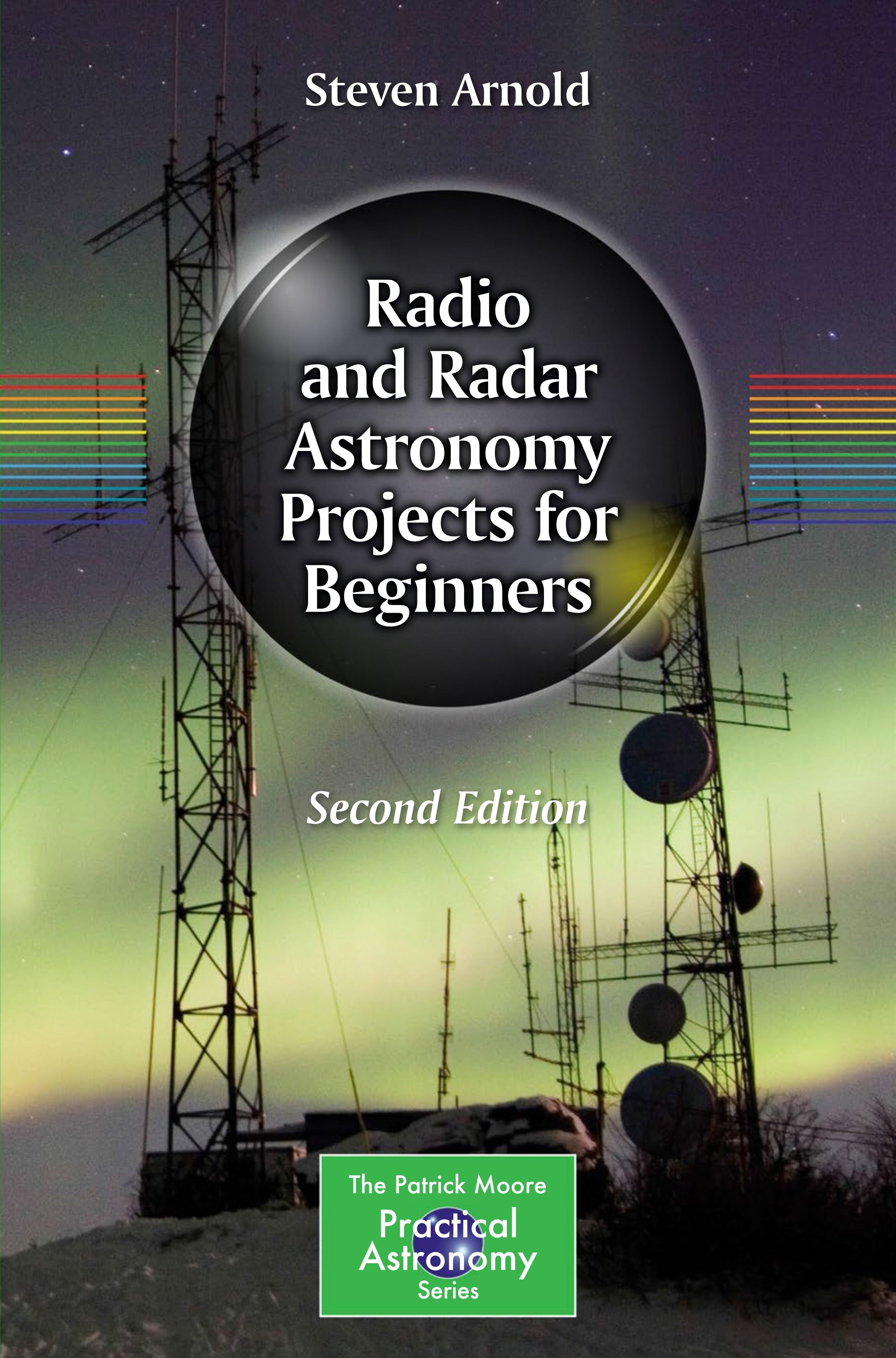

Steven Arnold

Radio and Radar Astronomy Projects for Beginners

Second Edition

The Patrick Moore Practical Astronomy Series

The Patrick Moore Practical Astronomy Series

Series Editor

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Dedicated to
Marjorie, Kate, Minnie, and Alfie

Preface

This second edition book is divided into three parts.

Part I: The History and Science of Radio Astronomy

This section now covers in much more detail the history and science of radio astronomy. It also introduces you to how things work, including receivers, antennas, and feed cables, etc. Also included are updates on the latest changes and advancements made in the field of radio astronomy.

Part II: Self-Build Tried and Tested Projects

These projects were covered in the first edition but now contain updates and extra information that the reader will find useful when choosing what equipment will be suitable for different observing sites.

