Chapter 1

# The "Wow!" Signal

## Big Ear

A huge antenna was erected in the countryside near Delaware, Ohio, between 1956 and 1963, built with the ambition of being one of the world's premier radio telescopes. These novel gizmos were unveiling an alien sky where stars are dark but previously invisible objects are bright, some blazing furiously spewing out radio waves—a celestial zoo of pulsars, quasars, black holes, and other bizarre objects. Early radio telescopes like this one were basically just radio receivers with big antennas pointed skyward, and celestial objects shining at radio frequencies made a hiss in the receiver when the antenna was pointed toward them.

The antenna's designer was John Kraus, a physicist and electrical engineer at Ohio State University in nearby Columbus who was playing a major role in the new science of radio astronomy. Kraus was a master of antenna design—the inventor of the helical antennas that sprout from many spacecraft—and had conceived a "Big Ear" that would intercept more radio sizzle from distant objects than any other existing radio telescope. It would be too big to track celestial objects by moving; it would instead passively survey the sky by letting the Earth's rotation sweep its searchlight-like beam across the heavens. Construction was slow, modestly funded by the National Science Foundation, with students working as engineers, electricians, and steelworkers.

In radio astronomy, you study the radio glow from distant objects to learn something about them, just as you study light in the more familiar optical flavor of astronomy; radio and light are both electromagnetic radiation. To collect the radio rain sprinkling down from the sky, you need big antennas—big buckets, in a sense. A parabolic dish-like shape has just the right geometry to reflect waves hitting it from directly in front so that they converge at a single focal point, concentrated and all arriving at the same instant, where you put a detector of some sort. Most optical telescopes use a mirror with the magical parabolic shape to do the reflecting, while "dish antennas" use a metal surface or mesh with the parabolic shape for the purpose. The reflected waves generate small voltages in the *real* antenna located at the focus of the dish, often just a stubby little metal rod. After lots of amplification, the voltage is measured to find the radio brightness in the direction the reflector is pointed.

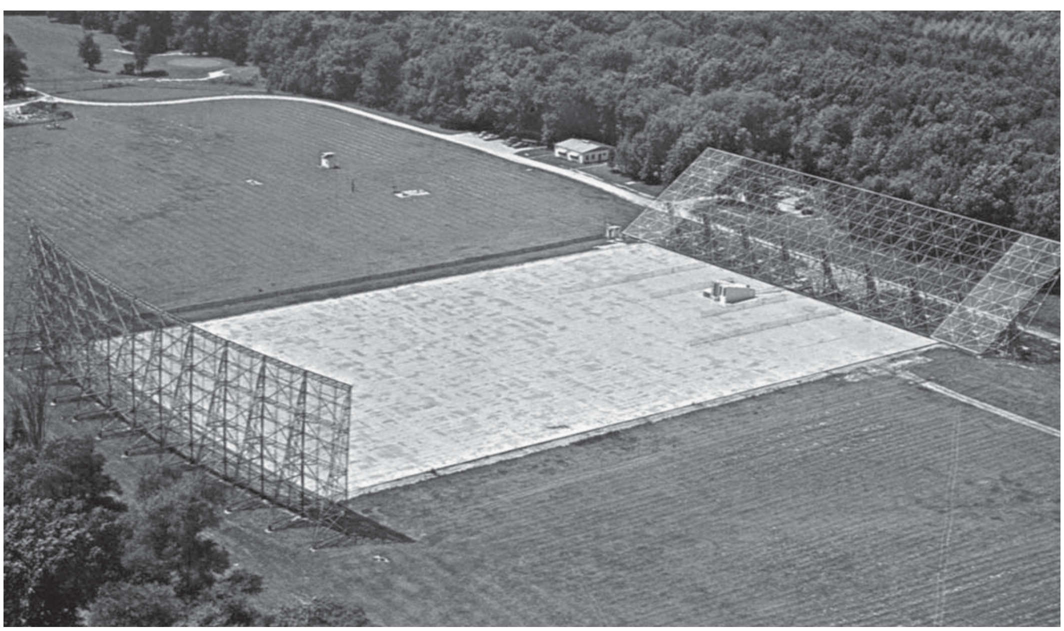

Figure 1.1. The Ohio State University Radio Observatory. The flat structure at right was tilted to reflect radio waves from the sky into the fixed parabolic section on the left, which reflected them back to converge into funnel-like feed horns on the ground in front of the flat reflector. Waveguides carried signals to an underground receiver room. The area between the reflectors was the size of three football fields. Photo courtesy of North American Astrophysical Observatory.

