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HIGHLIGHTING THE HISTORY OF FRENCH RADIO ASTRONOMY. 2: THE SOLAR ECLIPSE OBSERVATIONS OF 1949-1954

Wayne Orchiston
Centre for Astronomy, James Cook University, Townsville, Queensland 4811, Australia.
E-mail: Wayne.Orchiston@jcu.edu.au

and

Jean-Louis Steinberg
Paris Observatory (Meudon), Place Jules Janssen, F-92 195 Meudon Cedex, France.

Abstract: During the 1940s and early 1950s radio astronomers from a number of nations used observations of total and partial solar eclipses to investigate the positions of radio-emitting regions and to determine the distribution of radio emission across the solar disk. Between 1949 and 1954 French radio astronomers from the Ecole Normale Supérieure and the Institute of Astrophysics between them mounted four successful eclipse expeditions to Africa and northern Europe. This short paper lists the personnel involved, discusses their instrumentation, describes the observations made, and evaluates the significance of these observations in an international context.

Keywords: French solar eclipse expeditions, Ecole Normale Supérieure, Institute of Astrophysics, Paris, Markala, Dakar, Khartoum, Högby, solar corona.

1. INTRODUCTION

In the decade following World War II solar radio astronomy took great strides, as important research was carried out in Australia, England, France, Holland, Japan and Russia (e.g. see Edge and Mulkay, 1976; Orchiston et al., 2006; Strom, 2004; and Sullivan, 1984).

Arguably the most important early solar research conducted by the fledgling French radio astronomers at the Ecole Normale Supérieure (henceforth ENS) and the Institute of Astrophysics (IA) in Paris during the late-1940s and early-1950s was associated with a series of solar eclipses.[1]

At this time the angular resolution of radio telescopes was poor, and observations of total and partial solar eclipses offered a particularly elegant way of pinpointing the positions of localised regions responsible for solar radio emission. The reasoning was that as the Moon's limb moved across the Sun's disk and successively occulted and then unmasked different radio-emitting regions there would be associated dips and rises in the chart record. More than one observing site was desirable in that any dip in the chart record obtained at a single site would simply indicate that the emitting region was located *somewhere* along the arc subtended by the lunar limb *at that particular moment*. In contrast, by using several widely-spaced observing sites the intersections of the different limb profiles allowed the precise positions of the radio-emitting regions to be determined (e.g. see Christiansen et al., 1949a). As an added bonus, from observations of solar eclipses radio astronomers could also determine the distribution of radio brightness across the disk of the Sun and the shape of the corona at radio wavelengths. Dicke and Beringer (1946) were the first to pioneer the use of this technique in radio astronomy when they carried out observations of a partial solar eclipse on 9 July 1945.

Figure 1: Map of localities mentioned in the text (outline map courtesy of www.theodora.com/maps, used with permission).

Figure 2: The 7.5m Wurzburg antenna at Marcoussis used for the solar eclipse observations (courtesy: Observatoire de Paris, Meudon).

French interest in solar eclipses at this time was part of a world-wide phenomenon: other nations that mounted expeditions in the late 1940s and early 1950s to monitor variations in radio emission were Australia, Canada, England, Japan, Russia and the USA (see Hey, 1955 for a full list, and associated references).[2]

This paper focusses on four different solar eclipses that attracted French radio astronomers between 1949 and 1954. Observations were made from France and from different sites in Europe and Africa. For localities mentioned in the text see Figure 1.

Figure 3: The 7.5m Wurzburg antenna at Meudon used for the solar eclipse observations (courtesy: Observatoire de Paris, Meudon).

2. THE DIFFERENT ECLIPSE EXPEDITIONS

2.1 The April 1949 Eclipse

On 28 April 1949 a partial solar eclipse was visible from Paris, with just 26% of the disk masked at mid-eclipse, and this event was observed by staff from the ENS and the IA (see Laffineur et al., 1949, 1950; Steinberg, 1953). Three different radio telescopes and frequencies were used. Steinberg and Zisler from the ENS used an equatorially-mounted 3m dish on the roof of the Physics Laboratory and a 7.5m Wurzburg antenna located at Marcoussis (Figure 2) near Paris, which operated at 1,200 MHz and 158 MHz, respectively, while Laffineur from the IA accessed the 7.5m Wurzburg antenna sited at Meudon Observatory in Paris (Figure 3), which was tuned to a frequency of 555 MHz. All three radio telescopes were equipped with specially-developed low-noise receivers, but this instrumentation "… was better adapted to the study of energetic solar emission [i.e. bursts] rather than precise continuum measurements. " (Laffineur et al., 1949: 1636; our translation). During the eclipse, Hα spectroscopic observations were also made at Meudon Observatory.

