RUSSELL LECTURE

HECTOMETER COSMIC STATIC

Fifteen Meters Wavelength

Hecto is taken from the Greek word meaning one hundred, so this discussion will be about cosmic static at the longer wavelengths. Celestial radio waves were discovered about thirty years ago by Karl Jansky at a wavelength of fifteen meters. His antenna swept around the horizon once every twenty minutes. The recorder produced various bumps and dips on the graph. Some of these are shown on the first✓ picture. When the Milkyway was positioned around the horizon the traces gave long low swells with a single maximum. When the Milkyway arched overhead the traces gave two maxima separated by rather deep minima. The major maximum came from a region in Aquila while the minor maximum came from a region in Cassiopeia. The minima were produced when the antenna pointed to high galactic latitude. How Jansky unravelled all this is a fascinating scientific detective story in itself. The existence of celestial radio waves was confirmed during 1936 by Potapenko and Folland. They used an elementary type of slant dipole in the desert east of Los Angeles. Some years ago, using Jansky's data, I constructed the map shown in the second✓ picture. Only general features may be seen. If taken at face value, this line of endeavor does not appear promising. However the limitations are mainly those of the equipment.

During 1956 a much more elaborate fifteen meter antenna was constructed by C.A.Shain. Some of the results are shown in the third✓ picture. A wealth of fine detail is present including a new phenomenon, which is the numerous dark patches along the galactic plane. These are caused by absorption of the fifteen meter waves in clouds of ionized

The Large Magellanic Cloud is shown on fourth slide. These contours are quite different from those secured at higher [illegible] waves. The Cloud is worthy of a lecture in itself.

hydrogen gas. During the winter of 1960, a series of observations were made for me near the south galactic pole. The results are shown on the ~~fourth~~ 5th ✓ picture. Two small dark patches are present plus a peculiar structure which changes from a trough at left center to a ridge at top right. This is the kind of thing which passes for radio stars when using interferometers. Apparently the entire sky is covered with fine detail at fifteen meters' wavelength.

Radiations from Jupiter were discovered in 1955 by Burke and Franklin at about 14 meters wavelength.

Thirty Meters Wavelength

The first observations of cosmic static at a wavelength of thirty meters were made by Friis and Feldman during 1936 while testing an antenna for transatlantic radio telephony. Their brief tabulations show the radiation is coming from the region of Cygnus and the intensity is very high. The next observations were made by Shain and Higgins during 1951 and 1952 using an antenna better suited to radio astronomy purposes. The beam width was 31°N/S by 26°E/W and pointed straight up at declination -32°. The single profile along this declination is shown on the ~~fifth~~ sixth ✓ picture. The antenna temperature varied from over a million degrees near the plane of the Galaxy to about a half million degrees near the South Galactic Pole. The intensity of cosmic static continues to increase with wavelength and to be associated with the plane of the Milkyway. A minimum reading type of display incorporated a flying spot on a cathode ray tube with photographic integration.

During 1956 Ellis and Newstead performed a very interesting experiment. Simple interferometers were constructed to operate at wavelengths of 17 and 30 meters respectively.

Ratios of intensity at 17 meters to intensity at 30 meters were computed for each source. The three at low galactic latitude had markedly higher ratios than the three at high galactic latitude. About the same time a similar experiment was performed by Wells and Lovell. They compared the energy from strong sources in Cassiopeia and Cygnus and arrived at commensurate results. Apparently there is large absorption of the 30 meter energy by the ionized hydrogen near the plane of the Milkyway.

Radiations from Jupiter at 30 meters were detected by Smith at Santiago, Chile during 1960. They are similar in pattern but different in detail to the 15 meter energy.

These exploratory observations demonstrate an immense amount of information may be secured about celestial radio waves at 30 meters wavelength. New and better antennas will provide a wealth of detail.

