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Bioastronomy: The Search for Extraterrestrial Life Past Efforts and Future Plans

1. FROM THE ANCIENT GREEKS TO THE 19-TH CENTURY

The literature on the plurality of living worlds stretches back several thousand years: (1), (2), (3). As early as around 400 B.C., in his book "On Nature" the ancient Greek philosopher Metrodorus of Chios was writing: "It seems impossible, in a large field to have only one shaft of wheat and in the infinite Universe only one living world." Also around 50 B.C. in his book "De Rerum Natura" the Roman poet-philosopher Lucretius was writing: "Nothing in the Universe is unique and alone, and therefore in other regions there must be other earths inhabited by different tribes of men and breeds of beasts."

The subject has been debated extensively through the centuries and at times led to severe recriminations, such as the execution by the Inquisition of the Italian monk Giordano Bruno (burned at the stake on February 17, 1600), who had espoused the heliocentric theory of Copernicus and insisted that in the Cosmos there must be "an infinite number of suns with planets with life around them". About a century later the famous Dutch physicist Christian Huygens wrote in 1690 the book "Cosmotheoros", in which he argued that life can exist in many other planets. He also tried to reconcile the beliefs of the Church with the idea of the "Plurality of Worlds" by stating that "barren planets deprived of living creatures, which speak most eloquently of their Divine Architect, are unreasonable, wasteful and uncharacteristic of God, who has a purpose for everything."

The first scientific proposal to communicate with extraterrestrial intelligence was made around 1830 by the famous German astronomer and mathematician Carl Friedrich Gauss, who suggested to plant in Siberia a colossal forest in the form of an orthogonal triangle to signal to extraterrestrials, who might be observing the Earth with their powerful telescopes, that our planet is inhabited by intelligent beings who are familiar with the Pythagorean Theorem. Gauss, of course, was not funded to plant his forest, but he did plant the idea to try to communicate with extraterrestrial intelligence.

2. THE DAWN OF RADIO ASTRONOMY AND SETI

The beginning of the modern era for our radio searches must be set in 1932, when Karl Jansky of the Bell Telephone Laboratories, working with a very primitive radio antenna in New Jersey, found that besides terrestrial radio interference he was also receiving radio noise from the center of our Galaxy in the direction of Sagittarius. This was the first time that knowingly we had received radio waves from another part of the Universe.

In 1938 Grote Reber, a young electrical engineer, built in the back yard of his home near Chicago the first radio telescope, with a parabolic dish about 9.5 meters in diameter. In 1951 Harold Ewen and his thesis adviser Professor Edward Purcell of Harvard University, discovered the hydrogen line at 21 cm, which became the first spectral line known to exist at radio wavelengths. On October 4, 1957 the Soviet Union launched Sputnik I and thus opened the doors of the Space Era and of the exploration of our solar system. In 1959, G. Cocconi and Philip Morrison (4) published in NATURE their pioneering paper "Searching for Interstellar Communications", in which they recommended to search for radio signals from other advanced civilizations at the hydrogen line (the only radio line known at the time), "because this was the frequency that all cosmic civilizations would know."

They closed their paper saying: "The probability of success is difficult to estimate, but if we never search the chance of success is zero."

The call was answered almost immediately by Frank Drake (5), a 29 year old radio astronomer working at the U.S. National Radio Astronomy Observatory (NRAO) in Green Bank, West Virginia, who independently was also thinking along the same lines as Morrison and Cocconi. In the spring of 1960, Drake conducted the first radio search, his celebrated Project Ozma, using the 26-meter Tatel radio telescope of NRAO. He spent a total of 200 hours searching at the 21-cm line of hydrogen for radio signals from two nearby Sun-like stars, Epsilon Eridani (10.7 l.y.) and Tau Ceti (11.9 l.y.). Except for some exciting false alarms, the results were negative, but his experiment opened the doors for the Search for Extra-Terrestrial Intelligence, a term usually shortened into SETI.

