# THE OHIO SETI PROGRAM - THE FIRST DECADE

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## ABSTRACT

A full-time dedicated SETI progam has been in operation at Ohio State University since 1973. A 50-channel narrowband filter bank is in use near the 21 cm. hydrogen-line. All data is processed in real time and permanently recorded. A large portion of the northern sky has been surveyed and analyzed for large-scale structure. The only obvious non-random structure is caused by isolated narrowband pulses, which are anti-correlated with galactic latitude, and congregate in two specific areas. The origin of these pulses is unknown, although they may be partially due to instrumental effects.

## 1. INTRODUCTION

The Ohio State University Radio Observatory has been conducting a full-time dedicated SETI survey (24 hrs./day, 365 days/yr.) since 1973, with its large meridian-transit radio telescope. The telescope has a physical collecting area of 2200 sq. m., which is equivalent to a parabolic dish 175 feet in diameter. The beam size is 8 arcmin in right ascension and 40 arcmin in declination.

## 2. OBSERVING METHODS

The telescope operates in the survey mode, remaining at a constant declination for several days, while sweeping through all right ascensions. Then the declination is changed by a half beamwidth and the cycle is repeated. The total declination coverage of the antenna is -36 deg. to +63 deg. The telescope uses beam switching to provide two observations of any given source per day. The output of the receiver is actually the difference between two closely spaced beams on the sky. This technique also suppresses terrestrial interference and minimizes the effects of any receiver gain variations. The feed horns are of an unusual design, by John Kraus. Through the use of internal septa and lenses, and a curved tapered corporate waveguide matching network, they

*M. D. Papagiannis (ed.), The Search for Extraterrestrial Life: Recent Developments, 305–314.*

achieve an operational bandwidth of 350 MHz.

A 50-channel filter bank (10 KHz bandwidth/channel) is in operation near the 21 cm hydrogen line. The overall system temperature is about 100K. The center frequency of the filter bank is continuously computer controlled to track the 1420.4056 MHz rest frequency of hydrogen, Doppler corrected to the Galactic Standard of Rest (see references 1 and 2). Our galactic rotation velocity is known only to about + or - 25 km/sec, which causes an inherent frequency uncertainty of about + or - 125 KHz. The total bandwidth of the filter bank is 500 KHz, which encompasses about twice the frequency uncertainty range. In addition, a 200 MHz wide continuum channel is recorded by the computer and displayed continuously on a pen-chart recorder, for general monitoring purposes. A block diagram of the receiving system is shown in figure 1.

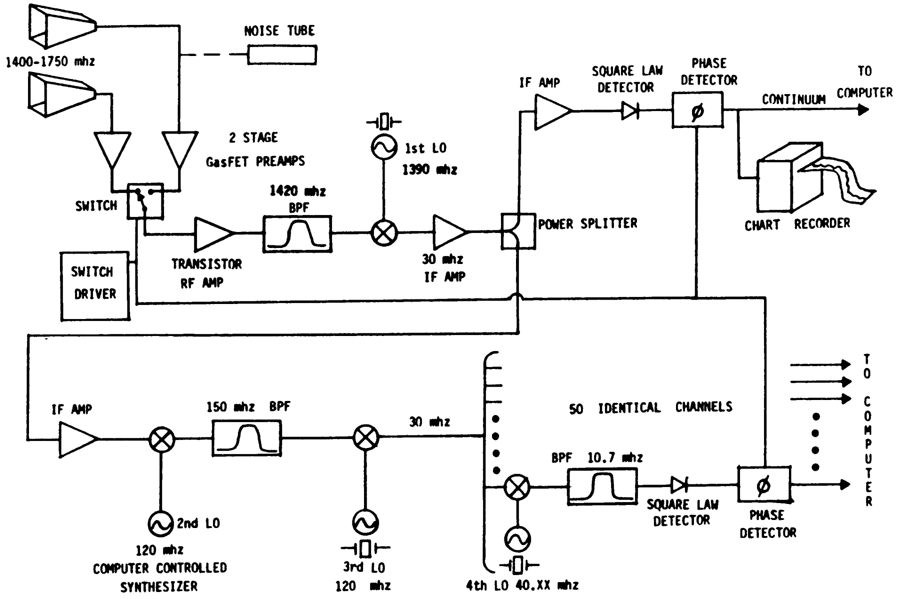

Figure 1. Block diagram of the receiving system.