The good news is that radio telescopes can see a previously invisible universe—stuff glowing at radio instead of optical wavelengths. The bad news is that much bigger telescopes are needed than with light because radio waves are much longer than light waves—roughly a million times longer at the frequencies used in a lot of radio astronom—and longer waves need wider reflectors. To get the same spatial resolution or sharpness of view as even a small optical telescope would require a dish many miles across, but it's very hard to build them much bigger than about 300 feet because gravity makes them sag out of shape when they are pointed in various directions.

Kraus's strategy for making a really big antenna was to build a slice through a 360-foot dish—a strip only 70 feet high but the full 360 feet wide—with the bottom edge supported by the ground so it would not sag. Anchored to the ground, it could not move to point at objects in the sky, so he bounced radio waves into it using flat panels 500 feet away, tilting them to point upward at various angles and letting the Earth's rotation sweep the antenna's view across the sky. Figure 1.1 shows the finished antenna.

When it began operating in 1963, the telescope delivered a remarkably detailed view of the radio sky, as shown in Figure 1.2. Its high sensitivity came from its large surface area, equivalent to a dish 175 feet in diameter. Its spatial resolution was as good as a 360-foot dish in the horizontal dimension

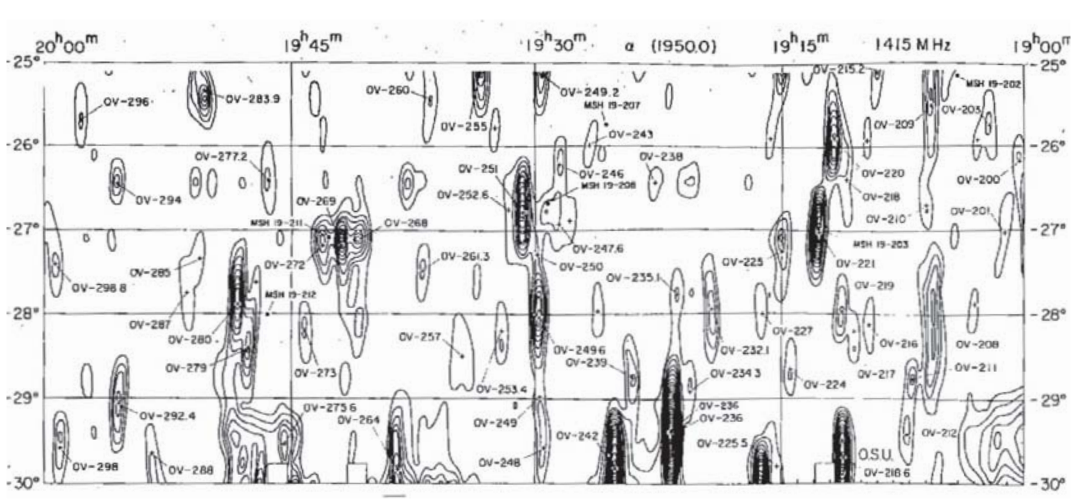


Figure 1.2. A radio map from the Ohio Survey at 1415 MHz. The map covers the area where the "Wow" signal was later detected, although no sign of it is visible here. Source strength is shown by contours and sources appear elongated because of the shape of the antenna, but most are actually point-like. Map courtesy of North American Astrophysical Observatory.