Part III: Radio Astronomy with a Software-Defined Radio (SDR)

This is entirely a new material showing how technology has progressed. It introduces the latest tools available to the amateur radio astronomer and walks readers through any pitfalls they may encounter setting up and running successful SDR equipment. Also included is advice on purchasing equipment, what software to use, where to get it, and how to set it up and use it. You will find in this section some fun projects to build. These are aimed at the beginner and move up to more advanced ones for the seasoned observer.

Note that credit lines are provided for figures taken from other sources. All other figures and images are my own.

Safety and Legal Matters

Please read this material before continuing through the rest of the book.

It is impossible to think of every eventuality, but if a few common sense precautions are put into practice, then no harm should come from building and using these projects.

Electrical Safety

1. *Electricity can kill!* If in any doubt about mains/grid power supply, consult a qualified electrician.
2. Remember it can get damp outside in the evening and early morning with dew from the grass and condensation as things cool down. Therefore, it is not advisable to have mains/grid power outside on an extension lead, as there is a risk of electric shock. There is the added danger that someone may trip over the lead in the dark.
3. If a soldering iron is being used, make sure it is not within the reach of children or pets, and allow it at least 30 min to cool down after use before putting it away.
4. If mains/grid power is to be used instead of batteries, seek the advice of a qualified electrician if in any doubt.

5. Please follow any instructions supplied with the kits carefully, especially where polarity is involved. Some electronic components are polarity sensitive. As a rule of thumb: check twice, solder once.
6. Replace any blown fuse with one of equal value.
7. If there is a local thunderstorm, switch off any receivers/monitors and computers and unplug antennas.
8. Under no circumstances apply mains voltage to a coax feed cable.

Do-It-Yourself (DIY) Safety

1. Take the precaution of wearing eye protection and other safety protection as and when the need arises.
2. If power tools are to be used, refer to the manufacturer's instructions and follow any advice given. The same applies to hand tools and others.
3. When soldering, make sure there is adequate ventilation to remove fumes generated by the soldering process.
4. Solder now comes in lead-free varieties, but it is still a good practice to wash hands after use or before eating or drinking.
5. When working at heights, for example, off a mast, be sure to wear the correct fitting harness. If working off a ladder, make sure it is the right ladder for the height. Do not overreach, and have someone trustworthy steadying the ladder.
6. If metal antenna masts are used, make sure they are earthed to prevent damage if struck by lightning.
7. When fitting the feed cable to a mast, allow enough cable to put a "U" bend at the base of the mast. This serves two purposes:
   (a) It will allow rain to drip off and not run along the cable.
   (b) If the antenna is struck by lightning and travels along the cable, it is more likely to discharge to earth at the base of the "U" bend, therefore hopefully protecting equipment further along.

Using Equipment in the Countryside

1. Please respect "no entry" and "private land" signs. Get the landowner's permission first before crossing their land.
2. Each country has its own laws regarding personal safety and the level to which this can be upheld. Take simple precautions such as carrying a cell phone and letting someone trustworthy know the plan and an estimated time of return. But, remember to stick to this plan.

3. It is also a good idea to carry extra food and water, plus a basic first aid kit, insect repellent, etc.
4. In the event of a thunderstorm, do not be tempted to shelter under a tree. Trees are basically full of water and make a good lightning conductor. However, the safest place is inside a metal-bodied vehicle.

Software Downloads

1. When software is downloaded from the internet, whether freeware or licensepaid, please respect the terms and conditions of its use.
2. If it is freeware and there is a donate button, consider leaving a donation of a few dollars, as this can be used to make improvements to the future versions of the software.
3. With the ever-increasing threat from cyber-attacks, it is a good practice to keep any anti-malware or anti-virus software up to date and scan any downloaded software with the aforementioned anti-malware or anti-virus software before it is opened or used on your computer.
4. A good idea is to have any personal information, files, documents, and images backed up elsewhere, perhaps on a separate hard drive or online “cloud” servers.

Software-Defined Radios (SDRs)

1. Software-defined radios (SDRs) are powerful tools capable of covering a large number of frequencies. Please respect the laws of the country in which it is being used. For example in the UK, it is not against the law to receive radio broadcasts from commercial or amateurs, but it is against the law to broadcast unless you have passed a radio operator’s test and have a license to do so.
2. Receiving frequencies used to handle sensitive information in most if not all countries is against the law for obvious reasons. If you alight on such a frequency, do not make any recordings and leave the frequency immediately.

Contents

Part I

The History and Science of Radio Astronomy

Chapter 1

A Brief History of Radio Astronomy

First Attempts at Receiving Radio Transmissions from the Sun

In the late 1880s, a scientist by the name Heinrich Hertz conducted a series of experiments where he successfully transmitted and received radio waves across his laboratory. After doing this, Hertz noted in his journal, "I have successfully transmitted and received radio waves and have found them of no practical use." The unit of frequency, Hertz (Hz), would later be named in his honor.

