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A Search of the "Wow" Locale for Intermittent Radio Signals

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In 1977 a search for extraterrestrial intelligence (SETI) at Ohio State University (OSU) recorded a strong signal near the 21-cm hydrogen line, which displayed several characteristics that might be expected of a candidate interstellar radio signal. The event was not repeatable with the OSU meridian transit radio telescope but could have been due to an intermittent source, which would be difficult to reobserve with a transit instrument. This article reports a search for the OSU signal using the fully steerable Harvard–Smithsonian 26-m radio telescope, tracking for up to 4 hr at a time to improve the chances of detecting an intermittent source. Despite higher sensitivity and longer cumulative observations, no signals resembling the OSU event were found. © 1994 Academic Press, Inc.

INTRODUCTION

An apparent radio signal near the 21-cm hydrogen line was recorded at the Ohio State University (OSU) Radio Observatory on August 15, 1977 (Kraus 1979), during a search for extraterrestrial intelligence (Dixon 1985). The signal, shown in Fig. 1, was so suggestive of a candidate interstellar radio signal that one of the project scientists wrote "Wow!" in the margin of the printed record, and that annotation has become a name for the event.

The signal may, of course, have been due to a manmade or natural source, but it displayed several characteristics that might be expected of a candidate interstellar radio signal.

First, the high intensity (30 times the average noise per channel), persistence over six observations, and narrow bandwidth (<10 kHz) indicate that it probably was a radio signal, rather than due to random noise or a natural radio source. Noise alone would not be expected to produce a single 30σ event on the 10-year time scale of the OSU search, and six successive events in a single channel are clearly not due to a random process. A search of reference works revealed no known radio astronomical objects to account for the event, and natural sources typically display a much wider bandwidth.

Second, the signal displayed a rise and fall of intensity matching the pattern of one beam of the antenna sweeping across a fixed celestial source at the declination observed (the signal did not appear in a second beam offset by several minutes of right ascension, suggesting that it might be intermittent). An aircraft or spacecraft would require a fortuitous combination of velocity, range, and heading to mimic this signature of a transiting celestial source.

Finally, the signal frequency (1420.356 ± 0.005 MHz) was near the 1420.405-MHz hydrogen hyperfine emission line, which has been suggested as especially appropriate for interstellar communication (Cocconi and Morrison 1959, Drake and Sagan 1973). The upper edge of the channel in which the signal was recorded was only a few kilohertz away from the frequency expected of a signal Doppler corrected to fall at the hydrogen frequency in the local standard of rest (Mihalas and Binney 1981) after correcting for terrestrial motion (Ball 1976) and peculiar solar motion (Delhaye 1965) along the line of sight.

The signal did not appear in a second beam of the antenna offset by 2^m50^s in right ascension when it swept across the same position. That could have been due to an intermittent celestial source that was "off" when the other beam swept past or some other cause. The possibility of a moving manmade source cannot be rejected, but there was no evidence of source motion during the 72 sec in which the signal was observed.

Approximately 100 additional transit observations were made at OSU but the signal was not seen again. Since those observations viewed the apparent source locale for only a few minutes each day, and summed to only 2 hr, they left open the interesting possibility that the signal might have been due to an interstellar beacon illuminating us for, say, a few minutes every few hours—a possibility that would be more efficiently investigated by tracking the apparent source for extended periods. No such observations have been reported (Tarter 1991) except for a modest search by the author using a 4-m antenna to obtain

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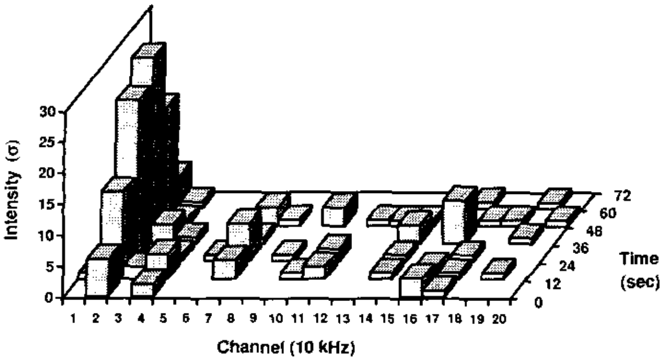

