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A Paper to be presented

at the A.A.A.S. Meeting in Boston

Symposium: Radio Astronomy

Date and Place: Saturday, December 26, 1953; afternoon session at the American Academy of Arts and Sciences, 26 Newberry Street, Boston, Massachusetts.

Speaker: Dr. Grote Reber, Research Corporation (paper to be presented, because of Dr. Reber's absence at the Boston Meeting, by Dr. John D. Kraus of Ohio State University.

Topic: GALACTIC RADIO WAVES

After the works of Maxwell and Hertz a logical deduction was that long wave electromagnetic radiation might be arriving from the sky along with starlight and sunlight. Apparently the first public speculation on this subject was by Sir Oliver Lodge in 1894 during a lecture before the Royal Institution entitled "Signalling Through Space Without Wires". He suggested that since we receive much more light and heat from the sun than from all the rest of the stars, the most likely place to observe celestial Hertzian waves was from the sun. During the period 1896 to 1899 he carried out such experiments in Liverpool. Unfortunately, even in that early day, the man made electrical disturbances due to arc lights and trolley cars in a great city were very large. These difficulties showed that the experiments should be transferred to the open country, which he recommended in 1900. Whether or not this was ever done and the outcome does not seem to be recorded in the literature.

Charles Nordmann read a paper before the Academie de Sciences in 1905 which gave an account of experiments carried out upon Mont Blanc to detect hertzian waves from the sun. Since all the results were negative he suggested that the hypothetical waves were absorbed in either the atmosphere of the sun or that of the earth. After these entries in the literature the subject seems to have been forgotten until it popped up many years later as a surprise.

Early in 1931 K. G. Jansky of the Bell Telephone Laboratories at Holmdel New Jersey, began making measurements of the direction of arrival of terrestrial atmospherics at 20 megcycles (15 meters). When no atmospherics were present the apparatus recorded small residuals. These were first noticed in August but thought bo be merely a low level local disturbance of man made origin. However by December it was observed that they seemed to appear in the east at dawn, pass thru south at noon and disappear in the west at dusk. Jansky's original paper on the subject of atmospherics was written shortly thereafter and shows a few sample traces depicting the residuals. He suggests that they may be generated in the earths upper atmosphere as secondary radiation caused by an unknown primary radiation from the sun. Then, as now, boards of editors lingered long over manuscripts. When the proofs came back it was May 1932. By then circumstances had changed and a note was added stating that the above conjectures need modification as these residuals now appear in the east before midnight, pass thru south near dawn and disappear in the west about noon. The paper finally got into print in the December 1932 issue of the proceedings of the Institute of Radio Engineers. His later papers clear up the situation and demonstrate that these residuals were really of celestial origin associated with the plane of the Milky Way. The original observations were merely fortuitous when the sun happened to be in Sagittarius which later turned out to be the most strong source of these celestial radiations. Jansky and his antenna are shown in the first slide. This structure was about 100 feet long and turned around once in twenty minutes. The output was recorded automatically.

The next published measurements were in 1937 by Friis and Feldman, also of the Bell Telephone Laboratories. They constructed the antenna equipment shown on the second slide. It was used as receiving terminal of a transatlantic radio link from England. These rhombics are in a line about 3/4 mile long from end to end. The main acceptance lobe is about 2½ degrees wide at a wavelength of 16 meters. By adjusting the electrical phasing between the various frequencies down to 9.51 megacycles (31.6 meters). At 18 megacycles the steering was limited to an altitude variation of about 20 degrees above the horizon. They were able to demonstrate that at suitable times the magnitude of the star static could be greatly changed by swinging the beam over this limited angle. Thus the source in the sky must be quite small. The writer computed the celestial position and found it to be in the region of Cygnus. It is now apparent they were observing the presently known source near declination $+40^{\circ}$ and right ascension 20 hours.