The first documented attempt at receiving radio waves from the Sun was in the early 1890s by Thomas Edison. Edison was not only an innovator but also a brilliant salesman with a knack for convincing investors to believe in his ideas. Why Edison woke up one morning with the belief that the Sun emitted radio waves is unclear. Regardless, Edison sent one of his assistants to the Lick Observatory in California with instructions on how to construct an antenna and receiver. Unfortunately, there are no documents surviving with details of the construction and design plans for Edison's receiver and antenna. After this first failed attempt to receive radio waves from the Sun, Edison made no further attempts to repeat his experiment. At the time, he

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The original version of this chapter was revised. The correction to this chapter is available at https://doi.org/10.1007/978-3-030-54906-0_20

S. Arnold, *Radio and Radar Astronomy Projects for Beginners*, The Patrick Moore Practical Astronomy Series, https://doi.org/10.1007/978-3-030-54906-0_1

was caught up in the great "Current War" with Nikola Tesla, wherein Edison had his direct current (DC) and Tesla had his alternating current (AC).

Around this time, radio waves were still new and not fully understood. The idea of wavelength and frequency was still years away. It was thought that radio waves could only travel in straight lines, like the beams of light coming from a lighthouse. No one was sure how they propagated, so a mysterious substance called "luminiferous aether" was invented to explain it. This aether was invisible but allowed radio waves to travel through it.

It wasn't until 1900, when Marconi demonstrated the first trans-Atlantic radio transmission from Poldhu in Cornwall to Newfoundland, that such long-distance radio transmission was proved possible. (It must be said that there is some conjecture concerning whether Marconi actually did make this radio transmission or not, and whether Marconi did in fact invent the radio. There is evidence that Nikola Tesla invented the radio, but Marconi beat him to the patent. We'll assume here that Marconi did make the transmission.)

After Marconi made this transmission, in a separate experiment, the idea that radio waves could only travel in straight lines was proven incorrect. Shortly thereafter, the belief in the aether, that mysterious medium that aided the propagation of electromagnetic waves, was finally abandoned.

Many theories were put forward how it was possible for radio waves to travel around the Earth. One theory suggested there could be a layer in the upper atmosphere that was able to reflect radio waves back down to the Earth and allow great distances to be covered. This theory turned out to be correct and will be covered in Chap. 4.

The first radio transmitters were nothing more than "spark coils." These work in a similar manner to the ignition coil on a petrol engine. A coil is charged up and when the electrical energy is released, a spark jumps across a gap between two electrodes. If this is fed to an antenna it makes a crude radio transmitter. There is no modulation to the signal—it is either on or off—but it is enough to send messages using Morse code.

Here is a link to a video showing a spark coil transmitter: https://www.youtube.com/watch?v=YSf93g0heUA.

Between the years of 1890 and 1897 a further attempt at receiving radio waves from the Sun was made by Sir Oliver J. Lodge. He built an antenna and receiver, but he too failed to receive anything. This attempt is not well documented, so it is not clear exactly why he failed. Maybe his equipment wasn't sensitive enough, he was trying the wrong frequency, or the solar activity was simply very low.

The next attempt to receive radio emissions from the Sun was made by two astrophysicists, J. Schiener and J. Wilsing between the years of 1897 and 1899. They constructed their own antenna and receiver and let their experiment run for just over a week, but they also failed to receive radio emissions from the Sun. From this, they incorrectly theorized that the atmosphere must therefore be absorbing all radio waves coming from the Sun. They were on the right track, as the Earth's atmosphere does absorb some radio waves.

These failed experiments added fuel to the theory of a reflective layer in the upper atmosphere that was capable of reflecting radio waves back towards the Earth and which in turn must also reflect any radio waves from the Sun back into space.

Between the years 1899 and 1901, and based on the incorrect theories developed from the week-long experiment, French graduate student Charles Norman took the interesting approach of taking his receiver and antenna up a mountain to an altitude of over 10,000 ft (3000 m). Norman thought that if Schiener and Wilsing were right about the atmosphere absorbing radio waves, he may be able to receive something at this altitude, as he was above the thickest part of the atmosphere. Yet he also failed to receive anything.

Experts looking back over his notes and equipment have agreed that Norman's equipment would have been sensitive enough to receive some radio emissions from the Sun. Unfortunately, he carried out the experiment at the time of solar minimum, and it was just a case of bad luck he didn't receive anything.

After all these early attempts ended in failure, the idea of receiving radio waves from the Sun went out of fashion, also in part due to the onset of the First World War. It wasn't until the middle of World War II that this mystery would finally be solved—more about this in later chapters.

First Attempts at Listening for Radio Signals from Space

The first attempts at listening for radio signals from space were carried out by Marconi and Tesla shortly after the invention of the radio in the early 1920s. Marconi fitted a radio receiver to a ship and sailed into the Atlantic Ocean to get away from human made interference. Tesla built a large radio transmitter in Colorado Springs. Tesla's device was capable of both receiving as well as transmitting signals. Both men heard strange whistling and chirping noises, and both failed to realize they were produced by the Earth itself within its own magnetic field.

