NRAO ONLINE 22

Ionospheric Research by Pawsey: 1947- 1954

A: Thermal Radiation from the Ionosphere, 1947-1953

In 1947, Pawsey began working on a problem concerning the ionosphere that may well have originated during his years at the Cavendish during 1930: what is the temperature of the various layers of the ionosphere, D, D and F? In both 1947 and 1949 he initiated experiments at RP to answer this question. In 1947 there were "instrumental difficulties". Then in 1949, "we made some false starts being tricked by not identifying man-made noise [which masked the weaker steady thermal emission from the ionosphere]". The main problem was (as Pawsey explained to Appleton): "Natural noise carries no label to distinguish it. I believe that a bit more experience may be helpful."

From August 1949 through June 1950, Pawsey, Gardner and McCready observed at two sites in a mountain gorge (450m, 65 km SW of Sydney) at Burrgorang Valley and on nine days in June 1950 at Rankins Springs (450 km W of Sydney). The observations were passive with no transmission at a number of medium wave frequencies near 2 MHz or 150 m. Both sites were well protected from local electrical interference such as motor cars, home generators and industrial plants.

The point was to observe during the daytime when the low ionosphere insured that atmospherics from distant thunderstorms were not observed. Pawsey, McCready and Gardner wrote in 1951, "Ionospheric Thermal Radiation at Radio Frequencies" in the *Journal of Terrestrial and Terrestrial Physics* (1951, vol 1, p 261). At Burragorang Valley the minimum noise level during the day was at low level with a value only slightly higher than the Rankins Springs values. Gardner and Pawsey (1953)[1]:

> [This excess at Burragorang Valley] is believed due to noise from electrical machinery in Sydney transmitted via the ionosphere. The noise level increases greatly towards night as the improved propagation brings in distant atmospherics and other noise. During the day atmospherics were seldom troublesome.

The idealised noise record over a whole day is shown in Fig 1 (their Fig 4, see Fig. 25.1 in the main book). Note that the scale is logarithmic.

Pawsey et al (1951) explained their rationale:

[1] Gardner, F. F., and Pawsey, J. L. (1953). "Study of the ionospheric D-region using partial reflections." *Journal of Atmospheric and Terrestrial Physics* 3, no. 6: 321-344.

At night the better propagation permits reception of atmospherics from a vast area. But, even so, the effects of individual atmospherics are obvious; the number is still not great enough to make the resultant average out to a uniform intensity. By day, propagation is much worse and the area of reception of atmospherics is correspondingly reduced. Hence the number of atmospherics should be smaller, and the degree of smoothing even less. Noise which shows an absence of impulsive disturbances can therefore not be due to atmospherics. Similarly, the fluctuating base-level at night may be evidence of ionospheric fading effects on noise (atmospherics and other) transmitted from a distance. Similar fluctuations by day appear to be evidence of reception of noise propagated from a distance, and the absence of fluctuations, when observed, suggests that on these occasions interference propagated via the ionosphere is not a main factor.

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An alternative argument for the rejection of atmospherics as the origin of the base-level may be derived from the well-known inaudibility by day of distant broadcasting stations which are readily audible at night. This may be interpreted as showing that the reduction of strength of stations is greater than that of noise. The primary factor in this reduction of both is the increase of ionospheric attenuation by day, a factor which, at a frequency of about 2 MHz, increases as the distance is increased. It follows that the day-time background of noise must originate at distances smaller than the stations concerned. This is consistent with an origin in thermal radiation in the ionosphere which is not subject to such attenuation, but it is most improbable that a steady background should result from atmospherics from within a small radius of say, 500 or 1000 km.

Thus, it was clear that the base-level was not due to man-made or atmospherics. There was a parallel with the base level of the steady emission of the corona as explained in Chapter 14.

The observations have shown that the *natural* noise level observed on an aerial at frequencies in the vicinity of 2 Mc/sec during the hours around noon frequently falls to an intensity corresponding to an equivalent aerial temperature between 200 and 300° K. It is not observed to fall below this, and at the times when this low level is observed the characteristics appear similar to those of thermal noise.

Further, there are reasons for believing that this level cannot be accounted for in terms of the integrated effects of great numbers of atmospherics. These facts are strong evidence for the hypothesis that there is a background source of random noise of this

> intensity. This background source is identified with thermal radiation from the ionosphere because, as will be shown, the measured intensity agrees, within the limits of the data, with that derived from other sources. This radiation, from a microscopic viewpoint, arises from the acceleration of [electrons due to] collisions [in the plasma].