Atmospherics

Atmospherics were encountered by Shain at 30 meters and caused him to invent a minimum reading display system. At longer wavelengths they become much more pronounced. Atmospherics are nearly vertical impulsive wavefronts which travel along the surface of the earth. Horizontal wire antennas are rather insensitive to such wavefronts, and are most susceptible to horizontal downcoming wavefronts of cosmic static. These characteristics make horizontal wires much more desirable than vertical wires or loops for antennas. The more elaborate and directive the antenna system is constructed with low side lobes, the less sensitive it becomes to atmospherics.

Listening tests reveal that atmospherics are not continuous. Frequent pauses occur. These pauses become the tropics. During a pause the observer may hear a strain of music or a few words of speech if he is tuned to a station. Between stations the observer will hear short bursts of the characteristic hiss of cosmic static. These observations caused me to independently invent a rather different version of the minimum reading device. It was perfected by Ellis and me during 1955. The recorder is a mechanical oscillograph with a period of about 0.05 second. Any pause in the atmospherics of four periods or about 0.20 second will allow the pen to drop to the base level of cosmic static if the pen is at full scale prior to the pause. If the pen is only slightly above base level, one period or 0.05 second will bring it down to the level of cosmic static. The ultimate performance of the device depends upon the quality of the mechanical oscillograph. The electronic driving system must be designed to take maximum advantage of its characteristics. During a long train of atmospherics a condenser, say one microfarad, is slowly charged through a high resistance, say 70 megohms. This gives a full scale rise time on the order of a minute. When a pause occurs the condenser is quickly discharged through a low resistance, say 2 kilohms. This gives a fall time of 0.002 second and is sufficiently less than the period of the oscillograph to take full advantage of this instrument. So far, only vacuum tube switching has been found practical because the back resistance must be very much greater than 70 megohms and the forward resistance very much less than 2 kilohms. To prevent the pen sticking to paper a substantial sinusoidal current is passed through the oscillograph. The period of this current must be much less than that of the oscillograph, say .01 seconds to prevent a thick line being drawn. A minimum reader using these parameters will pick out and record one pause of 0.20 second duration per minute or shorter pauses occuring more frequently.

The above type of instrument cannot be used with phase switching antennas because the atmospheric impulse may arrive having any phase. Dowden has recently invented a modification of the device which is applicable to antenna systems having two pairs of output terminals. An alternative method is that of Shain using a flying spot on a cathode ray tube with photographic recording. The atmospheric merely forces the spot off the screen in whichever direction its phase dictates. This produces a small gap in the trace during the presence of the atmospheric. The effect is similar to a receiver with a hole punching circuit. Such schemes fail of the gaps become an appreciable part of the total time.

Ionosphere

Aberrations due to the ionosphere are noticeable at 15 and 30 meters wavelength. At longer wavelengths the ionosphere becomes a dominating phenomenon. It is a shield interposed between the observer on the surface of the earth and the celestial sources of cosmic static. The shield may be an absorbing medium such as the D region or a reflecting medium such as the F region. Ultraviolet solar energy causes the D region near 90 kilometers altitude. Its presence during the day limits hectometer radio astronomy to the hours of darkness. The F region between 200 and 400 kilometers altitude is present both day and night. Its reflectivity decreases during the night, during the winter, during solar activity minimum; and is a function of position of the observer on the surface of the earth. Charged particles from interplanetary space are an important, if not sole, cause of the night time F region.

The present discussion will be limited to the transverse mode of propagation which has the electric and magnetic vectors at right angles and these are both perpendicular to the direction of energy propagation. The earth's magnetic field causes a plane wave to be split into two circular components rotating in opposite sense. These are

Called the ordinary or O wave and the extraordinary or X wave. At wavelengths up to about 100 meters both traverse the ionosphere freely and actuate the equipment similarly. They need not be considered separately except just as the ionosphere becomes transparent or opaque. All the energy from space arrives at the observer. By empirical examination of the vast collection of data upon the F region I found that it is most transparent to longer wavelengths at two regions of the earth. The best places are areas about five hundred kilometers in radius centered on Hobart and Winnipeg. These localities are near 45 degrees geographic latitude where the geomagnetic latitude is greatest. They are places near the agonic line where the compass points true north. The earth is about 3.4 per cent farther from the sun during the southern winter compared to the northern winter. This causes the F. region to be transparent to waves about ten per cent longer at Hobart than at Winnipeg. Other reasons for choosing Hobart are the more interesting parts of the galaxy overhead, the smaller number of interfering radio stations and the mild maritime climate with associated absence of local atmospherics.