3. DEVELOPMENTS IN THE 1960'S AND 1970'S

After the pioneering work of Frank Drake in 1960, progress in SETI was slow during the 1960's and the 1970's. The search for extraterrestrial intelligence was viewed with considerable reservation by the scientific community and was often associated with UFO's, science fiction, etc. As a result only a few brave scientists, mostly from the USA and the USSR, with little if any support even from their own institutions, continued to conduct radio searches, to write books such as the classic one by Shklovskii and Sagan (6), and to organize international meetings, such as the one held in September 1971 in the Soviet Union at the Byurakan Astrophysical Observatory which was co-sponsored by the US and the USSR Academies of Science and its proceedings, edited by Sagan (7), were published by the MIT Press.

In 1963 the second radio line was discovered. It was the line of hydroxyl (OH) at 18 cm, which actually is a group of four distinct spectral lines. More lines kept being discovered in the years that followed and we now have more than 100 radio lines from about 70 different molecules, ions, and radicals. The hydrogen line, however, has remained the most frequently used of these "magic frequencies", as they came to be known, but several of the others, including the hydroxyl line, the line of carbon monoxide, and others, have also been used in radio SETI.

In 1976 the two Viking probes landed on Mars, the planet which from the days of Percival Lowell (1855-1917) and his claims about Martian water-canals, had been considered the most likely place in our solar system to find life. Each of these Viking landers carried an elaborate biochemical laboratory and conducted several studies for biological activity in the soil of Mars. In spite of some initial excitement, the results finally proved negative, showing that at least now there is no life on Mars. Parallel missions to Venus by the Soviet Union showed that Venus, with a surface temperature of about 475°C (enough to melt lead), an atmospheric pressure 90 times bigger of the pressure on Earth (like being under 900 meters of water), and a complete absence of water, made Venus a very improbable place for life.

Thus we began to accept the idea that most likely our Earth is the only place with life in our solar system. Consequently, if we were to search for extraterrestrial life we would have to do it in other solar systems, of which there are many billions just in our Galaxy. But our instruments can not yet see planets around even the nearest of stars, and much less to do spectroscopic studies of such planets to infer the presence of life from the presence, e.g., of an oxygen atmosphere. Consequently, the only approach that is feasible now is to search for technologically advanced civilizations in other solar systems, with whom we can establish radio contacts. As a result SETI has become the only presently available path to discover extraterrestrial life.

Almost simultaneously, however, i.e., in the mid to late 1970's a kind of a revolt occurred within the SETI community. It was sparked by a paper by Michael Hart (8), and culminated with the conference "Extraterrestrials - Where Are They?" in November 1979 at the University of Maryland, the Proceedings of which were edited by Hart and Zuckerman (9). The revolt was based on the belief, supported by a considerable number of scientists including this author (10), that interstellar voyages at velocities V = 0.01 - 0.05c by large self-supporting space colonies, would not only be feasible, but essentially inevitable for most technologically advanced civilizations. As a result a colonization wave could sweep our Galaxy in less than 10 million years, establishing space colonies around every well-behaved star of our Galaxy, including our own Sun. Actually 10 million years is a very short period when compared to the more than 10 billion years age of our Galaxy, and therefore if indeed our Galaxy has been harboring advanced civilizations for billions of years, they must have colonized our Solar System, along with all the other stars, a long time ago. But then "Where Are They?" (A question that has become known as "The Fermi Paradox", after the famous Italian physicist Enrico Fermi who supposetely asked it at the Los Alamos National Laboratory in the summer of 1950.)

In the midst of these debates there was also an encouraging harbinger of better days to come. The International Astronomical Union (IAU), the prestigious international organization that represents all the astronomers of the world, and which is generally perceived as a rather conservative body, accepted my proposal to hold a one day session on "Strategies for the Search for Life in the Universe" at its 1979 General Assembly in Montreal. The meeting was very successful, and when Frank Drake and Michael Papagiannis summarized its results in an Open Evening Session, the large auditorium of the University of Montreal was packed with more than 1,000 astronomers from all around the world. The proceedings of this Session were edited by Papagiannis (11) and were published by Reidel in 1980.

