Chapter 2

Candidate Interstellar Signal

What does it take to make a good candidate for a signal from another world?

For starters, the signal must come from the sky, from a position fixed amid the stars. And it should be clearly artificial—more like a pure tone than the noisy hiss of natural sources, or different in some other way. An artificial signal that seemed fixed amid the stars is just what the Wow! appeared to be. This chapter shows why the signal seems like a good candidate, even though seen only once. The Wow is like a tug on a cosmic fishing line; it felt like something nibbling, although there's no proof that we got a call from ET.

Celestial signature

There are several reasons to think that the Wow came from a celestial source rather than a local transmitter. First, its strength showed the rise and fall always seen when celestial radio sources passed through the antenna's beam.

Second, the time it took to pass through the beam was almost exactly right for a celestial source viewed from the turning Earth with that particular antenna and in the direction it was pointed. Third, there was no sign that the source was moving like an aircraft or spacecraft.

The smooth rise and fall of intensity is the signature of a big antenna like Ohio State's sweeping across a radio source. The hiss of the receiver rises in strength as the beam approaches a source, is loudest when the antenna points straight at it, then fades away as the Earth's rotation sweeps the beam past—rather like the intensity of sound as a vehicle approaches, passes by, and then recedes into the distance. Figure 2.1 shows that the six intensities recorded for the Wow fit the bell-shaped antenna pattern almost perfectly, a sure sign that the signal came in through the antenna's skyward-pointed beam as the Earth turned rather than from a ground-based transmitter.

The amount of time it took the Wow to pass through the antenna's beam very nearly matches the expected transit time for celestial sources in the direction the antenna was pointed, which is another sign that the signal came in through the antenna. Sources should take about 36 seconds to transit the most sensitive middle half of the beam called the half-power beam width (HPBW

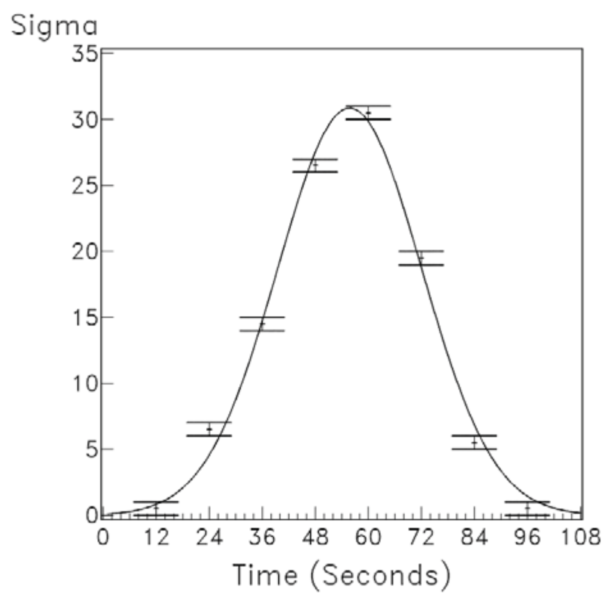

Figure 2.1. The intensity of the Wow signal in channel 2 and a fitted curve. The intensity measured at 12-second intervals is shown by small crosses, while the line is the Gaussian curve fit by statistical procedures and is the shape expected of the antenna's beam pattern. Error bars show the uncertainty of measurements in time (±6 seconds along the horizontal axis) and intensity (±0.5 sigma along the vertical axis). Data courtesy of North American AstroPhysical Observatory.

in unpronounceable jargon, the part halfway up the curve), and the signal took about 38 seconds—pretty close to the expected time, especially since the beam was known to have broadened a bit as the antenna aged. Transit time could range from just 32 seconds with the antenna pointed toward the celestial equator (declination 0°) to forever if pointed at the celestial north pole (declination +90°, essentially the north star). The Wow's transit time was close to matching even this detail, good evidence for celestial origin.