Critical Wavelength

The critical wavelength λ_0 is that wavelength at which a celestial radiowave will just get through a small hole in the F region at the zenith. Wavelengths longer than λ_0 will be totally reflected back into space. As the ratio of the observing wavelength λ to λ_0 decreases, the hole becomes larger as shown on the ~~sixth~~ seventh picture. This is the simple case of a homogeneous flat ionosphere and no magnetic field. A gradient in the ion density such as at sunset or sunrise will cause the hole to open toward the low density edge. The earth's magnetic field will shift the center of the hole north of the zenith at Hobart.

Beam steering of mechanically fixed arrays is usually limited to 45° from the zenith. If λ/λ_0 is less than 0.7 the hole will be open enough for most practical purposes.

The last solar activity minimum was during 1954. The graphs on ~~seventh~~ eighth picture show median critical wavelength for the O mode versus hours for the winter months at Hobart. It will be noticed that λ_0 increases rapidly after sunset and remains at a high value most of the night. Thus many observing hours are available. To the east of the agonic line λ_0 increases slowly to a high value for about an hour or so before dawn. To the west of the agonic line λ_0 increases rapidly to a high value for about an hour or so and then slowly decreases to dawn. These are characteristics only near solar activity minimum. The ~~eighth~~ ninth picture gives the scatter of λ_0 about the median. Occasionally the ionosphere becomes transparent to waves of twice the median wavelength. If a suitable amount of data is to be collected in a reasonable length of time; the best wavelength for observation λ is slightly less than the median.

Sixty Meters Wavelength

During 1961 Ellis continued his interferometry at 60 meters wavelength. Several sources exist with diameters of a few minutes of arc and appreciable intensity. Jupiter radiation is strong and has a background continuum of significant intensity. This may be due to long trains of overlapping pulses each of which has a few seconds duration.

Recently a fine new steerable array has been constructed by Ellis with a beam width of 15°N/S by 3°E/W. The ~~ninth~~ tenth picture shows a sample trace. Notice the deep absorption dip associated with the plane of the Milkyway. Centaurus is at the left and shows a small absorption dip associated with the ionized hydrogen gas in it. Several small sources may be seen along the bottom of the absorbing region of the Milkyway. These seem to be foreground objects between the observer and the

More sweeps at other declinations are shown on [illegible] [illegible], the third trace [illegible] near the center shows a small bright patch due to very high temperature material.

absorbing material. They may be the first true radio stars. The large strongly absorbing region is only within about twenty degrees of the galactic center. Obviously a vast amount of important data will be secured with this fine instrument during the next few years.

Unfortunately a new hazard has appeared which is equivalent to haze in the optical sky caused by cirrus clouds. It is due to low density blobs of electrons in or above the F region which cause scattering of the celestial radio waves and blurring of the image. During winter of 1960 it was present three nights out of four. During winter of 1961 it was present about one night out of two. It is hoped this hazard will become more attenuated and disappear toward solar activity minimum. The phenomenon will probably be more pronounced at hectometer wavelengths.

Gyrowavelength

The magnetic field of the earth causes the free electrons in the ionosphere to traversecurved paths between collisions. If the path is one complete circle during one period of the radiation field, a resonance occurs which is called the gyrowavelength λ_G. The free electrons absorb energy from the field and loose it in heat at their collisions with heavy particles. At Hobart the gyrowavelength is very close to 200 meters at 250 kilometers altitude. This phenomenon causes the X mode wave to be greatly attenuated over the wavelength range 100 to 400 meters with total absorption at 200 meters wavelength. The O mode wave is unaffected because it is turning in a direction opposite to the free electrons. Ionospheric sounding at Hobart shows negligible X mode energy traverses the ionosphere at 141 meters.