Despite the comparatively 'primitive' nature of the equipment, successful eclipse observations were made at all three frequencies, with the solar flux levels reducing by about 50%, 20% and 21% at 158, 555 and 1,200 MHz respectively (Laffineur et al., 1949). However, at 158 MHz fluctuations in the noise levels of ~20% were recorded both before and after the eclipse, so it was impossible to distinguish these variations during the eclipse from those that were associated with the masking and unmasking of features on the solar surface. For this reason, the radio astronomers decided not to subject the Marcoussis data to detailed analysis.

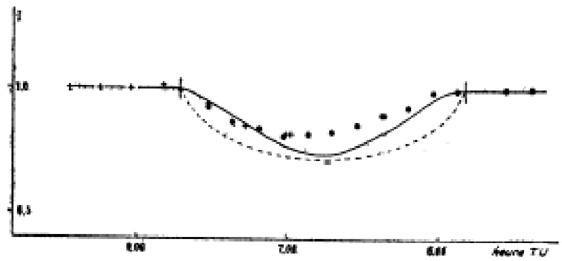

Figure 4: The 28 April 1949 eclipse curve. Dots represent measurements at 555 MHz and crosses at 1,200 MHz. The solid curve indicates the profile expected from a disk of uniform brightness, while the dashed line shows the expected profile if the radio emission derived from an annular ring (after Laffineur et al., 1950: 338).

Instead, Laffineur et al. (1950) published an eclipse curve that combined the results obtained at 555 and 1,200 MHz, and this is reproduced here in Figure 4. While several small sunspots were present at the time of the eclipse and were masked and unmasked by the lunar limb, the eclipse curve is far too crude to reveal any obvious variations in flux density levels; however, Laffineur et al (ibid.) did not note any such deviations during the eclipse observations.

Michard, from the IA, was responsible for the analysis of the eclipse curve, and this proved illuminating. He noted that the start and end times of the radio event did not differ markedly from those of the optical eclipse, suggesting that the radio Sun at these two frequencies was not appreciably larger than its optical counterpart. We now know this finding to be anomalous, and it would soon be challenged by subsequent French eclipse expeditions.

Meanwhile the shape of the Paris eclipse curve also was "… incompatible with the hypothesis of a [radio] Sun of uniform brightness." (Laffineur et al, 1950: 339; our translation) or an annular disk of uniform brightness. Rather the eclipse curve suggested that "It is necessary to suppose that at least a part of the solar radio emission derived from non-uniform sources distributed over the Solar disk." (ibid.). As we have noted, Michard was not able to associate this with the distribution of sunspots, so he proceeded to consider chromospheric plages, as observed in Hα with a spectroheliograph at Meudon. Upon reviewing the relative areas and intensities of the various plages present at the time of the 1949 eclipse, Servajean was able to generate a 'plage eclipse curve', and this was found to provide a better—but by no means precise—fit to the radio eclipse curve, as shown in Figure 5. It was noted that this finding matched that of the Soviet radio astronomers, Haikin and Chikhachev, when they observed the 20 May 1947 solar eclipse. Michard found that the 1949 eclipse demonstrated that "… an important fraction of the solar emission at decimetre wavelengths is generated by chromospheric plages. Note however that this conclusion rests on features that are at the very limits of possible detection ..." (Laffineur et al, 1950: 341; our translation). The authors concluded their paper by cautioning that the interpretation of radio data from relatively small-phase partial solar eclipses like the Paris one raises notable difficulties, so any results should be viewed as interesting, but no more than provisional. These would prove to be prophetic words.

2.2 The September 1951 Eclipse

In 1951 radio astronomers from the ENS observed an annular solar eclipse from a remote site in Africa (Arsac et al., 1953; Blum et al, 1952a, 1952b; Bosson et al., 1951; Denisse et al., 1952). The previous year Denisse had received a 1951 astronomical ephemeris which listed an annular solar eclipse on 1 September 1951, with the zone of totality extending from the Canary Islands to Madagascar and traversing the African continent. Along the path of totality was the small town of Markala, on the Niger River in French Sudan, 1,500km to the east of Dakar (see Figure 1). From a scientific viewpoint this was an ideal observing site: nearby there was a dam with locks, so the town was an industrial centre and included a metal-working shop.

A successful funding application[3] was made to the Bureau de Longitudes, but additional funds were required so Y. Rocard (Director of the Physics Laboratory at the ENS) proceeded to obtain Naval support. As a result, 6 tons of equipment were transferred by the Navy to Dakar, and then taken by train and truck to Markala. Meanwhile, the eclipse team of Blum, Denisse, Le Roux and Steinberg, plus two Naval personnel, flew directly from Paris to Dakar, and then transferred to Markala by train and road.[4]

The instruments used at Markala to observe this eclipse were an equatorially-mounted 1.5m diameter searchlight mirror attached to a 9,350 MHz receiver (Figure 6) and a 169 MHz ex-US radar antenna (Figure 7). Blum et al (1952a: 186; our translation) provide a useful description of the latter instrument: "… This equatorially-mounted antenna comprises an array of 16 half-wave dipoles placed in front of two flat reflectors: the support comprises the main component of a suitably inclined old American SCR 268 radar. The antenna has a half-power beamwidth of 9º in declination and 25º in right ascension. This low directivity allows for a manual pointing of the antenna."