In our meeting in Montreal the debate on the number N of advanced civilization in our Galaxy was very spirited and all four possible alternatives (N very small; N very large; N neither very small nor very large; N either very small or very large;) were vigorously supporteded respectively by M. Hart, T. Kuiper, F. Drake, and M. Papagiannis. These debates continued both in meetings and in the literature, and for a while they seemed to threaten the continuation of SETI. In retrospect it appears that they were a healthy development, because they brought more people into the SETI family. Also because after several heated debates a consensus finally began to emerge, namely that none of us can claim to know how extraterrestrial civilizations, far more advanced than ours, are likely to behave. Are they going to engage in interstellar travelling and galactic colonization? Would they continue to beam radio messages for newcomers for millions of years? Would they be interested in making physical or radio contact with a new civilization that has not yet settled its own problems? etc. Realizing that these debates could never lead to a consensus without any data, we were finally led to the obvious conclusion: Do not let these debates slow down the momentum we have gained in experimental SETI. Forge ahead, but encourage also the expression of alternative points of view through parallel experimental searches.

4. THE SCIENTIFIC RECOGNITION OF BIOASTRONOMY IN THE 1980'S

Following the fermentation period in the late 1970's and the successful one-day Session at the 1979 IAU General Assembly, there were several important developments in the first half of the 1980's. These finally established the scientific credibility of SETI and even gave a scientific name (BIOASTRONOMY) to this new branch of Astronomy. Actually all these big breakthroughs occurred in 1982, which was also an important anniversary, because it marked 50 years since the first detection of extraterrestrial radio noise by Karl Jansky in 1932, and 25 years since the launching of the first Sputnik in 1957. The major developments that occurred in 1982 were the following:

I. The International Astronomical Union (IAU), following the success of our one-day Session in Montreal and the publication of its proceedings, decided at its next General Assembly in 1982 at Patras, Greece, to establish a new IAU Commission (Section) under the title: IAU Commission 51 - Search for Extraterrestrial Life. Its first officers, elected for the period 1982 - 1985, were: Michael D. Papagiannis, President; and Nikolai S. Kardashev and Frank D. Drake, Vice Presidents. The new Commission grew rapidly (12), and now has close to 300 members from nearly 30 countries (about 250 astronomers members of the IAU, and about 50 Consultants, i.e., distinguished colleagues, from other related scientific fields).

II. The Astronomy Survey Committee of the National Academy of Science of the United States, which was charged to study and recommend the priorities for Astronomy and Astrophysics in the 1980's, published its report in 1982 (13), and for the first time it included SETI among these objectives and recommended the allocation of $20,000,000 for SETI in the decade of the 1980's.

III. NASA finally convinced the US Congress to withdraw its objections for SETI and began to fund SETI related projects at the rate of 1.5 - 2,000,000 million dollars per year.

IV. Carl Sagan (14) produced an international petition in support of the continuation of the search for extraterrestrial intelligence. It was signed by 70 prominent scientists from around the world, including 8 Nobel Laureates. It was published in SCIENCE, and was reprinted in several other journals and magazines around the world.

Two years later, our new IAU Commission 51 held its first IAU Symposium, June 18-21, 1984, in Boston, USA, bringing together about 150 prominent scientists and other participants from 18 countries spanning all five continents. This Symposium (IAU Symposium 112: The Search for Extraterrestrial Life - Recent Developments) received extensive coverage from several of the most respected news media, including a whole page article by Walter Sullivan in the New York Times. It is important to note also that the Symposium was co sponsored by four other major international organizations representing related fields: The IAF (International Astronautical Federation); COSPAR (International Committee on Space Research); ISSOL (International Society for the Study of the Origin of Life); and IUBS (International Union of Biological Sciences).

During the Symposium we also honored Prof. Philip Morrison of MIT for 25 years (1959-1984) from the publication of the pioneering paper in this field that he and Cocconi wrote in Nature in 1959. It is also interesting to mention that the co-chairmen of the Local Organizing Committee of the Symposium were Edward Purcell of Harvard, the co-discoverer in 1951 of the 21 cm line of hydrogen, and Philip Morrison of MIT, while Michael Papagiannis of Boston University chaired the Organizing Committee.