If the survey were run at the fastest possible speed (only one scan per declination setting), the entire sky visible to the telescope could be done in about one year. However, the survey rate is intentionally much slower than that, for several reasons:

a. Each declination is scanned at least twice and often three times or more, to provide cross-checking and data redundancy.

b. Normal observations are occasionally suspended temporarily for investigation of unusual objects detected, to survey specific objects over a wider frequency range, or for telescope calibration purposes.

c. Observations are occasionally interrupted for installation of new equipment or improved computer programs or for equipment repair.

d. Observations are occasionally prevented by particularly bad local weather conditions such as lightning, high winds, etc.

The regions surveyed this far are shown in figure 2. Naturally there has been a continuous improvement in the equipment and techniques in use over the years of this survey, so there is no intent to imply that this is a uniform survey. Nevertheless, improvements are generally made only at widely separated intervals, so the survey is indeed uniform any particular moderate area of sky.

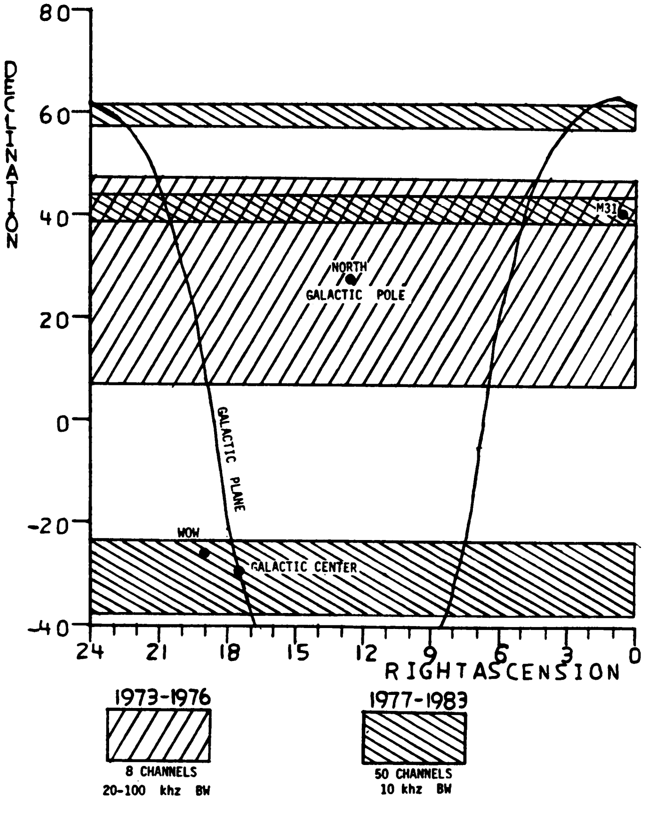

Figure 2. Sky regions surveyed thus far in the Ohio SETI program.

The region between +7 and +48 degrees declination was initially surveyed with an old 8-channel system, as described in (Ref. 4). The region between +40 and +43 degrees was chosen to include the nearby large galaxy M31, and it was surveyed over a much larger frequency range than normal, and doppler-corrected both to our Galactic Standard of Rest and in separate measurements to the velocity difference between our galaxy and M31. No unusual detections were made in the vicinity of M31.

The region between +63 and +57 was chosen to match the upper declination limit of the telescope, and is where the survey is currently operating, in the descending direction.

The region between -36 and -24 was chosen to match the lower declination limit of the telescope, and to include the galactic center, since that object is not visible to most large telescopes that have been used for SETI in the past.

The telescope runs largely unattended. The only person normally present at the observatory is a mechanical technician who cares for the telescope during normal working hours. Two undergraduate Electrical Engineering students are employed as part-time electronics technicians to repair the equipment, and they or a volunteer are typically present once a day to check on things. The SETI program itself is run entirely by volunteers, who have full-time positions elsewhere in the community, but donate their time to conduct the SETI program.

The Flag of Earth is flown at the observatory to emphasize that SETI is an activity of Mankind, with the specific people, organizations or nations involved being of secondary importance.