While both antennas were purchased from the US Army after the War,[5] the radio telescopes of which they formed a part were totally new instruments that were developed for this eclipse expedition; they were not existing instruments that were used in Paris or at Marcoussis for regular solar monitoring at this time.

Markala was just north of the central line of totality, and on 1 September 1951 the eclipse lasted from 11h 20m to 14h 39m UT. At mid-eclipse, 97.5% of the solar disk was masked by the Moon.

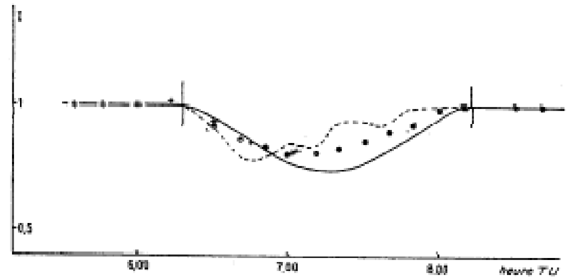

Figure 5: The 28 April 1949 eclipse curve and the expected profile if the emission was directly associated with Hα plages (the dashed line) (after Laffineur et al., 1950: 340).

The primary aim of the radio observations was to "… obtain eclipse curves of the solar emission at 169 MHz (1.78 m wavelength) and at 9 350 MHz (3.20 cm wavelength) and then to deduce the brightness distribution of solar emission at these wavelengths as well as the positions and strengths of possible more-or-less localised sources of emission." (Blum et al., 1952a: 184; our translation). There was also an added interest: "… to compare the total measurements made by Hagan, Haddock and Reber in 1950 with annular eclipse observations … [as] such a comparison may prove to be interesting for limb-brightening studies." Denisse et al., 1952: 191).

Figure 6: Setting up the Markala 'searchlight antenna' (courtesy: Observatoire de Paris, Meudon).

Thanks to excellent meteorological conditions and an absence of solar burst activity[6] at the time (Bosson et al., 1951), successful observations of the eclipse were made at Markala, but instrumentation problems meant that some of the observations at 9,350 MHz made after the mid-phase of the eclipse could not be used in the subsequent analysis. The resulting eclipse curves are reproduced in Figures 8 and 9. Denisse et al. (1952: 192) note that the 169 MHz result eclipse curve "… is the first published on a metre wave-length in a period of solar radio quietness."

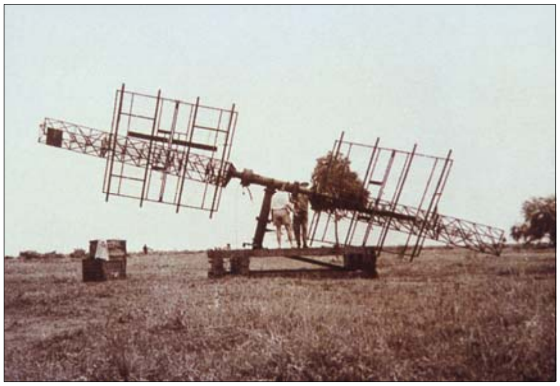

Figure 7: The Markala 169 MHz radar antenna (courtesy: Observatoire de Paris, Meudon – Archives de Nançay).

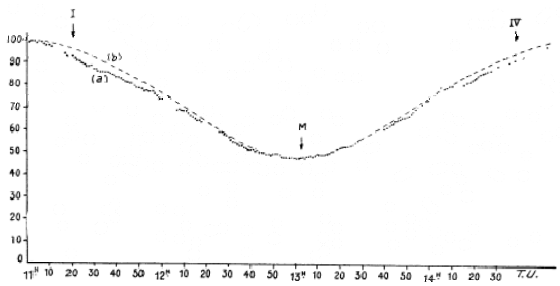

Figure 8: The 1 September 1951 169 MHz eclipse curve (a), and the profile expected for a uniformly bright disk of 1.35 solar radii. The ordinate shows relative intensity of the emission and abscissa Universal Time (after Blum et al., 1952a: 190).

