2. A Science is Born

2.1 A Touch of History

In 1886, Heinrich Hertz accidentally constructed the first radio transmitter and receiver. In a darkened lecture theater at the Technical College in Karlsruhe, in Germany, Hertz had set up an experiment to test what happened when an electrical current flowed in an open circuit (that is, a circuit with a gap in it). As he explained the setup to his wife, Elisabeth, he switched on a spark generator, used to produce current, and one of them noticed a simultaneous spark that flashed in an unrelated piece of equipment at some distance away from his main experimental apparatus. Whoever noticed it first, Heinrich or Elisabeth, is unknown to us, but it was Heinrich who made the leap of curiosity that underscores the nature of scientific research. Hertz asked "Why?" and started a systematic search for an answer.

Eighty years later historians of science would report that Hertz was at least the sixth physicist to see this odd effect, but he was the first to follow up on his key question. He proceeded to design a series of brilliantly simple experiments, one after another, in search of an answer. He was able to show that an invisible form of radiation, which he called 'electric waves,' carried energy through intervening space. Hertz was also able to demonstrate that the electric waves were a phenomenon very similar to light. In fact the speed of those waves through the air was the same as that of light. Today we know that both light and Hertz's electric waves are forms of electromagnetic radiation (see Appendix A.3). Over time, the Hertzian waves (a name used very early in the twentieth century) came to be called radio waves. Their frequency is measured in cycles per second, now called Hertz (Hz). In Appendix 3.1 the relationship between frequency and wavelength is explained. For the bulk of our story we will refer to the frequency of radio waves.

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Hertz died tragically at the young age of 35 of blood poisoning from an infected tooth. If he hadn't, he surely would have won a Nobel Prize in Physics for his discovery.

After showing that radio waves behave much as light does, except that they are utterly invisible, Hertz did not ask how far they might travel through space. That was left to Guglielmo Marconi, the Italian physicist who performed a series of obsessively creative experiments to prove that radio waves could travel enormous distances and even pass through rock. He was wrong in this latter belief, but he did show that radio signals could traverse the Atlantic Ocean. The reason that the radio waves made it across despite the curvature of the earth was because the earth's atmosphere is surrounded by an electrically conductive layer known as the ionosphere and radio waves bounce off that layer to be reflected across the ocean. That wouldn't be understood until decades later. Meanwhile, Marconi was happy to know that radio waves did go all the way around the earth and it was not long before ships at sea could signal one another across the ocean using radio waves. In 1912 the infamous sinking of the Titanic spread awareness that radio transmitters could be used to send an SOS far and wide.

Marconi did wonder whether there might be radio waves reaching earth from space but his equipment would not reveal the existence of the wondrous invisible universe for the same reason that he could signal across the Atlantic. At the low radio frequencies that Marconi used, the reflecting ionosphere not only allows radio signals to bounce around the curvature of the earth, it also prevents radio waves from space from penetrating to the earth's surface. Those that do arrive from space are absorbed or reflected back. (Only if their intrinsic frequency is higher than about 20 MHz do such radio waves reach the ground unimpeded, but back then not much was known about building receivers at such frequencies.)

2.2 The Birth of Radio Astronomy

Karl Guthe Jansky, the father of radio astronomy, was employed at Bell Laboratories, which, in 1927, introduced the first transatlantic radiotelephone. For a mere $ 75 one could speak for three minutes between New York and London, but the radio links were