The whistling noises are now known as "whistlers." These are very low frequency (VLF) signals from lightning discharges that have traveled up into the ionosphere and interacted with the Earth's magnetic field lines. The chirping noises are now known as "tweeks." These too are VLF signals. Tweeks are created by charged particles from the solar wind interacting with the Earth's magnetic field. VLF signals are strange-sounding signals.

It is no surprise that when they were first heard, it wasn't known whether they came from space or had a more paranormal nature.

From this experience, Tesla became obsessed and went on to build a radio receiver that came to be known as his "spirit radio." When using his spirit radio Tesla heard even stranger sounds that he thought sounded like voices, which led him to believe he was picking up spirit voices of the dead. The Fig. 1.1 below is a modern version of Tesla's spirit radio.

Edison tried looking for spirit voices within the amplified white noise of his phonograph. When this failed, he theorized building a device to communicate with the recently departed and record their spirit voices for relatives to hear. This device came to be known as the "telephone to the dead,"

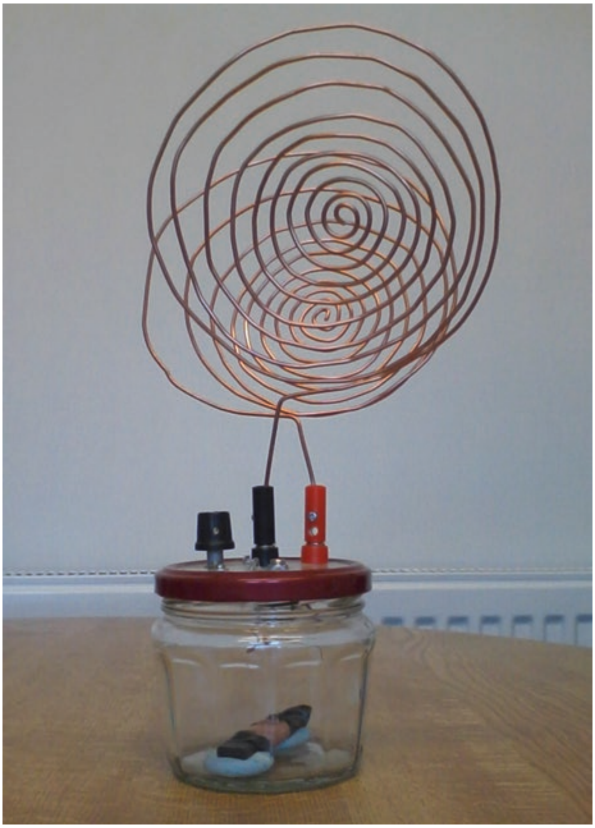

Fig. 1.1 A modern copy of a Tesla spirit radio

or the “spirit telephone.” There is no record of this device being found or even if it was built.

Anyone interested in building a Tesla spirit radio please see Chap. 19.

The Discovery of the Ionosphere

In the early to mid-1920s, extensive work was carried out by a number of scientists and researchers to prove the existence of a reflective layer high up in the Earth’s atmosphere. Over several years, radio signals were bounced off this reflective layer and the returning signals were studied in order to try and understand its properties.

This reflective part of the atmosphere, later to be known as the ionosphere, was found to reflect certain frequencies of radio waves like a mirror reflecting a beam of light. It was first thought that no radio waves could travel through the ionosphere. As the technology improved, however, it was demonstrated that the ionosphere would indeed allow certain radio waves to pass through it, so long as they were at the right frequency.

A practice called “sounding the ionosphere” was then introduced. This involved reflecting radar beams off the ionosphere from the Earth’s surface to study its properties and understand its effects at different frequencies. Other attempts to understand the ionosphere’s properties included sending transmitters high into the Earth’s atmosphere using high altitude balloons. Even rockets have been used, but this took place later, after reliable rocket technology had been developed.

Ionospheric studies and testing are carried on up to the present day, analyzing changes to the structure of the ionosphere and any changes due to seasonal variation. Today, satellites are employed to help perform tests involving the ionosphere.

In 1927 a scientist named Sydney Chapman proposed the first mathematical model of the Earth’s ionosphere. This was considered at the time to be the best model to explain the then-known properties of the ionosphere and took into account how the ionosphere changes throughout the year.

The Birth of Radio Astronomy

In the early 1910s, the fastest way to send communication across the Atlantic Ocean was to use telegraph. The wires for telegraph equipment had to run along the bottom of the Atlantic Ocean. Such underwater cables are very expensive to lay and command a large investment, so Bell Laboratories started looking into the idea of using trans-Atlantic radio telephone calls as a cheaper alternative. But every time they tried making radio telephone calls, they encountered interference. The origin of this interference was unknown; some theorized it could be a competitor deliberately trying to cause problems.

