S E C T I O N V

RADIO SEARCHES - RECENT OBSERVATIONS

5.0 INTRODUCTION, The Editor.

5.1 SETI OBSERVATIONS WORLDWIDE, Jill C. Tarter.

5.2 PROJECT SENTINEL: ULTRA-NARROWBAND SETI AT HARVARD/SMITHSONIAN, Paul Horowitz and John Forster.

5.3 THE OHIO SETI PROGRAM - THE FIRST DECADE, Robert S. Dixon.

5.4 A SEARCH IN THE INFRARED TO MICROWAVE FOR ASTROENGINEERING ACTIVITY, V.I. Slysh.

5.5 SEARCH FOR STRONGLY POLARIZED RADIO EMISSION FROM E.T.I., AND AN OPTIMISTIC APPROACH TO THE GREAT SILENCE (FERMI'S PARADOX), J.P. Vallee.

5.6 LUNAR REFLECTIONS OF TERRESTRIAL RADIO LEAKAGE, Woodruff T. Sullivan, III and Stephen H. Knowles.

5.7 EAVESDROPPING DETECTION OF RADIO SIGNALS FROM OTHER PLANETS, WITH ONE BIT IMPLEMENTATION TECHNIQUES USING EXISTING COMPUTERS, Stephen H. Knowles.

INTRODUCTION

The publication of this Volume coincides with the 25-th anniversary of the first radio search. It was conducted in 1960 by Frank Drake, a young (29) radio astronomer on the staff of the National Radio Astronomy Observatory (NRAO) at Green Bank, West Virginia, USA. With his celebrated Project Ozma, which he named after the Princess of the mythical kingdom of Oz, Drake opened on April 11, 1960, the doors for the many SETI projects that were to follow.

He used the then new 85 ft radio telescope at Green Bank and one of the first parametric ampliphiers available. It was provided by the President of Microwave Associates, Dana Atchley Jr., and was driven from Boston to Green Bank by his chief engineer Sam Harris, who showed Drake how to use it. Drake and his colleagues at Green Bank constructed an essentially one channel receiver which could shift its frequency by about 100 Hz per minute and thus slowly scan through the spectral region surrounding the 21 cm hydrogen line. The project lasted for about three months focussing on two nearby, Sun-like stars, Tau Ceti and Epsilon Eridani. In 1979 Drake was writing "with the Arecibo telescope and our 1008 channel receiver, we duplicate everything that was done in Project Ozma, actually do it better, in less than a second." With the new multichannel spectrum analyzers now becoming available we will be able to do thousands of Ozmas per second. People ask sometimes "since technology is advancing so fast, why not wait until it becomes better before undertaking such a search?" I believe the answer probably is: Because we don't know at what level the technology would be sufficient, and also because to climb a ladder you need to start from the lower rungs and climb one rung at a time.

Project Ozma had the full support of Otto Struve, a distinguished astronomer who was then the Director of NRAO. While in its planning stage, it received a strong boost from the publication of the Cocconi and Morrison paper in NATURE, who were independently thinking about the same problem. During the three months of Project Ozma they logged a total of 200 hours of observations, and generated great publicity in the media which brought out several other people who shared the same ideas. Notable among those that visited Drake at Green Bank during the Project Ozma were Theodore Hesburgh, the very young then President of Notre Dame University and a highly respected theologian, and Bernard M. Oliver, the Vice-President for research of the Hewlett-Packard Corporation who now heads NASA's SETI program. It is inspiring to see that people like

M. D. Papagiannis (ed.), The Search for Extraterrestrial Life: Recent Developments, 263–270.

https://doi.org/10.1017/S0074180900146601 Published online by Cambridge University Press

Drake, Morrison, Oliver, and Hesburgh, who were the pioneers of SETI, have remained the dedicated leaders of this effort through the years and with their enthusiasm and their example have brought many more people into this new field.

It is also interesting to mention an uncanny experience that Drake and his colleagues had at the very beginning of Project Ozma. The first night they observed Tau Ceti without anything unusual happening. When it set around noon of the next day they switched to Epsilon Eridani, and a few minutes later it happened. The chart recorder went off scale and a loudspeaker, which was connected to the receiver, started blasting bursts at the rate of eight per second. After the first shock, they decided to turn the radiotelescope to another position on the sky to check the signal for terrestrial interference. The signal stopped, but when they turned the telescope back to Epsilon Eridani the pulsing signal was gone too. Frustration. They continued to monitor this target on the same frequency and after ten days the signal came back. Excitement, but it was also picked clearly by a simple horn antenna which they had installed by the window to check for terrestrial sources. The signals had to be manmade, most probably being transmitted from a passing, high flying airplane. Such false alarms are rather common experiences in most SETI projects, and are one of the hazards of the trade because when they occur they tend to raise the heartbeat of the observers to rather dangerous levels.