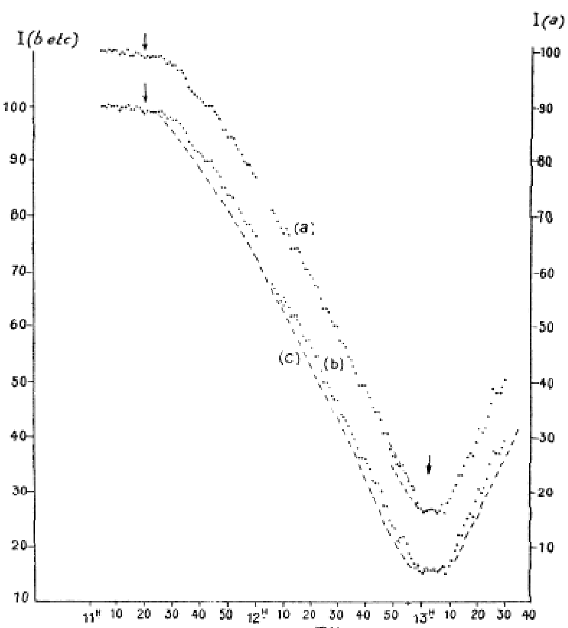

Figure 9: The 1 September 1951 9,350 MHz eclipse curves. (a) shows the uncorrected curve, and (b) after correction for the presence of sunspots. The dashed curve, (c), is the profile expected for a uniformly bright disk of 1.07 solar radii. The ordinate shows relative intensity of the emission and abscissa Universal Time (after Blum et al., 1952a: 190).

Optical observations made at the L'Observatoire du Schauinsland and at the U.S. Naval Observatory at the time of the eclipse revealed the existence of two small groups of sunspots on the solar disk, near the eastern limb (see Figure 8 in Blum et al., 1952a: 193). Interestingly, the 169 MHz eclipse curve shows a slight decrease in emission at about the time these two spots would have been covered by the lunar limb. Blum et al. (1952a) explain this fluctuation and others in the eclipse curve as due to receiver noise or interference, but measurements made at 169 MHz between 10 and 12 hrs UT on September 1-3 (inclusive) indicated that the intrinsic level of solar emission did not vary by >1% (Blum et al., 1952a: 191). This implies that some of the fluctuations that exceed 2% in the Figure 8 eclipse curve may be genuine and not artifacts, and could have been associated with radio-emitting regions that had no photospheric correlates at the time. In this context it is interesting to note that when they observed the 1 November 1948 partial solar eclipse, Australian radio astronomers found several localised sources of 600 MHz emission that had no optical counterparts but were associated with sites that had featured sunspot activity on the previous solar rotation.

The 9,350 MHz (b) eclipse curve was also interpreted in the light of the two small sunspot groups, with Blum et al. concluding that

> The decrease of 3% in the signal, which coincides with the occultation of the group of sunspots in question corresponds rather well to the preceding estimations [provided to the authors by J. Pawsey and F. Haddock].
>
> One can state that this occultation [of the sunspots] was very rapid and occurred in the short time of just one minute (from 12 h 58 to 12 h 59); this corresponded to the position of the Moon on the solar disk indicated in Figure 5, during which sunspot B was being occulted.
>
> While more important the occultation of sunspot A did not lead to any decrease in [radio] intensity. (Blum et al., 1952a: 192-193; our translation).

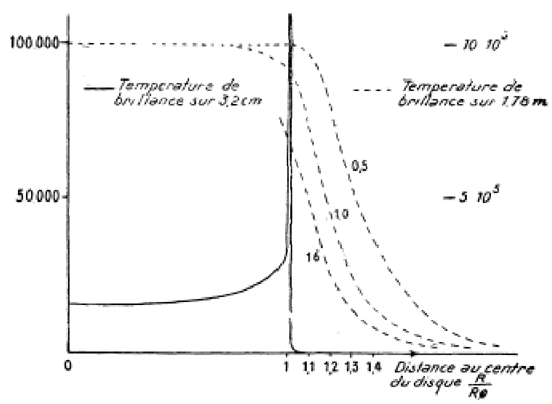

Figure 10: Calculated solar brightness temperature curves for 169 MHz (1.78m) and 9,350 MHz (3.2 cm) based on the eclipse curves in Figures 8 and 9 (after Blum et al., 1952a: 195).

The eclipse curves in Figures 8 and 9 were also used to investigate the distribution of radio brightness across the solar disk and the areal extent of the radio corona. At 169 MHz the radio event began 16 minutes before the first optical contact and ended well after the latter, confirming that emission at this frequency derives from the solar corona. From the deviation between curves (a) and (b) in Figure 8, Blum et al. (1952a) were able to demonstrate that the radio Sun exhibited significant limb-brightening at this wavelength (see Figure 10). This was a significant result (see Bosson et al., 1951), and built on D.F. Martyn's important paper of 1948.

When it comes to interpreting the 169 MHz eclipse curve, the distribution of radio brightness depends on the temperature of the corona, hence the three different values (1.6, 1.0 and 0.5 million degrees) represented in Figure 10.[7] The 169 MHz results showed the radio Sun at this frequency to be asymmetrical and in the form of a flattened ellipsoid with a radio diameter 1.4 times the equatorial diameter of the optical Sun (Bosson et al., 1951). To elaborate:

> An approximate model which takes account of our observations is indicated in Figure 8 [Figure 12, here]. It is evident that our observational curve does not allow us to be specific about the detailed distribution of the radiation: the proposed model only aims to bring out the most significant features of the asymmetry that are likely to represent the true distribution. (Blum et al., 1952a: 196; our translation).