Between the years of 1930 and 1932, a young telephone engineer named Karl Jansky (1905–1950), working for Bell Laboratories in America, was tasked with investigating the interference that was plaguing these long-distance high frequency communications at 20.5 MHz. Jansky's job was to find the source of the interference and come up with a solution to the problem.

Jansky built himself a large antenna that could be moved on a circular track. This contraption was affectionately nicknamed the "merry-go-round" antenna (Fig. 1.2).

Jansky's antenna used two pairs of Ford Model T wheels to support the frame, allowing him to move it single-handedly in the hope that through altering its direction he could narrow down the direction of the interference problem. He found after running his equipment for a short time that the interference seemed to come at regular intervals: every 23 h 56 min and 4 s. This meant it happened nearly 4 min earlier each day.

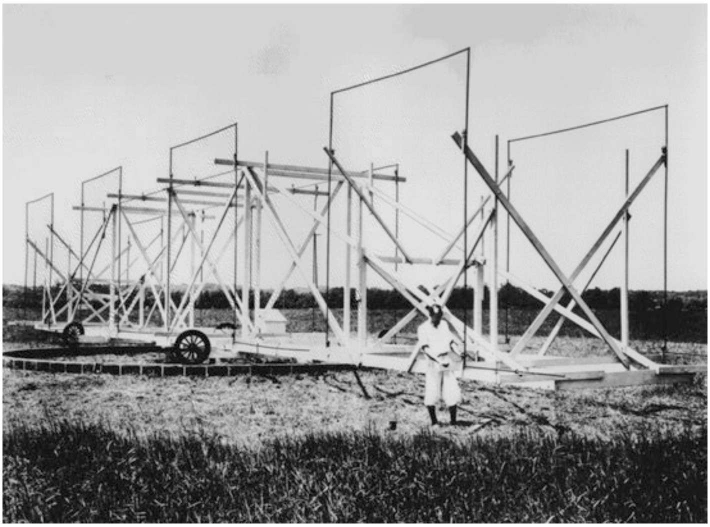

Fig. 1.2 The "merry-go-round" antenna. Its creator, Karl Jansky can be seen right of centre. (Image courtesy of NRAO/AUI)

This must have left Jansky scratching his head, as Jansky was an engineer, not an astronomer. Most astronomers would have soon realized what this could be. The Earth doesn't rotate on its axis in exactly 24 h, but takes 23 h 56 min and 4 s, and therefore, a point in space such as a star rises approximately 4 min earlier each day. Finally, Jansky concluded that the source of the unknown interference must be coming from the sky and space itself. This was the first such signal received from space.

Thereafter, Jansky tried to narrow down which part of the sky the interference was coming from. This sounds easier than it actually is because, as we will find out later, radio telescopes have very poor angular resolving power. And it is very difficult to pinpoint an exact point in the sky. In order to identify the location of this radio emission as accurately as he could with his equipment, he estimated the beam width of his antenna, then consulted star maps to know what part of the sky—or more importantly which constellation—was passing through the antennas beam at the exact time the interference was detected.

Jansky did this over a number of days, watching to see when the signal received by the antenna was at its strongest. He then came to the conclusion that the source of the radio emissions or interference was coming from the part of the sky that contained the constellation of Sagittarius. The design of the antenna made it impossible to narrow it down any further than this.

Bell Laboratories received Jansky's report and the accompanying realization that the source of the interference was of an extraterrestrial origin, and therefore, nothing could be done to solve the problem. Jansky asked for extra funding in order to investigate this radio source further and try and pinpoint the exact part of the sky from where it was being emitted. The funding to build a larger antenna and more sensitive equipment was refused. Despite his protests that this first-ever extraterrestrial signal warranted close investigation, the funding was never granted.

Jansky published his findings in 1933—a year that would go down in history as the start of the science of radio astronomy.

Jansky died in 1950 from a heart condition at the young age of 44. In his honor, the unit used in radio astronomy to represent the energy or "flux" coming from a radio source is called the "Jansky." A crater on the far side of the Moon is named in his honor, in recognition of his discovery of the first radio source beyond the Earth.

There is a podcast on Jansky available through www.365daysofastronomy.org. This podcast was written and recorded by Dr. Christopher Crockett of the United States Naval Observatory, as part of Dr. Crockett's astronomy word of the week series. The podcast, dated April 11, 2012, is well thought out and presented and worth tracking down. Here is the link: www.cosmoquest.org/x/365daysofastronomy/2012/04/11/april-11th-astronomy-word-of-the-week-jansky/.

The First Radio Telescope

Nothing was done to follow Jansky's discovery until Grote Reber (1911–2002) came along. As a young electrical engineer, Grote Reber was intrigued by Jansky's results about the mysterious source of extraterrestrial radio emissions and wished to follow up on such research, taking them to what Reber described as a "logical conclusion."