In the 25 years that have passed since the first SETI project, there have been close to 50 searches, including a few in the optical and in the infrared, about half of which were conducted in the last seven years. The international participation has also increased impressively. Major radio observatories in Australia, Canada, France, Germany, Holland, USSR and USA have participated in this effort, with Japan getting ready to join the group with its new 45m Nobeyama millimeter radio telescope. We have logged so far close to 120,000 hours of observations, about 100,00 of which come from the two SETI dedicated facilities, the Ohio State University Radio Observatory which has been in operation since 1973, and the Harvard-Smithsonian Oak Ridge Radio Observatory which has been operating since March 1983. They both are on a continuous, 24 hrs/day observing schedule which piles up rapidly observing hours.

It must be noted, however, that not all of these search times are equivalent because of continuous technological improvements. We have already mentioned a comparison of Project Ozma with the 1979 Arecibo. But this can be true even for the same project. The Ohio SETI Program, e.g., during its first four years was only using an 8 channel system with a 20-100 kHz bandwidth. Since 1977, however, it has been using a 50 channel system with a 10 kHz bandwidth. Similarly, during its first two years Project Sentinel was operating with a 65,500 spectrum analyzer covering a total bandwidth of only 2 kHz. This is about to be replaced by an 8.4 million spectrum analyzer that will expand the total bandwidth more than 200 times to 420 kHz by increasing also the channel bandwidth from 0.03 to 0.05 Hz. Thus technological advances produce better surveys which supercede all previous work.

Technological progress has been improving steadily the quality and the range of our searches. Some of these technological developments are also of value to other areas of radioastronomy as well as to other fields. Most notable among them are signal recognition algorithms which try to process in real time huge amounts of data, and the new generation of mega-channel spectrum analyzers now coming into the scene. These new analyzers will expand immensely the frequency range of our searches. Still the ranges of the different search parameters (frequencies, frequency resolution, signal strengths, angular resolution, polarization, time coverage, sky coverage, etc) constitute a very complex multidimensional problem that is often referred to as the "Cosmic Haystack". To what extent will we keep searching in this haystack? This is another question that people often ask. I think it is too early to ask questions of this sort, because we have only just started. If we could maintain a steady pace during the next 15 years, I believe we will be able to explore a considerable segment of these different ranges at a reasonable resolution. Of course we can always refine our measurements and do the whole thing over at a higher resolution, but if a comprehensive, well planned search over a 10-20 year period were to produce no results, it is possible that the interest of both the scientists and of the funding agencies will begin to wear out, and we will probably stop to take a break. But before we start debating what are we going to do then, we must first go on with a well planned systematic search, which will answer our fundamental questions about other stellar civilizations to a considerable degree of confidence.

The Co-Chairmen of the corresponding Session of the Symposium were Edward M. Purcell and Edward Lilley of Harvard University, to both of whom I am deeply indebted not only for their help in this Symposium, but also because they were my two Ph.D thesis advisers at Harvard who introduced me to radio astronomy and space research.

The first paper of this Section is an excellent review by Jill Tarter of NASA-Ames and of the University of California-Berkeley. She is a very active SETI observer and she has also become the record keeper of all the SETI projects carried out around the world. The second part of her paper is a summary of all the SETI programs up to the time of our Symposium (June 1984).

Here I must interject to provide some additional information on the Soviet SETI program for which Jill says she had no recent communications. I visited Moscow in August 1984, right after our IAU Symposium, and I was received very warmly by all our Soviet colleagues (Troitskii, Shklovsky, Kardashev, Slysh, Muhkin, Gindillis, et al.) I was told that the 100 1m radiotelescopes array was never implemented, primarily because of a long illness of Dr. Troitskii, an internationally acknowledged leader in this field. Thank God he was fine in August 1984 when I saw him in Moscow, but there were no plans to reinstate the project. Our Soviet colleagues are now more interested in infrared observations to check for superstructures, such as Dyson Spheres, constructed by Supercivilization. Dr. Shklovsky, who unfortunately died suddenly in March 1985, was negative about searches, presumably because he had become convinced that there are no other stellar civilizations to

https://doi.org/10.1017/S0074180900146601 Published online by Cambridge University Press

communicate with. His great scientific prestige and his important position as the Director of the Astrophysics Division of the Institute for Space Research of the USSR Academy of Science had certainly a damping effect on all younger scientists who might have wanted to become involved in experimental SETI. With his passing it is possible that SETI work might be revitalized in the Soviet Union. A new 65 m millimeter radio telescope is now being constructed in a region between Samarkand and Tashkent under the supervision of Drs. Kardashev and Slysh, both of whom are distinguished scientists and strong supporters of SETI. It is possible that this new instrument might also be used for SETI in the future.