## 3. REAL-TIME DATA ANALYSIS

Most data reduction is done by an on-line computer in real time, and the techniques have evolved over many years of development and trial. For each of the 50 channels, the following analyses are made independently:

a. Data samples are taken once per sidereal second for 10 successive seconds.
b. The array of 10 points is examined for internal consistency. Any disparate points are discarded.
c. The remaining points are averaged, creating a basic 10-second integration time.
d. Running values for baseline and noise standard deviation levels are calculated over the preceeding several minutes, with points further in the past being progressively downweighted. Anomalous data points (caused by continuum radio sources, etc.) are tested for and omitted from these calculations.
e. The baseline and noise level values are tested against pre-established normal limits. If either falls outside the limits, that channel is flagged as being not working and an appropriate message written out.
f. The baseline is subtracted from the data point, and the remainder is normalized to the standard deviation of the noise level. Thus the output is directly in units of its own standard deviation.
g. These results are printed out on a line printer every 10 seconds, along with the corresponding observational parameters. These include right ascension and declination

(corrected to 1950.0 true), galactic coordinates, local solar time, and the local oscillator frequency.

While the next 10 second period of data is being accumulated, the previous one is being searched for likely intelligent signals, using the following techniques:

a. Any signal exceeding about 5 sigma is selected for possible consideration.
b. If the signal is present in two or more adjacent channels, it is rejected as being too wideband to be of interest.
c. If the signal persists for more than about 5 successive time periods, it is rejected as being too extended in angular size to be of interest.
d. In addition to the above signal strength tests, the normalized cross-correlation function between the known antenna pattern and the observed data points is calculated. Any small-diameter radio must vary in intensity according to the antenna pattern as it drifts through the beam, so this test is in essence a matched filter detection method. A hybrid correlation value/signal strength threshold is used to screen out statistical fluctuations from likely signals.
e. If any of the above tests are passed, a "detection" is declared, an appropriate message is written out on the printer, and the relevant data are stored on the computer disk. Every several days, the disk records are converted to punched cards for permanent storage.

The computer printouts are inspected carefully, and used as a basis for manually editing the signal detections. Any detections that were caused by known equipment malfunction, lightning, interference, etc. are removed from further consideration. The continuum recordings are very helpful in providing useful information for this purpose. Any extraordinary signals detected are sufficient grounds to alter the observing schedule of the telescope so as to continuously observe the signal. Auxiliary equipment is available to analyze the spectrum of a signal to a resolution of of several hundred hertz, and to monitor and record it aurally. This is useable only when staff members are physically present.

At long intervals (years) all the accumulated signal detection records are statistically analyzed as a group, to determine if there is any correlation among them as to sky location, frequency, time, etc.

## 4. A DECADE OF DATA

This far about 30,000 "detections" have been recorded and archived, using the 50 channel system. Maps of this data have been prepared in many different ways to search for significant non-random distributions of the detections. For each sky region (as defined above), separate maps were prepared in each of two coordinate systems - declination vs. right ascension, and declination vs. Eastern Standard Time. Within each coordinate system, separate maps were prepared for each of four types of detection - single high data point, 2 successive high data points, 3 succesive high data points, and good fit to the antenna pattern. Within each detection type, separate maps were prepared for two varieties of intensity measurement - average number of detections per day (ignoring the intensity of the detections), and average intensity (including the intensity). For the purpose of mapping, detections were averaged into bins measuring 30 minutes of time in RA or EST, and 20 minutes of arc in declination. All detection averages were normalized to a single day total, to remove any effects due to varying numbers of days having been spent observing at different declinations. Finally, all maps were made in two forms - a contour map and a map showing explicitly the numerical values at the appropriate locations.

All of these maps were searched for obvious areas of non-randomness. All such anomalous areas found were examined in more detail by preparation of large-scale maps of the anomaly itself, and the original data records were examined for each detection which contributed to the anomaly.

A number of individual transient extraterrestrial signals that match the antenna pattern have been received but none of them have persisted long enough to be positively identified. The most prominent example in the object that has come to be known as the "WOW" signal, observed in 1977 (see reference 3). The long horizontal feature appearing in figures 3 and 4 at about -26 degrees declination was caused by 174 days of observations in the WOW vicinity, over a very wide frequency range. There may exist many as yet undiscovered individual signals in the data archive. No thorough search has yet been made for them.