141 meters wavelength

Initial observations at 141 meters were made by me at Hobart during the winter of 1955. The antenna consisted of two horizontal half wave dipoles producing a pattern about 90°N/S by 60°E/W. The data in the ~~tenth~~ twelfth picture show that the energy comes from all over the sky with slightly more from the plane of the Milkyway. It was a successful exploratory experiment to test the techniques, demonstrate the existence of the phenomenon and measure its approximate magnitude. The maximum intensity turned out to be about $1.5 \pm 0.3 \times 10^{-19}$ jansky per steradian from Sagittarius. By early 1956 solar activity was rising rapidly and λ_0 decreasing correspondingly. Consequently, the subject was dropped for the time being.

By 1960 circumstances seemed auspicious to undertake more detailed experiments leading toward a survey of the sky. A steerable array having a beam about 8°N/S and 8°E/W has recently been constructed. It is a completely filled in circular aperture, having tapered illumination; and steerable in a north-zenith-south plane up to about 50° from the zenith. Compensating networks have been installed allowing spectral measurements to be made by sweeping rapidly over the range 125 to 160 meters wavelength. The band width can be doubled or even tripled by improvements in the compensators. These are the electrical equivalent of the doublet lens invented by Dolland over a hundred years ago. The ~~eleventh~~ thirteenth picture shows the array of 128 poles taken from a small hill to the northwest. The pick up area is about one square kilometer. The 14th picture is same from closer. The ~~twelfth~~ fifteenth picture ~~is~~ shows the setting of one of ~~looking south through~~ the line of trusses which carry overhead wires for adjusting the direction array points. Pictures 15 thru 22 show erecting one of the poles Land is available to build a second identical array five kilometers to the east, or to expand the present array and produce a beam 4°N/S by 4°E/W. Neither, either or both possibilities will be undertaken depending upon the coming level of solar activity.

Longer Wavelengths

The ~~eighth~~ ninth picture showed that λ_0 occasionally increases markedly above the median value. During winter of 1955 a few sample observations were made at 215 meters and 576 meters wavelength. Each time the ionosonde measured λ_0 in excess of 215 meters cosmic static appeared on the appropriate recorder as characteristic bumps, swells and rises above the base line. On three occasions small bumps shown in the ~~thirteenth~~ twenty third picture appeared on the 576 meter cosmic static recorder. In each case the ionosonde recorded λ_0 to be in excess of its limit of 300 meters. The inference is that occasionally for part of an hour, cosmic static may traverse the ionosphere at 576 meters wavelength by means of the O mode. These occurrences are too rare and fleeting to be astronomically useful during the present epoc. Please note the rough background always point considerably above the zero level dots.

Z mode propagation

An electromagnetic wave may propagate through an overdense medium by the longitudinal modes provided a magnetic field is available. In the longitudinal mode the magnetic vector remains perpendicular to the direction of energy propagation. The electric vector tips forward so that a component of it is parallel to the direction of energy propagation. The latter is approximately along the magnetic field lines. The longitudinal ordinary mode is called the Z mode for identification. This matter has been extensively investigated by Ellis. The twenty fourth ~~fourteenth~~ picture shows the ionospheric circumstances associated with the Z mode echo on an ionosonde. If there is insufficient electron density to cause a reflection, the Z mode will pass entirely through the ionosphere. This situation occurs when $\lambda_0 < \lambda < \lambda_Z$. The hole will be on the order of one degree in diameter. Circumstances can be improved if the observer is placed above the lower O mode reflection level so that the ray need only traverse the top half of the ionosphere. The ~~fifteenth~~ twenty fifth picture shows this situation. The satellite must orbit between the upper Z mode and upper O mode reflection levels. The twenty sixth ~~sixteenth~~ picture gives the amount of sky surveyed out in one month at a wavelength of 300 meters. A few practical problems still remain before this method can be exploited.