(right ascension, in astronomer's jargon, like longitude projected on the sky) but only one-fifth as good in the vertical dimension (called declination; like latitude) because it was only 70 feet high. Big antennas are directional like searchlight beams, and bigger antennas have narrower beams. Ohio State's beamwidth was about two-thirds of a degree tall and one-eighth of a degree wide, a spot on the sky a bit taller than the Moon (which is a half-degree across) and a quarter as wide.

The observatory surveyed the sky for years and discovered thousands of new radio sources glowing at a frequency of 1415 MHz (frequency is measured in cycles per second but is termed Hertz, after Heinrich Hertz who first demonstrated radio; a frequency of one million cycles per second is termed one megahertz and abbreviated MHz). The Ohio Sky Survey produced maps and catalogs with nearly 20,000 radio sources, more than half of them previously unknown; some turned out to be among the most powerful and distant objects ever found.

By 1972, the big survey was finished. Larger telescopes had been built elsewhere, some using the Kraus design, and the interests of funding agencies were changing. One of the biggest radio telescopes on the planet was left with no financial fuel for astronomical research.

## The first full-time search for ET

Bob Dixon, a former student and later collaborator of Kraus's, spent the summer of 1971 at NASA's Ames Research Center in Mountain View, California, where several dozen scientists and engineers gathered to brainstorm about detecting radio signals from other worlds. Experts in astronomy, biology, computers, design of antennas, engineering, and many other areas developed a preliminary design for interstellar radio receivers and published their findings as a book titled *Project Cyclops: A Design Study of a System for Detecting Extraterrestrial Intelligent Life*. The book argued that intelligent beings might exist on planets orbiting other stars, and that we could detect their broadcasts with special receivers, which were described in detail. The report proposed a large-scale search that might have required hundreds or thousands of big antennas and cost billions of dollars. That ambitious Cyclops system was never built, but the study blazed a trail for later searches and laid the foundation for a NASA search that would go on the air nearly 25 years later.

When Dixon returned to Ohio, he proposed using the unemployed telescope to begin the world's first full-time search for interstellar broadcasts, and Kraus agreed. They lacked funding but had a huge antenna and a good receiver; by December of 1973, they were on the air listening for signals from other worlds. They used an eight-channel receiver tuned near the 1420 MHz frequency of hydrogen thought to be attractive for interstellar broadcasting, a part of the radio spectrum also known as 21 centimeters because of its wavelength (scientists like to use frequency and wavelength interchangeably; waves arriving 1,420 million times per second and traveling at the 300,000 km/sec speed of light have peaks about 21 centimeters or 8 inches apart). The system ran night and day recording the strength of the receiver's output at each frequency on a long roll of strip chart paper, and Dixon and colleagues scanned miles of charts looking for the signature of a radio signal from the stars. They slowly surveyed the 70% of the sky visible from their site after the fashion of their earlier astronomical survey but now looking for radio transmissions.

For more than ten years, the Ohio State project was the world's only full-time search for ET (Project META at Harvard was the second, beginning in 1985). A dozen searches had been done elsewhere, but most were brief and covered only short lists of stars. Ohio was the first to survey a large part of the sky with something that could be fairly called an interstellar radio.

By 1977, a 50-channel receiver was installed and the search was computerized. The "front end" of the receiver was a low-noise amplifier chilled by liquid nitrogen to make it as quiet and sensitive as possible. Each channel consisted of a 10 kHz-wide slice of the radio spectrum, like 50 AM radios tuned to adjacent frequencies. The receiver outputs were fed into an IBM 1130 computer—resembling an office desk more than a computer—which averaged the voltage of signals in each channel for ten seconds to increase sensitivity, like a long photographic exposure. After digesting this for two seconds, the computer would print a line of numbers to record the intensity of the noise detected in each of the channels, hammering out roughly a hundred pages of fan-fold paper each day.