Reber applied several times to Bell Laboratories, but his applications were repeatedly refused, not because of his qualifications or his intention to follow up on Jansky's work, but because they came in the mid-1930s, amidst the Great Depression. Taking matters into his own hands, Reber decided in 1933 to build his own radio telescope (Fig. 1.3).

The antenna was the first radio telescope purposely built to study the sky. The diameter of the dish was 29.5 ft (9 m). Reber constructed it by himself, in his own garden! He built the telescope frame and shaped the dish to give

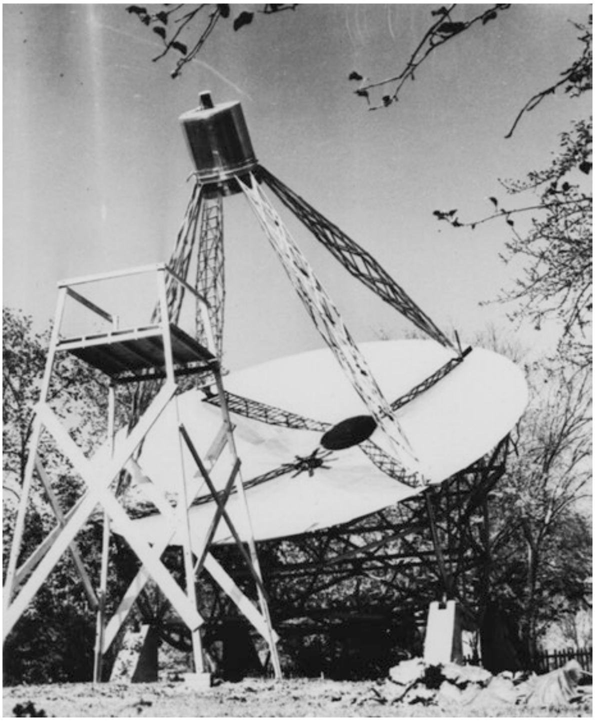

Fig. 1.3 Grote Reber's homemade radio telescope. (Image courtesy of NRAO/AUI)

it its parabolic shape. He also built all his own receivers. This was long before the miniaturization of electronics with the use of transistors and microprocessors.

The receivers would have been made up of a collection of vacuum tubes (valves) used in the amplifiers and receiver circuits. Vacuum tubes are very fragile, being made of glass, and are difficult to manufacture, so they would have been expensive. Vacuum tubes demand more electrical power to operate and take time to "warm up" before they will operate properly.

When he had finished, Reber had a radio telescope that could only be moved in altitude (up or down), while the azimuth (east-west) movement of the telescope depended on the rotation of the Earth. Thereafter, he started to make sweeps of the sky, but he found that the interference from the local neighborhood, especially from the sparks of vehicle ignition systems, made this very difficult. He tried at different times of the day and found the best time to observe was from midnight to 6 am when most people were in bed. Between these times things quietened down enough to allow him to make useful observations with his equipment. This is still true today.

Reber's day would start in the morning with breakfast and then a 30-mile (50 km) drive to his place of work, in a radio factory. He would work a full day, then drive the 30 miles (50 km) back home. On arriving home around 6 pm he would have his evening meal, then try and grab a few hours of sleep. Just before midnight, he would rise and start observing with his radio telescope from midnight to 6 am. Then, once again, he would eat breakfast and drive to work. And so it went on night after night. He did this for a number of years until he had created the first radio map of all the sky that he could observe from his location. That's dedication!

Reber's map by today's standards would be considered rather crude, but he did confirm Jansky's findings of a radio source in the constellation of Sagittarius. He also found strong radio emissions coming from other areas of the sky and published his findings in 1938.

The American National Radio Astronomy Observatory (NRAO) research center based in West Virginia went on to employ Reber as a consultant from the early 1950s onward. Reber donated his homemade radio telescope to the NRAO, and it is now sited at the NRAO's Greenbank Science Center where it is preserved and maintained. It has been fitted with a turntable that allows it to be turned in azimuth.

In 1954 Reber moved to Tasmania and worked at the University of Tasmania, where he carried on with the study of radio astronomy. He died shortly before his 91st birthday.

There is a very good podcast available on online, which includes an interview with Grote Reber. The podcast can be found at the NRAO's Mountain Radio website. Here is the direct link: https://www.gb.nrao.edu/epo/mra/

Grote.mp3. In the podcast, Reber is interviewed by a member of the Greenbank Radio Telescope staff. Reber talks about how he built his radio telescope and the problems that he had to overcome in doing so.

Here is another link to a podcast, dated August 31, 2009, about Grote Reber: www.cosmoquest.org/x/365daysofastronomy/2009/08/31/august-31st-grote-reber-the-first-radio-astronomer/.

The Outbreak of World War II

In 1939, at the outbreak of World War Two in Europe, a veil of secrecy descended over most of the world.

Countries taking part in the war could ill afford luxuries such as funding research into subjects like radio astronomy. A great deal of academic research was put on hold, but this did not mean that scientists escaped the war—rather, they were reassigned, given new war-related duties such as code breaking or weapons and technology research.