A signal from an aircraft or spacecraft would zip through the beam much quicker. Visualizing the beam projected on the sky, its width was about one-quarter that of the Moon and its height a bit taller; an aircraft would cross such a small angle quite quickly. Satellites in low-Earth orbit shoot across the sky at four degrees per minute, usually moving from east to west, and would cross the beam in just a few seconds.

Satellites that travel north-south are one possibility that Ohio could not completely rule out. That kind of orbit has been used for some spy satellites, and such a satellite at just the right very distant range could conceivably pass through the beam mimicking a celestial source, although that would be quite a coincidence. Satellites are usually seen repeatedly while the Wow was seen only once, and the 21-cm band Ohio was listening on is both protected by law and monitored by radio astronomers of many nations—which would make it a dumb choice for a secret satellite.

Having the same antenna signature as a natural celestial source, you might think the Wow was one. But there aren't any there.

No strong natural sources

It's very unlikely that the Wow was a natural radio source because the only ones in the vicinity are weak, about one-thousandth of its strength.

The strength of the signal is thought to have been in the range of 54 to 212 janskys (according to estimates by Jerry Ehman and Russ Childers, respectively), which is quite strong as radio sources go. Natural sources range from a few thousand janskys for the strongest sources other than the Sun, down to thousands or millionths. The jansky is a measure of spectral power named for Karl Jansky—the amount of power that falls on a given area and over a given amount of the spectrum, and one jansky is 10^{-26} of a watt falling on an area of one square meter and in a one Hertz slice of frequency, written as 1 x 10^{-26} $W/m^2/Hz$ or 1 Jy. For those unfamiliar with this scientific notation, it replaces insanely awkward numbers like 0.00000000000000000000000001 with compact ones like 1.0 x 10^{-26}, where the negative exponent tells you how many places to move the decimal point to the left; a positive exponent means you move the decimal point to the right, so 1 x 10^2 or 10^2 means 100.

Ohio State's earlier astronomical survey found no sources near the Wow locales down to one-tenth of a jansky, a sensitivity where more than ten thousand radio sources can be detected. More sensitive later observations found a few hundredth-jansky sources, but at that faint level roughly a million sources glow across the sky, and some would fall near the Wow locales by chance.

No suspect star

Stars don't shine at the hydrogen frequency (only *cold* hydrogen does), so finding a prominent star at the Wow locales would be surprising—hinting that the source of the signal might be somebody living in that neighborhood.

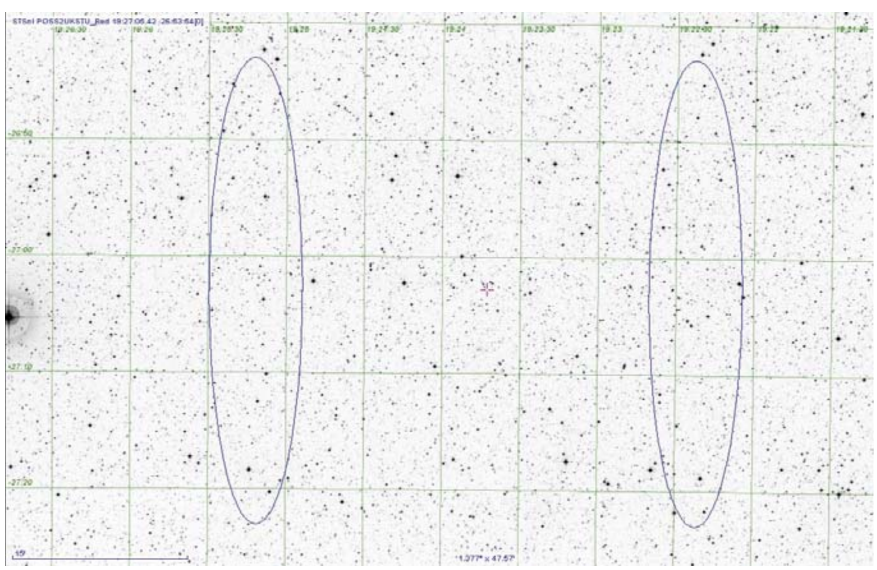

Figure 2.2. Stars in and around the antenna's two beams at the time of the Wow peak intensity. The horizontal axis is right ascension and the vertical axis is declination; the source should be near the vertical axis of one of the two beams, at right ascension $19^h 22^m 22^s$ (right) or at $19^h 25^m 12^s$ (left) both at declination -27^0 03′ (epoch 1950). Credit: STScI POSS2UKSTU_Red visualized with Aladin.

