History of the Department of Physics at UWA

Issue No. 9: "Wallal: the 1922 Solar Eclipse Expedition to Test Einstein's Theory"

Presented by John L. Robins

Introduction.

In 1922 an expedition was undertaken to obtain photographs, taken during an eclipse of the sun, from which the bending of light as it passed by a massive body such as the sun could be measured. Such measurements were required to test Einstein's newly proposed Theory of Relativity. The most favourable site on earth from which to make these measurements was a spot on Eighty Mile Beach on the northern coast of Western Australia. There was nothing there but a telegraph station and a cattle station called Wallal Downs and the general consensus was that it would be impossible to use such a location for measurements involving very large yet delicate equipment. There was no port, so the equipment would have to be taken ashore through the surf in rowing boats from the ship and then be transported to the site by donkey teams. All mounts for the telescopes would then have to be assembled on site. It was only through the strong and enthusiastic advocacy of Professor A.D. Ross that the expedition to Wallal was undertaken and five teams from observatories and universities around the word participated. The result was that the most accurate measurements made to that date were achieved.

There are many accounts detailing various aspects of this expedition. The article I have chosen to reproduce here gives a rather good balance between the reason for the expedition, the extreme difficulties experienced and overcome, the magnitude of the measurements undertaken and the internationally acclaimed high precision results obtained. The article contained many references which I have chosen not to include as they interrupt the flow of the story which is the principal purpose of this historical account. Anyone wishing to follow-up on the scientific literature or details should access the original article or contact me, the presenter of this History.

Sources.

The text is a paper titled "Wallal: The Total Solar Eclipse of 1922 September 21" by P.M. Jeffery, R.R. Burman and J.R. Budge, 1989 in *Proceedings of the Fifth Marcel Grossmann Meeting on General Relativity*, (eds. D.G. Blair and M.J. Buckingham) World Scientific, Singapore, pp. 1343-50. The *Fifth Marcel Grossmann Meeting on General Relativity* was held in Perth in 1988 at The University of Western Australia.

The photographic plates shown here are taken from a monograph, held in the UWA Library (FIZ 530.11) titled "A Popular Introduction to Einstein's Theory of Relativity with an account of the tests made by the Wallal Solar Eclipse Expedition" by Alexander D. Ross. The monograph was published by E.S. Wigg & Son, Ltd., Perth. 1923. Credits for the photographs are given to J. Dwyer, V.J. Matthews and Ross himself.

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WALLAL: THE TOTAL SOLAR ECLIPSE OF 1922 SEPTEMBER 21

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Abstract: The opening session of MG5 included the presentation to The University of Western Australia of a Marcel Grossmann Meetings Award for its contributions to relativistic astrophysics. These began with the key part played by A.D. Ross in the 1922 expedition to Wallal, on the northern coast of Western Australia, to measure with great care the deflection of starlight by the Sun during a total solar eclipse. Specially designed photographic equipment of very high quality was used and the weather was excellent. As a result, far more stars were observed than during the famous 1919 expeditions.

Background

After its full presentation in 1915 and 1916, Einstein's general theory of relativity excited the astronomical community by the possibility of its observational verification. Astronomers would take up Einstein's challenge of 1907 and 1911 - to try to observe the deviation of starlight by the Sun during total solar eclipses.

The idea of deflection of light by the Sun was hardly new: it had been suggested by Newton and Laplace*, and J. Soldner in 1801 had performed a calculation that would have given about half the general relativity value had he not made a numerical error*. But, coming as it did well before the development of photography, Soldner's work failed to catch the imagination of astronomers as Einstein was able to a century later with his similar pre-general relativity calculations of 1907 and 1911.

A Cordoba Observatory expedition in 1912 failed owing to bad weather*. E. Freundlich examined old photographic plates for the effect, but reported lack of success in 1913*. In 1914, a Lick Observatory expedition to Russia failed because of cloud, and an expedition from the Berlin-Babelsberg Observatory was withdrawn from the field owing to the outbreak of war*.

The Great War delayed the mounting of further expeditions, and observations in the USA by a Lick team in 1918 were inconclusive because of an instrumental deficiency*. It was not until the famous British expeditions of 1919, to Principe Island (in the Gulf of Guinea) and Sobral (in northeastern Brazil), that some success was reported. Clouds interfered at Principe and an instrumental problem vitiated some of the Sobral results*. Significant measurements were obtained for only a few stars — 5 at Principe and 7 at Sobral. It is therefore hardly surprising that several groups were interested in carrying out observations during the total eclipse of 1922 September 21.