The Proceedings of the Symposium were published in 1985 by Reidel in a 600 page volume. The Editor was Michael D. Papagiannis (15) and the volume contained about 75 papers from about 100 authors and co-authors. The contributions were arranged into 8 Sections, for each one of which the Editor prepared a comprehensive Introduction to familiarize new readers with background data and the state of the art in that area. The success of this Symposium, prompted NATURE to invite Prof. Papagiannis (16) to write a review article to summarize all the recent developments in this new field, which was published in November 1985.

Finally in November 1985 we had again the triannual General Assembly of the IAU, this time in New Delhi, India. Frank Drake was elected the new President of IAU Commission 51, and was also honored for the 25-th anniversary of his first search (Project Ozma) in 1960. Also the Executive Committee of the IAU and the IAU General Assembly approve the new name (BIOASTRONOMY) for IAU Commission 51, which Papagiannis had advocated from its inception. Thus the name of the Commission now is: IAU Commission 51 - Bioastronomy: Search for Extraterrestrial Life, and the new term Bioastronomy is rapidly gaining international recognition.

The second international meeting of IAU Commission 51 was held in Hungary in June 1987, and had the title: IAU Colloquium 99 - Bioastronomy: The Next Steps (17). The Proceedings were edited by Prof. George Marx of Hungary, who organized this very successful meeting, and were published by D. Reidel in 1988 (18). The same year G. Marx became also the 3rd President of IAU Commission 51, which will hold its third international meeting in June 1990 in France with the title: Bioastronomy - The Exploration Broadens.

In summary, a lot of progress has been made in these 30 years, from 1960 when Frank Drake carried out the first radio search, to 1990. Now this young, but very active new branch of Astronomy called BIOASTRONOMY, is well established and its work has the support of Governments, of National and International Academies, and of major International Scientific Organizations. Is fair, therefore, to say that after its hard early years, Bioastronomy has finally reached adulthood.

5. SEARCH PROJECTS FOR EXTRATERRESTRIAL INTELLIGENCE

In the 30 years from the first radio search of Frank Drake, we have carried out about 60 search projects, most of them at radio frequencies, but also a few in the optical and in the infrared. Dr. Jill Tarler of the NASA Ames Research Center is maintaining an active file of all these projects. So far we have accumulated more than 200.000 hours of observations, using astronomical facilities in 10 countries (United States, Soviet Union, Australia, Canada, France, Germany, Holland, England, Argentina and Japan). Almost all of these radio searches have been conducted at selected "Magic Frequencies", as they are called, such as the hydrogen line at 21 cm and the hydroxyl lines at 18 cm, in the hope that other stellar civilizations will choose for their communications one of these universally known frequencies, to make it easier for newcomers like us to pick them up.

Probably more than 90% of the searching hours we have accumulated have been at the hydrogen line. Unfortunately, however, this reasoning has not payed off and we are now beginning to re-orient our efforts toward searches that will cover a much broader range of frequencies. This was technically impossible in the early days of SETI, but technology has advanced immensely in these 30 years, and we can now analyze for signals simultaneously huge numbers of different frequencies using a new instrument called a Multi-Channel Spectrum Analyzer (MCSA).

It must be said that the failure to pick up any signals in these 30 years has disheartened some of the searchers, but there may be legitimate explanations for it. Papagiannis (19), e.g., has suggested that the reason may be that if indeed there is an extensive network of intercommunicating advanced civilizations throughout the Galaxy, they must all know the exact location of each other. Therefore they must have divided the whole Galaxy into Regional Jurisdictions around each one of these civilizations, which will have the responsibility to look for emerging new civilizations in their own jurisdictions, and to notify them of the existence of the galactic network. Consequently, we are likely to be contacted by only one civilization, the one nearest to us, and not by all the millions of stellar civilizations that may exist in our Galaxy, that has several hundred billion stars. Why the headquarters of our region have not yet notified us, may have several explanations, including the fact that if they are located, say 100 light years away, they will not yet know that we can transmit and hence that we capable of receiving radio signals, since our earliest radio broadcasts, that began in this century, have not yet reached that far.

