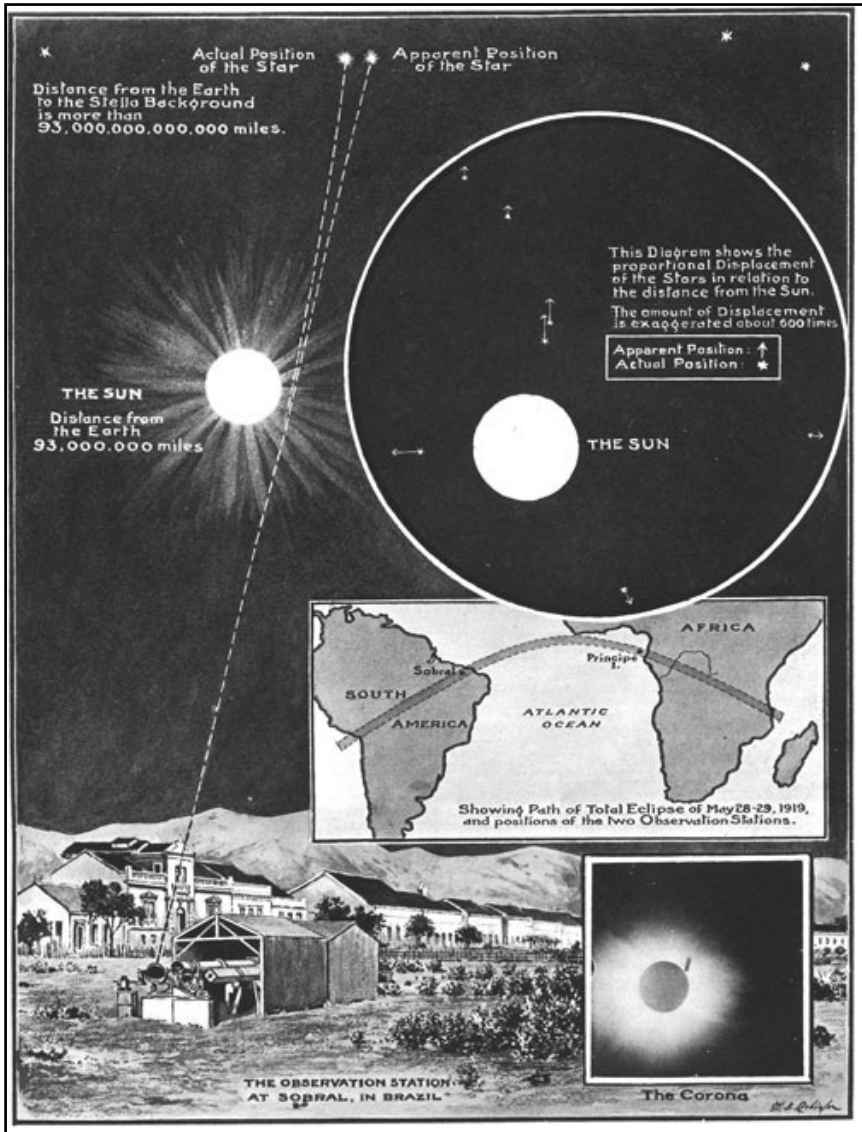
Gravitation bending of light 19 Jan

- Chronology
  - 1911 E computed the deflection of light with the gravitation redshift term but space flat. $\theta=2M/r$
  - 1914 Erwin Freundlich mounted an expedition to measure bending during an eclipse. Fail because of WWI.
  - 11/18/1915 E published a theory of gravity that is OK for vacuum but incorrect inside a star. He calculated the bending was $\theta=4M/r$.
  - 11/25/1915 E published the correct theory of gravity.
  - 1/16/1916 E reads Schwarzschild's paper on his metric before the Prussian Academy.
  - 5/11/1916 Schwarzschild died.
  - 5/29/1919 Crommelin measures eclipse in Sobral, Brazil.
  - 11/1919 Dyson, Eddington, & Davidson announce results of deflection at Royal Society.