Radio astronomy has been attempted from satellites. Unfortunately the data secured has been of such a nature that no sidereal effects have been detected. Apparently most of the observed energy is either generated in the exosphere or is of man-made origin arriving from the surface of the earth. I suggest that the satellites flew at too low a level. They should be above the upper O mode reflection level in picture fifteen if much cosmic static is to be detected.

Y mode

The longitudinal extraordinary mode I have chosen to call the Y mode to differentiate it from the transverse extraordinary mode commonly known as the X mode. When the path is closed the Y mode propagation characteristics produce whistlers at wavelengths approximating 100,000 meters. The radio astronomy interest is when the path is open. The Y mode can propagate through an over dense medium with very small absorption until it gets near the gyro level λ_g. At this level the electric vector is parallel to the direction of propagation and the wave spins with zero forward motion. Very soon the wave energy is completely dissipated in heat energy by collisions. When the forward velocity is zero the refractive index is infinite. The twenty-seventh ~~seventeenth~~ picture shows this situation for a 500 meter wave. Complete absorption occurs at about 2300 kilometers above the ground.

At the O mode reflection level, coupling can occur between the O mode and the Y mode. The circumstances are rather similar to reflection of light by a mirror. Light is not merely bounced off the mirror like a billiard ball. The incident wave causes eddy currents to be set up in the mirror. These eddy currents collapse and give birth to a new wave which is the reflected wave. The reflected wave will have a circular polarization opposite to the incident wave. Lack of perfect conductivity or smoothness of the mirror inhibits the formation and collapse of the eddy currents. Thus the reflected wave is weaker or of skew direction. Fortunately the ionosphere need be homogeneous over a volume of only a few wavelengths in the coupling region. This is a moderate requirement for waves of a few hundred meters length. The path will be open and allow cosmic static to arrive at the earth if the wave from space can pass through the gyro level in the O mode. This means the upper λ_o level must be below the λ_G level. A similar transformation occurs at the lower λ_o level and the wave arrives at the ground in the O mode. These processes were dreamed up gradually to explain various data.

576 meters Wavelength

Examination of the ~~thirteenth~~ twentythird picture shows a small night-time background at 576 meters significantly higher than the daytime level. During 1956 and 1957 I made further measurements at 576 meters using a steerable array of eight dipoles in phase. The pickup area was approximately one square kilometer. Solar activity had increased so that λ_o was always below 576 meters. No leakage of the O mode through the ionosphere was detected. The large array gave an enhanced energy pickup and the small background of 1955 became a significant signal. By steering and manipulation of the phasing it was possible to demonstrate that the energy was arriving from an area in the sky less than three degrees wide north/south. The ~~eighteenth~~ twentyeighth ✓ picture shows the collection of this data. The major maximum is near 2100RA with a minor maximum near 0400RA. The minimum is near 0700RA. By 1956 many records showed night-time level the same as daytime level. These merely mean that the Y hole was closed because the λ_o level rose to a higher altitude than the λ_G level which remains fixed at any given wavelength. By spring 1957 such records were in the great majority so the installation was shut down. Obviously the upper O mode coupling level had been hovering around the gyro level which is at 3000 kilometers altitude for 576 meters wavelength.

The ~~nineteenth~~ twentyninth ✓ picture shows a symbolic representation of the earth's magnetic field. Instead of a true dipole field in free space the lines are drawn as circles through the center of the earth. The effect of this representation is to compress the field greatly at several earth radii but only slightly at a half radii. Currents flowing in the exosphere could readily accomplish this and prevent the earths field from spreading a great distance into space. In any case, by this representation, an important situation occurs. It can be seen that at the 576 meter (520 kc) gyro level the field lines point to declination 42° north. Thus, it seems, that at Hobart 43° south latitude I was in fact scanning a strip at 42° north declination where the observed maxima are the plane of the Milkyway and the minimum near the north galactic pole. The intensity from the direction of radio star Cygnus A is about 0.4×10^{-19}jansky per steradian.