## 5. A GALACTIC LATITUDE DEPENDENCY

A preliminary search through all the maps indicate that most of them exhibit no obvious non-random structure. Obvious examples of non-random structure occur only on maps of single isolated detections and in the vicinity of the galactic equator and center. There is a general anti-correlation between the number of detections and galactic latitude, as shown in figures 3 and 4. Note that the declination scale is significantly larger than the right ascension scale in these maps. It is not known what causes this dependency, but one possible non-cosmic explanation is the apparent noise level that occurs near the galactic equator. In that vicinity, the background temperature is increased due to continuum and hydrogen-line radiation. That vicinity is also much "rougher" due to complex galactic structures. Both of these effects combine to raise the real-time running noise level value used to normalize the raw data. This in effect turns down the gain of the receiver so that a received signal must be stronger in that area than in others to be detected. The magnitude of effect is not known, although it is clearly in the correct direction. On the other hand, if the typical detections made over the whole sky are due to statistical fluctuations (which is most reasonable), then the same average number of detections should also occur in the galactic plane. A conceivable explanation is the probability distribution of the observed galactic structure may be sufficiently different from that of the background noise level to make the standard deviations calculated under the two different conditions be incompatible. One last puzzling complication is the fact that the maps of the same sky region showing other detection methods (two and three successive high points, and good fit to the antenna pattern) show NO dependency on galactic coordinates (or indeed on anything).

## 6. TWO APPARENT GALACTIC HOT SPOTS

There are two discrete areas near the galactic equator that appear to exhibit much greater than the average number of single-point detections. Both are of sufficient angular extent as to rule out any single emission source, and the two areas are quite different from one another.

The northernmost area is located slightly earlier than the galactic center in right ascension, and at the same general declination, as shown in figure 3. This area is the most prominent object on the "detections per day" map, yet it does not appear on the "average intensity" map. This implies that it was caused by a large number of low level detections. Inspection of the raw data verifies that this is the case. There were 92 isolated detections exceeding 5 sigma, with the highest being 19 sigma. There appears to be no channel (ie. frequency) dependency. This area was observed twice, in September 1977 and May 1978 and the same behavior was observed both times, although the detections in September were much more numerous than in May. One possible non-cosmic explanation of this is the fact that as the antenna beam approaches the galactic center, it encounters a steep gradient in continuum intensity. Since the real-time running noise level is calculated over a preceeding time period, it may fall behind the actual current value. This could cause galactic structure to be detected more frequently than normal. This area is rather narrow in declination, which is generally a suspicious occurence in a survey of this type. Nevertheless, inspection of the raw data does show that the area is wider than a single declination scan, and the detections do occur randomly throughout all the days spent observing in this area.

The southernmost area is about two degrees south of the galactic center and somewhat later in right ascension, as shown in figure 4. This area is the most prominent area on the "average intensity" map, yet it does not appear on the "detections per day" map. This implies that it was caused by a smaller number of very high intensity detections. Inspection of the raw data reveals 41 isolated detections exceeding 5 sigma, 11 exceeding 20 sigma, and the highest being 30 sigma. This area was surveyed twice, in December 1977 and June 1978 and the same behavior was observed both times. This repetitive behavior between observations spaced by six months appears to rule out terrestrial interference. We are as yet unable to advance any explanation for this phenomenon.

Pulse-like detections could easily be generated internally in the digital system by occasionally dropping a bit, or by loose connections,

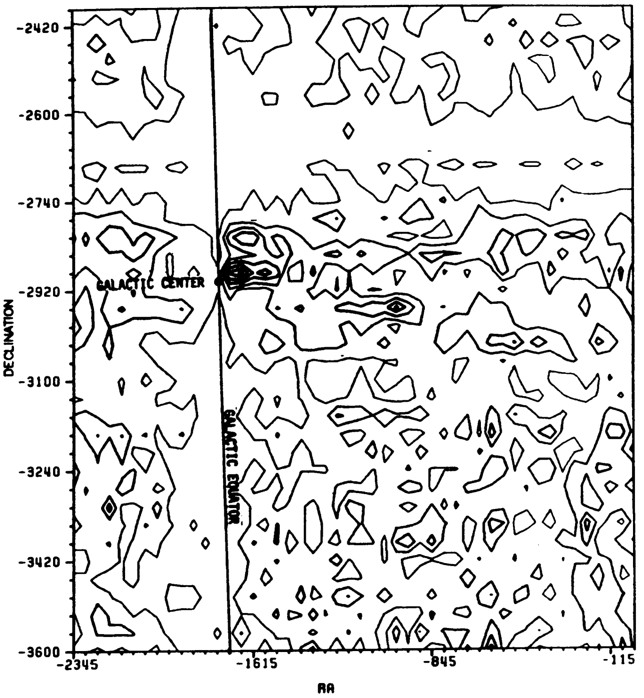

Figure 3. Map of the average number of isolated single-point detections per day, disregarding their intensities.

intermittant component failures, etc. However it is difficult to understand how this could affect all the channels at different times, or how it could be related to specific sky areas.

