Chapter 1

Overview: Discovering an Invisible Universe

Objectives: Upon completion of this chapter, you will be able to describe the general principles upon which radio telescopes work.

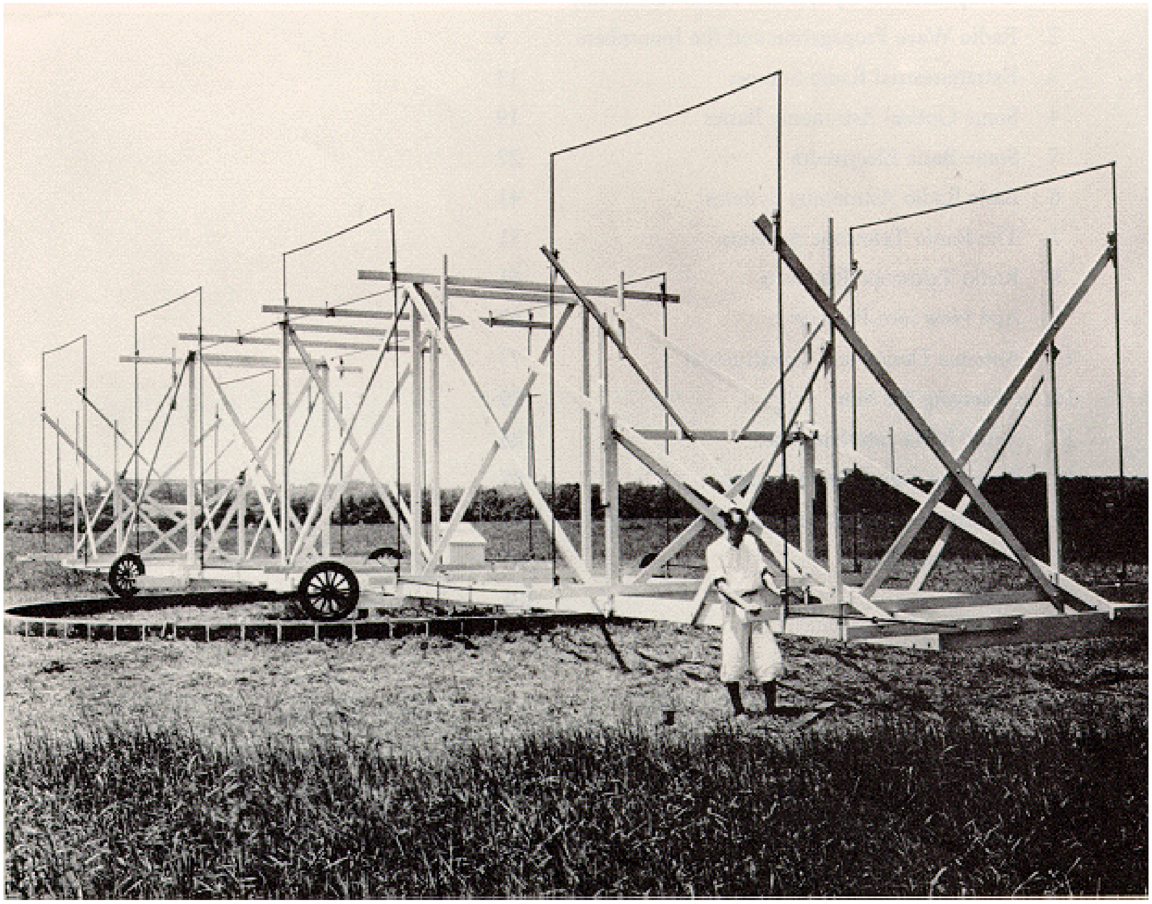
Before 1931, to study astronomy meant to study the objects visible in the night sky. Indeed, most people probably still think that's what astronomers do—wait until dark and look at the sky using their naked eyes, binoculars, and optical telescopes, small and large. Before 1931, we had no idea that there was any other way to observe the universe beyond our atmosphere.

In 1931, we did know about the electromagnetic spectrum. We knew that visible light included only a small range of wavelengths and frequencies of energy. We knew about wavelengths shorter than visible light—Wilhelm Röntgen had built a machine that produced x-rays in 1895. We knew of a range of wavelengths longer than visible light (infrared), which in some circumstances is felt as heat. We even knew about radio frequency (RF) radiation, and had been developing radio, television, and telephone technology since Heinrich Hertz first produced radio waves of a few centimeters long in 1888. But, in 1931, no one knew that RF radiation is also emitted by billions of extraterrestrial sources, nor that some of these frequencies pass through Earth's atmosphere right into our domain on the ground.