2100 meters wavelength

A few weeks measurements were made at 2100 meters wavelength using these same antennas. The general background level of energy was much higher than at 576 meters but no significant reproducable sidereal effect could be found. Apparently during the epoc of 1957 the Y hole was always closed at 2100 meters. The observed energy was all produced in the exosphere of the earth. It seems probable that these schemes of measuring cosmic static could be exploited up to a few kilometers wavelength by going to high geo~~graphic~~magnetic latitude and choosing times near solar activity minimum, A likely situation has been found at Sawyer Valley on Macquarie Island south of Tasmania.

Wavelengths longer than a few kilometers may never reach the surface of the earth even at solar activity minimum. The limiting factor could be the solar atmosphere instead of the terrestrial exosphere. If such be true, observations from artificial satellites or the moon will be of no assistance. To overcome this difficulty the observer must move farther out in the solar system away from the sun; say to the surface of Mars. Phobos and Deimos are both too small to construct long wave antennas. Their diameters are respectively about 19 and 10 kilometers. The asteroids, Ceres, Pallas, Juno and Vesta offer better possibilities as they are farther from the sun than Mars and vary from 770 to 190 kilometers in diameter.

Intensity

When allowance is made for difference of direction, the intensity of cosmic static continues to rise from 141 to 576 meters wavelength. I predict the rise will continue into the wavelengths of kilometers and tens of kilometers; also the observed phenomena will be markedly different compared to hectometer wavelengths. In particular, I suggest an energy sink exists at very long wavelengths. This sink is the repository of degraded thermal energy which has been interpreted as the running down of the Universe. Such energy cannot escape from the sink by any thermodynamic means. However, under the particular circumstances, electrodynamic processes are available. These pump the energy out of the sink in the form of high velocity particles and constitute a rebuilding of the Universe. The pumping process becomes more effective at longer wavelengths. Consequently a peak will be found in the intensity versus wavelength function. Beyond the peak the intensity will drop to zero as the wavelength approaches infinity. As a laboratory test of this matter, I constructed a small electrostatic motor which ran nicely when supplied with voltage comprising a continuum of periods. No nonlinear devices such as rectifiers were used.

Solar Activity

Hectometer radio astronomy is dependent upon auspicious conditions in the ionosphere and exosphere which in turn are dependent upon lack of solar activity. Much effort has been expended upon measuring the magnitude of the peaks of solar activity. Unfortunately the minima have been looked upon as merely low periods. This is because most indexes of solar activity such as spot counts, occurrences of flares, magnetic storms, etc. drop below values having numerical significance. In other words, how low is low remains unknown. Probably the earths atmosphere is the most sensitive indicator available. I suspect that there are as great variations in the depths of the minima as there are in the heights of the peaks of solar activity. By looking through old log books and making listening tests, I am of the opinion that the minimum of the early thirties was much lower than that of the middle fifties.

The ordinary solar activity cycle rises rapidly from minimum to maximum and then declines slowly to the next minimum. This produces a saw tooth shape curve of spot counts. High maxima and low maxima alternate. The past maximum has been higher and come down faster than any on record. It is the only peak with a symmetrical shape. Due to these unique characteristics it is not possible to predict what is going to happen next. However history may provide us with an opportunity to guess at the future. It should be recalled that with quite elementary equipment Galileo observed many large fine spots. Fifty years later with much better equipment astronomers could find only a few occasional small spots. Their opinion seemed to be that Galileo used considerable poetic licence in describing the spots he saw. Apparently a period of great solar activity at the beginning of the seventeenth century was followed by a long period of low solar activity from toward the end of the seventeenth to the middle of the eighteenth centuries. I suggest that we may be living during a time of great solar activity similar to that of Galileo. Perhaps the sun will so go, or maybe already has gone, through a cataclysmic activity. This will be followed by a half century or more of very low activity. Such conditions will be most favorable to hectometer radio astronomy and space travel.