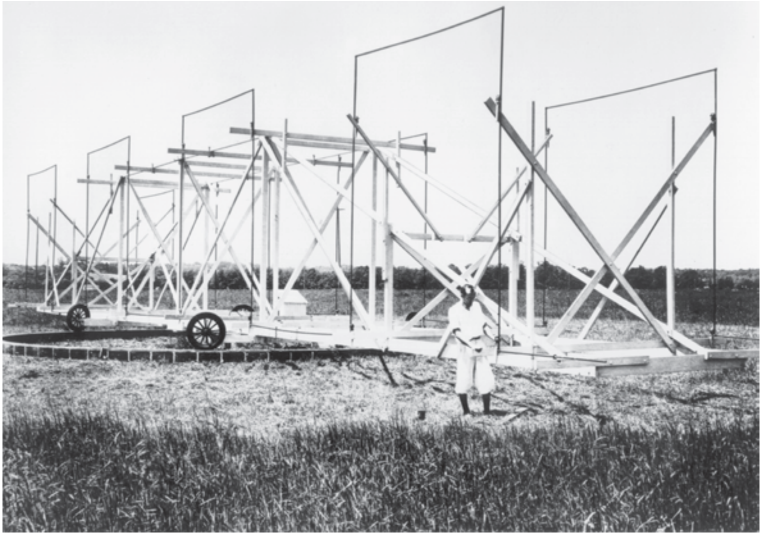

Fig. 2.1 Karl Jansky, working at Bell Telephone Laboratories in Holmdel, NJ, in 1928 built this antenna to receive radio waves at a frequency of 20.5 MHz (wavelength about 14.5 m). It was mounted on a turntable that allowed it to be rotated to be oriented in any direction, earning it the name "Jansky's merry-go-round." He duly discovered the direction from which the mysterious hissing radio signals were arriving, the Milky Way, in particular its center in Sagittarius. (Credit: NRAO/AUI/NSF)

terribly susceptible to electrical interference. The first system operated at the extraordinarily low frequency of 60 kHz (that is, at the very long wavelength of 5 km) and in 1929 a change was made to frequencies in the range 10–20 MHz. But the new telephone links were still susceptible to electrical disturbances of unknown nature, which plagued the connections. Jansky was assigned the task of locating the source of the interference. To carry out his studies he built a rotating antenna (Fig. 2.1) operating at 20.5 MHz and by 1930 began making regular observations. In 1932 he reported that local and distant thunderstorms were two sources of radio noise and a third source was "a very steady hiss-type static, the origin of which is not yet known."

During the following year he demonstrated that the source of the signals was outside the earth and presented a report entitled "electrical disturbances apparently of extraterrestrial origin." And so radio astronomy was born.

Just imagine this: When Jansky became convinced he had picked up radio waves from space he enjoyed what few people ever experience—the thrill of discovery—finding something no one had ever known about before. That is part of the reward, the joy, and the excitement of doing scientific research.

Fifty years later, at the National Radio Astronomy Observatory in Green Bank, West Virginia, distinguished radio astronomers gathered to celebrate the anniversary of Jansky's discovery. A report entitled "Serendipitous discoveries in radio astronomy"[1] grew out of that meeting and it presents the human side of the birth and growth of this science.

"Serendipity" is a term coined by Horace Walpole, the writer and historian, who used it to refer to the experience of making fortunate and unexpected discoveries, according to the fairy tale about the three princes of Serendip (an old name for Ceylon). Serendipitous discoveries are those made by accident, but also by wisdom; however, no one will make an accidental discovery unless that person is capable of recognizing that something of significance is occurring. Jansky was such a person.

In January 1934, in a letter to his father, Jansky wrote:

> Have I told you that I now have what I think is definite proof that the waves come from the Milky Way? However, I'm not working on the interstellar waves anymore.

His boss had set him to work on matters of more immediate concern, matters, which were:

> … not near as interesting as interstellar waves, nor will it bring near as much publicity. I'm going to do a little theoretical research of my own at home on the interstellar waves, however.

Jansky did not take an interest in his new discoveries to the point of building his own antenna so as to pursue his explorations over the weekends. Jansky's boss, who ruled with an iron hand, was later to encourage him to write another report, and in 1935 Jansky interpreted the sky waves as coming from the entire Milky Way. But he did not know why and suggested that either a lot of stars were contributing or perhaps something in interstellar space was the cause. He realized that if the waves were due to stars he should have detected the sun. As observed from the surface of the earth

[1] K. Kellermann and B. Sheets (eds.), *Serendipitous Discovery in Radio Astronomy*, National Radio Astronomy Observatory, Green Bank, WV, 1983.

the Milky Way happens to reach its maximum brightness in the radio band close to Jansky's chosen frequency. It is brighter at still lower frequencies, but those radio waves do not penetrate the ionosphere. Furthermore, the ionosphere experiences daily changes of its characteristics and in the daytime blocks out the sun's radio emission. Thus Jansky's antenna was blind to its radiation. The mid-1930s were also a time of sunspot minimum, which meant that the ionosphere was transparent to 20 MHz at night. Had Jansky been observing at sunspot maximum, the ionosphere, whose reflecting properties vary with time of day and season as well as sunspot cycle, would have blocked out all 20 MHz radio waves from space and he would not have discovered the signals from the Milky Way.