The searches we have conducted so far, can be divided into 3 general categories instigated by J. Tarter (20): Directed, Shared or Parasitic, and Dedicated. In the sections that follow we will present typical examples in each one of these three categories.

6. DIRECTED SEARCHES

These searches use a major observatory for a relatively short period to carry out a specific SETI project. Typical examples are:

Tarter, Clark, Cuzzi, Duquet and Lesyna used the Arecibo radiotelescope to observe 210 solar-type stars in a 4-MHz band around the magic frequencies of both H and OH. They also used the one-bit tape-recording technology and a CDC 7,600 computer to obtain a spectral resolution of 5.5 Hz. In another project Lord and O'Dea used the 14-m millimeter radiotelescope of the University of Massachusetts to look for powerful beacons at the 115-GHz (2.6mm) line of CO along the north rotational axis of the Galaxy, a potentially magic location for beacons operated by supercivilizations.

Another interesting search was undertaken in 1983 by R. Freitas and F. Valdez who used the Hat Creek radio observatory to conduct a search at the 1,516-MHz line of Tritium. Since Tritium has a half-life of only 12.5 years, if found in the vicinity of normal stars it could only be of artificial origin, possibly the by-product of huge nuclear fusion plants. The same workers had earlier used the 30-inch optical telescope of the Kitt Peak National Observatory (KPNO) to conduct a search for artifacts and probes placed in our Solar System by extrasolar civilizations. They looked at the magic locations of the L4 and L5 Lagrange points of the Earth-Moon and Earth-Sun systems, which are the most stable regions in space, and therefore the regions from where extraterrestrial stations could be observing the Earth.

In 1978, Sullivan, et al. (21) of the University of Washington, proposed that an alternative search strategy would be to eavesdrop on nearby stars for radio signals leaking unintentionally into space from other advanced civilizations. As a test, Sullivan and Knowles (22) used the large Arecibo antenna to observe the radio leakage of the Earth, in the 150-500 MHz range, from its reflections from the Moon. Strong television stations and powerful military radars were the most prominent sources. The space surveillance radar of the US Navy in Archer City, Texas, e.g., which operates at 217 MHz emitting pulses of 1.4×10^{10} W into a band-width of only

0.1 Hz, could have been detected by a civilization with an Arecibo technology up to a distance of 20 light years. Knowles (23) and Sullivan did also a limited eavesdropping search on a few nearby stars. The data were obtained with the Arecibo radiotelescope and the Mark I VLBI (Very-Long-Baseline Interferometrer) system. They were analyzed for ultra-narrowband signals over a wide frequency range using a computer to create large Fourier transforms from tape-recorded one-bit time histories of the telescope voltage output. The "one-bit spectral analysis", is no substitute for a large MCSA, but can be used in parallel utilizing otherwise idle computer time. Although this test-run found no signals, it showed that eavesdropping on nearby stars is an alternative search technique that must be explored further.

7. SHARED AND/OR PARASITIC SEARCHES

These searches, they either re-analyze for ETI signals old, archived data that had been obtained for other purposes, or they share in a parasitic or piggyback fashion the data being obtained by a radiotelescope for an unrelated project and process them for ETI signals in real time. Thus F. Israel of the Netherlands working first with DeRuiter and then with Tarter, re-analyzed many of the 21-cm "noisy" sky maps that had been obtained with the Westerbork array and had been kept by the Dutch astronomers, searching for strong sources in positions that coincided with known stars. In another project Cohen, et al. (24) re-analyzed their own surveys of globular clusters, looking for narrowband signals at frequencies associated with OH and H_2O masers, at 18 and 1.35 cm respectively, that might be tapped by supercivilizations to produce strong signals in certain directions.