http://www.gettyimages.com/detail/90731681/SSPL
Photograph (bromide print) showing the instruments used by the British expedition sent to observe total solar eclipse on 29 May 1919 from Sobral in Brazil. Sir Arthur Eddington at Cambridge University organised the eclipse trip to try and test Einstein's Theory of Relativity. During the event, two heliostats with moveable mirrors were used to direct images of the eclipsed Sun into a pair of horizontal telescopes. Measurement of photographs taken through these instruments was checked for any deflection of star positions adjacent to the Sun. Einstein suggested that the large mass of a star like our Sun would bend the path of any starlight if it passed close-by. (Photo by SSPL/Getty Images)



11/22/1919 Illustrated London News

LIGHTS ALL ASKEW IN THE HEAVENS

Men of Science More or Less Agog Over Results of Eclipse Observations.

EINSTEIN THEORY TRIUMPHS

Stars Not Where They Seemed or Were Calculated to be, but Nobody Need Worry.

A BOOK FOR 12 WISE MEN

No More in All the World Could Comprehend It, Said Einstein When His Daring Publishers Accepted It.

New York Times

The Eclipse Expedition to Sobral.

The voyage out in the *Anselm* was extremely enjoyable, save for a few hours in the Bay of Biscay. We were met at Lisbon by Dr. Oom, who took us over the Observatory, and then showed us some of the principal sights in a motor-car drive. We went ashore at Madeira, and had a farewell lunch with Prof. Eddington and Mr. Cottingham, who had four weeks to wait here for the Principe steamer. On arrival at Para our packing-cases were passed through the customs unopened, thanks to the kind help of the British Consul. We had the choice of leaving immediately for Sobral or of waiting nearly a month; we decided on the latter course, which was certainly the right one, as we afterwards found that nothing was arranged for our reception at Sobral at that date. We took advantage of the delay to continue our voyage to Manaos on the *Anselm*. We thus saw 1000 miles of the luxuriant forests of the Amazon, with their denizens of gorgeous plumage. We also contrasted the turbid yellow Amazon water with the beautiful clear green of the Tapajos and the dark brown of the Rio Negro.

The captain took us a trip up the latter in a motor-launch, enabling us to see the forest at close quarters. We also went by tram to Flores on two occasions, and walked from there into the forest. We saw coffee and pine-apples cultivated on a small scale in front of the cottages, and the sensitive plant (native name Malisa) which shuts up on being touched. We also saw the whole ground alive with troops of leaf-cutting ants, each carrying its green burden.

The Booth Company have made elaborate floating wharves at Manaos, which adapt themselves to the change of 60 feet in the level of the river at the wet and dry seasons. There were great accumulations of goods (rubber, nuts, cotton, fibre, &c.), and the *Anselm* had no difficulty in filling up.

On our return to Para we were introduced to the English and American Club, and made the acquaintance of most of the English-speaking community, including the American Consul and Mr. Binns, the manager of the Tramway Company. He gave us free passes over the system, besides helping us in many other ways. These passes enabled us to explore the city in comfort, and to see something of the dense primeval forests that still exist within a few miles of it.

We left for Camocim on April 24 in the steamer *Fortaleza*; we arrived, after a somewhat tedious voyage, on April 29. Our various introductions to the agents at Camocim and Sobral (Messrs. Nicholau and Carneiro) proved so effective that from the moment of reaching Camocim we were in the position of personally-conducted tourists, and found everything arranged for us. The railway journey of 80 miles to Sobral is not devoid of interest, as the line skirts several mountain ranges. But as Sobral was approached the barren aspect of the country, due to the severe drought, became very depressing, although relieved

Crommelin, A. C. D.
The Observatory, Vol. 42,
p. 368-371 (1919)

We, together with the members of the Carnegie Commission, were the guests of the Brazilian Government during the whole of this first visit to Sobral. In addition to our board, all labour that we required was freely placed at our service; further, a motor-car, the first that had ever been seen in Sobral, was brought from Rio for our use. In this we twice made the ascent of Mt. Meruocca, 2700 feet high, some six miles to the N.W. of Sobral. A well-engineered road, ascending the steep slope in a series of zigzags and corkscrews, had been constructed as a relief work in the previous drought; we were really the first to make full use of it, wheeled traffic being almost unknown in the district.