The predicted path of totality crossed a place that provided not only the greatest period of totality for any possible observing station, but also the likelihood of best visibility*. Unfortunately, this optimum viewing location was situated on an extremely remote part of the largely-uninhabited northern coast of the state of Western Australia, almost 1500 km in a direct line from the state capital, Perth. However, some encouragement ensued when investigation showed that a cattle station, called Wallal Downs, existed nearby on Eighty Mile Beach, situated between Port Hedland and Broome.

This site was enthusiastically recommended by A.D. Ross, and it is apparent that it was largely due to this that an expedition to Wallal was mounted.

The Expedition

The isolation of this area - with its landscape reminiscent of the Mojave desert - clearly involved severe transportation problems. In spite of the obvious difficulties, extensive negotiations between the government of Australia and the organisers of what was to become known as the 'Crocker Expedition' (after W.H. Crocker of the Board of Regents of the University of California) led to provision being made for the transport of scientific parties with naval escort to the Wallal site by ship and donkey train, as well as for assistance with the establishment of a base camp and the setting up of apparatus.

Unloading at Wallal

Wallal Camp and Donkey Team

The scientific personnel consisted of an American party led by W.W. Campbell (Lick Observatory, University of California), a Canadian party led by C.A. Chant (University of Toronto), an Indian party led by J. Evershed (Kodaikanal Observatory), a group from Perth Observatory (led by C. Nossiter), A.D. Ross of the University of Western Australia, the New Zealand Government Astronomer (C.E. Adams), J.B.O. Hosking of Melbourne Observatory and a private party from England. The Wallal population was further augmented during the expedition by visitors from Port Hedland, about 250 km to the west.

On 1922 August 20, a 20-strong scientific team and a naval contingent of 10 left Fremantle on the S.S. 'Charon'. At Broome, the expedition was joined by the Kodaikanal team before travelling about 280 km southwest to Wallal on an eighty-ton schooner 'Gwendolen', towed by a small steamer. An Admiralty chart had proved to be of no help to the naval commander (Lt-Commander Quick) in locating Wallal, but it had been found listed in a Post Office directory*.

The expedition arrived at Wallal beach on August 30, and disembarked safely despite heavy surf and the 26-foot tide in this region. Proceeding by donkey train, the party set up camp rather more than a mile from the beach on a site characterised by clumps of spinifex grass and low wattle trees, a belt of which would shelter the instruments. The problems posed by the remoteness of the site are well documented in Campbell's report on the expedition. A remark of his - 'The flies and the dust, having free access to all parts of the camp, brought their own crop of discomforts.' - is helpful in visualising conditions at the campsite*.

Wallal was not the only site in Australia at which this eclipse was observed. Adelaide Observatory and the University of Adelaide mounted an expedition to Cordillo Downs in northeastern South Australia, while Melbourne Observatory, Sydney Observatory, the University of Sydney and the Astronomical Society of New South Wales jointly conducted observations at Goondiwindi in southeastern Queensland.

The 15-foot Cameras.

The Canadian Party's Camera

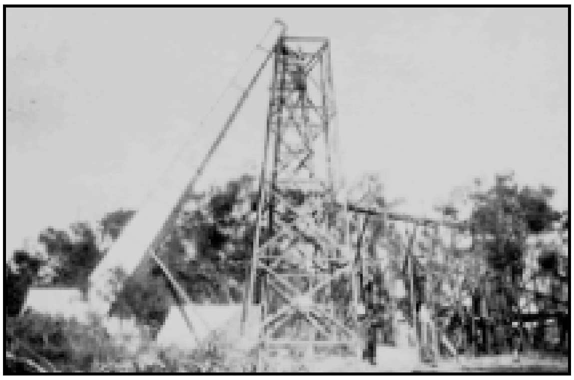
Scientific Equipment

Although the specific objective of the expedition was to measure the deflection of light, the opportunity was naturally taken to make a detailed study of the solar corona. In addition, visual observations of eclipse phenomena, including shadow bands, were made by Ross and others. The observational equipment set up at Wallal included the following instruments for the light deflection and coronal observations:

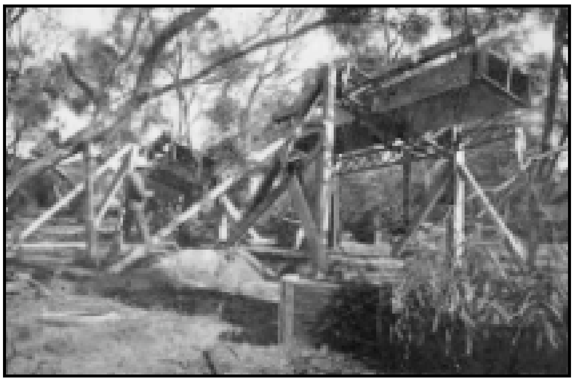
(1) Lick Observatory's twin cameras with apertures of 5 inches and focal lengths of 15 feet - for the light deflection observations;
(2) Lick's twin cameras with apertures of 4 inches and focal lengths of 5 feet - for accurate photography of the Sun's immediate surroundings, in order to assist with the light deflection observations and perhaps to record any unknown objects in the Sun's vicinity;

(3) Lick's Schaeberle camera with aperture of 5 inches and focal length of 40 feet - for large-scale photography of the solar corona;
(4) Several spectrographs - to record the coronal spectrum;
(5) Lick's Floyd camera with a 5-inch aperture and 66-inch focal length - to photograph the corona on a scale corresponding to the spectrographic observations;
(6) Toronto's 11-foot camera - for the light deflection observations;
(7) Perth Observatory's 12-inch reflector and small twin cameras – for coronal photography.

The most spectacular of the cameras was the Schaeberle, which required a forty-foot tower to be built pointing at the position of the eclipsed Sun.



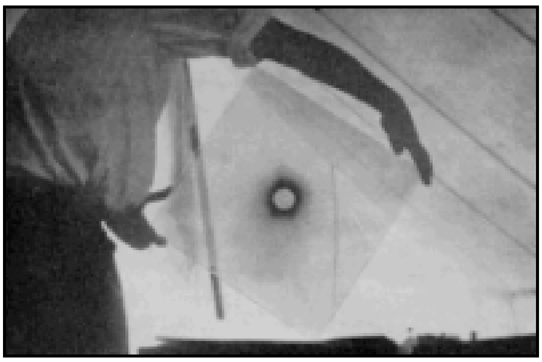
The 40-foot Schaeberle Camera



The 5-foot and 15-foot Cameras

The Lick 5-foot and 15-foot cameras are described in Ross's booklet*. They were built to Campbell's design, with quadruplet lenses and very rigid girder construction, and their frames were covered with rubberised cloth, rendering them light-tight. The polar axis was carried by strong wooden supports erected on cement piers, with the movement regulated by a clock which paid out wire, so allowing a long girder arm to travel slowly down an inclined beam. Each camera pair was fitted with a long guiding telescope to ensure accurate movement during the exposure. The cameras were sheltered in a louvred canvas house to maintain uniform temperature.

The “Einstein” House



Negative Photographic Plate of Eclipse

Ross noted that the quadruplet lenses gave 'wonderful definition' over the 17-inch by 17-inch photographic plates used*. He wrote:

'The focal areas were exceedingly flat. In the case of the 5ft. cameras, the focus did

> not vary by so much as l-20th inch over the plates. In the case of one of the 15ft. cameras, the variation was about l-40th of an inch, and in the case of the other 15ft. camera, it was too small to be detected. As these lenses gave fields of 15 and 5 degrees diameter respectively, the excellence of the workmanship was marvellous.'*

Alignment of the giant cameras took several days, as it was necessary to ensure that the images of the eclipsed Sun would fall as close as possible to the centre of the photographic plates*.

A variety of auxiliary devices provided temperature, pressure, humidity and wind measurements. Of particular importance was accurate time. This was obtained by 'wireless' from Annapolis, Bordeaux and Perth and Adelaide observatories; in addition, regular timing signals were sent from Perth to the Wallal telegraph station.

Observations

The various cameras, spectrographs and telescopes were assembled, erected and tested in readiness for September 21. Photographic plates showing the background stars in the absence of the Sun had been taken at Tahiti. The coordinates of the observation site were determined by the Perth Observatory team to be 19° 46' south latitude and $8^h\ 2^m\ 43^s.7$ (120° 40' 56") east of Greenwich.

Work continued through the previous night, for the photographic plates could be made ready only in darkness. About 10 minutes before totality was due to begin, at approximately 1340 hours Western Australian Standard Time, the plate holders were slipped into position*.