In 1980, S. Bowyer and D. Werthimer of the University of California-Berkeley and their co-workers, built an automated 100-channel spectrum analyzer to siphon through it, from the intermediate frequency (IF) stage, data obtained by a radiotelescope for an unrelated project. This parasitic or piggyback SETI device was named SERENDIP and was used with the Hat Creek and Golstone antennas. It was later upgraded to SERENDIP II (25 & 26), which has a 131,072-channel fast Fourier processor with a resolution of 0.49 Hz per channel. It was being used in a parasitic mode with the 300 ft radio telescope of NRAO, while the telescope was conducting a search for pulsars, but unfortunately this large but old radio telescope collapsed in November 1988, and the project was discontinued. The SERENDIP II analyzes the data for narrowband peaks above a 6σ threshold over the entire 30-MHz IF band of the radiotelescope searching through increments of 50 kHz in 10 seconds or less. Data of unidentified peaks are recorded for further investigation. The system can operate unattended on a 24-hr basis with practically any radiotelescope.

Papagiannis (27) undertook a search for large artificial objects (such as space colonies and materials processing plants) in our Solar System, and especially in the asteroid belt, which is an ideal source of raw materials, to test the theory of galactic colonization, i.e., the possibility that the entire Galaxy might already have been colonized by more advanced civilizations. He used the Infrared Astronomy Satellite (IRAS) data bank of infrared sources in our Solar System, which was developed at the Jet Propulsion Laboratory by the IRAS Asteroid Workshop, to look for objects with unusual infrared signatures in our Solar System.

8. DEDICATED SEARCHES BY OBSERVATORIES FULLY COMMITTED TO SETI

Dedicated searches are performed by radio observatories that have become SETI dedicated facilities and conduct searches on a continuous basis. There are two such projects now in operation, which account for about 80% of the observing hours accumulated thus far. The oldest of the two is the Ohio SETI Program, having been in operation since 1973 under the direction of J. Kraus and R. Dixon (28). It uses the meridian-transit radiotelescope of the Ohio State University which has a collecting area of 2,200 m^2, equivalent to a parabolic dish 53 m (175 ft) in diameter, and at 21 cm a beam pattern of 8 arc min in RA and 40 arc min in Dec. The search is conducted at the line of hydrogen (Doppler shifted in the rest frame of the galactic center) and is using a 50-channel filter bank with a resolution of 10 kHz per channel.

The data obtained are archived and 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" (1.4 - 1.7 GHz) that is bracketed by the H and the OH lines, the two components of water. The Ohio SETI Program has been sustained with modest support from NASA, the tireless efforts of Kraus and Dixon, and the unselfish dedication of many enthusiastic volunteers.

Paul Horowitz of Harvard University and his collaborators have been operating since March 1983 the other SETI dedicated facility that is using the 84-ft radiotelescope of the Oak Ridge Harvard-Smithsonian Observatory near Boston. This project is supported by the Planetary Society, a private organization headed by C. Sagan and B. Murray. Initially it used to have two 65,536-channel spectrum analyzers, one for each polarization, with a resolution of 0.03 Hz per channel. With the telescope set at a particular declination, the search sweeps a 0.5° band around the sky, covering the entire available sky (about 80% of total) in about one year. During the first 2 years of operation (1983-85) they covered all of the accessible sky, first at the hydrogen line at 1,420.40575 MHz and then at one of the four OH lines at 1,667.3590 MHz. A potential source stays in the antenna beam for about 2.5 min. The system searches automatically for large peaks in any of its channels and archives anything potentially meaningful. Because of the expected swept-Doppler signature produced by the Earth's rotation, the system is very good in rejecting radio interference, though they too had two false alarms of almost 50σ when they got the Sun into their beam.

The problem with this first search was its very narrow (2 kHz) total bandwidth around the hydrogen line. This necessitated a continuous correction for all the Doppler shifts due to the motions of the Earth relative to the direction of the antenna, and assumed that the transmitting civilization will also correct for all Doppler shifts, including the relative motion of our two stars (the radial component of the peculiar motion) which can be of the order of 100 kHz, and therefore was about 50 times larger than the 2-kHz total bandwidth of the system. It also required that the extraterrestrials would be beaming their signals specifically to our Solar System. To overcome these restrictions, Horowitz and his team (29) built a brand new MCSA with 8.4×10^6 channels and a frequency resolution of 0.05 Hz per channel, which is giving them a total bandwidth of 420 kHz that is enough to account for practically all of the Doppler effects. This new system, which was named Project META, started operating in September 1985. It has already covered twice all of the available sky at the hydrogen line, and is now repeating the survey at double the hydrogen frequency.