We found a fertile fruit-growing region at the summit, decidedly cooler than the plain, so that many of the inhabitants of Sobral live on the heights during the hottest month (October). The summit would not have been at all suitable for an eclipse station, as cloud and mist frequently overhung the mountain, and, in fact, nothing of totality was seen from there.

The members of the Carnegie Commission from Washington, Mr. Daniel Wise and Mr. Andrew Thomson, were quartered in the same house as ourselves, so that we saw much of their work, which dealt respectively with terrestrial magnetism and atmospheric electricity. Mr. Wise found an ideal location for his self-recording instruments in the basement of our house, the diurnal variation of temperature being very small. Their visual observations were made on the racecourse, close to our own camp. Incidentally, Mr. Wise redetermined our latitude, his value, $-3^{\circ}\ 41'{\cdot}5$, being $0''{\cdot}2$ north of the value given by Dr. Morrize. As the region had not been systematically surveyed, we found satisfaction in this close accordance.

The eclipse day opened very unpromisingly, the proportion of cloud at first contact being about 9/10. There were, however, useful glimpses of sunshine, which gave opportunities of placing the Sun's image at the assigned point on the plates, and of finally rating the driving clocks. The cloudiness during the early stages was doubtless the cause of the fall of temperature during totality being unexpectedly small; perhaps this latter fact was connected with the dead calm that prevailed during totality. From our experience of the locality we apprehended sudden gusts as the air cooled, and had arranged wind-screens, which fortunately were superfluous. A large clear space in the clouds reached the Sun's neighbourhood just in time, and for four out of the five minutes of totality the sky round the Sun was quite clear. For one minute about mid-totality there was thin cloud in this region; this, while hiding the stars, gave well-defined images of the inner corona and prominences, so that our photographic record of these is scarcely less complete than if we had specially endeavoured to secure them.

The darkness during totality was not great; we estimated that the illumination was about the same as that 25 minutes before sunrise. The corona was very brilliant, probably at least three times as bright as the full Moon; its type may be described as intermediate, the streamers being widely distributed in solar latitude, while there are some indications of polar plumes. A great V-shaped rift near the highest point of the disc was the first feature to strike the attention; nearly opposite to this was the great arched prominence, which was photographed on the same day with the spectroheliograph at Cambridge (see *Monthly Notices*, June). It was a most conspicuous object even to the naked eye, and the plates show much interesting detail. We did not find it practicable to take observations of contact times or duration of totality, but the latter was evidently very close to the predicted value $5^{m}\ 9^{s}$. The development of the plates was carried on at night by Mr. Davidson; he found it possible to get the water sufficiently cool by the use of porous earthenware pots, and further by placing the developing dish in an outer dish containing melting hyposulphite of soda. The astrographic plates show twelve stars, those taken with the 4-in. lens seven stars, the images of the latter being particularly well-defined.