The measured temperatures of 240 K to 290 K in the D layer at heights of 70-80 km were found to be in agreement with other observations.

B: D layer Investigations - Low Levels of the Ionosphere, 1951-1953

The next phase of ionospheric research by the RP group was motivated by a deficiency in the determination of the temperature of the D layers; the temperatures were satisfactory but the determination of the "height to which they referred, a knowledge of the electron distribution with height was required" (Gardner and Pawsey, 1953). The D region is the layer of the ionosphere that is chiefly responsible for medium (0.5 to about 2 MHz) and shortwave attenuation (about 2 to 30 MHz). The publication appeared in 1953: "Study of the Ionospheric D-region using Partial Relections" by Frank Gardner and J.L.Pawsey in *Journal of Atmospheric and Terrestrial Physics,* vol 3, p 321.

In early March 1951, Pawsey went with his family to Burragorang Valley (65 km SW of Sydney), a deep valley (450 metres) that would later become Burragorang Lake as it was dammed by the Warragamba Dam, completed in 1960. For the first time the 2.28 MHz pulse echo system was used to investigate the structure of the D region. A normal pulse echo method was employed (ionosonde, now also chirpsounder) with transmitter and receiver separated by 20 or 30 km from the transmitter (provided by George Munro of the Radio Research Board); the transmitter had a peak power of 1 kilowatt with a pulse length of 30 microseconds (9 km). There were six observing campaigns from 2 March 1951 to 12 May 1952.

The key aspect of the new echo (radar) observations was that for the last session in 1952 circular polarisation was used: right hand for the ordinary ray in the ionosphere and left hand for the extraordinary ray, the two magneto-ionic components of the echoes. "At a given time the ratio of the two is a function of height alone. This is explained in terms of the differences in partial reflection coefficients at the place of reflection together with differential absorption [in the D layer]." From the ratio of the extraordinary to ordinary return ratios, it was possible to derive the differential attenuation and thus electron density (using a standard ionospheric model). The data for 12 May 1952 showed a dramatic change in the extraordinary to ordinary ratio from 2.5 at 65 km (in the D layer) to 0.2 at 85 km. The density profile (electrons per cubic cm) is shown in Fig.2. The precipitous rise from 100 cm^{-3} to 1000 cm^{-3} from 70 to 85 km is clear.

The additional new results from these series of observations over the full 14- month span was the geometry of the D region, overlaid by the major E layer of higher density. Two distinct (see Fig.3; see Fig. 25-2 in the main book) regions were apparent: a region at about 70 km where distinct strata form by day and a second more prominent region of higher electron density at about 90 km which extended up to the E layer at 110 km.

Within a few days (7 March 1951)[2], Pawsey wrote an enthusiastic letter to Fred White, CEO of CSIRO in Melbourne and a well-known ionomer (to use the Ron Bracewell term for practitioners of ionospheric research) describing the first data with the ionosonde at Burragorong from Sunday, 4 March 1951. The fact that the noise levels at this site were so low (the key to the success of the research of 1949-1950) was decisive. "[The noise levels are] several orders of magnitude lower than most observers [at other sites] had recorded. This is due to its being remote from electrical machinery. We have often wondered what could be seen of ionospheric echoes using the high sensitivity which such low noise-levels permit. The answer is a glorious conglomeration extending down to 70 km or a little lower [in the D layer of the ionosphere.]

Pawsey had drawn a sketch of the ionogram produced at noon 4 March 1951. The figure shown in Fig 4 (see Fig. 25.3 in the main book) is quite similar to his Fig 3. Pawsey was enthusiastic as he explained to White (a fellow ionomer, the word invented by Bracewell for ionospheric scientists) in a letter from 7 March 1951: "The interpretation of the D-region echoes may be quite a difficult question. The thing that is pretty evident is that there is a lot of information just waiting to be picked up by anyone who takes systematic records over a reasonable period at such high sensitivity." Pawsey ended his first impressions of the new system with a prescient statement of the scientific method that he espoused: "And then a lot of new observational material has a habit of stimulating the associated theory."

C: Pawsey's Concerns for Geoffrey Builder's (1906-1960) Ionospheric Research at the University of Sydney- July 1953

On 23 July 1953, Pawsey wrote Appleton on a variety of topics; the emphasis was on the D layer research carried out by Gardner and Pawsey. One of the topics was the role of Geoffrey Builder at the Sydney University School of Physics; earlier he had been a graduate student of Appleton's at Kings College University of London with a PhD in 1933. Later, he designed the apparatus for the British ionospheric expedition to Norway during the International Polar Year in 1932-1933, led by Appleton. After working for the Radio Research Board in Sydney and AWA during WWII, he joined the School of Physics in 1947, becoming a Senior Lecturer in 1950. After

[2] NAA C3830 Z3/1 and also CSRIO KE 20/2.