As Blum et al. (1952a: 197) note in their concluding remarks, this is an entirely new result which alone justified this study.

2.3 The February 1952 Eclipse

On 25 February 1952 a solar eclipse was visible in Africa and Europe, and this was observed by ENS radio astronomers from Onsala, Paris, Bizerte and Dakar (Arsac et al., 1953; Blum, pers. comm., 2007; Blum et al., 1952b; Denisse et al., 1952), and by an IA team from Khartoum and Paris (Laffineur et al., 1952; Laffineur et al., 1954). The eclipse was seen as total in Khartoum, and was partial in Onsala, Paris, Bizerte and Dakar.

The equipment used at Dakar (French West Africa, see Figure 1) comprised the same 169 MHz radio telescope that was based at Markala the previous year (Denisse et al., 1952), while identical 169 MHz antennas were set up at Marcoussis (Blum et al., 1952b), and at Bizerte in Tunisia. Meanwhile, an ex-WWII Wurzburg antenna was used at Onsala in Sweden (Blum, pers. comm., 2007).

Successful observations were made from all of these sites, and the resulting eclipse curves for Dakar and Paris are shown in Figure 11 (along with the 1951 169 MHz curve, for comparison). These 1952 results wholly confirmed the initial 1951 finding that at 169 MHz the radio Sun was an asymmetrical flattened ellipsoid (Figure 12). To elaborate, this figure shows that coronal emission from the equatorial regions was relatively more important than emission from the polar regions (Blum et al., 1952b) and

> … at the time of optical contacts, a decrease of 0-1 per cent was observed in Paris in 1952, 8.5 per cent in Markala in 1951 and 12-13 per cent in Dakar in 1952 … [Figure 12 presents] A tentative model of the radio-sun observed on a wavelength of 1.78 m … (Denisse et al., 1952: 192).

In his review of early radio eclipse observations, Hey (1955: 529) regards these combined 1951-1952 eclipse results as important, adding that: "Optical data have previously shown that the coronal density may be expected to vary with heliographic latitude, but the radio eclipse observations offer a useful means of studying the coronal distribution and its departure from spherical symmetry."

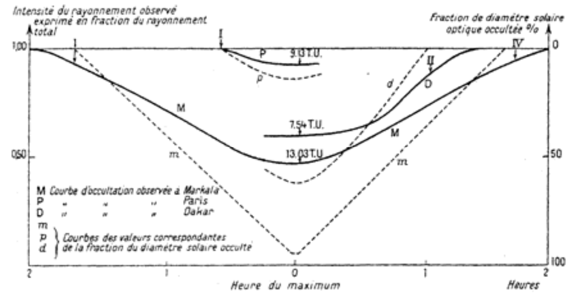

Figure 11: The 25 February 1952 169 MHz Paris (P) and Dakar (D) eclipse curves, plus the 169 MHz Markala curve (M) obtained in 1951 (after Blum et al., 1952b: 1597).

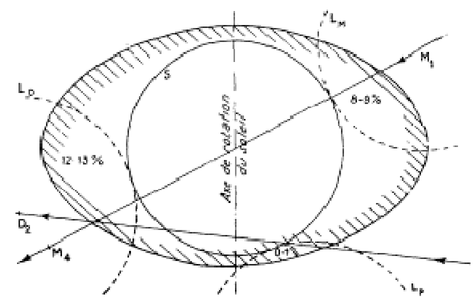

Figure 12: Form of the radio Sun at 169 MHz, based on a combination of the 1951 and 1952 solar eclipse curves (after Blum et al., 1952b: 1598).

In contrast to the modest Dakar exercise, the French mission to Khartoum under Laffineur's direction was a grand affair, and was liberally funded by the Bureau of Longitudes. The expedition involved optical and radio astronomy, and had three primary objectives: (1) to record solar radio emission at 255 and 555 MHz during the eclipse; (2) to photograph the solar corona at 5,303 Å and 6,374 Å with a Lyot coronograph; and (3) to carry out photometric, polarimetric and spectroscopic observations of the corona (see Laffineur, Michard, Pecker, Dollfus, Vauquois and d'Azambuja, 1954).

Figure 13: The 6m radio telescope at the Khartoum observing station (courtesy Dr A. Dollfus).

The radio observations at Khartoum (see Figure 1) were conducted by Laffineur, with occasional assistance from Michard and Pecker. The radio telescope used was a 6m diameter equatorially-mounted parabola (Figure 13) with twin dipoles for simultaneous operation at 255 and 550 MHz.