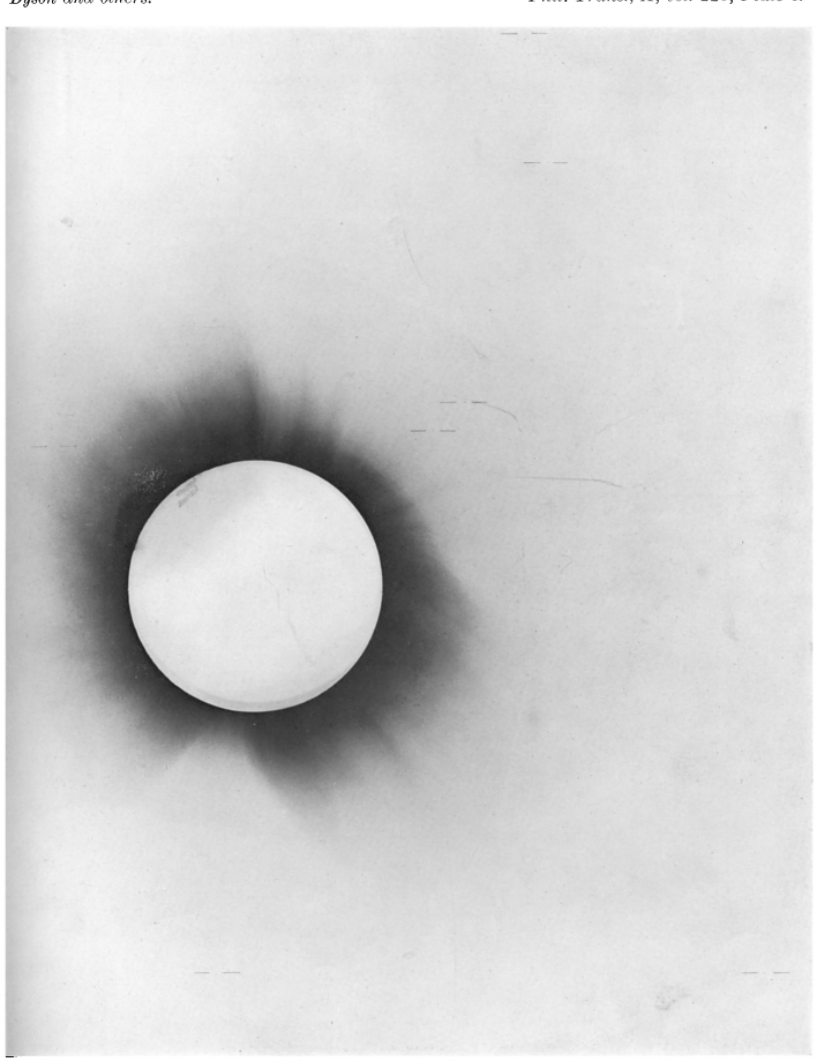
After the development was finished, we were both very glad to take a month's rest at Fortaleza after the enervating climate of Sobral; Fortaleza enjoys cool breezes from the Atlantic, and we soon felt the benefit of its bracing air. It is scarcely necessary to add that we once again experienced the greatest kindness and hospitality both from the Brazilians and from the small circle of British residents. We availed ourselves of an invitation to stay at the Seminary, as the hotels were inconveniently crowded, owing to the meeting of several Government Commissions.

We returned to Sobral towards mid-July, and obtained our check-plates of the eclipse field, which was now sufficiently distant from the Sun to photograph in the morning. We affixed hour circles of millimetre paper to the cœlostats to enable us to set them on the required field, a matter of some difficulty otherwise. Fortunately the Sun's declination was now nearly the same as at the eclipse, so that it could be used to graduate our circles. Obtaining check-plates up to an altitude of 40° (that during totality was 44°) we felt justified in closing the work, and taking the steamer *Fortaleza* to Para, whence we proceeded to Maranhão, where we caught the cargo steamer *Polycarp* for Liverpool. We had the pleasure of meeting on board several of our fellow-passengers on the *Anselm*. After a prosperous voyage we reached Liverpool on Aug. 25, our heavy baggage having been left to follow by a later boat.

A. C. D. Crommelin.

The Sources of Stellar Energy.

Whence comes the store of energy which is continually radiated into space by the Sun and stars? The answer usually given is that by the gradual shrinkage of the star great quantities of gravitational energy are converted into heat, which replaces the



Dyson, Eddington, & Davidson,
1920, A Determination of the Deflection of Light by the Sun's Gravitational Field, from Observations Made at the Total Eclipse of May 29, 1919, Philosophical Transactions of the Royal Society of London. Series A, 220, 291.

parallel to the vertical by $\frac{1}{12000}$ of their amount (or a corresponding expansion of horizontal distances).

Unless such a distortion is admitted, the discordance between the mean results of the eclipse and comparison plates is much greater than would be anticipated from the mutual agreement of the results from individual pairs of plates. Admitting the distortion, the theoretical value of the "Einstein effect" represents the observations better than might have been anticipated; and the larger value derived from the observations gives *too* good an agreement, which appears to be mainly a matter of chance.

The observed distortion of the field can be explained by an alteration of the cœlostat mirror by the Sun's heat, introducing a cylindrical curvature of at least 12 kilometres radius. So minute a distortion is not improbable.

Princeton University Observatory:
1920 *November* 6.

Russell, 1920, Note on the Sobral eclipse photographs, MNRAS, 81, 154.