Harry Messel arrived as the new Head of the School of Physics, Builder ceased working on ionospheric research. Pawsey wrote to Appleton:

> I am rather sorry, because I think he is a most competent person in this field. [Pawsey had had discussions with Builder about continuing the D region echo work.] You see, a storm, in the form of Professor Harry Messel, has hit Sydney University. Messel is a most extraordinary dynamic personality. He does the impossible at times: he recently got promises of £30,000 from Sydney business men. He is a theoretical nuclear physicist and is attempting to set up a first-class research centre in cosmic rays and theoretical nuclear physics in Sydney. I wish him all success. But it is a little hard on the "Builders" in the School and I think that Geoffrey withdrew into his shell for a while.

Builder was a senior lecturer and apparently did give up his ionospheric physics endeavours. According to the Australian Dictionary of Biography article by R.W. Home (vol 13, 1993), Builder was "an enterprising and sympathetic teacher….who developed ideas on the fundamentals of relativity theory that continue to provoke discussion…. Builder died of a coronary occlusion on 17 June 1960 in Sydney." [This was a comparable age as Pawsey, who died in 1962 at age 54.]

D: The 6 -9 September 1954 Ionospheric Conference at Cambridge, UK

During the sunspot minimum of 1954 (e.g. number of sunspots in 1954 was 46 compared to 93 in 1952 and 208 in 1955), the solar group of Wild only observed the sun at Dapto infrequently due to the lack of solar activity. During this period, Paul Wild and Jim Roberts observed the far northern source Cygnus A (maximum elevation 15 degrees) for about two hours a day, determining the dynamic spectra over the frequency range 40 to 70 MHz (i.e. frequency versus time) over a period of 18 months when 200 records were obtained. The study of the details of the ionosphere and its motions was a field in which Pawsey had worked throughout his career. Clearly, his influence can be seen in the planning and interpretation of the results. In September 1954, Pawsey presented a summary of these data (published by Pawsey 1955, *The Physics of the Ionosphere*, "Radio Star Scintillation due to Ionospheric Focusing", page 172.) In 1956, Wild and Roberts published two papers with details of these results (*Nature*, vol 178, p. 377 "Regions of Ionosphere Responsible for Radio Star Scintillation" and *Journal of Atmospheric and Terrestrial Physics*, vol 6, p 55 , "The Spectrum of Radio-star Scintillations and the Nature of Irregularities in the Ionosphere"). The latter publication provides a more detailed account. Three different types of observations were obtained: swept-frequency spectroscope to obtain dynamic spectra, a swept-frequency interferometer to study spatial deviations at various frequencies and a triangle spaced antenna system to study lateral sizes and motions of the scintillation pattern on the ground.

The purpose of these investigations is succinctly summarised by the authors in the second 1956 paper:

> Most of our knowledge of the terrestrial ionosphere has been obtained with the use of radio waves transmitted from the earth, reflected from the various layers of the ionosphere and received again at the earth. With this method, investigation is restricted to regions below the layer of maximum electron density. The discovery of extra-terrestrial radio sources now permits the study of the ionosphere by means of radio waves transmitted from outside. This method is of special interest, because it may allow us to study regions above the layer of maximum ionization.

The new data of the mid-1950s revealed that ionospheric gradients could act like giant prisms, leading to focusing by single lens-like structures. These structures were on the order of 10 km. The features on the ground were elongated. The daytime scintillations arose in the E layer and the night-time arose from the higher F layer.

Pawsey's summary from 1955:

> These relatively systematic high intensity 'ridges' would not be observed if scattering were from a number of randomly distributed scattering centres. They are most simply explained if each 'ridge', single or multiple, is due to focusing caused by a single lens-like irregularity in the ionosphere. The duration of the typical 'ridge' is from 10 to 40 seconds, the interval between, from 30 to 250 seconds. If the time variation is accepted as due to drift of the pattern over the ground, the ridge on the ground has a width from 1 to 4 kilometres and the spacing between ridges is from 5 to 20 kilometres. The drift speed is commonly about 100 metres per second.