About this time the writer became interested in the subject. The antenna shown on the third slide was constructed at Wheaton, Illinois during the summer of 1937. It is a dish made of galvanized iron on a wooden framework which provides motion along the north-zenith-south meridian. Thus the instrument might be called a radio telescope on a meridian transit mounting. The dish has a diameter of 31 feet 5 inches and a focal length of 20 feet. Initial tests were made the following spring and summer. The first try was at 3300 megacycles (9 centimeters) using a crystal detoctor made from sphalerite, a natural zinc sulfide, and a high gain audio amplifier. Later two type 955 acorn tubes in a push pull regenerative circuit were substituted as detector at a frequency of 910 megacycles (33 centimeters). No celestial radiation could be detected. The first successful results were obtained early in 1939 at a frequency of 162 megacycles (1.85 meters), with a five stage tuned radio frequency receiver using type 954 acorn tubes. Gradually the quality of the results improved and two surveys of the galazy were made at respectively 160 and 480 megacycles.

Ahother early survey was made by Hey, Parsons and Phillips in England during 1947 at a frequency of 64 megacycles. Their antenna is shown on the fourth slide. It consists of four Yagi type antennas side which could be positioned to any azimuth by rotating the cabin.

Recently at Ohio State University a group headed by J. D. Kraus has constructed the antenna shown on slide five. It consists of a large number of helices mounted upon a movable bill board. In effect this is another version of a meridian transit radio telescope. The novel design allows the size of the structure to be enlarged from time to time as the results warrant and the funds become available. The operating frequency may be anywhere from 200 to 300 megacycles limited by the characteristics of the helices. By changing the size of the helices other operating frequencies may be obtained.

The results secured by these equipments will now be discussed in ascending order of frequency. All data is plotted in form of constant intensity contours in galactic coordinates. The units are different for the various investigators so the absolute intensity is not directly comparable from one frequency to the next. However the various sets of data are probably internally consistent and thus some idea may be secured in different directions of the nature of the radiation at these various frequencies. In general the resolution increases with increasing frequency.

The sisth slide shows Jansky's data taken at 20.5 megacycles (14.6 meters) during 1932. It is replotted by the writer. The region of maximum intensity is around 340° longitude which is in the constellation of Sagittarius. A second maximum is vaguely suggested around 100° longitude.

The seventh slide shows contours at 64 megacycles (4.7 meters) by Hey, Phillips and Parsons taken in 1947. The clustering along the galactic equator is apparent. A saddle can be seen in Puppis near 190° longitude. The Cygnus source is within the loop at 45° longitude. Three small sources are in region of Sagittarius. There seems to be some doubt of the reality of these as they may be the result of side lobes in the antenna acceptance pattern. They do not show in any of the higher frequency surveys. However until someone builds and operates better equipment which is able to confirm or deny their existence, it will be well to accept the data as portrayed.

The eighth slide shows contours at 160 megacycles (1.875 meters) taken by the writer in 1943. A lower latitude and less equipment limitations allowed a more complete picture to be secured. The lowest minimum is in region of Perseus at longitude 100°. In this direction we are closest to outer edge of the Milky Way. The strong source in Cassiopeia is within the loop at 80° longitude. The maxima in Cygnus and Sagittarius are also pronounced.

The ninth slide shows contours at 250 megacycles (1.2 meters) taken at Ohio State in 1952. A swelling of the contours at longitude 5° in Aquila and a marked extension above Sagittarius into Scorpio are to be noted. The tenth slide is a sample drift curve taken at declination -38°. Numerous small sources may be observed. However the outstanding feature is the great intensity of the general background radiation near the plane of the galactic equator.

The eleventh slide shows contours at 480 megacycles (0.625 meters) taken by the writer in 1946. The particular features in Aquila and Scorpio may be seen. The region of Cygnus near longitude 45° is now split into two parts. The loop with arrow marked 1.6 is the very intense source known to the australians as Cygnus A. The loop with arrow marked 1.2 is another much extended source they call Cygnus X. Cassiopeia may again be seen near 80° longitude. The loop marked 0.9 at 150° longitude is now known to be the Crab Nebula.

The twelfth slide shows contours at 1210 megacycles (0.248 meters) taken by the a stralians Piddington and Minnett during 1951. The two sources in Cygnus are quite evident and the swelling in Aquila is faintly apparent. However the extension into Scorpio is not obvious.

