35. MOUCHET, M., BONNET-BIDAUD, J.M., BUCKLEY, D.A.H. & TUOHY, I.R., The UV variability of the intermediate polars TW Pictoris (H 0534 - 581) and TX Columbae (1H 0542 - 407), *Astron. Astrophys.*, **250**, 99-106, 1991.
36. SMITS, D.P. Photoionization modelling of metal-enriched nova shells. *Mon. Not. R. astr. Soc.*, **248**, 217-228, 1991.
37. SMITS, D.P. Theoretical He I line intensities in low-density plasmas. *Mon. Not. R. astr. Soc.*, **251**, 316-317, 1991.

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The Radio Sky

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When gazing up at the Milky Way, the bright band of stars extending across the night sky, we can easily understand how astronomy has become a popular field for scientific and recreational study. For this very aesthetic reason many people perceive astronomy as "looking at the stars". It is no accident that the naive layman's view of astronomy is distorted in this way; our senses have been tuned to match the output of a nearby star, the sun. The human eye is most sensitive to radiation from that part of the electromagnetic spectrum where the sun has its peak output, a narrow band of wavelengths between about 0.4 and 0.7 micrometres (microns). Modern astronomy involves the detection of radiation from a span of about 15 decades (factors of ten) of the electromagnetic spectrum, from wavelengths of about 10^{-14} metres in the TeV gamma-ray regime through to 10 metre radio waves.

Besides our natural inability to detect radiation other than light and warmth (infrared), the earth's atmosphere and ionosphere shield us from much of the other radiation of extraterrestrial origin. Molecular absorption in the atmosphere blocks much of the incident infrared, ultra-violet, X-ray and gamma-ray radiation, while the ionosphere reflects the low frequency radio waves. This atmospheric filter is obviously transparent to visible light. Another major transparent "window" covers the radio region of the electromagnetic spectrum, from wavelengths of about 1 millimetre to 10 metres. Modern radio astronomy is the study of the celestial electromagnetic radiation that falls within these 4 decades of wavelength.

Like many discoveries in astronomy, the emergence of radio astronomy as a science was itself serendipitous. In 1932 Karl Jansky[1], a radio engineer working for Bell Laboratories,, reported

> *"a very steady hiss type static, the origin of which is not yet known".*

He had been using a radio antenna and receiver operating at 20.5 MHz to investigate the origin of radio interference that was disrupting transatlantic radio-telephone links. In the next year [2] he reported that the radio noise signals were of extraterrestrial origin, and in 1935 he postulated that the radio waves had their origin in the Milky Way, our own galaxy [3]. Jansky's measurements of the celestial "hiss" were the first radio astronomy observations to be made of the radio wavelength emission from our galaxy. Jansky's name is now used as the unit of flux density: $1\ \mathrm{Jy} = 10^{-26}\mathrm{Wm}^{-2}\mathrm{Hz}^{-1}$. The small magnitude of this unit gives some indication of the faintness of the celestial radio radiation. Jansky's employers did not share his enthusiasm for studying this "cosmic static", and he was not able to continue his work in this area.

The first person to study the spatial distribution of this celestial radio radiation was Grote Reber, a professional engineer and radio amateur. He built the first steerable "dish" antenna radio telescope, the forerunner to all the large instruments that exist in the world today, in his garden at home. In 1940 Reber reported his results in the *Astrophysical Journal* [4].

This was to be the first radio astronomy article to be published in a mainstream astronomy journal. In the final paragraph of this *research note* Reber concluded that:

"The foregoing observations confirm previous evidence that radiation in the radio spectrum is apparently coming from the direction of the Milky Way. The intensity is a function of galactic longitude."

In a later article to the *Astrophysical Journal* [5], he published the first maps of this "cosmic static" radiation (see figure). The abstract of this paper reads:

"Cosmic static is a disturbance in nature which manifests itself as electromagnetic energy in the radio spectrum arriving from the sky. The result of a survey of 160 megacycles per second show the centre of this disturbance to be in the constellation of Sagittarius. Minor maxima appear in Cygnus, Cassiopeiae, Canis Major and Puppis. The lowest minimum is in Perseus. Radiation of measurable intensity is found coming from the sun."