The eclipse was successfully observed, and at mid-eclipse the intensity of emission from that part of the corona not masked by the Moon's disk was 30.5 ± 1% of the total emission received from the non-eclipsed Sun at 255 MHz and 19.5 ± 1% of that normally received at 550 MHz (Laffineur et al., 1952). The derived eclipse curves are reproduced in Figure 14. Observations of coronal intensity at 5,303 Å were made at the time (see Figure 15), and when Laffineur et al. incorporated these into their analysis, the theoretical eclipse curve and the actual values obtained at 550 MHz were in remarkable conformity, as shown in Figure 16. Similar corrections for variations in coronal intensity were incorporated into the analysis of the 255 MHz data, and again there was an excellent correspondence between the observed eclipse curve and the theoretical curve (see Figure 17).

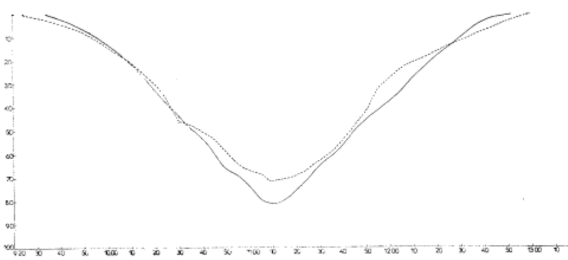

Figure 14: The 25 February 1952 Khartoum 255 MHz (dotted line) and 555 MHz (solid line) eclipse curves (after Laffineur, Michard, Pecker and Vauquois, 1954: 362).

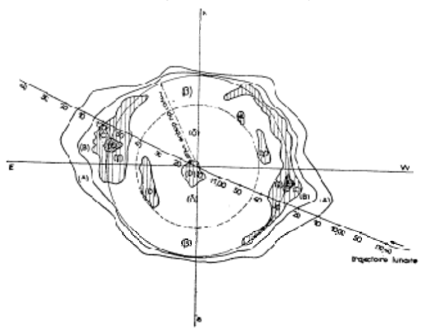

Figure 15: Isophotes of coronal intensity at 5,303Å derived from observations made at Pic du Midi and at Khartoum (after Laffineur, Michard, Pecker and Vauquois, 1954: 366).

While the Khartoum observations were in progress, parallel observations at 255 MHz were made with the 7.5m Wurzburg antenna at Meudon. The radio astronomers noted that "At the maximum of the partial eclipse at radio wavelengths, 13 minutes after the optical event, the remaining radio emission was 83% that recorded when the Sun was not in eclipse." (Laffineur et al., 1952: 1529; our translation).

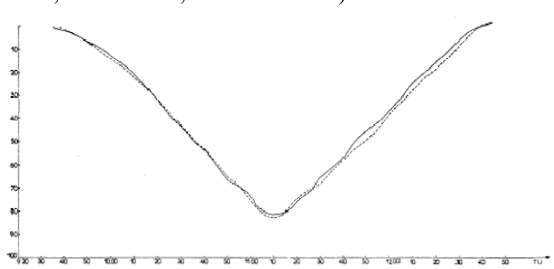

Figure 16: The 25 February 1952 555 MHz eclipse curve (solid line) and the theoretical curve (dotted line) corrected for localised variations in coronal intensity (after Laffineur, Michard, Pecker and Vauquois, 1954: 369).

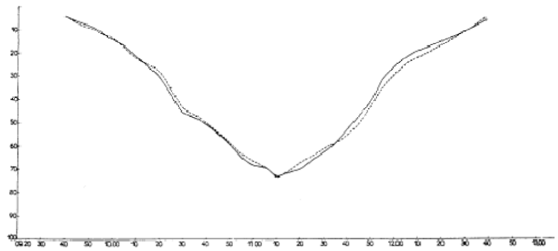

Figure 17: The 25 February 1952 255 MHz eclipse curve (solid line) and the theoretical curve (dotted line) corrected for localised variations in coronal intensity (after Laffineur, Michard, Pecker and Vauquois, 1954: 373).

2.4 The June 1954 Eclipse

On 30 June 1954 Laffineur's group from the IA in Paris observed a solar eclipse from Meudon (Paris) and Högby in Sweden (Laffineur, 1957; Laffineur et al., 1954). This eclipse was seen as total in Sweden and was partial in Paris. The Bureau of Longitudes once again provided funding for the overseas expedition.

The observing site at Högby (see Figure 1) was situated 8 km north of the line of totality, and the 6 m diameter radio telescope that had been used at Khartoum in 1952 was set up there. It again operated at 545 MHz, but a new equatorial mounting was required given the very different latitude of the observing site. The observers at Högby were Laffineur, Coupiac and Vauquois. Meanwhile parallel observations by Begot and Christiansen were carried out at Meudon with the 7.5 m Wurzburg antenna, which operated at both 255 MHz and 545 MHz (Coupiac et al., 1955).