FIG. 1. The 1977 OSU signal, in channel 2 of the 50-channel receiver. The rise and fall of intensity in channel 2 is characteristic of the transit antenna sweeping across a fixed source. Observing periods of 10 sec are separated by 2-sec data processing periods. Channels 1–20, shown here, cover 1420.379 to 1420.579 MHz in the LSR reference frame (cf. text). Channels 21–50 contain no features above 3.5σ and are not shown. The vertical scale is a graphic respresentation of the original printed record, which recorded the absolute value of the signal difference between the two beams in integer multiples of $1\sigma = 4 \times 10^{-23}$ W/m^2; signals $< 1\sigma$ were not recorded. Several additional features larger than 3.5σ in absolute value are apparent in channels 16, 7, and possibly 4 and may be associated with the channel 2 signal (the intensities are correlated with those in channel 2, $r = 0.99$), but are not discussed further in this paper.

15-min transit observations with low sensitivity (Gray 1985).

This article reports a search with a large, fully steerable antenna, dwelling on the apparent source positions for up to 4 hr in order to improve the chances of detecting an intermittent celestial source if one exists.

OBSERVATIONS

Observations were made with the 26-m steerable antenna at the Harvard–Smithsonian Observatory at Oak Ridge, Massachusetts, using the META 8.4×10^6-channel, 0.05-Hz resolution spectrum analyzer (Horowitz *et al.* 1986).

Two primary positions had to be observed because the OSU system did not in 1977 distinguish between the two beams of its dual-beam antenna system, creating an uncertainty as to which beam the signal was received in and therefore in position. The two resulting positions were RA $19^h25^m12^s$ and $19^h22^m22^S$ (both $\pm 5^S$) at a declination of $-27° 03' \pm 20'$ (1950) (J. D. Kraus, personal communication), called the *leading* and *trailing* positions, respectively.

Each position was observed for 4 hr on one day and up to 4 additional hours on a second day, resulting in about four times OSU's accumulated observing time. Shorter observations were made north and south of each position, since the 30-arcmin HPBW of the 26-m antenna at 21 cm does not quite cover the declination uncertainty. Observations are summarized in Table 1.

The maximum sensitivity of the META system is 4×10^{-24} W/m^2 per channel, using a detection threshold of 19.5 times the average noise level. Peaks in the spectrum due to noise alone are expected to exceed that threshold about 5 times per hour. Sensitivity is degraded for signals falling between spectral bins (up to 3.9 dB), for sources not on the beam axis (3 dB for 15 arcmin off-axis), or polarization mismatch (3 dB for linearly polarized signals). Combined, these effects might degrade sensitivity to 4×19^{-23} W/m^2. This is still superior to the 2×10^{-22} W/m^2 sensitivity of the 50-channel, 10-kHz resolution OSU system (referenced to a 3.5σ threshold),[1] provided the signal extends over not more than about five META 0.05-Hz channels.

META is relatively immune to terrestrial RFI. Its local oscillator is "chirped" at the terrestrial Doppler rate, here about 0.1 Hz/sec, so that terrestrial signals at a constant frequency are spread over many channels while an extraterrestrial broadcast, Doppler corected for motions at its source, would remain in one or a few channels.

Three 400-kHz bands were observed in both circular polarizations. Each band was centered on the 21-cm hydrogen line, Doppler corrected to three different rest frames in succession: heliocentric/local standard of rest (LSR), galactic barycenter, and cosmic blackbody. The OSU signal frequency would fall in the heliocentric/LSR band; the other bands were included to obtain greater frequency coverage. Each band and polarization were observed for 20 sec in succession, taking 2 min to step through all six combinations. Any single-channel peak greater than 19.5 times the average noise per channel in the 8.4×10^6-channel spectrum was archived for subsequent analysis.