Unfortunately, the beams covered many stars, shown in Figure 2.2, and none of them seem likely suspects. A check of three sun-like stars in the vicinity was done in the early 1980s by David Talent, who examined their light for unusual features such as spectral signs of artificial elements that a civilization might spice its star with to mark it as the home of intelligence, or perhaps dumping radioactive waste. No strange spectral features were seen, but lots of other stars were in the beams and have not been checked.

Narrow bandwidth

The antenna said the signal had the signature of a source in the sky, but the receiver said it was a radio transmission. Most natural sources are noise-like and spread over a wide band of frequencies, but the Wow signal did not spill out of a 10 kHz-wide channel—the width of an AM radio station—which is strong evidence that it was a radio signal.

Natural radio sources come in two flavors. Continuum sources radiate across much of the spectrum, and would light up many or all channels of the receiver, while spectral line sources radiate at a single frequency, although the frequency is almost always broadened by random motions in the clouds of interstellar gas where the lines originate. No way is known for either sort of source to produce an emission as narrow as the Wow. Its frequency was near the 21-cm hydrogen spectral line, but hydrogen is always broadened to roughly 100 kHz or 10 Ohio channels, and its intensity has never been seen to flare up or disappear over a few minutes.

Radio signals, on the other hand, are usually narrow. Transmitters concentrate their energy in a narrow range of frequency, and receivers use a tunable filter to pass just the slice of frequencies containing a desired signal. That lets a signal of interest stand above the clamor of noise that fills the electromagnetic spectrum, such as unwanted chatter at other frequencies, natural snap crackle pops from lightning and other causes, and hiss in receiver circuits due to electrons flowing through them. The fact that the Wow did not spill out of a single channel is a strong sign that it was a radio signal, although it says nothing about where it came from; many man-made radio signals would be just as narrow.

A magic frequency?

Ohio State was listening near the hydrogen frequency because some scientists had suggested it as a likely choice for first contact between stars—broadcasters might choose a "magic" frequency that searchers could guess, without tuning across the vast radio spectrum.

The Wow frequency was reported as 1420.3556±0.005 MHz, which is within about one 10-kHz channel of where hydrogen would fall, after making corrections for Doppler effects caused by motions of the Earth and Sun. Correcting for those motions yields the local standard of rest (LSR in jargon), a frame of reference used by astronomers to mean floating amid the nearby stars. The uncertainty in the LSR is several kilometers per second, which amounts about 10 kHz at this frequency, so the signal could have been exactly at the hydrogen frequency or up to 20 kHz away.

What are the chances that a signal would fall in a channel that says "hydrogen"? Signals could have fallen into any of the fifty receiver channels with equal odds, but only three or so channels would seem to correspond to hydrogen. That's a 3/50 or 6% chance of saying "hydrogen" and a 94% chance it would not. So it's somewhat improbable that interference would fall so near the hydrogen frequency, although not wildly unlikely.

To dismiss the Wow as man-made interference, we would have to believe that a number of pretty unlikely events occurred at the same time: that a secret spacecraft crossed the antenna's beam in just the right way to mimic the transit of a celestial source, and that it was transmitting in the protected hydrogen band, and that its frequency happened to fall almost exactly where the hydrogen frequency would fall in the local standard of rest.

Doppler-corrected?

The Wow frequency seems close to the magic hydrogen frequency only after we make some adjustments to compensate for our various motions, and the fact that it comes close to saying "hydrogen" after those adjustments makes the signal's frequency seem especially intriguing.