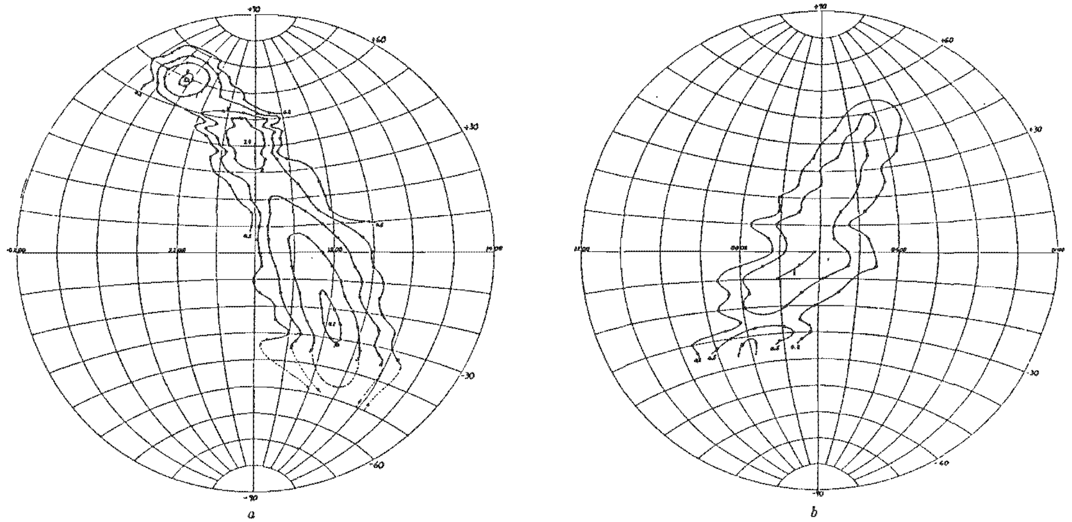

FIG. 4.—Constant intensity lines in terms of 10^{-22} watt/sq. cm./cir. deg./M.C. band

This article by Reber reported the results of the first radio continuum survey of the sky. It proved conclusively that the radio radiation was somehow connected to the stars of the Milky Way, even if the stars themselves were not directly the sources of the emission. Some fifty years later we in the Radio Astronomy Group of the Department of Physics and Electronics at Rhodes University are continuing this work, producing images of how the sky would appear to creatures with large "radio eyes".

In the 1940's the professional astronomers had two major problems with this new astronomical phenomenon: they had no theory to explain the cosmic radio emission, and they did not have the necessary radio engineering skills to build the instrumentation needed to study these emissions. The rapid development of radar technology during and immediately after the war provided the scientists with the technology required to do more sensitive observations, but theories explaining the phenomenon took some time to appear.

By extrapolating his results for the sun Reber was able to show that the emission from the Milky Way could not be of stellar origin. Whipple and Greenstein [6] were not able to attribute the radiation to hot interstellar dust because temperatures in excess of 100000K were required. Measurements at different frequencies showed that the intensity of the radio emission decreased towards shorter wavelengths, which provided some clue to the origin of the radio waves. Henyey and Keenan [7] proposed that a mechanism that was more consistent with the measurements by Jansky and Reber was the interaction of free electrons with hydrogen ions (protons). Today we know that this *bremsstrahlung* mechanism is indeed responsible for the radio waves we detect from the ionised hydrogen clouds that constitute the emission nebulae surrounding hot O and B type stars.

This mechanism of radio emission from ionised hydrogen was sufficient to explain the radiation from a number of "sources", but did not explain satisfactorily much of the observed radiation. The explanation of the second main mechanism for celestial radio radiation had to await the discovery of the interstellar magnetic field (from observations of starlight polarization) and the postulate that there were mechanisms for accelerating cosmic ray electrons (even though these had not been detected at the earth). High energy cosmic ray electrons follow a spiral path while moving along magnetic field lines. These spiralling electrons give rise to *synchrotron* radiation, which converts part of their kinetic energy into radio radiation.