All we needed to detect this radiation was a new kind of "eyes."

Jansky's Experiment

As often happens in science, RF radiation from outer space was first discovered while someone was looking for something else. Karl G. Jansky (1905-1950) worked as a radio engineer at the Bell Telephone Laboratories in Holmdel, New Jersey. In 1931, he was assigned to study radio frequency interference from thunderstorms in order to help Bell design an antenna that would minimize static when beaming radio-telephone signals across the ocean. He built an awkward looking contraption that looked more like a wooden merry-go-round than like any modern-day antenna, much less a radio telescope. It was tuned to respond to radiation at a wavelength of 14.6 meters and rotated in a complete circle on old Ford tires every 20 minutes. The antenna was connected to a receiver and the antenna's output was recorded on a strip-chart recorder.



Jansky's Antenna that First Detected Extraterrestrial RF Radiation

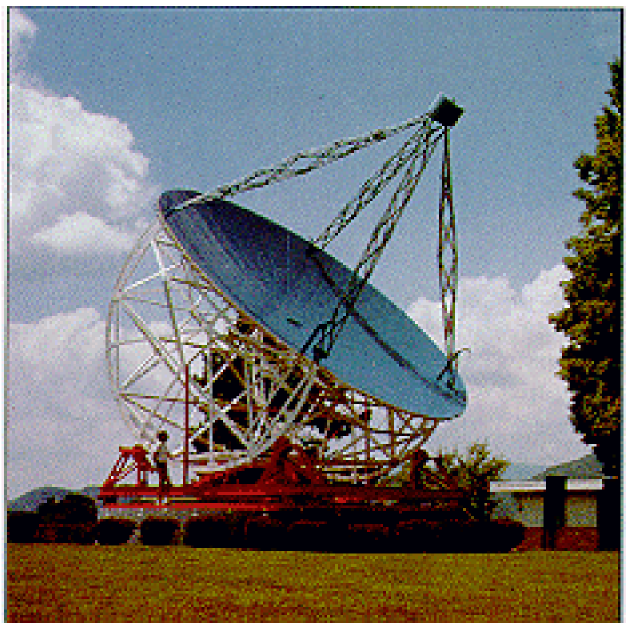
He was able to attribute some of the static (a term used by radio engineers for noise produced by unmodulated RF radiation) to thunderstorms nearby and some of it to thunderstorms farther away, but some of it he couldn't place. He called it " . . . a steady hiss type static of unknown origin."

As his antenna rotated, he found that the direction from which this unknown static originated changed gradually, going through almost a complete circle in 24 hours. No astronomer himself, it took him a while to surmise that the static must be of extraterrestrial origin, since it seemed to be correlated with the rotation of Earth.

He at first thought the source was the sun. However, he observed that the radiation peaked about 4 minutes earlier each day. He knew that Earth, in one complete orbit around the sun, necessarily makes one more revolution on its axis *with respect to the sun* than the approximately 365 revolutions Earth has made about its own axis. Thus, with respect to the stars, a year is actually one day longer than the number of sunrises or sunsets observed on Earth. So, the rotation period of Earth with respect to the stars (known to astronomers as a sidereal day) is about 4 minutes shorter than a solar day (the rotation period of Earth with respect to the sun). Jansky therefore concluded that the source of this radiation must be much farther away than the sun. With further investigation, he identified the source as the Milky Way and, in 1933, published his findings.

Reber's Prototype Radio Telescope

Despite the implications of Jansky's work, both on the design of radio receivers, as well as for radio astronomy, no one paid much attention at first. Then, in 1937, Grote Reber, another radio engineer, picked up on Jansky's discoveries and built the prototype for the modern radio telescope in his back yard in Wheaton, Illinois. He started out looking for radiation at shorter wavelengths, thinking these wavelengths would be stronger and easier to detect. He didn't have much luck, however, and ended up modifying his antenna to detect radiation at a wavelength of 1.87 meters (about the height of a human), where he found strong emissions along the plane of the Milky Way.