Frater and Ekers (2012, in their biographical memoir for Wild) has pointed out the Wild-Roberts results received little recognition in the next 20 years; at the time theoretical work by Soviet scientists showed that the diffractive scintillations described by the Cambridge model were modulated by the refractive scintillations which had been described by Wild and Roberts in 1956. Frater and Ekers, 2012: "This power-law model has now been successful in describing scintillations in the ionosphere, the solar wind, and the interstellar plasma. Had Paul's demonstration of the importance of refractive effects been accepted at the time, scintillation theory would have advanced much more rapidly."

Fig 1

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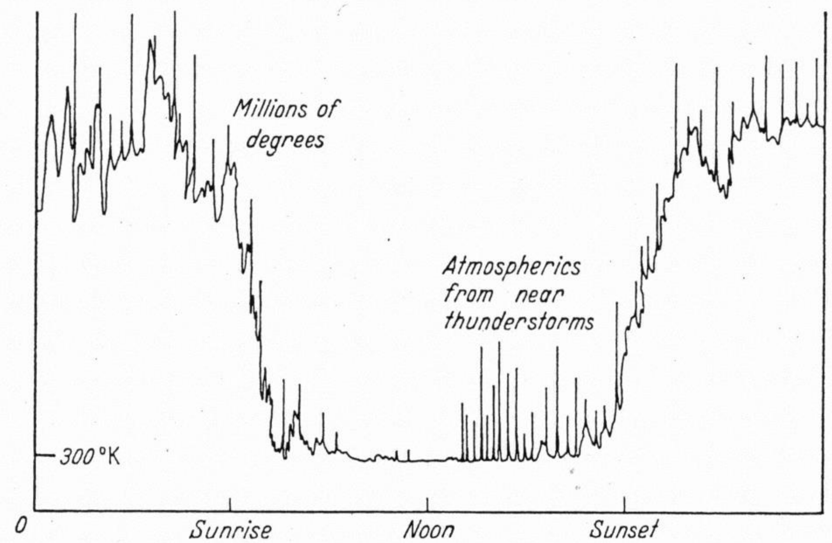

Fig. 4. Idealized noise record over whole day. By night—High level, severe fluctuation, continuous series of loud crashes audible. By day—Low steady base-level, often no crashes audible.

Above Fig 1. The idealised sketch noise record covering a whole day. Credit: Fig. 4, "Ionospheric thermal radiation at radio frequencies", Pawsey, J. L., McCready, L. L., & Gardner, F. F. (1951). *Journal of Atmospheric and Terrestrial Physics*, *1*(5-6), 261-277. Note the intensity scale is logarithmic. See Fig. 25.1 in the main book.

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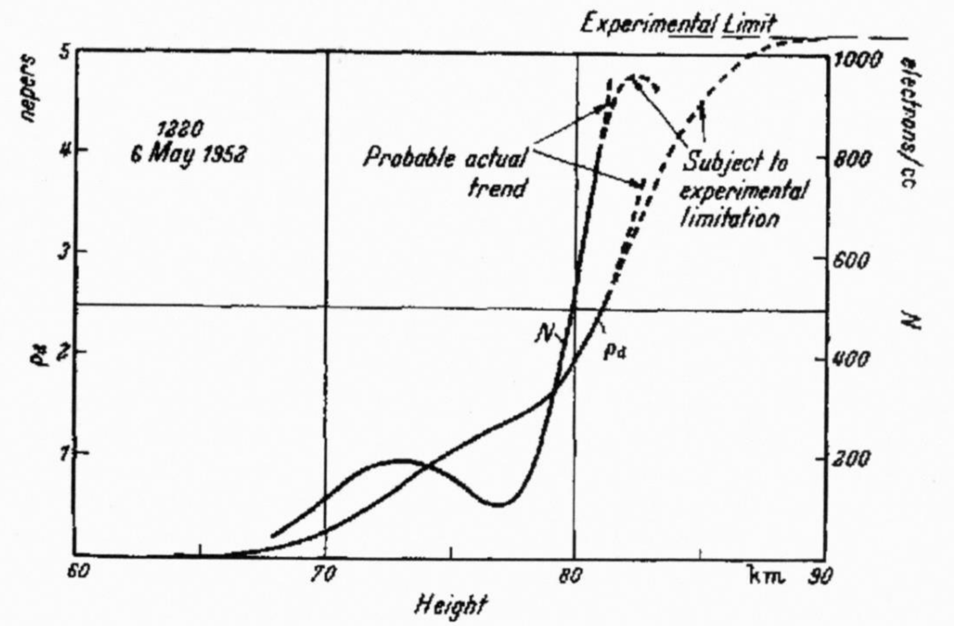

Fig. 16. Values of integrated differential absorption ρ_d versus height near noon on **6** May **1952**, and the derived electron density distribution, N

Above Fig 2 Density profile (right hand scale) for the ionosphere from 6 May 1952 , heights from 60 to 90 km. Credit: Fig. 16, "Study of the ionospheric D-region using partial reflections", Gardner, F. F., and Pawsey, J. L. (1953). *Journal of Atmospheric and Terrestrial Physics* 3, no. 6: 321-344.