These galactic cosmic ray electrons obtain their energy from a number of sources: supernovae, neutron stars, the stellar winds of hot late type stars, and possibly accretion onto black holes. Some of the most prominent radio sources seen in radio maps of the Milky Way are the loops of emission from supernova remnants (SNR). The compressed, expanding shells formed after supernova explosions provide both the energetic electrons and magnetic field necessary for synchrotron emission. Electrons from all of these energetic sources diffuse into interstellar space to interact with the interstellar magnetic field, giving rise to the "ridge" of radio emission that coincides with the band of stars that we identify as the Milky Way. We see that although stars do not emit significant radio radiation themselves, they are the ultimate sources of energy that power both bremsstrahlung and synchrotron radio emission processes.

During the 1950's radio astronomy blossomed, and many radio astronomy telescopes were built. Unlike ground-based optical telescopes, radio telescopes are diffraction limited. This means that the resolving power of a radio telescope antenna depends on its physical dimensions and operating wavelength. For example, the 26 metre antenna at the Hartebeesthoek Radio Astronomy Observatory (HartRAO) has a beamwidth of 20 arcminutes when operating at a wavelength of 13 centimetres. In order to match the arcsecond resolution of optical observations, radio astronomers turned to interferometric techniques which effectively increase the size of the telescope to the distance between the element antennas.

With this increased resolution radio astronomers started studying individual radio emitting objects (such as SNR and extragalactic quasars). The development of spectral line observations in the radio wavelength range, the discovery of quasars, and the discovery of pulsars added momentum to the move towards the study of individual objects of specific interest. Although radio astronomy started off as the mapping of the radiation from the Milky Way remarkably few "all-sky" radio maps have been made. In fact there is only one all-sky map of the radio sky with a resolution better than 1 degree. This map has a resolution of 51 arcminutes, and was observed by Glynn Haslam and coworkers [8] at a frequency of 408 MHz (a wavelength of 74 centimetres). They used three of the world's largest steerable dish antennas: The Bonn 100 metre telescope, the 76 meter (250 foot) Mark I at Jodrell Bank, and the 64 metre dish at Parkes in Australia. Obviously they needed to use telescopes in both hemispheres in order to cover the whole sky. These observations took more than 10 years to complete, resulting in nearly 400000 independent "pixels" of radio brightness covering the whole celestial sphere.

These figures explain the paucity of maps of the radio sky: many hours of telescope time are needed to make the observations, vast amounts of data are generated, and results only become available after a long period. In these days of competitive science funding such long-term projects are not popular!

Nevertheless, many other maps have been made of selected regions of the sky, particularly regions at low galactic latitude. A recent article in *Bulletin d'Information du Centre de Donnees Astronomiques de Strasbourg* [9] lists the all radio surveys published since 1955. A few notable examples are listed here. Wolfgang Reich at the Max Planck Institute for Radio Astronomy in Bonn used the 25 metre Stockert antenna to produce a 21 centimetre map of the entire northern hemisphere with a resolution of 35 arcminutes [10]. In 1965 Dr George Nicolson, now director of HartRAO, published a 960 MHz (31 centimetre) map of the southern Milky Way [11]. The observations for this map were made with the Hartebeesthoek 26 metre antenna while it was still being used as a NASA space facility. More recently Reich and co-workers have been mapping the northern galactic plane at a wavelength of 11 centimetres using the Bonn 100 metre antenna [12].