When we look out into space, everything is in motion and frequencies are shifted higher or lower by the Doppler effect, so we need to tune our receivers higher or lower depending on how fast we are approaching a source or receding from it. The Sun zips along at about 20 kilometers per second compared with the average velocity of local stars—much faster than a rifle bullet—and the Earth shares that motion along with its own motion orbiting the Sun, speeding up as it's pulled near and slowing down as it swings away. The Earth is also spinning, swinging an observer at the equator in a circle at a half-kilometer per second—a thousand miles per hour—although hardly moving at all at the poles. This medley of motion causes Doppler shifts in frequency; the reason we don't usually notice it is that the distance between our transmitters and receivers rarely changes very fast because we're all riding the same merry-go-round.

To get rid of pesky Doppler effects, radio astronomers add up the velocities along the telescope's line of sight, calculate the frequency shift (about 4.7 kHz for every kilometer per second at the hydrogen frequency), and often tune the receiver to make that shifted frequency fall in the center of their dial. Figure 2.3 shows Doppler shifts in all directions at the time the Wow was detected; in the direction the antenna was pointed, hydrogen at rest would be

Declination (1950)																								
90.0	-81	-81	-81	-81	-81	-81	-81	-81	-81	-81	-81	-81	-81	-81	-81	-81	-81	-81	-81	-81	-81	-81	-81	-81
80.0	-94	-92	-89	-86	-82	-78	-74	-70	-67	-65	-64	-64	-65	-67	-70	-73	-77	-81	-85	-89	-92	-94	-95	-95
70.0	-104	-100	-95	-88	-80	-72	-65	-58	-52	-48	-46	-45	-47	-51	-57	-64	-71	-79	-87	-94	-100	-104	-106	-106
60.0	-111	-106	-98	-88	-76	-65	-53	-43	-35	-29	-26	-26	-28	-34	-42	-52	-63	-75	-86	-97	-105	-111	-114	-114
50.0	-115	-108	-97	-85	-70	-55	-41	-28	-17	-9	-5	-5	-8	-16	-26	-39	-54	-68	-83	-96	-107	-115	-119	-119
40.0	-115	-107	-94	-79	-62	-44	-27	-11	2	11	16	16	12	3	-9	-25	-42	-60	-77	-93	-106	-115	-120	-120
30.0	-112	-102	-88	-71	-52	-31	-12	6	20	31	36	36	32	22	8	-10	-29	-49	-69	-87	-101	-111	-117	-117
20.0	-106	-95	-80	-61	-40	-18	3	23	38	49	55	56	50	40	24	6	-15	-37	-59	-78	-93	-105	-111	-111
10.0	-96	-85	-69	-49	-27	-4	18	39	55	67	73	73	68	57	41	21	-1	-24	-47	-67	-83	-95	-101	-101
0.0	-83	-72	-55	-35	-13	10	33	53	70	82	88	88	83	71	55	35	13	-11	-33	-53	-70	-82	-88	-89
-10.0	-68	-57	-41	-21	1	24	46	67	83	95	101	101	96	85	69	49	27	4	-18	-39	-55	-67	-73	-73
-20.0	-50	-40	-24	-6	15	37	59	78	93	105	111	111	106	95	80	61	40	18	-3	-23	-38	-49	-55	-56
-30.0	-32	-22	-8	10	**29**	**49**	69	87	101	111	117	117	112	102	88	71	52	31	12	-6	-20	-31	-36	-36
-40.0	-12	-3	9	25	42	60	77	93	106	115	120	120	115	107	94	79	62	44	27	11	-2	-11	-16	-16
-50.0	8	16	26	39	53	68	83	96	107	115	119	119	115	108	97	85	70	55	41	28	17	9	5	5
-60.0	28	34	42	52	63	75	86	97	105	111	114	114	111	106	98	88	76	65	53	43	35	29	26	26
-70.0	47	51	57	64	71	79	87	94	100	104	106	106	104	100	95	88	80	72	65	58	52	48	46	45
-80.0	65	67	70	73	77	81	85	89	92	94	95	95	94	92	89	86	82	78	74	70	67	65	64	64
-90.0	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81
RA	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1

