to a gravitational action from the sun, *b* to optical refraction in the sun's atmosphere, and *c* to optical refraction in the earth's atmosphere. The bearing of the geophysical observations will be chiefly in relation to *c*.

3. Let α_0 be the gravitational deflection of a light ray grazing the sun's limb, α_r, the gravitational deflection of the ray at the distance ρ from the center of the sun expressed in units of the sun's radius; then, according to the Einstein law of gravitation, we have

$$\alpha_r = \frac{\alpha_0}{\rho} = \frac{1''\!.74}{\rho}.$$

The deflection by this law should everywhere be the same on a circle concentric with the sun, *i. e.*, *condition* (*1*) the deflection should vary alone with the inverse distance, not also, for example, with heliographic latitude; furthermore, the deflection should be strictly radial, *i. e.*, *condition* (2) the deflection should coincide in direction with a line drawn to the center of the sun. Plotting Crommelin's actually observed deflections, for each of the 7 stars, in magnitude and direction, as was done in Fig. 1 by the Department of Terrestrial Magnetism, a careful examination shows that there are systematic departures from both conditions (1) and (2) which apparently can not be explained wholly by errors of observation.[2] In addition we have the fact that the resulting value of α_0, No. 3 in Table I., is 1″.98 instead of 1″.74, or about 14 per cent. larger than the theoretical value. What was the chief cause of the superposed effects?

4. Table 2 contains our resolved components of the observed light deflections, namely, the strictly radial component, α_r, and α_p, the component perpendicular to the radius, representing the non-radial effects or angular departures, β, from radiality, exhibited in Fig. 1. *A* is the positon angle of the star counted continuously in the direction N, E., S., W., from the north end of the declination or geo-axis; the north end of this axis for Sobral at mid-totality was about 16°.8 east of the north end of the sun's axis of rotation. The two columns giving the probable errors, as deduced by us from the individual data derived from Crommelin's 7 plates, show that the average probable error for both the radial and non-radial components is about $+0''.04$. The angular departure, β, it will be observed, varies from $-28°$ to $+37°$; a plus value means an angular departure in the positive direction of the angle *A*, *i. e.*, in the direction N., E., S., W. The sign of α_p corresponds with that of β. How many of the 7 plates gave a plus or a minus β is shown in the last two columns. It will be seen that for stars 6 and 10, the minus sign greatly predominates and for stars 2 and 11, the plus sign greatly predominates.

TABLE II

Radial and Non-Radial Components of Observed Light Deflections at Sobral, Brazil, May 29, and Angular Departures for Radiality

Based on results from 7 photographic plates obtained by Dr. A. C. D. Crommelin with a 4-inch lens of 19-foot focus and using an 8-inch cœlostat.

No.	Star	Pos. Angle	Dist.	Einstein Deflection	Observed Deflection		Probable Errors		Angular Departure		
		A	ρ		Radial	Non-Radial	Rad.	N. R.	β	+	=
3	κ_2 Tauri	351°.8	1.99	0″.88	1″.02	−0″.05	0″.02	0″.02	− 2°.9	3	4
2	Pi. IV. 82	96.0	2.04	0.85	0.97	+0.16	0.04	0.05	+ 9.6	6	1
4	κ_1 Tauri	352.0	2.35	0.75	0.84	+0.01	0.03	0.03	+ 0.8	2	5
5	Pi. IV. 61	215.6	3.27	0.53	0.54	−0.02	0.05	0.04	− 2.5	3	4
6	υ Tauri	6.3	4.34	0.40	9.56	−0.16	0.04	0.04	−16.0	1	6
10	72 Tauri	15.0	5.19	0.34	0.32	−0.17	0.05	0.04	−27.9	0	7
11	56 Tauri	273.6	5.38	0.32	0.20	+0.15	0.06	0.02	+37.2	7	0

5. Table II. shows the following facts:

(*a*) The observed radial component is greater than the Einstein theoretical value for the first five stars (Nos. 3, 2, 4, 5 and 6) and less for the two most distant stars (Nos. 10 and 11). (The observed radial deflections for the two stars, Nos. 6[3] and 11, which depart most from the Einstein values, correspond, respectively, to deflections at the sun's limb of

[2] Dr. Silberstein has also directed attention to the existence of the non-radial effects. *Monthly Notices, R. A. S.*, Vol. 80, pp. 111–112.

[3] Curiously, Eddington's observed deflection for star 6, according to data kindly supplied recently, also departs most markedly from the Einstein law; in his case, however, the deflection reduced to the sun's limb is about 55 per cent. too *low* for that star.

$2''.43$ and $1''.11$, thus exhibiting a range of 75 per cent.)

(*b*) The observed non-radial component, which according to the Einstein law (1) should be zero, varies from $-0''.17$ to $+0''.16$; it amounts at times to one tenth of the Einstein radial deflection at the sun's limb and is from 3 to 7 times the probable error.

(*c*) The value of the deflection at the sun's limb as deduced from stars Nos. 3, 4, 6 and 10, near the sun's axis, is $2''.02$, and from stars Nos. 2, 5 and 11, near the sun's equator, $1''.88$; the two values differ $0''.14$ or 8 per cent. (The observed deflection therefore is a function not simply of distance alone, as required by the Einstein law, but also apparently of the position angle.)