Jansky failed to pursue his discoveries any further because there were other projects to be done and "star noise could come later" he was told by his employers. It was to be years before significant follow-up work began. A few astronomers in the United States and Europe had become aware of Jansky's work, but any plans to look more closely at his discoveries had to be shelved when World War II broke out. Of course, most astronomers knew absolutely nothing about radio receivers and antennas, so how could they get involved? Optical astronomers were just not equipped with the skills necessary to tinker with radio sets. After the war it was mostly radio physicists who launched the new science, and they had to learn astronomy in the process.

After he made his discovery, Jansky wrote to the famous physicist, Sir Edward Appleton:

> If there is any credit due to me, it is probably for a stubborn curiosity that demanded an explanation for the unknown interference and led me to the long series of recordings necessary for the determination of the actual direction of arrival.

Such stubborn curiosity is the hallmark of good scientists. Jansky trusted his data and continued his measurements for confirmation. His persistence led to the discovery that the source of the static, the hiss as he originally called it, was located in the astronomical heavens.

The story of radio astronomy is replete with apparently amazing cases of fortuitous discoveries, but such discoveries require more than good luck. They require a prepared mind and dedicated effort to follow up on what might at first have seemed to be a preposterous new observation. What would have been more preposterous, at least back in 1933, than to learn that radio waves were reaching the earth from all sorts of strange astronomical objects, and even from the beginnings of time and space?

2.3 Caught Between Two Disciplines

In 1933 John Kraus, then at the University of Michigan, attempted to detect the sun by using a searchlight reflector to focus the radio waves. He failed because the receiver was not sensitive enough. This was the first use of a reflector-type radio telescope. At the Serendipity meeting, Kraus stated that meaningful accidental discovery occurs only as the result of "being in the right place with the right equipment doing the right experiment at the right time." Another noted astronomer, R. Hanbury Brown, added that the person should "not know too much," otherwise the discovery might not be made!

This summarizes an interesting phenomenon. Many research scientists, especially the theoretically inclined, 'know' so much that their chance of making a lucky or creative discovery may be severely curtailed. If we know too much, our vision may be narrowed to the point where new opportunities are not recognized. Jansky knew a little astronomy, but not enough for it to get in his way and cause him to reject the possibility that radio waves originating in the cosmos might be real.

Grote Reber, a professional engineer and radio ham in his spare time, was one of the few people who recognized the interesting implications of Jansky's discovery.[2] Reber was certainly not hampered by any astronomical prejudices about whether or not the cosmic radio waves could exist. Instead, he was interested in verifying their existence and followed up on Jansky's work. To this end, Reber built the world's first steerable radio dish antenna (Fig. 2.2) in his backyard and mapped the Milky Way radiation during the period 1935–1941. Figure 2.3 shows an example of Reber's data. He pointed out that the new field of radio astronomy was originally caught between two disciplines. Radio engineers didn't care where the radio waves came from, and the astronomers

[2] A wonderful summary of Reber's life has been written by Ken Kellermann and form a chapter in "The New Astronomy: Opening the Electromagnetic Window and Expanding our view of Planet Earth", Editor Wayne Orchiston (Springer: Dordrecht) 2005.