A similar SETI project is now in preparation and will begin operating in 1990 or in 1991 in La Plata, Argentina, again with the support of the Planetary Society. It will have the advantage that it will be able to cover the southern skies that are not accessible to the other two SETI dedicated facilities, both of which are in the United States and hence have no access to the southern skies.

9. THE NASA SETI PROGRAM FOR THE 1990'S AND BEYOND

The search for ETI radio signals is a multidimensional problem which because of its complexity is often called the "Cosmic Haystack." The dimensions of the search space include: Coverage of the sky; Frequency range; Sensitivity; Bandwidth; Polarization; Signal modulation; On-off periods, etc. Initially investigators, especially in the United States, had hoped that extraterrestrial civilizations would be transmitting at the hydrogen line to make contact easy. But extensive, although not exhaustive, searches by many investigators at the hydrogen and a few other magic frequencies produced no positive results.

With the rapid advancement in our technology, NASA is now preparing to embark on the next generation of radio searches, namely to undertake a systematic search over a wide frequency range (rather than the old magic frequencies) in the microwave window (1-10 GHz) of the atmosphere of the Earth, which at the upper frequency end is terminated by the presence of water vapor in the atmosphere of the Earth, and at the lower frequency end is terminated by the radio noise of the Galaxy which increases as the frequency decreases. The 1-10 GHz range, however, is relatively free of radio noise, and therefore it is best suited for interstellar communications. Embedded deep into the microwave window is the "water hole" (1.4-1.7 GHz) which is probably the most attractive frequency range for interstellar radio communications. A point of great concern, however, is the rapidly growing use of this frequency range for other purposes, which unavoidably will interfere with future radio searches.

It is generally believed that radio signals will be narrowband to reduce peak power. Therefore, in order to have a good signal-to-noise ratio we need receivers with very narrow bandwidths, and since we need to explore a wide frequency range we need a large number of narrowband channels. This function is fulfilled by a MCSA, essentially an electronic high-resolution radio spectrometer, which in the past 30 years has evolved from MCSA's of a few channels, to MCSA's with $8x10^6$ channels and possibly more. We have already mentioned the ultra-narrow-band MCSA with $8.4x10^6$ channels constructed by Horowitz for his Project META. NASA is now developing an $8.25x10^6$-channel MCSA, that will have a much broader total bandwidth. This new MCSA is being developed by a group at Stanford University headed by Peterson (30) and Linscott. The complete MCSA will have 112 units, each with 73.728 channels for a total of 8,257,536 channels. The highest frequency resolution will be 1 Hz per channel, giving a total bandwidth of about 8 MHz. It will also be able to analyse simultaneously the incoming 8-MHz frequency band into channels of 32, 1,024 and 73,728 Hz. In all cases, it will examine both the left-hand and the right-hand circular polarizations of the incoming signals.

The MCSA performs a complex Fourier transform that yields the real and imaginary amplitudes of the signal, which are then squared and added to give the actual power for each bin (channel). If the signal exceeds a predetermined threshold chosen by the desired signal-to-noise ratio, it is flagged for further tests. Sophisticated signal detection algorithms are also being developed by NASA. Considerable effort is being made to achieve online processing of the data, which is not an easy task given the huge volume of incoming data with an $8x10^6$-channel MCSA. Emphasis is also placed on the ability to detect pulsed signals and signals with a Doppler frequency drift. It is expected that the first $8x10^6$ channel MCSA would be ready around 1990, but more realistically the whole system, including all the signal processing instrumentation, will probably become operational in the mid 1990s. A prototype unit with 73,728 channels, together with several of the new signal recognition algorithms, has already undergone tests with the Goldstone antenna. In a recent test, they were able to pick up the very weak (1 W) signal beamed by the Pioneer 10 spacecraft towards the Earth from a distance of about 35 AU (about 5 billion km), i.e., from the edge of our solar system. They were also able to see clearly the frequency drifts imposed on this monochromatic signal by the rotation of the Earth and the relative motion of the Earth and the spacecraft.