Jill Tarter notes that SETI projects might be divided into the following three categories:

I. Directed. They use a major observatory for a relatively short period for a specific SETI project.

II. Shared. They reanalyze for SETI signals old data obtained for other purposes, or they obtain data for SETI in a parasitic mode analyzing essentially the data being obtained by a radio telescope for a different project.

III. Dedicated. They use a radio facility exclusively for SETI. To the two professional SETI dedicated facilities now in operation (Ohio State University and Harvard-Smithsonian), three amateur SETI facilities, have been added in the last few years.

This multiplicity of approaches expands impressively the time devoted to SETI, but lacks to some extent in organization and coordination: When the NASA program will become operational later in this decade, we will have both, i.e., a central, well orchestrated major project, supplemented by a considerable number of other projects exploring other alternative ideas and strategies. This seems to be the most prudent approach, because not only it enhances our chances for success but it also provides room for more people to become involved in this field which makes this new branch of astronomy stronger and more vigorous.

In the next paper Paul Horowitz of Harvard University and his assistant John Forster describe Project Sentinel, one of the two SETI dedicated operations in the world. It uses an 84-ft dish and two dual polarization 65,536-channel receivers with an ultra-narrow bandwidth of 0.03 Hz per channel, for a total bandwidth of only 2 kHz. The ultra-narrow bandwidth is based on the premise that extraterrestrial civilizations will transmit in an ultra-narrow band to conserve energy, which however cannot be much narrower than the 0.03 Hz bandwidth used because interstellar inhomogeneities broaden the signal by Doppler shifts in scattered paths. This is called the Drake-Helou spreading after the two scientists who computed this broadening of the signal. The search is also based on the assumption that the extraterrestrials are beaming a hydrogen line (or some other magic frequency) signal that has been corrected for all the Doppler effects in their solar system (orbital velocity around their star, etc), as well as for the relative motion of our two stars. Consequently, all we need to do to receive a pure signal centered exactly on the hydrogen line frequency, is simply to take out all the Doppler effects due to the motion of the Earth.

These assumptions are quite restrictive, especially the one expecting them to correct their frequency for the relative motion of our two stars. This motion is typically of the order of 20 km/sec which at the H-line produces a Doppler shift of about 100 kHz, which is 50 times larger than the 2 kHz total bandwidth of their receiver. To overcome this potential problem, Horowitz and his team are now building a new spectrum analyzer with 8.4 million channels and an overall bandwidth of 420 kHz which is expected to become operational within 1985. Their search covers the entire northern sky, i.e., about 80% of the entire sky, in about half a year, sweeping a half-degree one beamwidth band around the sky each day. A potential source stays in the beam for about 2.5 minutes. The system searches the data for large peaks and archives anything suspicious along with the pertinent parameters. It is very good in rejecting terrestrial interference, but they did have two major false alarms with almost 50 sigma peaks when they got the Sun in their beam. During the first two years of operation they have swept the entire sky first at the hydrogen line frequency (1420.40575 MHz) and then at the OH-line (1667.3590 MHz). The project has been supported by the Planetary Society, a private organization headed by Carl Sagan and Bruce Murray, at a very modest level (about $20,000 per year) and about $100,000 to build the new 8-million channel analyzer. It is a tribute to the ingenuity and dedication of Paul Horowitz that so much has been achieved so inexpensively.

Robert Dixon of the Ohio State University describes in the next paper the oldest SETI dedicated program, the Ohio SETI Program, which has been now in operation for 12 years. Actually in the last two years there was a serious threat that the radio observatory would be dismantled because the owner of the land wanted to convert it into a golf-course. The entire scientific community rallied to the support of the Ohio State University Radio Observatory and the Symposium participants adopted a very strong resolution in their support. The danger seems now to have been averted, at least for the time being.