During this period, the United Kingdom invented a new system for “RAdio Direction And Ranging”—RADAR. The first attempts were very basic, tall wooden masts with wires strung between them. These transmitted a radio signal, while a separate mast and antenna were used to receive the returning echo. This returning echo was then shown on an oscilloscope screen, with the operator having to make their best guess regarding what the signal meant and how far away an object was.

As the war raged on, the call for better radar equipment increased and a number of instillations were built to give radar cover to the entire east coast of the United Kingdom. The remains of these installations are still visible along the Norfolk and Suffolk coastlines of the UK.

All the radar installations were in contact with each other by telephone. The advantage of having a larger number of installations was that each station could compare their signals to the ones on either side to see who had the strongest echo. This information was used to give a better and more accurate way of judging an object’s distance and direction of travel. It was the job of the station with the strongest echo to call the results in to the senior person so a decision could be made on the best course of action. Despite being very basic, the system allowed enough warning to act against enemy units over the North Sea.

Some radar operators reported receiving a large echo on their equipment that seemed to be coming from over mainland Europe. Was this an attempt by the enemy to block or jam the radar? Had they developed their own radar? If so, what could be done about it?

In 1942 a group of technicians lead by J.S. Hey (1909–2000) was sent to find the origin of this large echo. After an exhaustive search and a thorough examination of the equipment, Hey and his colleagues thought the only possibility left was the Sun. Could the Sun indeed be the source of the signal that the radar operators had reported receiving?

After consulting with astronomers observing the Sun, they confirmed that a large group of new sunspots had appeared on the Sun's disc. This revealed the connection between solar activity and radio emissions from the Sun. Hey didn't publish his findings until 1946, after the end of the war. During the war, Grote Reber had also detected emissions from the Sun, and he published his results in 1944.

Advances in wartime technology also led to the invention of a new piece of equipment, called the cavity magnetron. This was a key development that gave rise to a more accurate radar unit. Using smaller wavelengths that readily reflected off an object, the cavity magnetron could provide greater detail and allow smaller objects to be found and tracked more effectively. This also meant that radar units could be made smaller. Small enough now to be fitted into an airplane, these units gave rise to airborne radar.

It must be noted that this progress came at a price. In the rush to develop the cavity magnetron, safety wasn't given as high a priority, and several people were irradiated, some quite badly. In the workshops where the cavity magnetron was developed, every time it was switched on, people reported that the cheese in their sandwiches started melting. When the radar units were fitted into airplanes, there was very little in the form of shielding, as weight was an issue. The less shielding used, the more fuel and bombs could be carried. The lack of shielding from these new radar units gave rise to similar reports by the flight crew that bars of chocolate they had been carrying with them had melted, providing further evidence that the shielding was inadequate. The workings of the modern microwave oven are a spin-off of the technology used to develop the cavity magnetron, but the shielding problem surrounding the leaking of microwave energy has been adequately addressed.

At this point in the war, radar equipment could be made smaller and more efficiently. Portable anti-aircraft units were now available, and mobile radars mounted on trailers could be towed anywhere they were needed.

While the radar operators were using this new portable equipment, they reported receiving short-duration echoes that lasted from less than a second up to around 5 s. This was another mystery to be solved.

By this time, V1 and V2 rockets were being sent over from mainland Europe. The V2 rockets traveled at high velocities approaching supersonic speeds. (The technology from these V2 rockets would eventually put astronauts on the Moon.) Did these short-duration echoes have anything to do with these new weapons? Hey and his colleagues looked into all possibilities that might explain their existence. His team came up with a different theory—that these echoes could be coming from meteors as they entered the Earth's atmosphere.

After the end of World War II, there were lots of ex-army portable radar units being sold off cheaply to try and recoup some of the money that the war had cost. Hey got hold of some of these units and carried out experiments using the radar units to prove this theory. In 1944–1945, using astronomical data from past meteor shower observations, he proved that the short-duration echoes really did come from meteors. This will be covered later in Chap. 16.

This leads to an interesting story about the Parkes Radio Telescope in Australia. For years, the Parkes Radio Telescope kept picking up short-duration pulses, only fractions of a second in length. They were quite random in nature, with more happening during the day. After an exhaustive search, the source of these pulses still could not be found, until 1 day a research student found the culprit: the microwave oven in the visitor's center! If the user pulled open the door before the microwave had stopped, the minute leak of microwave radiation caused a pulse to show up on the large radio telescope.

There is a good film showing how the first radar was developed. It is available online from movie streaming services, called "Castles in the Sky." Produced by the BBC and starring Eddie Izzard as Robert Watson-Watt.

Project Diana: The Moon Bounce Experiment

Project Diana was an attempt by the United States to bounce a radar signal off the Moon using a modified Second World War radar transmitter and receiver. The name "Diana" was chosen for this project because the goddess Diana in Roman mythology was said to hunt animals at night by the light from the Moon.