The corrected 545 MHz eclipse curve obtained at Högby is reproduced here in Figure 18, and Laffineur et al. note that it

> … presents fewer deviations than that observed two years previously; this is easily explained by the fact that the 30 June 1954 eclipse was associated with fewer active chromospheric and coronal regions than in 1952. It is remarkable to note that at the moment of totality the residual radiation was at 11% compared to 19.5% in 1952. (Laffineur et al., 1954: 1590; our translation).

Similar eclipse curves for 255 MHz and 545 MHz were obtained at Meudon (see Coupiac et al., 1955: 277), but no attempt was made to interpret any of these curves in terms of localised radio-emitting regions or the shape and size of the radio corona at 545 MHz.

3. DISCUSSION

By the time the 1949 eclipse occurred, four earlier solar eclipses had been observed at radio wavelengths (see Hey, 1955: 526-527), so the French radio astronomers were not the first to use partial or total solar eclipses as a means of investigating coronal physics. Yet despite the preliminary nature of their 1949 results, Steinberg (1953: 281; our translation) was proud to record: "To our knowledge, this is the first time that a partial eclipse of the Sun has been observed so intensively by means of radio astronomical techniques." Because of the notorious 'tyranny of distance' he was clearly unaware—at this time—of the 1 November 1948 eclipse, which was observed by five different teams of Australian radio astronomers from three quite separate geographically-spaced sites, and at three different frequences (see Christiansen et al., 1949a, 1949b; Minnett and Labrum, 1950; Piddington and Hindman, 1949).

Having said this, the French radio astronomers were the first to derive the form and areal extent of the radio corona at 169 MHz, when they analysed the 1951 and 1952 eclipses, while the way in which Laffineur accommodated variations in coronal intensity at 5,303 Å when deriving the expected eclipse curve at 555 MHz in 1952 was a particularly elegant piece of research.

One of the remarkable features of the 1949 eclipse was that it brought together radio astronomers from the Ecole Normale Supérieure and the Institute of Astrophysics, and even resulted in two joint publications. In general, there was a distinct element of rivalry between members of these two groups, so the eclipse collaboration was a notable anomaly. The fact that the event was visible from Paris and that neither institution decided to mount an expedition to attempt observations from the line of totality was an obvious factor, and it is telling that Laffineur and Steinberg mounted quite separate African expeditions in order to observe the 1952 eclipse (although the ENS initiative devolved quite naturally out of the 1951 eclipse program). The Bureau of Longitudes was instrumental in funding the Steinberg and Laffineur expeditions in 1951 and 1952 respectively, and it is interesting that no pressure was applied by this body, or the Academy of Science, to encourage collaborative expeditions on these occasions. Such scientific 'arm-twisting' was not unknown in other countries when the research potential of a particular major scientific investigation was obvious.

4. CONCLUDING REMARKS

Between 1949 and 1954 French radio astronomers from the Ecole Normale Supérieure and the Institute of Astrophysics in Paris observed four different solar eclipses. The 28 April 1949 partial eclipse was observed in Paris by a combined team from both institutes, and chromospheric plages were invoked to interpret the observed eclipse curve at 555 and 1,200 MHz. On 1 September 1951 a partial solar eclipse was observed from a site on the Niger River in Africa by an ENS team, and they were able to demonstrate that the radio corona at 169 MHz took the form of a flattened ellipsoid (that mirrored the shape of the optical corona at this time). Separate teams from the ENS and the IA observed the 25 February 1952 eclipse from Sweden and Paris and three different sites on the African continent, and on this occasion the ENS team was able to confirm the previously-reported elliptical nature of the radio corona, while Laffineur's group found that coronal irregularities went a considerable way towards explaining the nature of the eclipse curves obtained at 255 and 550 MHz. The final eclipse in this series observed by French radio astronomers was visible on 30 June 1954 and was monitored from Högby (Sweden) and Paris by Laffineur's group from the IA. While eclipse curves were obtained at both 255 and 545 MHz, no attempts were made to analyse these, and this marked the end of French interest in the radio properties of solar eclipses.

Radio astronomers at the ENS then went on to develop a range of different instruments that allowed them to investigate solar emission at various wavelength outside of eclipse, while those in the much smaller IA team threw their energies into constructing the Saint Michel Interferometer which was designed for Galactic and extragalactic research. These initiatives marked the launch of a campaign by French radio astronomers to develop sophisticated instrumentation dedicated to specific research programs and outputs (see Denisse, 1984). Gone were the days when surplus WWII equipment (as was used at Markala and Dakar) or small simple antennas (as employed at Khartoum and Högby) would suffice. French radio astronomy had entered a new era.