Their instrument is a meridian-transit radio telescope with a collecting area of 2,200 m^2, which is equivalent to a parabolic dish 175 ft (53m) in diameter. The beam size is 8 arcmin in R.A. and 40 arcmin in DEC. The telescope stays at a constant declination for several days sweeping through all right ascensions. It has a 50-channel filter bank with a bandwidth of 10 kHz/channel, and therefore a total bandwidth of 0.5 MHz centered at the hydrogen line. The system temperature is about 100 K. In addition a 200 MHz continuum channel is recorded by the computer for reference and is displayed continuously on a chart-recorder. During the first three years of operation (1973-76), when the system had only 8 channels, they had covered about 41% of the accessible sky (-36 to +63 DEC). With the new 50 channel filter band they have now covered 21% of the accessible sky including a 40-43 DEC band that includes the Andromeda Galaxy (M31), our large galactic neighbor.

The Ohio group had also its share of false alarms, the largest of which occurred in 1977. It has become known as the "WOW" signal, after the word the operator of the telescope scribbled on the chart next to this peak. Repeated attempts to re-acquire this signal have not produced any results. The data are being archived and are being

https://doi.org/10.1017/S0074180900146601 Published online by Cambridge University Press

analyzed for statistical effects with respect to celestial coordinates. Several improvements are being planned for the future, including expanding the frequency range to cover the entire "water hole" (1400-1750 HMz), i.e., the frequency range from the H-line to the OH-lines. This project has been sustained with a very modest support from NASA and the unselfish dedication of many volunteers. Flying high above the Ohio State University Radio Observatory is the Flag of Earth, (the blue disk of the Earth superimposed on a yellow segment of the Sun and the black background of space with a small white moon next to the Earth) to emphasize, as Bob Dixon said, that SETI is an activity of all Mankind. This flag was designed, authored as he prefes to say, by James Cadle of St. Joseph, Illinois.

At the end of our Symposium, Bob Dixon presented me on behalf of all of the participants with this beautiful Earth Flag, which I keep in my office with fond memories of this first IAU Symposium on the Search for Extraterrestrial Life.

V.I. Slysh of the Space Research Institute, Moscow, USSR, discusses a search in the infrared and in the microwave regions for products of astroengineering by supercivilizations, such as the so called Dyson Spheres. These are spherical shells, constructed from the rearrangement of all the planetary materials that exist around a star, which allow a supercivilization to trap almost all of the energy radiated by the star, which is ultimately reemitted by the shell as infrared or microwave radiation. The 1983 survey with the Infra-Red Astronomy Satellite (IRAS), which carried detectors operating at 12, 25, 60 and 100 microns, ought to have been able to detect all Dyson Spheres with a temperature between 50 and 400 K within 1 kpc from the Sun. The author discusses several cases from the IRAS survey with spectra peaking in the 10-100 micron region, but he also examines the possibility of confusion with thick circumstellar dust shells and the means to resolve such ambiguities.

I must interject here a personal comment on the difficulties I have with the concept of the Dyson Spheres. If a supercivilization were to collect all the solid matter (Hydrogen, Helium, Neon, Argon, etc, would be of no structural use) available in our planetary system, they would end up with a structural mass of about 10 Earths. Consequently a shell built around the Sun at a radial distance near the orbit of Venus ($r \sim 10^{13}$ cm) would have a surface density of only about 45 gm/cm^2 and for a typical density ρ = 3-4 gm/cm^3 a thickness of only d = 10-15 cm. Such a super-thin shell (the equivalent of a shell with a 100m radius and the thickness of a single atom) would buckle immediately under the gravitational pull of the Sun, which is equivalent to a uniform external pressure P, where:

$$P = \frac{GM_O \rho d}{r^2} = 60 \text{ dyn/cm}^2 \qquad (1)$$

The internal stress S of this shell would then be,

$$S = \frac{2\pi r^2 P}{2\pi r d} = \frac{r}{d} P = \frac{GM_O \rho}{r} = 5\times10^{13} \text{ dyn/cm}^2 \qquad (2)$$

The buckling loads of such a shell is given by the expression,

$$S = \frac{E \cdot d}{r} [3(1-n^2)]^{-1/2} \qquad (3)$$

where E is Young's Modulus of Elasticity and N^2 is the Poisson ratio with typical values of 0.2-0.5. By equating (2) and (3) and neglecting the factor with the Poisson ratio which is of order unity, we obtain the value that E must have to prevent the buckling of the shell.

$$E > \frac{GM_{\odot}\rho}{d} = 4x10^{24} \text{ dyn/cm}^2 \qquad (4)$$

which is a trillion times higher than any known material (high-stress stainless steel, e.g., has E = 200 GN/m^2 = $2x10^{12}$ dyn/cm^2).