Figure 2.3. All-sky map of Doppler shifts for a source at the hydrogen frequency viewed from the Ohio State site at the time of the Wow detection, with shifts in kilohertz. The Wow position is between the values for right ascension (RA) 19 and 20 hours, near declination -30°. Shifts at declinations below the local horizon are included. Calculations are based on a program by John Ball.

shifted down about 40 kHz compared to its frequency in the lab because we were moving away at the time. The Wow frequency was about 10 kHz lower than that—within one channel of where a signal sent out at the hydrogen frequency would be expected to fall (it did not fall in the center of Ohio's channels because they were also correcting for our motion around the galaxy).

Years later, in observations discussed in a subsequent chapter, hydrogen in the Wow direction was found to be shifted 15-20 kHz lower than where our local motion would put it, presumably due to its own local motion—putting the Wow frequency very nearly where it would fall if its source was amid that distant hydrogen. The fact that the signal was close to the magic hydrogen frequency after these arcane adjustments adds to its interest as a candidate interstellar signal but hardly proves it was one.

In 1998 Jerry Ehman, who first noticed the signal, reported that he believed its frequency was 100 kHz or ten channels higher than originally given, due to a design oddity in the receiver. If that is correct, then the signal is not so remarkably near the hydrogen frequency, although it is still in the hydrogen band.

Peculiar pattern

Another intriguing aspect of the Wow is that several other signals seem to accompany it, forming the peculiar-looking pattern shown in Figure 2.4. Features in channels 4 (maybe), 7, and 16 look like a second signal stepping in frequency, and having the same source as the signal in channel 2 because the intensity of the features increases along with that of channel 2 as the antenna sweeps across the source. The features in channels 7 and 16 are almost certainly real because fluctuations in the background noise would not produce even one peak that strong over several days, but the channel 4 feature is iffy—a four-sigma noise peak is expected in some channel every minute or so, although its intensity does follow the antenna pattern.

Taken together, the features look rather like a pattern well-known to physicists and astronomers: the Lyman series of spectral lines emitted by hot hydrogen at ultraviolet wavelengths, illustrated in Figure 2.5. Some writers have suggested that broadcasters might use patterns such as the series