In the southern hemisphere the Rhodes Radio Astronomy Group are the only astronomers doing successful large scale radio continuum survey work. For the last 12 years we have been using the HartRAO facility to record the radio brightness distribution of the southern sky, and we hope to complete the observations in the next year. We make our observations at a wavelength of 13 centimetres (a frequency of 2300 MHz). The radio maps we produce [13],[14] have a resolution of 20 arcminutes, which is the highest resolution ever achieved for large-scale survey data. We intend to cover the whole sky south of +32 degrees declination (the northern horizon at Hartebeesthoek), which will result in nearly 3000000 independent data points. At a wavelength of 13 centimetres the brightness of the radio sky is, on average, 100 times less than at 74 centimetres. Despite this "disadvantage", our radio maps have a better signal-to-noise ratio than the 408 MHz data, which is a tribute to the equipment at HartRAO.

What scientific value do these radio sky maps have? The most immediate application of the data is the study of the diffuse galactic synchrotron emission, and the detection and identification of galactic and extra-galactic radio sources. Comparison of the radio data with other astronomical survey data (such as the IRAS far-infrared, ROSAT X-ray, and Cos-B cosmic ray surveys) will give us a better understanding of the structure and dynamics of our galaxy, and the nature of objects such as SNR. A new application for the data has arisen from the current interest in the cosmic microwave background (CMB) emission. Many astronomers throughout the world are trying to detect "ripples" or "anisotropies" in the CMB (the recent COBE satellite mission being one of the most publicised experiments). In order to interpret their data correctly the workers in this field need to know the nature of the galactic "foreground" emission. The few large scale radio sky maps that exist are the only data that are available for this purpose.

A very important requirement of "pure science" research at a university is that it must impart transferable skills to the students who are involved in the research. Radio astronomy survey work certainly fulfils this requirement because besides learning more about physics and astronomy the researcher acquires a working knowledge of computer programming and interfacing, digital and analog electronics, signal processing, control theory, and telecommunication techniques.

What work will we do in the future? We are already planning our new sky survey project: mapping the emission from the galactic plane at a wavelength of 3.6 centimetres. At this wavelength we will achieve a resolution of 6 arcminutes. To survey the whole southern sky at this resolution would be a mammoth task, but we only plan to map a strip about 10 degrees wide along the galactic plane. We hope that we will be able to make these observations using a "polarization radiometer", which will effectively quadruple the amount of information we will collect during the observations. The polarization data will allow us to study the structure of the magnetic fields within the radio sources.

Although many radio astronomers no longer continue with the pioneering survey work that gave rise to the whole subject, there are still groups around the world who are using radio telescopes to extend the human visual senses so that we can appreciate the full spectrum of the Milky Way, and not just be limited to one small wavelength band.

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References

1 K.G. Jansky, *Proc.I.R.E.* 20, p1920 (1932).
2 K.G. Jansky, *Proc.I.R.E.* 21, p1387 (1933).
3 K.G. Jansky, *Proc.I.R.E.* 23, p1158 (1935).
4 G. Reber, *Ap.J.* 91, pp621-624 (1940).
5 G. Reber, *Ap.J.* 100, pp279-287 (1944).
6 F.L.Whipple & J.L.Greenstein, *Proc.Natl.Acad.Sci.USA* 23, p 177 (1937).
7 L.G.Henyey & P.C.Keenan, *Ap.J.* 91, pp625-630 (1940).
8 C.G.T.Haslam, U.Klein, C.J.Salter, H.Stoffel ,W .E.Wilson, M.N.Cleary, D.J.Cooke & P.Thomasson, *Astron.Astrophys.* 100, pp209-219 (1981).
9 E.C.Campbell, *Bull.Inform. CDS* 40, pp43-70 (1992).
10 W.Reich, *Astron.Astrophys.Suppl.* 48, p219 (1982)
11 G.D.Nicolson, *Publ. Astron.Soc.Pacific* 77, pp260-268 (1965).
12 W.Reich, E.Furst, P.Steffen, K.Reif & C.G.T.Haslam, *Astron.Astrophys.Suppl.* 58, pp197-248 (1984).
13 J.L.Jonas, G.de Jager & E.E.Baart, *Astron.Astrophys.Suppl.* 62, pp105-128 (1985).
14 P.I.Mountfort, J.L.Jonas, G.de Jager & E.E.Baart, *M.N.R.A.S.* 226, pp917-926 (1987).