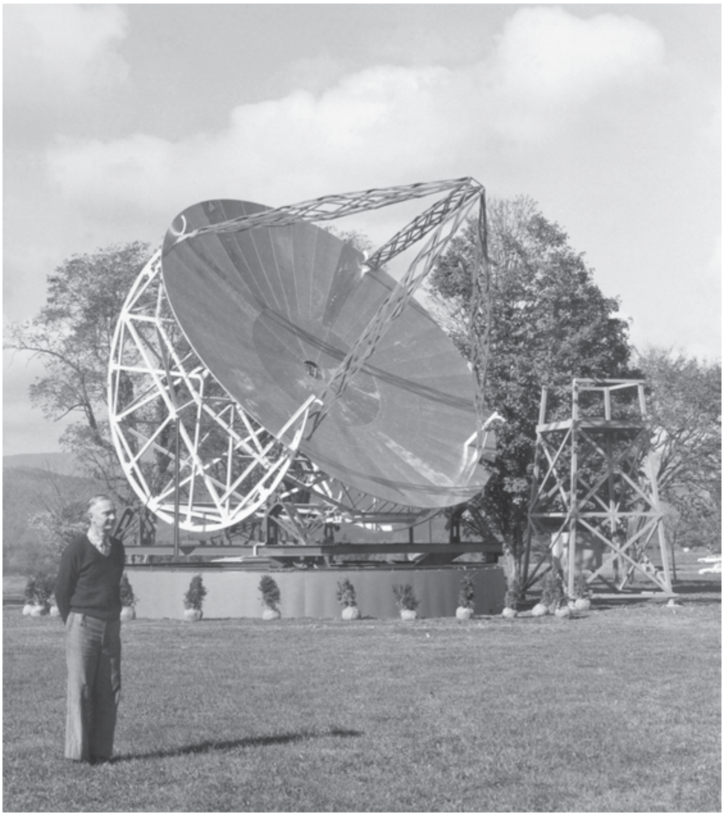

Fig. 2.2 Grote Reber standing in front of world's first radio telescope, in its restored state at the NRAO in Green Bank, West Virginia. Reber originally built this is his back yard in Wheaton, Illinois, c. 1938, much to the consternation of his neighbors. (Credit: NRAO/AUI)

> … could not dream up any rational way by which the radio waves could be generated, and since they didn't know of a process, the whole affair was (considered by them) at best a mistake and at worst a hoax.

The very essence of research is that once an observation is made it requires some understanding and interpretation in order to formulate a plan for making further observations. It was initially very difficult for astronomers, entirely ignorant of radio technology, to interpret or understand the significance of Jansky's or Reber's epoch-making discoveries.

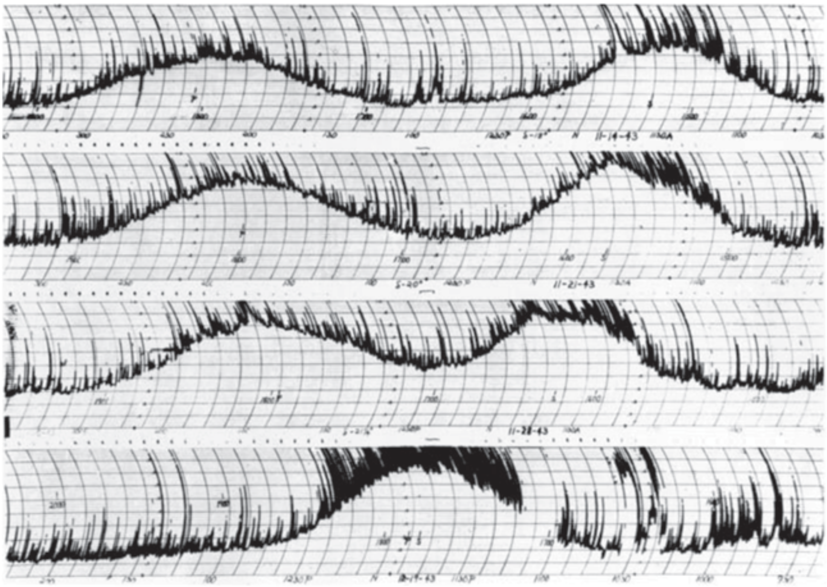

Fig. 2.3 Chart recordings from Reber's telescope made in 1943. The spikes are produced by terrestrial interference (electrical sparks) seen against the changing signal due to radio emission from the Milky Way as the radio telescope is scanned across the sky. (Credit: NRAO/AUI/NSF)

Jesse Greenstein, of Caltech, one of the few astronomers who did get involved before World War II, summed up the dilemma confronting the astronomer of those prewar days:

> I did not say that the radio astronomy signals would go away someday, but I didn't know what next to do.

How could anyone know what next to do? The mystery of where the radio waves originated was a profound one, not easily solved. Significant new technologies had to be combined with astronomical knowledge in order to carry out radio astronomical research. If the science was to flourish, either astronomers had to learn about radio engineering or radio engineers had to learn astronomy. The new science therefore grew slowly. The intrusion of World War II may actually have speeded up its growth somewhat because of the intense research in radar techniques, which led to the very rapid development of precisely those types of radio antennas and receivers that the radio astronomers were to require for their work. After the war radar dishes and receivers became freely available as war surplus equipment.