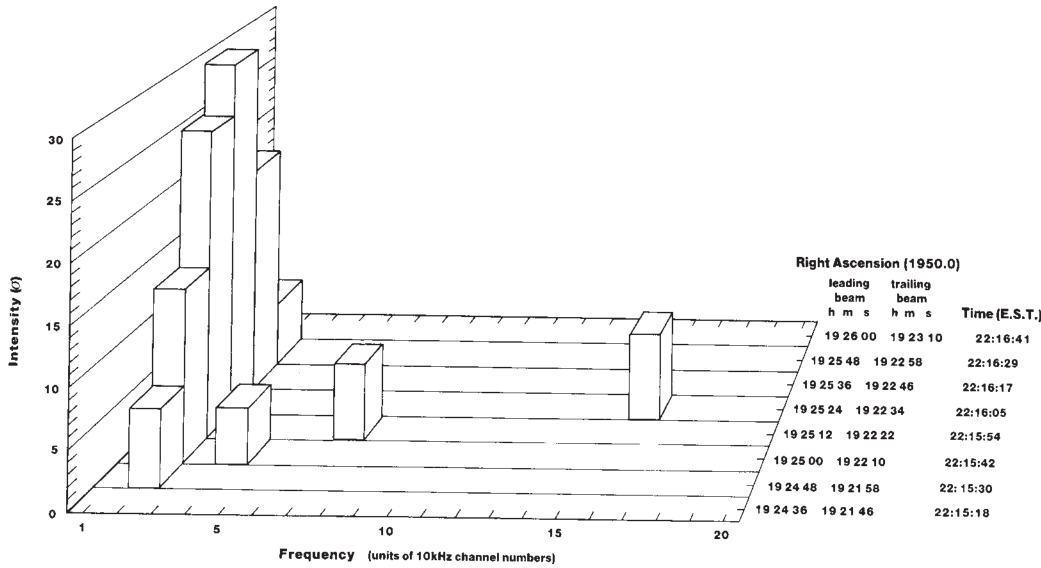

Figure 2.4. Features stronger than 3 sigma in channels 1 through 20. The intensity in channels 4, 7, and 16 was 4, 6, and 7 sigma, respectively, increasing along with the signal in channel 2 as though they had the same source (having a correlation coefficient of r=0.99). Data courtesy of North American AstroPhysical Observatory.

of prime numbers 2, 3, 5, 7, 11, 13, 17… to prove a signal is artificial, and the Lyman series might serve the same purpose because many astronomers would recognize it—and realize that it's out of place in the radio spectrum.

The Wow pattern is not a good statistical match to the pattern of Lyman wavelengths, although the pattern does match the pattern of strengths of the lines if some assumptions are made (a feature in channel 3 undetected just before the beam began sweeping over the source, and a feature outside the band where channel 93 would have fallen). That does not prove anything, because with only a few data points and some convenient assumptions it's not

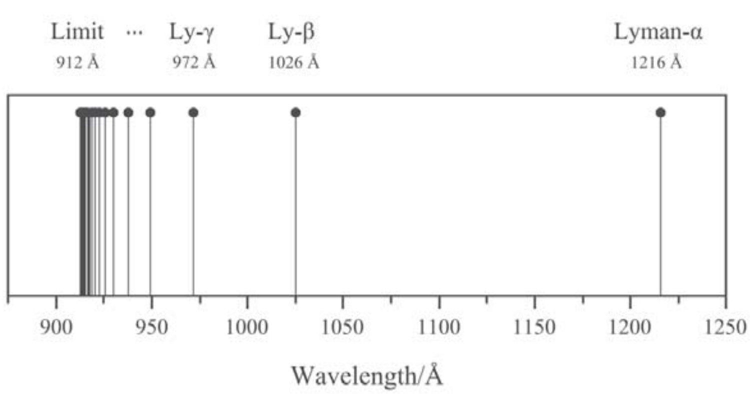

Figure 2.5. The Lyman series of spectral lines in the ultraviolet spectrum. Source: Wikipedia.

too tough to match something, but the peculiar pattern is another facet of the Wow signal that makes it interesting.

WHY SO ELUSIVE?

If the Wow did come from a celestial source, how could Ohio's roughly one hundred additional observations have failed to detect it again? The fact that it was detected in only one of the two beams suggests one answer—that it might have been intermittent.

Most searches for ET have assumed that signals are present all of the time, but that requires broadcasters to either radiate isotropically in all directions continuously, which would be awfully expensive, or to radiate signals toward us all the time with a big antenna, which would be awfully lucky for us.

Transmitting in all directions continuously would require the equivalent of thousands of power plants to reach out 500 light years, so broadcasters might put the signal "on the air" only part of the time. Broadcasting for only one second in ten thousand, for example, would reduce the cost by the same factor saving lots of power plants, but would result in an intermittent signal that would require searchers to listen for several hours to catch.

Transmitting with a highly directional antenna illuminating just one or a few stars at a time is another way that broadcasters might save power, and could result in intermittent signals. The savings are an accountant's delight: only one percent of the output of one big power plant would be needed to signal across 500 light years if focused by an antenna the size of the 1,000-foot radio telescope we have at Arecibo, Puerto Rico, assuming in both examples a receiver using a similar antenna. But a searcher can't see the signal when the antenna is not pointed in his (or hers or its) direction, so the broadcast would appear to be intermittent and would seem elusive.

Intermittent signals might result from something as mundane as rotating planets—for example, fixed antennas sweeping a transmitting beam across the sky once each day. Distant observers would see the signal briefly as the beam swept across them but would have to wait until the source made a complete rotation to see it again. That sort of broadcast strategy might please alien engineers as well as accountants because the antenna would not need to move to track targets. Such signals would be hard to detect with the quick looks of our typical searches, but would repeat periodically.