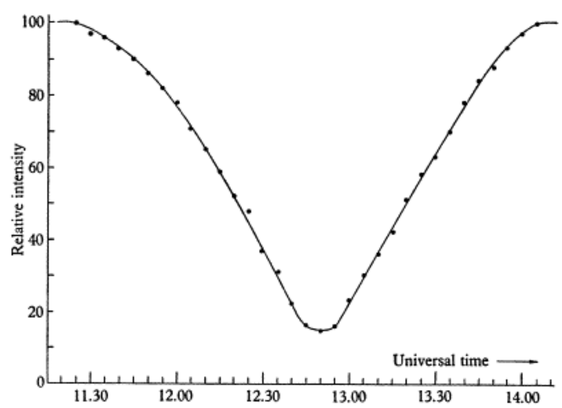

Figure 18: The 30 June 1954 545 MHz eclipse curve from Högby (after Laffineur, 1957: 304).

5. NOTES

1. This is the second in a series of papers documenting developments in early French radio astronomy. The first paper dealt with Nordmann's unsuccessful attempt to detect solar radio emission in 1901 (see Débarbat. Lequeux, and Orchiston, 2007).
2. Recently, the Australian observations were reviewed by Orchiston (2004) and Orchiston, Slee and Burman (2006), and a poster paper about the French *and* Australian eclipse programs was presented at the January 2007 meeting of the American Astronomical Society in Seattle (see Orchiston, Lequeux, Pick, Slee and Steinberg, 2007).
3. The Bureau of Longitudes provided a grant of 300,000 francs (Arsac et al., 1953).
4. Two other ENS staff members (Arsac and Lestel) and two navy personnel (Bosson and Seligman) were involved in building and testing the scientific equipment destined for the expedition.
5. These searchlight mirrors were particularly plentiful after the War, and were readily available.
6. Solar burst activity was most pronounced at frequencies below 200 MHz, but was rarely an issue at 9,350 MHz where the daily incidence of solar emission closely mirrored variations in sunspot area (e.g. see Minnett and Labrum, 1950: 65).
7. In 1946, Martyn and Pawsey published adjoining theoretical and observational papers in *Nature* establishing a coronal temperature of ~10^6 degrees at 200 MHz.

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Dr Wayne Orchiston is a Senior Lecturer in Astronomy at James Cook University, Townsville, Australia. His main research interests relate to Cook voyage, Australian and New Zealand astronomical history, with emphasis on the history of

radio astronomy, comets, historically-significant telescopes, early astronomical groups and societies, and transits of Venus. He has published extensively, and has edited the book *The New Astronomy. Opening the Electromagnetic Window and Expanding our View of Planet Earth* (2005). He also has a book on early Australian radio astronomy, co-authored by Woody Sullivan and Jessica Chapman, which will be published by Springer in 2007. He is the Chair of the IAU Working Group on Historic Radio Astronomy.

Dr Jean-Louis Steinberg joined the underground French Communist Party in June 1941 (at the age of 19), in order to resist the German occupiers and their French collaborators. In June 1944 he was arrested with three other members of his family under the German and French 'racist' laws. They were all sent to Auschwitz where they were so beaten, overworked and starved that three of them died; only Jean-Louis survived, thanks largely to help from the underground anti-fascist network in the camp.

Back in France after the War, Jean-Louis began working in radio astronomy with J-F. Denisse and E-J. Blum at the Ecole Normale Supérieure. He concentrated on technology and observations in the microwave range, while Blum focussed on metre waves and Denisse on plasma physics. In 1951 they observed a solar eclipse from Africa at cm and meter wavelengths. On his return from the 1952 URSI Congress in Sydney, Steinberg began developing the Nançay radio astronomy field station, building teams and, with them, designing and using microwave equipment and a variable baseline interferometer. In 1960 he and J. Lequeux wrote a book on radio astronomy, which was subsequently translated into English and Russian. From 1960 through to 1965, he and M. Parise led the design and construction in Nançay of the large radio telescope for dm waves, with a collecting area of 7,000 square metres. In 1962 he was appointed Editor-in-Chief of the French journal, *Annales d'Astrophysique*, which he and his wife ran until 1969. He then showed that this journal had very little audience, and convinced the authorities and his own colleagues to start the European journal, *Astronomy and Astrophysics*. For the first five years he was one of the two Editors-in-Chief. From three volumes a year, this journal has grown into a weekly. In 1965, following Denisse's suggestion, Steinberg began developing space research at Meudon Observatory. The founding group comprised just two individuals, but the laboratory now has 250 technicians, engineers and researchers and has successfully flown experiments on many projects (either French, or in collaboration with NASA or the Soviet Union). Jean-Louis has authored or co-authored about 80 scientific publications, and has received several scientific prizes and awards. Together with Damiel Périer, he has also written a book about his life and that of his family titled *Des Quatre, Un Seul est Rentré* (or, *Out of Four, only One Returned*).