To reduce interference from local transmitters, two feed horns were used to collect the radio waves focused by the big reflector. They were oriented side by side but slightly offset, so that a celestial source would be detected first in one and then in the other a few minutes later. The receiver subtracted whatever one horn was hearing from the other, so local signals appearing in both horns at the same time would cancel out, but signals from a celestial source would not cancel because they appeared in just one horn at a time. Two feed horns gave the antenna two beams, like two searchlights side by side, and a celestial source would normally be detected twice several minutes apart as each of the beams swept across it.

This was the Ohio group's interstellar radio at the time the Wow was detected—big, cleverly rigged to filter out interference, and with a record of having discovered half of the radio sources known.

## The Wow signal

On August 15, 1977, the antenna was pointed about 20 degrees above the southern horizon. As night fell, the beam swept across the Milky Way, lighting up many channels with the radio glow from clouds of hydrogen gas in the galactic plane, then the hiss in the receiver subsided back to the usual steady background level.

Just after 11:15, channel number two of the receiver began registering a signal. The signal's intensity increased during the next half minute as the most sensitive center of the beam swept closer to the source, rising to an unusually strong 30 times the background level when the antenna pointed straight at it. The intensity of the signal then decreased for the next half minute as the Earth's rotation swept the beam past the source. Nobody was there to hear or see it; the printer just hammered out a line of numbers every 12 seconds as it always did while recording the radio sky.

Jerry Ehman later reviewed the accumulated computer printout. He had worked on the big astronomical survey and was the project's volunteer computer wizard. He wrote parts of the computer program that looked for signals, cleverly working within the machine's absurdly tiny but fast 16-kilobyte memory. Ehman had a sharp eye for interference, having seen and rejected many false leads; he knew exactly what the signature of an interstellar radio transmission should look like.

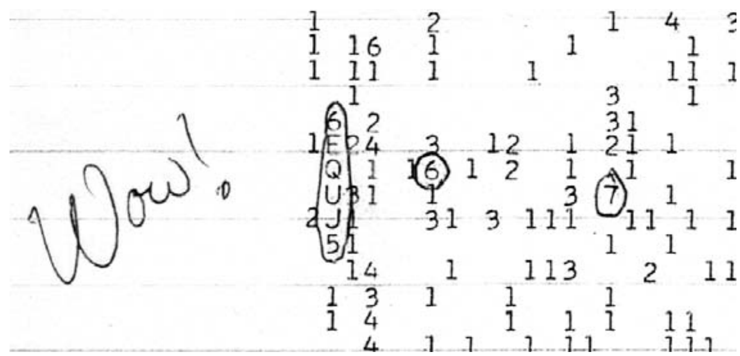

Figure 1.3. Detail of original printout showing Jerry Ehman's "Wow!" annotation and the signal recorded as the characters 6, E, Q, U, J, 5. Courtesy of Jerry Ehman and Bob Dixon, North American AstroPhysical Observatory.

When he saw the sequence of symbols representing the signal, he circled them and scribbled "Wow!" in the margin, because it was exactly what the search sought—a radio signal from the sky, seemingly from a celestial source. It was much stronger than the background noise and matched the signature of a celestial source passing through one of the antenna's beams. The absence of responses in adjacent channels was the signature of a radio signal, as opposed to a natural source which would light up many channels. What he saw is shown in Figure 1.3. Figure 1.4 is a slightly edited version showing all 50 channels and the signal with letter codes converted to numbers.

A chart makes it easier to visualize what the telescope saw. Figure 1.5 shows the intensity in each channel for the six time periods during which the

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Channel Number (10 kHz channels)

Figure 1.4. Intensity of the receiver responses for all 50 channels, recorded at 12-second intervals. The Wow signal is the vertical series of numbers 6, 14, 26, 30, 19, 5 in the second column from left, converted from the original printout which used letters to represent intensities over nine. The Right Ascension coordinates on the right include some but not all corrections. Data courtesy of North American AstroPhysical Observatory.