RESULTS AND DISCUSSION

No obvious signals were apparent in the events exceeding threshold, shown in Fig. 2, and the event statistics are consistent with those expected from noise alone. Neither the amplitude of the largest peaks, nor the number of events recorded at any position was significantly greater than the expected values due to noise (see Table I).

The largest noise peak expected in N samples is $P = P_0 \ln N$, where P_0 is the mean power per bin (Horowitz

[1] The very different detection thresholds are due to the different event distributions and data rates of the two systems; they are comparable in that a few events per hour above the threshold are expected in each system. META employs a FFT with no averaging and noise events yield an exponential distribution, while OSU forms each observation by averaging ten 1-sec integrations and the mean values have a Gaussian distribution with far fewer events far out along the tail.

TABLE I
Positions Observed and Summary of Results

Position observed	RA (1950.0)	Date (1987)	Dec. (1950.0)	Hours observed	Peaks per hour $>19.5P_0$	Largest peak observed (P/P_0)	Largest peak expected (P/P_0)
Trailing	$19^h22^m22^s$	Aug. 17	−27°03′	4.0	5.0	22.8	22.4
Trailing		Aug. 19[a]	−27°03′	4.0	3.5	22.5	22.4
1 HPBW North		Aug. 19	−26°30′	0.8	5.0	20.8	20.8
1 HPBW South		Aug. 19	−27°30′	0.7	4.3	23.3	20.7
Leading	$19^h25^m12^S$	Aug. 18	−27°03′	4.0	2.7	21.2	22.4
Leading		Aug. 20	−27°03′	3.0	3.3	21.0	22.1
1 HPBW North		Aug. 18	−26°30′	0.8	3.7	20.9	20.8
1 HPBW South		Aug. 18	−27°30′	1.4	2.1	21.5	21.3

[a] During the first 2 hr the antenna was pointed 1/2 HPBW east of the position shown.

and Sagan 1993). In only one set of observations was a significantly larger than expected peak recorded, $23.3P_0$, compared with $20.7P_0$ expected for the observing time at that position; but a peak as large as $23.9P_0$ is expected to occur sometime during the 19 hr of cumulative observations.

The number of events per hour expected to exceed the $19.5P_0$ threshold is about 4.5, given that the probability of $P > TP_0 = \exp(-T)$ where T is a threshold, and the 1.3×10^9 samples/hr obtained. Only one 4-hr set of observations yielded a higher than expected event rate, and only by two events.

There is no statistical evidence, then, for either strong narrowband signals or an excess number of weaker signals at the positions observed. That negative result does not rule out other signal types which the search was not designed to detect. Major limitations are:

1. Signals spread over tens of hertz or more, due to intrinsic bandwidth, modulation, or dispersion by the interstellar medium (Drake and Helou 1978, Cordes and Lazio 1991) might not deposit sufficient energy in a single bin to be detected by the narrowband META spectrometer. Narrow-bandwidth (~1 Hz or less) signals are, however, thought to be efficient for interstellar signaling (Oliver and Billingham 1971). Similarly, narrow-bandwidth signals drifting in frequency might not remain in a single bin of the META spectrometer long enough to be detected. But it would be relatively easy for a directional broadcast to be Doppler corrected, and it appears possible for omnidirectional broadcasts to be corrected as well (Dixon 1974).

2. Signals repeated less often than every 4 hr could have been missed, and for sources more than about 15 arcmin away in declination, signals repeated less often than every half-hour could have been missed due to the shorter observing time. But signals repeated less often than every 2 hr are very unlikely to have been detected by OSU's transit survey in the first place, assuming a simple periodicity.

3. Signals persisting for less than about 2 min could have been missed while the spectrometer was examining other bands or polarizations. But the OSU signal was detected for 72 sec—the transit time through the full-power beam width—and it seems reasonable to assume that it persisted for at least twice that time.