A number of things may be deduced from the above sets of data. Over a frequency range of 60 to 1 all contours show the same gross outlines with the energy arriving from predominently along the galactic equator. Aside from the discrete sources there is a large amount of natural detail to these galactic radiations or Cosmic Static as the writer likes to call them. The detail appears to differ from one frequency to another. Thus the various regions may have different intensity versus frequency functions. Increases in resolving power will provide still greater increases in detail at all frequencies. Unfortunately at the higher frequencies where resolution is most easily obtained the entire phenomenon gets fainter and fainter so that less and less instead of more and more information is secured. Apparently these sets of contours are working progressively down the slope and out toward a tail of the intensity versus frequency characteristic of the phenomenon. The peak, if indeed there is a peak, is probably in the decameter region of wavelengths or at still lower frequencies. In regard to the source of these background radiations the writer can only observe thet they are obviously not thermal. Many conjectures have been proposed but they are not worth repeating. It seems that to get a grasp upon the entire situation more effort should be made at the lowest possible frequencies preferrable down toward 10 megacycles or as low as the ionosphere will allow any results to be secured.

To this end the writer came out to Hawaii two and a half years ago for the purpose of engaging in some low frequency interferometry from the top of Mount Haleakala. The thirteenth slide shows this old volcano. The cinder cones at the top are about a mile above the clouds or nearly two miles above sea level. The fourteenth slide shows Kole Kole hill atop Haleakala. The fifteenth slide shows the installation upon Kole Kole hill for measuring Cosmic Static. The elevation is 10,020 feet. From this place there is water entirely around the horizon except for about 20 degrees of azimuth to the south east which is blocked by the island of Hawaii. Over there are two volcanoes nearly 14,000 feet high. However after inspecting the tops of Mauna Loa and Mauna Kea, the lower Haleakala was chosen because of its much greater accessibility. The sixteenth slide is a diagram of the ray structure from a source as it rises from the sea. T_1 is on the horizon with T_2 and T_3 progressively later. After T_3 the reflected ray is blocked by the far edge of the crater and the interference pattern disappears. The seventeenth slide is a view of the eastern horizon. This may be seen as the demarkation between the black water and lighter haze. The horizon is about 140 miles away. Below is Haleakala crater with the far rim 7 miles distant. Cinder cones in bottom are 500 to 800 feet high. The eighteenth slide is a sample trace of Cygnus A rising, taken at 19.6 megacycles (15.3 meters). Time progresses from right to left. The 59th second omitted. Because the earth is a ball a phenomenon known as divergence is encountered. When a beam of parallel rays falls upon a curved surface the reflected beam will be spread out in a divergent angle. This weakens the intensity of the ray reflected from the sea so that it cannot properly reinforce or cancel the direct ray from the sky. Thus the first couple of lobes of the interference pattern are incompletely formed. As the angle at the sea increases from grazing incidence the divergence decreases rapidly and the pattern improves. These effects can be seen in the trace shown. The fur on the trace is mostly terrestrial atmospherics coming in via the ionosphere from the Indies. Later in the night as the cutoff frequency decreases the atmospherics disappear and the recorder draws nice smooth curves. Local atmospherics are practically unknown. The lobes in the pattern are about 20 minutes of arc apart. Thus for the pattern to exist the source must be only about a minute of arc or so in size. From here on, the discourse would be mostly about the discrete sources which is the subject of the evening speakers. Suffice to say, that data is still being taken and will be reported upon in due time.

Something should be said about apparatus. Fifteen years ago the electronic equipment was the major problem. The securing of sufficient sensitivity to detect much less measure the cosmic static phenomenon was quite a trick. This state of affairs remains at wavelengths shorter than half a meter. However at wavelengths longer than a meter the electronic equipment has become so good that measurements can be made using even the crudest of collectors such as a simple dipole. Present problems relate mostly to design and construction of collector devices having large resolving power. These problems are usually in the domain of the civil and mechanical engineer. At decameter waves such problems not only become aggravated but other even greater ones are encountered relating to wave propagation thru the ionosphere. Unfortnately, at this late date, practically nothing is known of the region above the maximum ion density of the F_2 layer. Situations encountered in Hawaii suggest that up above the F layer is a region of great and nearly permanent absorption. It is into this region that the F layer recedes during a magnetic storm with accompanying poor radio propagation conditions. This adds to the difficulties encountered in decameter wave observations of Cosmic Static. By such devices Mother Nature is well able to keep her secrets from the prying eyes of men.