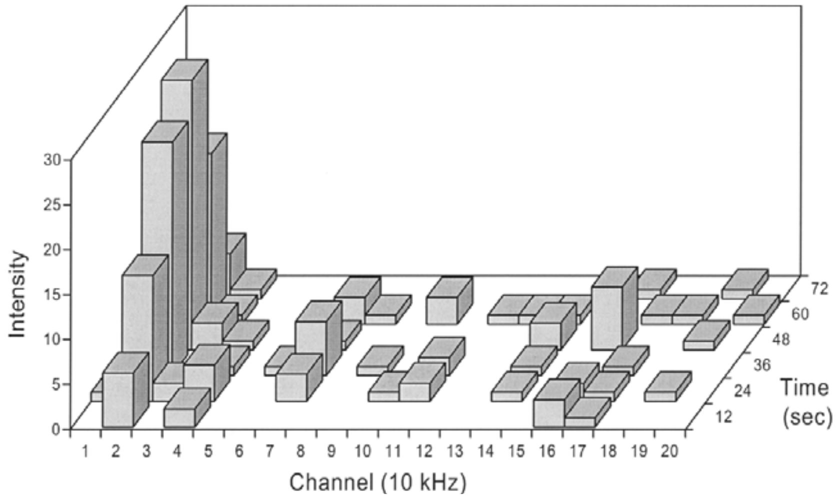


Figure 1.5. Intensity in each channel, showing the rise and fall of the signal in channel 2. Channels 21-50 contained no features stronger than 3 sigma and are not shown. Data courtesy of North American AstroPhysical Observatory.

signal was recorded. The rise and fall of intensity in channel two is due to the antenna's bell-shaped beam sweeping across the source; the signal's strength was probably constant.

The Wow was the strongest signal ever detected by the Ohio State search, other than obvious interference. Its intensity was recorded in units of sigma—how many times stronger it was than the average variation in the background noise (called standard deviation in statistics jargon; called root mean square or rms by engineers). Statistics says that in a system like Ohio's, making 250 averaged measurements per minute (50 channels, five times a minute), random noise might produce a value as strong as three sigma every few minutes or four sigma every hour (going as $\log(n)$), but bigger peaks would be rare and a 30 sigma peak would not be expected in thousands of years.

The Ohio group knew that the Wow was not a natural radio source because their own earlier survey had found none in the vicinity. They found no record of spacecraft that might account for the signal, although secret satellites could not be entirely ruled out. But the frequency band where the signal was seen is reserved for radio astronomy under international agreements and is monitored by astronomers of many nations, which would make it an awfully conspicuous choice for clandestine satellites. Aircraft, near-Earth orbiting spacecraft, and other possible local sources of interference seemed unlikely since the signal passed through the beam in just the time expected of celestial sources.

One aspect of the event was puzzling: a celestial source should be detected twice—first in one beam, then in the other beam a few minutes later as the source passed through the side-by-side beams—but the Wow signal was detected in only one beam.

A simple explanation would be a source turning on or off during the few minutes between the two beams sweeping across it. Few natural radio sources appear and disappear in a matter of minutes, and almost all natural sources make a wideband hiss that would be spread over many channels. Radio transmissions, however, switch on and off easily and might appear intermittently. Many kinds of interstellar transmissions might be intermittent—a narrow beam pointed our way from time to time, for example, or a broadcast in all directions turned on only now and then, or perhaps an antenna something like Ohio State's sweeping its beam across the sky shining our way periodically once each "day".

Alternatively, the signal might have been changing in frequency in just the right way to have drifted into or out of the band during the time between beams sweeping past the source. That would require a fortuitous draft rate, but with channel two so near the edge of the band it's a possibility.

The Ohio search had found just what it sought—a radio signal that appeared to come from a celestial source, a candidate interstellar broadcast. But it would have to be detected repeatedly to confirm that intriguing possibility, and the signal proved elusive. The Ohio group looked at the area on a hundred days during the next few years, although only for a few minutes each day, totaling about four hours. Finding nothing, they returned to their all-sky survey. Their system was best at slowly and systematically mapping the sky, discovering sources that others could study in greater detail by tracking them with steerable telescopes.