This search assumed a simple temporal model, with a signal repeated every few hours. More elaborate models could account for OSU's single-beam detection and the absence of subsequent detections at both OSU and META. Consider, for example, a high-gain antenna pointed in our direction for one full day out of every, say, 30 days, and cycling every few minutes between transmission and reception. The OSU system would be likely to detect the transmission in one beam and detect nothing in the other beam, provided the OSU antenna was at the right declination on the right day. The latter probability is higher than might be expected, in the range 3/30 to 9/30, because 1 to 3 days are typically spent at each declination, which is then advanced by 1/2 HPBW; a source would be in the HPBW for between 3 and 9 consecutive days during a full-sky survey. Yet such a source could be missed in OSU's 100 days of reobservations because they never continued for more than 15 consecutive days, and would probably be missed by the 4-day META search.

SUMMARY

No evidence of radio signals resembling the 1977 Ohio State University signal was found in extended observations of the apparent source coordinates, capable of de-

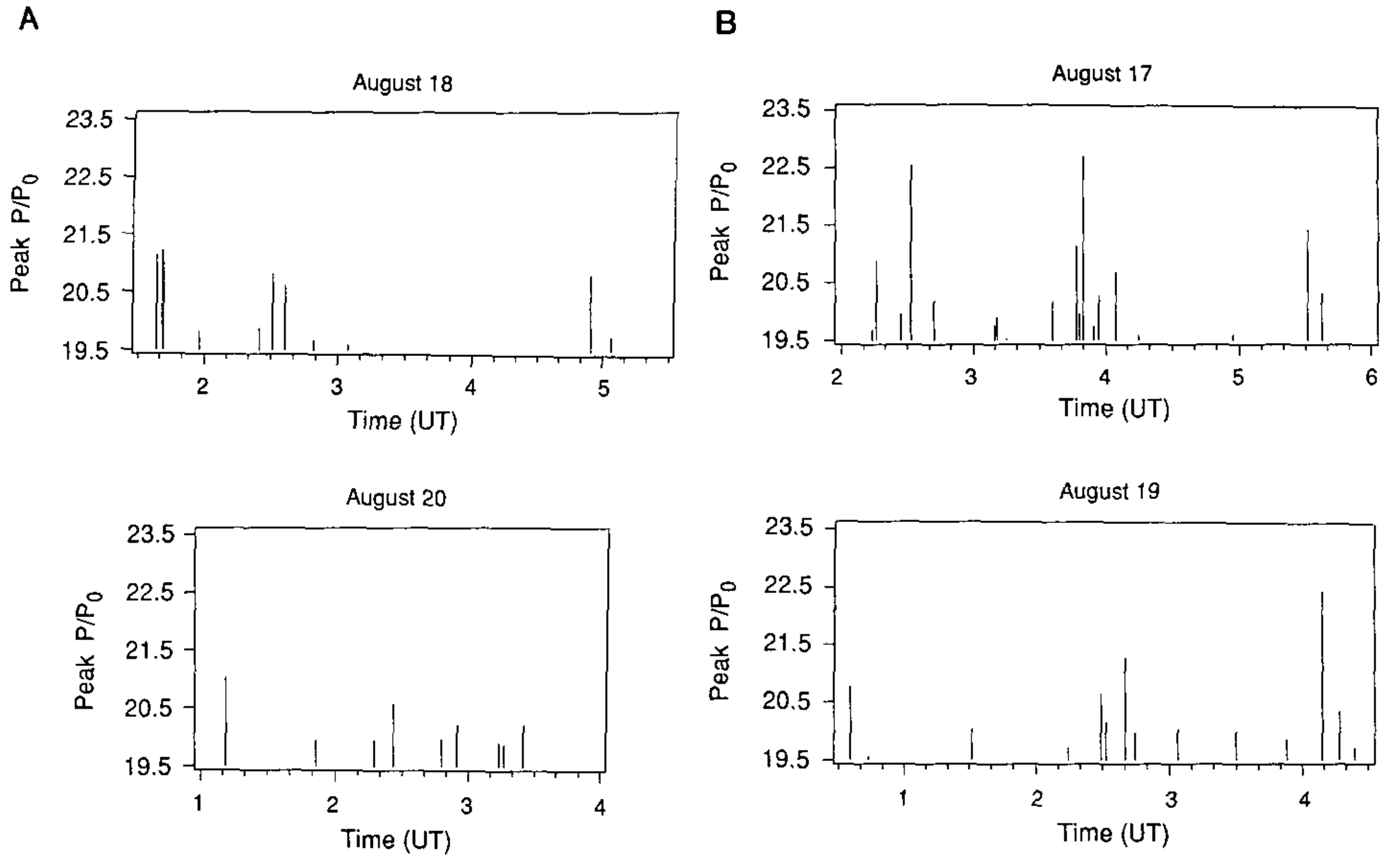

FIG. 2. Peaks over 19.5 times the average power per bin, observed in 1987 with the Harvard–Smithsonian/META telescope, at the leading position (A) and the trailing position (B). Shorter observations north and south of those positions are not shown.

tecting signals repeated as rarely as every 4 hr. It appears unlikely, then, that the OSU signal was due to a narrowband, Doppler-corrected 21-cm interstellar transmission illuminating us every few hours from the positions observed, which had been an open and intriguing possibility.

The observations reported here do not rule out the possibility of a source with wide bandwidth, large-frequency drift rate, or quiescent periods longer than 4 hr, and they do not rule out the possibility of a source at a declination outside of the range observed. The possibility of course remains that the OSU signal was caused by a manmade or natural source.

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REFERENCES