From the above it follows that the construction of a spherical shell around a star from the material present in its planetary system is an impossible task. What is possible, however, is to have a large number of independent space structures in orbit around the star, but these would intercept only a relatively small fraction (~1%) of the star's radiation. Consequently such stars, would display a normal spectrum with only a small excess in the infrared.

J.P. Vallee of the Herzberg Institute of Astrophysics, Ottawa, Canada, together with Martine Simard-Normandin have conducted a search for strongly linearly polarized signals, reasoning that since no natural source emits radiation that is more than 70% linearly polarized while artificial signals (radio/TV) can be highly polarized, discovery of highly polarized signals would indicate the presence of extraterrestrial intelligence. They used the 46-meter radiotelescope of the Algonquin Radio Observatory and a cooled parametric amplifier tuned at 10.6 GHz (2.8 cm) to search for highly polarized signals near the center of the Galaxy, which they argued would be an ideal location for relay stations for telecommunications through the Galaxy. No signals were discovered, but they argue that the "Great Silence", which all searches have encountered up to now, might be purposely imposed on all emerging civilizations during their formative years.

Woodruff T. Sullivan, III of the University of Washington and Stephen H. Knowles of the Naval Research Laboratory, describe their observations to check experimentally the radio leakage of the Earth by observing the reflection of these signals from the Moon with the large Arecibo antenna. As it was predicted in the model developed by Sullivan and his colleagues in 1978, military radars and strong television stations were the main sources observed in the 150-500 MHz range. Military radar pulses, such as the U.S. Ballistic Missile Early Warning System (BMEWS), are the most powerful radio sources on Earth. The strongest of them seems to be the 217 MHz space surveillance radar of the U.S. Navy (NAVSPASUR) which is located in Archer City, Texas and radiates pulses of $1.4x10^{10}$W into a bandwidth of 0.1 Hz. These radar pulses could be detected by stellar civilization with an Arecibo technology to a distance of about 20 light years. It is interesting that the existence of this powerful radar was unknown to Sullivan and Knowles who discovered it with with this experiment from its powerful reflections from the Moon.

The video carrier of TV transmissions is a very narrow band signal (0.1 to 1.0 Hz) and carries about half of the total transmitted power. The strongest of the TV stations could be detected by an Arecibo-like antenna up to about 3 light years. Thus, with the Moon acting as a convenient mirror of our technological civilization, we were able to study what an extraterrestrial civilization could observe if they were to eavesdrop on our planet and study the prodigious radio leakage of our civilization. From the daily changes of the radio signature of the Earth they would be able to figure out the spinning rate of the Earth, and from the Doppler shifts of these signals its orbital period and its distance from the Sun. Eavesdropping is certainly a valid search strategy, especially for nearby stars, because it is capable of revealing the presence of advanced civilizations that have no interest in establishing communications with the Earth.

In the last paper of this section Stephen H. Knowles of the Naval Research Laboratory describes a technique developed by him and Woody Sullivan to conduct an "eavesdropping" experiment not with hardware (scanning slowly over a wide spectral range, or using a megachannel spectrum analyzer), but rather with software using a data analysis technique called "One-Bit Spectral Analysis" which can be implemented on several general-purpose computers. This system is not a substitute for the large spectrum analyzers which are much faster. It offers, however, several other advantages such as the ability to process the data using a variety of search strategies. One can try, e.g., varying bandwidths with the same data, or try several hypothesized rotation rates for the transmitting planet which cause an apparent chirp or frequency drift in the radio signals that reduces the possible integration period of the signals. Radio signals from the Earth, e.g., would have a maximum doppler drift rate of about 0.1 Hz/sec at 1 GHz, limiting coherent integration time to 10 seconds if no compensation is made, which is easy to do with the computer in a one-bit system. In addition, for limited runs, this system can utilize dead-time (early morning, weekend, etc) on many medium to large size computers. These advantages make this new technique a very useful method for searches over large spectral ranges, such as those needed for eavesdropping studies, which certainly ought to be included in a comprehensive search strategy. Knowles reports also that this technique was used in the analysis of a limited sample of data which were obtained with the Arecibo radiotelescope and the Mark I VLBI system from a few nearby stars. While no detections were made, Knowles says, the method was checked out to their satisfaction.

The picture that is emerging from all these searches is that SETI is rapidly becoming more international with scientists from many countries joining in the effort, more diversified with a variety of techniques and strategies being pursued, and more ingenious with many new processes coming into practice. All these developments speak well for the prospects of SETI in the next 10-20 years.

THE EDITOR

https://doi.org/10.1017/S0074180900146601 Published online by Cambridge University Press