The radar equipment used was a SCR-271 early warning radar unit and was army surplus left over after World War Two. A transmitter and receiver were built for the purpose on a site in New Jersey and were modified by Major E.W. Armstrong, an army consultant during the war and famous for pioneering the use of frequency modulation.

The transmitter was designed to transmit at a frequency of 111.5 MHz in 0.25-s pulses. It was hoped that the power of the transmitter, some 3000 W, would be enough to send the pulses through the ionosphere, all the way to the Moon and back to the Earth.

The antenna could only be moved in azimuth, which meant scientists had to wait for the Moon to be in the right part of the sky and within the beam of the transmitter before any attempt could be made. The first successful detection of an echo from the Moon was done by J.H. Dewitt and E. King Strodola in January 1946. The received returning echoes arrived approximately 2.5 s after transmission. This will be covered later in Chap. 17.

The Early Jodrell Bank

In 1945, British scientist Bernard Lovell (1913–2012) had returned to his post at Manchester University in the United Kingdom after his wartime service working on the development of radar. There, he wanted to carry on with research into cosmic rays. Cosmic rays are highly energetic particles that enter the Earth's atmosphere and nowadays are thought to originate from some of the most violent explosions in the universe, such as those from supernovae. Lovell had a theory that went against Hey's theory. He believed that the "meteor echoes" received by the portable radar units were in fact cosmic rays entering the Earth's atmosphere, and radar could be a way to prove this.

Radar and radio observations taken from the city of Manchester were useless because of the level of interference from the inhabitants of the city. A more remote and radio-quiet observing site was needed for Lovell to make his observations. Luckily for Lovell, Manchester University rented a plot of land approximately 20 miles (32 km) south of the city. This area, named Jodrell Bank, was used by the University as a botanical garden.

A team was sent to Jodrell Bank with a portable radar unit. At that time, the site was nothing more than a large, open expanse of land with a small wooden building housing the agricultural workers' tools. The radar unit was fitted with a Yagi antenna and mounted onto a trailer, then set up on the side of the wooden building. This building would become the headquarters for the equipment and staff while at the Jodrell Bank site.

By December of 1945, the team at Jodrell Bank had proved that Hey was right and that the radar echoes did come from ionized meteor trails, and not as Lovell had first thought from cosmic rays. Lovell realized that he would need a more sensitive radio telescope if he was going to detect cosmic rays.

In 1947, the researchers at the newly named Jodrell Bank Experimental Station built a 218-ft (66-m) parabolic reflector made of wire mesh, which pointed towards the sky. There was a mast in the centre of the wire mesh reflector. This mast could be moved around by tightening or slackening a number of guide ropes used to support the central mast, meaning the radio telescope was slightly steerable a few degrees or so in either direction from the zenith. As the Earth rotated, the team built up, strip by strip, a map of the sky that could be seen from their location.

Lovell never detected any echoes from cosmic rays, but the telescope made the first detection of radio emissions from the Andromeda Galaxy. This proved the existence of radio emissions outside our own Milky Way Galaxy.

Pleased by the results from this telescope, but frustrated by the limited steering and the inability of the telescope to cover a greater area of the sky, Lovell put forward plans to design and build a fully steerable radio telescope with a larger collecting area or dish. The new radio telescope design was to have a parabolic dish with a diameter of 250 ft (76 m) made of wire mesh. The structure was to be mounted on its own track so that the whole assembly could be turned in azimuth. Either side of the receiving dish was to be a tower. Each of these towers would have an electric motor and a huge bearing inside a room at the top. These bearings would support the entire weight of the receiving dish assembly and allow the dish to be pointed at any angle in altitude, giving the radio telescope a huge altazimuth mount.

The First Attempt at Interferometry

The construction of a radio telescope is very different from that of an optical telescope. The mirror of a large telescope has to be made to very high specifications and must have the correct shape to bring all the wavelengths of visible light to the same focusing point.

A radio telescope's collecting area can be made of solid sheet metal bent to form a parabolic dish. In some cases this metal can be in the form of a wire mesh. The shape of the collecting area is still important to bring the radio waves to a common focus. Just like an optical telescope the larger the collecting area the better the resolution. Radio telescopes have very poor resolution—as a 100,000 times worse—compared with their optical counterparts. The poor resolution is largely attributed to the fact that radio telescopes work at longer wavelengths, somewhere in the region of 100,000 times longer than those used by optical telescopes.

To put this in perspective: To get the same resolution with a radio telescope as an optical telescope with a 78.7-in. (2-m) mirror, the radio telescope would require a parabolic dish measuring 124.3 miles (200 km) in diameter.

It would be a technological nightmare to try and build a radio telescope with a parabolic dish measuring this diameter. It is more feasible to build a number of smaller dishes that can be placed at intervals, adding up to a col-