Since the Nautical Almanac had been estimated to be in error by 27-30 seconds, it came as no surprise when totality arrived 16 seconds earlier and ended 20 seconds earlier than the Almanac predictions. Totality lasted 5 minutes, 15.5 seconds*.

A report on Perth Observatory's contribution to the expedition, published by the Western Australian Astronomical Society, recorded that 'The Sun rose on the 21st in a perfectly clear sky. As the day wore on, the temperature increased, reaching a maximum of 93 deg. at 12.15 p.m., just after first contact.' The report further noted that 'As totality approached, the fowls retired to their roosts, and the sheep, horses and cattle came from under the shelter of the trees and commenced to feed, just as they are accustomed to do in the cool of the evening at sunset. The flies, which were very numerous during the whole of our stay at Wallal, were much affected by the changed conditions, and appeared to become quite paralysed, so that one could pick them up as if they were dead.'*

Activities at the observation site before and during the eclipse are well described in Campbell's report*, but perhaps the most interesting description of the visual effects during the eclipse is that given by Ross*, quoted from in the next section. Ross* recorded that the meteorological conditions on the day were 'of the highest excellence'. The temperature fell by about eight degrees Fahrenheit during the eclipse*.

The plates were developed at Wallal and Broome. Preliminary measurements on one of the plates was carried out with a measuring microscope erected in the radio station at Broome.

Ross's remarks* on the magnitude of the effect being looked for are illuminating:

> 'It is to be remembered that even the maximum possible deflection of 1.75 seconds of arc corresponds to a displacement of only l-2000th of an inch on the plates of the 5ft. cameras, or to 3-2000ths of an inch in the case of the 15ft. camera. As the actual measurements had to be carried out on stars at some distance from the Sun's edge, the actual displacements of the observed stars ranged from about half down to less than one-tenth of the above amounts. These figures will illustrate the extraordinary accuracy obtained in the investigations.'

A.D.Ross's Contribution

Alexander David Ross became Foundation Professor of Mathematics and Physics at the University of Western Australia in 1913. With the separation of the two disciplines, he became Foundation Professor of Physics in 1929. He retired in 1952 and died in 1966. An obituary notice appeared in The Australian Physicist*.

Professor Ross was certainly instrumental in convincing the sponsors of the Crocker expedition that Wallal was an accessible location. A.R. Hinks of the Royal Geographical Society, a former astronomer, had been asked by the Astronomer Royal (Sir Frank Dyson) to investigate the geographical conditions of the 1922 eclipse, and had addressed the 1920 March 12 meeting of the Royal Astronomical Society on his findings. His talk, as reported in the issue of The Observatory magazine for the next month*, included the following:

> 'The eclipse track reaches Australia at Ninety-Mile (sic) Beach, a hopeless part of the coast, and strikes into the great desert. There are no facilities for landing. "You can approach within 4 miles of the shore in small boats." The desert is inaccessible, except to camels. There are no railways within hundreds of miles, and motor cars are out of the question. The first place which is feasible is Cunnamulla in South Queensland. ...'

Ross and Thomson published a rebuttal* of Hinks's rejection of Wallal as an observing site, and advance copies of the data were forwarded to leading observatories and standing eclipse committees. Ross corresponded with Campbell, Director of the Lick Observatory (and later President of the University of California), who eventually agreed to come. It seems clear that the Wallal expedition owed its existence to Ross's enthusiastic advocacy.

Ross wrote a booklet and several papers concerning the work carried out at Wallal. A number of extracts from his account* of the eclipse follow.

The first section, entitled General Observations, includes these descriptive comments:

> 'Twenty minutes before totality there was a distinct change in the general illumination of the landscape, the light becoming of a somewhat livid color. The sky had turned a darker blue, ...'
>
> 'Twelve minutes before totality the sky had assumed a yellowish color round the horizon. ...'

> 'Four minutes before totality the light was very striking in its color, objects in the landscape appearing much as if viewed at normal times through yellowish (Fieuzal) sun glasses. Thereafter the light became much more livid, and by two minutes before totality white objects assumed bluish and purplish tints.'
>
> 'About ten second (sic) before totality I took up a position facing southwards, holding a camera to be used in an attempt to photograph the Moon's shadow in the sky. ... About 3.0 or 2.5 seconds before second contact the gradation (of intensity from east to west across the southern sky) was certainly noticeable, and I believe that a snapshot taken then might have recorded it. ...'