## 7. FUTURE PLANS

The survey is being expanded to cover the entire Water Hole region (1400-1750 MHz). The observing procedure will be modified such that any detection made will automatically activate a frequency zoom technique to focus on that particular object with successively increasing frequency resolution, and with more detailed data recording. A moving feed system is being designed to allow tracking of specific objects for 1 hour, and vernier declination scanning of 1 degree. The declination movement will provide immediate determination of the declination of any detected signals. The Gasfet front-end amplifiers will be cooled to liquid nitrogen temperature. The survey will continue indefinitely, since even after the entire visible sky is surveyed once, the equipment and techniques will have improved so much that successive deeper searches are warranted.

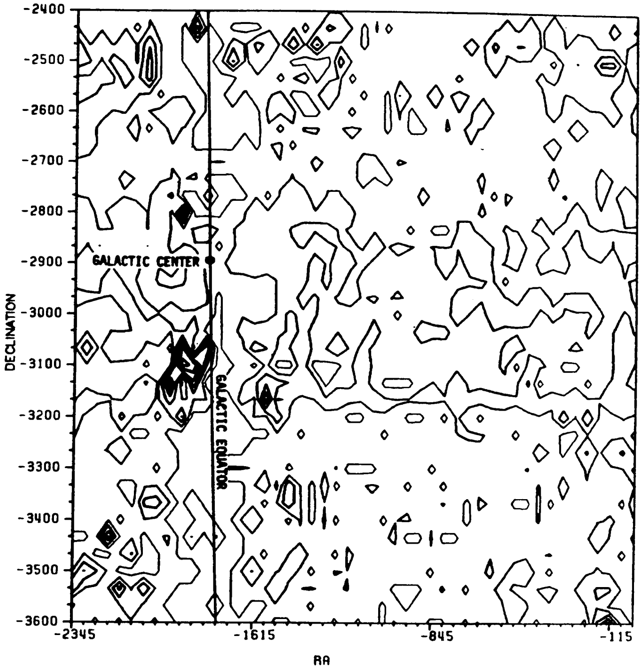

Figure 4. Map of the average intensity of isolated single-point detections.

## 8. CONCLUSIONS

There appear to exist two areas near the galactic center that emit strong narrowband (less than 10 kHz) pulses (less than 10 seconds in duration).There may be an instrumental explanation for one, but there is no obvious explanation for the other. These phenomena may or may not ultimately be shown to be of physical significance, but they do indicate the type of phenomena that can only be detected by a thorough all-sky survey.

A common strategy in SETI observations, including those described here, is to survey an entire area of sky or selected list of targets, analyze the data, and then reobserve any objects that appear to be unusual. Our experience has shown that this is not generally the most effective strategy, because no specific detections have ever been found a second time. Since detections are so rare, a better allocation of the equipment and telescope is to automatically stop the survey as soon as a detection is made, track that sky direction for as long as necessary, and activate auxiliary equipment to record and analyze the incoming data in the greatest detail possible. In this mode, the telescope spends more of its time observing (at high efficiency) and perhaps identifying "known" signals (as defined by the detection criteria) and less time searching (at low efficiency) for new ones.

## 9. ACKNOWLEDGEMENTS

This program and paper could not exist without the almost entirely volunteer work, contributions and assistance from many people. These currently include Jim Bolinger, Joe Byrd, Jon Guthrie, Max Habibi, Herb Johnson, John Kraus, Gene Mikesell, Dave Raub, Dave Reynolds, Mark Selover, Yiang Tan, Del Waggoner (all of Ohio State University), Jerry Ehman of Franklin University, Mike Brooks of Bell Labs., Robert Dirosario of the University of Dayton, Bill Brundage of NRAO, Tap Lum of UC-Berkeley, Ellen Barber of the Columbus School for Girls, Marc Abel of Upper Arlington High School, and many others too numerous to mention.

We acknowledge with great appreciation the financial support of NASA and the Ohio State University, as well as generous equipment donations from the Digital Equipment Corp., Bell Laboratories and the Accuray Corporation.

## 10. REFERENCES

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