6. After various trials the following preliminary formulæ were found to represent the observed quantities with good approximation:[4]

$$\alpha_r = \frac{1''.77}{\rho} + \frac{0''.29}{\rho} \sin^2 (A - 239^\circ), \tag{2}$$

$$\alpha_p = 0''.0323\rho \sin 2 (A - 233^\circ). \tag{3}$$

The close agreement in the independently-derived phase angles, 239° and 233°, led to the impression that some common cause produced the superposed radial effect, represented by the second term in (2), and the non-radial effects represented by (3). Now the position angle of the zenith for Sobral at mid-totality of the eclipse, projected on the plate, is 241°.6, which value could be substituted with fair approximation in place of the phase angles for (2) and (3). Thus the second term of (2) and the single term of (3) were found to be related in some manner to the local zenith. The effect of terrestrial atmospheric refraction on the sun and the stars is to shift them apparently all towards the zenith, those farthest from the zenith being shifted most. The question accordingly arises whether the superposed effects with which we are concerned may not have resulted from incomplete elimination of differential refraction effects in the earth's atmosphere. It may be observed also that by the introduction of our second term in (2), the value of the deflection at the sun's limb was reduced from $1''.98$ to $1''.77$, which agrees closely with the Einstein value.

7. With the effective aid of my colleague, Mr. W. J. Peters, in charge of the reduction of the atmospheric-refraction observations made aboard the *Carnegie,* the possible outstanding effects resulting from incomplete elimination of differential refraction effects in the earth's atmosphere have been investigated. The differential terrestrial refraction effects between the sun and each of the 7 stars were rigorously computed by two different methods for the time of exposure of the eclipse plates and the prevalent meteorological conditions. Lacking complete details regarding the precise times of exposures of the check-plates obtained before sunrise between July 12 and 18, our computed differential-refraction effects for the check-plates are for the present only tentative ones. The examination as far as it can be made at present indicates that outstanding effects in the differences between the differential terrestrial refraction effects for the eclipse-plates and the check-plates, may largely, if not completely, account for the non-radial effects in the observed light deflections, as also decrease the value ($1''.98$) of the radial deflection at the sun's limb. This is a matter that can be more definitely determined when the original data and complete details regarding the reductions of the measures are available. *The present indications are that precise allowance for differential terrestrial refraction effects may bring Crommelin's results into closer accord with the Einstein law of gravi-*

[4] The sum of the residuals squared on the basis of formula (1) was 0.093, whereas on the basis of (2) the sum was reduced to 0.037. Were the non-radial effects regarded solely as errors of observation, then the sum of the squares amounts to 0.106; however, the sum of the squares of the residuals resulting by applying formula (3) is but 0.016. Other formulæ were also established giving a still closer representation of the observed quantities than do (2) and (3), however, they did not admit of physical interpretation as readily as those given. This matter will be discussed more fully in the complete paper.

tation. Possibly also when reductions of the photographic measures have been made with every possible refinement, some outstanding effect may be disclosed to be referred to optical refraction in the sun's atmosphere, especially for stars in the polar regions like Nos. 3, 4, 6 and 10, where the length of the light path through the solar atmosphere would be considerably less than for stars 2, 5 and 11, in the equatorial regions (*cf.* § 5*c*). A future communication will give further consideration to this matter.

8. In the foregoing paragraph nothing has been said as to the possibility of irregularities in the differential refraction effects in the earth's atmosphere such as have been disclosed by various investigators and which may not have affected every ray alike over a star field embracing about two degrees of arc. In brief, the actual differential terrestrial refraction effects, because of atmospheric conditions during totality of the eclipse or during the times when the check-plates were exposed, or because of the manner of mounting of the instrumental appliances, may have been appreciably different from those derived from mathematical formulæ and standard refraction tables. It would seem that in future tests of the Einstein effect, atmospheric-refraction observations and allied meteorological observations should be included as a necessary part of the program of work.

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WASHINGTON, D. C.,
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FOURTH YEAR OF THE NEOTROPICAL RESEARCH STATION

THE work of the New York Zoological Society Station in British Guiana began in 1916. Owing to the difficulty of transportation at the time of the war, there was a lapse during 1917, but work was resumed in 1918 and 1919. The station is now entering its fourth year. It has been directed with great ability by Mr. William Beebe, Honorary Curator of Birds at the Zoological Park, and has been supported by personal contributions of the trustees of the Zoological Society.

The distinctive research feature of this station is intensive biologic observation in one region, in fact, in one locality, as distinguished from the observations of Darwin, Bates, Waterton, Chapman, and many other explorers in the great biologic field of South America. The area chosen by Director Beebe is the eastern edge of the tropical rain-forest of South America, which extends unbroken across the greater part of the continent. The fauna and flora are uniform with those of the entire Amazonian region. The locality in Bartica District, British Guiana, at Kartabo, the point of junction of the Mazaruni and Cuyuni rivers, has proved ideal in every way as a permanent site for this station. Within ten minutes walk are sandy and rocky beaches, mangroves, grassland, swamp, and high jungle, each with a growth of life peculiar to itself. Free exposure to the trade winds, the absence of flies and mosquitos, invariably cool nights, excellent buildings assigned by the government—all these features contribute to the wide range of life and the unbroken health of the scientific staff.

This region affords a vast opportunity for studying the faunal and floral complex, independent and interrelated adaptations in all grades of life in vertical as well as horizontal life zones. The vertical division of the fauna and flora in distinctive zones, extending from the tree summits to the subsoil, is a biologic contribution of importance. The observations of the station extend from color changes and adaptations to anatomical and functional characters of the archaic as well as of the highly modernized forms of life.

All together seventy-five papers have been published on the scientific observations of this station, parts of which have already been reviewed in the volume "Tropical Wild Life" issued by the society in 1917. Three papers appeared in the first volume of *Zoologica* (1907–1915), and it has been decided to reserve the third volume of *Zoologica* exclusively to scientific papers on the station.

During the year 1919 Director Beebe's