As well as more detail on the visual effects, this section includes a note of stars visible (down to third magnitude) at certain times, a note of the times at which Ross closed some spectrographs - he was assisting J.H. Moore* to obtain coronal spectra - and comments on changes in the sea breeze during the eclipse.

The second section, entitled Shadow Bands, begins:

> 'I took up a position beside a horizontal white sheet about 1 minute 15 seconds before totality, and was at once conscious that the phenomenon was present. There was a shimmering effect over the entire sheet, ...'

After a giving a detailed description of the shadow bands, and reporting an unsuccessful attempt to photograph them, this section continues with:

> 'The bands were still visible 20 seconds before totality when I had to leave for other observations. No observations were made by me after totality.'

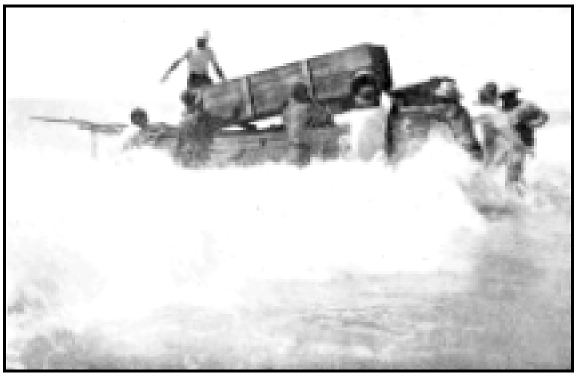
This section then records some quantitative shadow band observations made by P. Kennedy (State Electrical Engineer for the Post Office), J.W. Barker and T. Roberts (both of the Royal Australian Navy). The paper also reports on coronal observations and photographic observations of sky brightness.

Ross does not appear to have been directly involved in the light deflection work, but certainly took a very close interest in it. He wrote both a popular account* of the subject and a technical assessment* of the results.

In addition to producing the papers already referred to, Ross reported to the Australasian Association for the Advancement of Science on the shadow band observations* and on his photographic measurement of the sky brightness during the eclipse*, and later wrote a paper on his photographic study of the intensity of the corona during the eclipse*.

Deflection Results

Results of light deflection observations at eclipses from 1919 to 1952 are conveniently tabulated in Weinberg's book*. He lists five papers from the 1922 eclipse, four of which came from the Wallal expedition. There is one by G.F. Dodwell and C.R. Davidson (1924) on the results from Cordillo Downs, one by C.A. Chant and R.K. Young (1924) and three (two in 1923 and one in 1928) by W.W. Campbell and R. Trumpler. The last of these recorded an analysis of measurements on 145 stars, with radial distances from the solar centre ranging from 2.1 to 42 solar radii. The light deflection, reduced to the solar surface, was deduced to be 1.82 ± 0.20 seconds of arc, consistent with the general relativity prediction of 1.75 seconds.



Return Journey, loading through surf

Epilogue

The 1919 expeditions, particularly Eddington's to Principe, are justly famous, but less is heard about the Wallal expedition. Yet it produced much good data - the product of the specially designed high-quality photographic equipment and the excellent meteorological conditions experienced at the observing site - and the results must have considerably boosted confidence in general relativity.

The intense popular interest generated at the time is evinced by Campbell's tribute*: 'The hospitality extended, the interest shown, and the assistance afforded, were of a standard higher than I have ever observed in any other part of the world on any occasion.'

With the discovery of the quasi-stellar radio source 3C279, which is close enough to the ecliptic to be occulted by the Sun, the initiative in this field passed from the optical astronomers to the radio astronomers. As a result of the much greater angular accuracy available from very-long-baseline interferometry, together with the use of several frequencies to enable refraction by the solar corona to be subtracted, much more precise data was obtained. Far more accurate and convincing verifications of Einstein's prediction followed.

Footnote [by original authors]: We have retained the units used in the original publications. Conversions are as follows; 1 inch = 2.54 cm; 1 foot = 12 inches ≈ 30.5 cm; 1 ton ≈ 1 tonne; 1 mile = 5280 feet ≈ 1.61 km; 93 degrees Fahrenheit is about 34 degrees Celsius; 8 Fahrenheit degrees are about 4.5 Celsius degrees.

* [Reference omitted. For reference details, please refer to the original publication or contact the Presenter of this History series.]

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