2.4 Postwar Years—Radar Everywhere

England, Australia, France, the Netherlands, the United States, and Canada were the important centers for postwar radio astronomy. The radio engineers and physicists drawn into radar research during the war became the first generation of professional radio astronomers. The equipment they used to launch their research work was scrounged, begged, or borrowed from military surplus.

In 1946 in Canada, Arthur Covington, of the National Research Laboratories, began taking regular observations of the sun at 3000 MHz (10.7 cm wavelength), a choice dictated by the availability of surplus radar components. For decades this work was to provide the data for anyone interested in knowing how active the sun was on any given day. The solar radio data showed that the sun's radio brightness is directly correlated with the 11-year sunspot cycle and also revealed that the radio emitting regions on the sun must be at temperatures of over one million degrees.

Radio astronomers in the Netherlands did their early work with a German war surplus radar antenna (Wurzburg dish). Since 1944, when H. C. van de Hulst, a graduate student working with J. H. Oort, had given a talk on how radio observations might contribute to our understanding of the universe, the Dutch had focused their attention on searching for radio emission from hydrogen gas between the stars, with ultimate success in 1951 (see Chap. 6).

The Cambridge radio astronomy effort, under Martin Ryle, made heavy use of two Wurzburg dishes combined as an interferometer, which were used to accurately locate some of the strongest radio sources in the sky with sufficient accuracy that optical identifications could be made. In 1948 Ryle and F. G. Smith discovered a very strong radio source in the constellation of Cassiopeia, which came to be known as Cas A. This naming scheme reflected a naive expectation that radio sources could be labeled by the constellation in which they were found and that using letters of the alphabet to indicate successively weaker sources would suffice. That system did not survive long and today millions of radio sources have been detected. Nevertheless, this appellation continues to be used for some of the first, and brightest, radio sources discovered back then.

Smith succeeded in improving the radio measurements to the point where an accuracy of 1 arc min allowed the optical astronomers on Palomar mountain to photograph the position and discover the filamentary remains of a supernova in Cassiopeia that coincided with the radio source Cas A (see Chap. 4). The position of Cygnus A (Fig. 1.3) was also measured accurately enough to lead to its identification with a very faint, distant galaxy.

During the later phases of the war, radar antennas in south England had been pointed just above the horizon to detect incoming V2 rockets, and in the process they accidentally picked up echoes from meteor showers. As meteors burn up in the atmosphere they produce ionized trails, which reflect radar signals. This discovery interested Bernard Lovell, of the University of Manchester, who was searching for similar echoes from the trails left by cosmic rays striking the atmosphere. As a pioneer in World War II aircraft radar development, Lovell had access to surplus radar equipment, which the University allowed him to park at their botany research station at Jodrell Bank, south of Manchester. (A peculiar coincidence: Jansky lived in a town called Red Bank, New Jersey; Lovell set up shop at Jodrell Bank, England; the U.S. National Radio Astronomy Observatory is located at Green Bank, West Virginia. This surfeit of banks in radio astronomy locations is still no reflection on the profession's remunerative benefits!)

Lovell's observations revealed no cosmic ray echoes, but more and more meteor trails so that meteor astronomy remained a focus for research at Jodrell Bank. As the radio antennas grew in size, so did their potential for doing radio astronomy. Lovell subsequently propelled Britain into the forefront of the science by masterminding the construction of what was for many years the world's largest fully steerable radio telescope, the 250 ft diameter Mark I, shown in a later incarnation in Fig. 1.1. Completed just before the world's first artificial satellite, Sputnik I, was launched in 1957, the Mark I was the only radio telescope in the world capable of picking up radar echoes from the satellite's carrier rocket and played an important role in stimulating the United States to get more active in radio astronomy, and to develop a more effective radar system for national defense.

2.5 The Southern Skies

Observation of the southern skies fell to the Australian radio astronomers led by J. L. Pawsey, studying the sun, and J. G. Bolton, studying other radio sources, who also began by using surplus ra-

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