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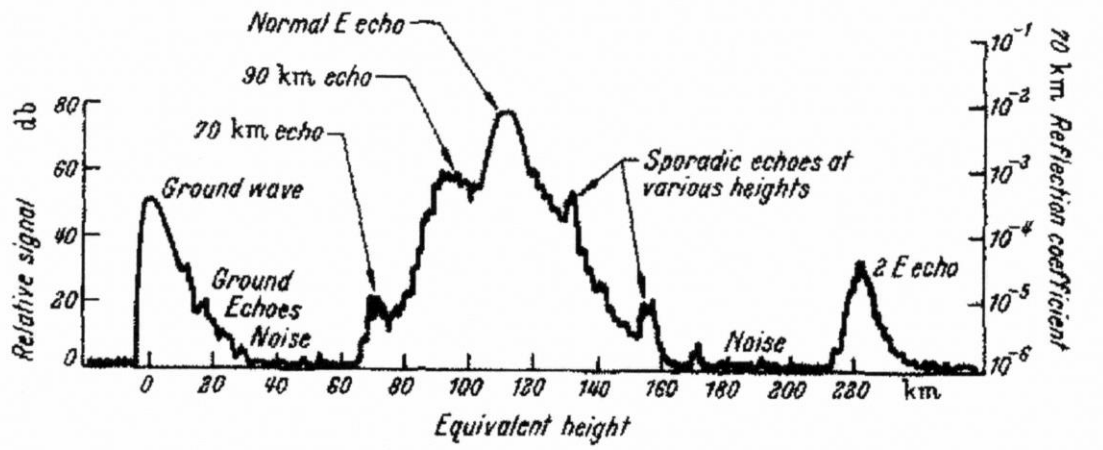
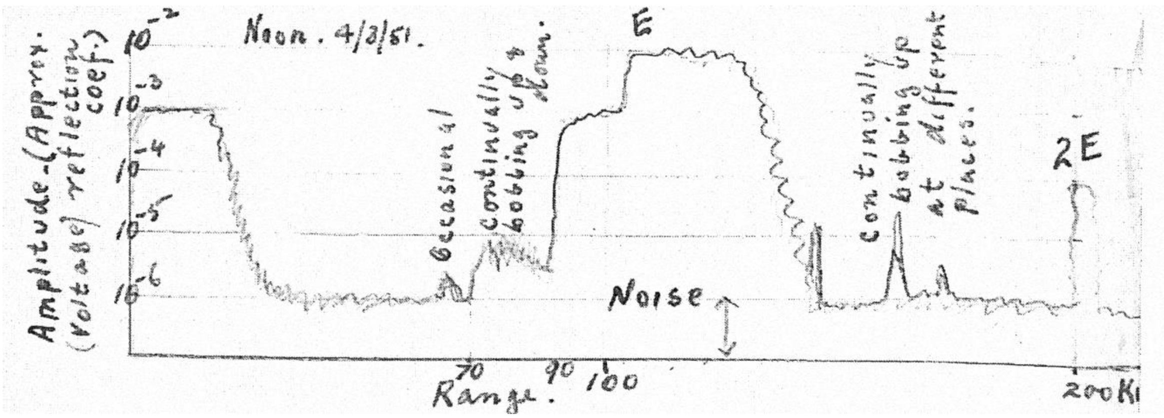


Fig. 3. Sketch of typical midday echo pattern (note severely compressed scale)

Above Fig 3 Sketch of typical midday echo pattern from ground level to over 200 km. Credit: Fig. 3, "Study of the ionospheric D-region using partial reflections", Gardner, F. F., and Pawsey, J. L. (1953). *Journal of Atmospheric and Terrestrial Physics* 3, no. 6: 321-344. See Fig. 25.2 in the main book.



Above Fig 4 A hand drown sketch by Pawsey in a letter to Fred White from 7 March 1951. White was a fellow "ionomer" ,the term invented by Ron Bracewell. Credit: NAA C3830 Z3/1 See Fig. 25.3 in the main book.