Reber's Radio Telescope

Reber continued his investigations during the early 40s, and in 1944 published the first radio frequency sky maps. Up until the end of World War II, he was the lone radio astronomer in the world. Meanwhile, British radar operators during the war had detected radio emissions from the Sun. After the war, radio astronomy developed rapidly, and has become of vital importance in our observation and study of the universe.

So What's a Radio Telescope?

RF waves that can penetrate Earth's atmosphere range from wavelengths of a few millimeters to nearly 100 meters. Although these wavelengths have no discernable effect on the human eye or photographic plates, they do induce a very weak electric current in a conductor such as an antenna. Most radio telescope antennas are parabolic (dish-shaped) reflectors that can be pointed toward any part of the sky. They gather up the radiation and reflect it to a central focus, where the radiation is concentrated. The weak current at the focus can then be amplified by a radio receiver so it is strong enough to measure and record. See the discussion of Reflection in Chapter 4 for more about RF antennas.

Electronic filters in the receiver can be tuned to amplify one range (or “band”) of frequencies at a time. Or, using sophisticated data processing techniques, thousands of separate narrow frequency bands can be detected. Thus, we can find out what frequencies are present in the RF radiation and what their relative strengths are. As we will see later, the frequencies and their relative powers and polarization give us many clues about the RF sources we are studying.

The intensity (or strength) of RF energy reaching Earth is small compared with the radiation received in the visible range. Thus, a radio telescope must have a large “collecting area,” or antenna, in order to be useful. Using two or more radio telescopes together (called arraying) and combining the signals they simultaneously receive from the same source allows astronomers to discern more detail and thus more accurately pinpoint the source of the radiation. This ability depends on a technique called radio interferometry. When signals from two or more telescopes are properly combined, the telescopes can effectively act as small pieces of a single huge telescope.

A large array of telescopes designed specifically to operate as an array is the Very Large Array (VLA) near Socorro, New Mexico. Other radio observatories in geographically distant locations are designed as Very Long Baseline Interferometric (VLBI) stations and are arrayed in varying configurations to create very long baseline arrays (VLBA). NASA now has four VLBI tracking stations to support orbiting satellites that will extend the interferometry baselines beyond the diameter of Earth.

Since the GAVRT currently operates as a single aperture radio telescope, we will not further discuss interferometry here.

What’s the GAVRT?

The technical details about the GAVRT telescope will be presented in the GAVRT system course in the planned training sequence. However, here’s a thumbnail sketch.

GAVRT is a Cassegrain radio telescope (explained in Chapter 4) located at Goldstone, California, with an aperture of 34 meters and an hour-angle/declination mounting and tracking system (explained in Chapter 7). It has S-band and X-band solid-state, low-noise amplifiers and receivers. Previously part of the National Aeronautics and Space Administration’s (NASA’s) Deep Space Network (DSN), and known as Deep Space Station (DSS)-12, or “Echo,” it was originally built as a 26-meter antenna in 1960 to serve with NASA’s Echo project, an experiment that transmitted voice communications coast-to-coast by bouncing the signals off the surface of a passive balloon-type satellite. In 1979, its aperture was enlarged to 34 meters, and the height of its mounting was increased to accommodate the larger aperture. It has since provided crucial support to many deep-space missions, including Voyager in the outer solar system, Magellan at Venus, and others. In 1996, after retiring DSS-12 from the DSN, NASA turned it over to AVSTC (associated with the Apple Valley, California, School District) to operate as a radio telescope. AVSTC plans to make the telescope available over the internet to classrooms across the country for radio astronomy student observations. NASA still retains ownership, however, and responsibility for maintenance.

Recap

1. Because the static Jansky observed peaked 4 minutes earlier each day, he concluded that the source could NOT be ______ __________.
2. Radio frequency waves induce a _____________ in a conductor such as an antenna.
3. The proportion of RF energy received on Earth is __________ compared with the amount received in the visible range.
4. The GAVRT was formerly a part of NASA's ___________ __________ ________________ of antennas supporting planetary missions.

1. the sun 2. current 3. small 4. Deep Space Network (DSN)

For Further Study

- *History and principles of radio telescopes*: Kaufmann, 114-116; Morrison et al., 165.
- *Radio Interferometry*: Morrison et al., 165.