Ball, J. A. 1976. Appendix A: Subroutine DOP for reduction of radial-velocity data. In *Methods of Experimental Physics*. Vol. 12: *Astrophysics*, Part C: *Radio Observations*. (M. L. Meeks, Ed.), pp. 308–314. Academic Press, New York.

Cocconi, G., and P. Morrison 1959. Searching for interstellar communication. *Nature* **183**, 844–846.

Cordes, J. M., and T. J. Lazio 1991. Interstellar scattering effects on the detection of narrow-band signals. *Astron. J.* **376**, 123–134.

Delhaye, J. 1965. Solar motion and velocity distribution of common stars. In *Galactic Structure* (A. Blaauw and M. Schmidt. Eds.), p. 73. Univ. of Chicago Press, Chicago.

Dixon, R. S. 1974. An isotropic frequency-independent antenna system for simultaneous omnidirectional doppler shift removal. *IEEE Trans. Antennas Propag. AP-22* **5**, 707–709.

Dixon, R. S. 1985. The Ohio SETI Program—The first decade. In *IAU Symposium 112, Proceedings*. Reidel, Dordrecht.

Drake, F. D., and G. Helou 1978. *The Optimum Frequencies for Interstellar Communications as Influenced by Minimum Bandwidths*. NAIC Report 76, Ithaca, NY.

Drake, F. D., and C. Sagan 1973. Interstellar radio communication and the frequency selection problem. *Nature* **245**, 257–258.

Gray, R. H. 1985. Small SETI systems. In *The Search for Extraterrestrial Intelligence*, pp. 205–212. NRAO Green Bank.

Horowitz, P., B. S. Matthews, J. Forster, I. Linscott, C. C. Teague, K. Chen, and P. Backus 1986. Ultranarrowband searches for extraterrestrial intelligence with dedicated signal-processing hardware. *Icarus* **67**, 525–539.

Horowitz, P., and C. Sagan 1993. Five years of Project META: An all-sky narrow-band radio search for extraterrestrial signals. *Astron. J.* **415**, 218–235.

Kraus, J. D. 1979. We wait and wonder. *Cosmic Search* **1**, 31–34.

Mihalas, D., and J. Binney 1981. Stellar kinematics: The solar motion. In *Galactic Astronomy, Structure and Kinematics*, 2nd ed., p. 400. Freeman, San Francisco.

Oliver, B. M., and J. Billingham 1971. *Project Cyclops: A Design Study for a System for Detecting Extraterrestrial Life.* NASA CR 114445.

Tarter, J. 1991. *Summary of SETI Observing Programs*, SETI Institute, October 1991.