The Wow might be elusive, then, because it illuminates us rarely for any one of these reasons; Ohio State's follow-up observations might not have looked long enough or at the right time to catch it on a subsequent occasion. And, since their "looks" were daily transits on a periodic schedule, a source that was also periodic might need to come back into synchronization again before it could be detected—and that might not happen for hundreds of days as we shall see later.

An alternative explanation for appearing in just one beam could be a signal drifting in frequency at just the right rate to stay in channel 2 while it was in one beam, but drift through channel 1 undetected and out of the band before the second beam swept past (or drift into the band after the first beam swept past). A drift rate in the range of 100–140 Hz/sec would do the trick. Some drift in the frequency of interstellar broadcasts is expected due to our motion, although only around 1 Hz/sec, and an unknown amount of drift might be caused by motion of the transmitter. A broadcaster might intentionally sweep the frequency across the radio spectrum, but that would make a signal harder to find repeatedly, at least with our present-day searches.

No hoax

The topic of aliens is fertile ground for fantastic claims and outright lies. Pictures of flying saucers are common, and many are admitted fakes; some UFO pictures *look* like hubcaps or pie tins because they *are*.

Was the Wow a hoax? I've found no reason to think so.

The reputations of the Ohio State scientists argue against hocus-pocus by observatory staff. John Kraus, founder and director of the observatory, was a prominent figure in the development of radio astronomy. He literally wrote the book on the subject—his *Radio Astronomy* textbook is a standard on many an astronomer's bookshelf, and he also wrote the textbooks *Antennas* and *Electromagnetics*. Bob Dixon, the SETI project director, never sounded a false alarm during decades of supervising the world's longest-running search. Jerry Ehman, who first noticed the signal, had worked on the original Ohio survey and subsequently became a professor at Franklin University. All have been cautious in their claims.

Kraus wrote that "it could have been a signal from an Earth-launched space probe of which we are unaware" and "it could have been a signal from an extraterrestrial civilization... but... this is pure speculation." Ehman regards the origin of the signal as an open question: "... since all of the possibilities of a terrestrial origin have been either ruled out or seem improbable, and since the possibility of an extraterrestrial origin has not been able to be ruled out, I must conclude that an ETI (ExtraTerrestrial Intelligence) might have sent the signal that we received as the 'Wow' source."

The fact that the signal appeared in only one beam and not twice as expected of celestial sources argues against monkey business by insiders. Anyone intending to fake the response of the antenna to a celestial source would know that a signal should appear twice and would presumably fabricate data for both beams to create a more convincing deception.

A prank by an outsider also seems unlikely. It would have been difficult to introduce a spurious but convincing radio signal into the system from outside, and it's unlikely that an outsider could have gotten access to the locked receiver room to fiddle with software or printout. Few outsiders would know how the strength of a signal should rise and fall, or other esoteric aspects of the telescope.

Summary

The Wow signal had several characteristics expected of an interstellar radio signal. Most strikingly, it had the same signature as a celestial source passing through a beam of the antenna, yet the only natural radio sources in the vicinity are a thousand times fainter. The signal had the narrow bandwidth typical of radio signals, yet there was no sign that it was from an aircraft, spacecraft, or other man-made source. The signal's frequency was close to the hydrogen frequency often suggested for interstellar communication, and several weaker signals that seem to come from the same source form an intriguing pattern.

The signal was not seen again in roughly one hundred days of additional observations at Ohio State, perhaps because the source is not always "on" or not always pointed in our direction or drifts in frequency. Something like a lighthouse, for example, might illuminate us so rarely that detecting it even once was lucky, and Ohio State's re-observation attempts would not have had a good chance of detecting such a source a second time.

Learning more about the Wow signal would require it to be seen repeatedly. The next few chapters recount my attempts to re-detect it, the only efforts other than Ohio State's, to the best of my knowledge.