The NASA SETI Program is headed by Dr. John Billingham and Dr. Bernard Oliver, and includes about 15 well-known scientists at 3 California institutions (NASA-Ames, Jet Propulsion Laboratory, and Stanford University) that share the responsibility for this program. The NASA SETI Program will be a bimodal search consisting of two components: the Targeted Search (31) which will be primarily the responsibility of NASA-Ames, and will emphasize sensitivity to weak signals by concentrating only on a number of discrete sources, and the Sky Survey (32), which will be primarily the responsibility of the JPL group and will emphasize sky coverage by scanning the entire sky.

The Targeted search will focus on 800-1,000 specific targets, including the 773 F, G, and K, Sun-like stars up to a distance of 25 pc (81.5 light years) that are included in the Royal Greenwich Observatory Catalogue, and a variety of other targets including stars with peculiar spectra, and galaxies. It will have a peak spectral resolution of 1 Hz and will concentrate in the frequency range surrounding the "water hole". It will use the largest possible antennas including the 305-m Arecibo, the 53-m (equivalent) Ohio State, the 64-m Goldstone (California) and Tidbinbilla (Australia) antennas of NASA's Deep Space Network, the 91-m NRAO, and possibly the 100-m Bonn (Germany) antenna. It is interesting to note that when the 1,0000-ft Arecibo antenna with a system temperature of 35 K is compared with Drake's 85-ft Tatel antenna at NRAO with a 350 K system temperature, Arecibo would be able to do the 200 hour search of Project Ozma in a fraction of a second. It is estimated that the NASA SETI Program will take between 5 and 10 years, depending on how many of the 8-million channel MCSA will be available. With a starting time in the mid 1990's, we can expect it to be completed around the year 2,000, or the year 2,001 as someone with a sense of cosmic humor once said.

10. SOME CONCLUDING THOUGHTS

A simple comparison of the original Project Ozma, with the Arecibo radiotelescope with an MCSA, makes it obvious that we have made colossal technological progress in just three decades. A related question often asked is why don't we postpone our searches until our technology would become more effective? I believe the answer has two parts. The first is that we never know in advance the level of technology needed to succeed. It would have been a grave mistake, e.g., to have asked the Wright brothers to wait for the discovery of the jet engine before trying to fly. They succeeded with far less, and on 17 December 1903 they opened the doors of the new field of aviation. I am sure that even if Drake could have known that 25 years later Horowitz would have had an $8x10^6$ MCSA for a search around the hydrogen line, he still would have gone ahead with his Project Ozma, and rightfully so. The second reason is that technology is like a ladder that we must climb one rung at a time, starting from the lowest ones. But as we climb higher, the horizons broaden and many new technological developments materialize, such as the jet engine in aviation and the $8x10^6$ MCSA in SETI, which benefit also many other fields.

After millenia of thinking and philosophizing about the "Plurality of Worlds", we have finally entered the experimental era. We have already used space probes to search for primitive life in our Solar System, and we are now searching with our radio, optical and infrared telescopes for other advanced civilizations in the Galaxy. It is a special privilege to live in the era that tries to answer experimentally profound old questions about the prevalence of life, and especially of life with intelligence in the Universe. With the NASA SETI Program as the central force, and the many other parallel special searches now in progress or planned for the near future, we can expect that in the next 10-20 years we will learn much more about the presence of other advanced civilizations in our Galaxy. If we were to find them, this would certainly be the greatest discovery of all time. But even if after concerted efforts we were to conclude that we must be one of very few, if not the only advanced civilization in the Galaxy, this too would be an important discovery. Because knowing how rare our civilization is among the hundreds of billions of stars in our Galaxy, would hopefully make us realize how cosmically important it is to preserve it.

REFERENCES

1. Bell T. E.: Griffith Observer 1978, 42, No 8, 2.
2. Goldsmith D.: The Quest for Extraterrestrial Life, Univ. Sci. Books, Mill Valley CA 1980.
3. Dick S. J.: Plurality of Worlds, Cambridge U. Press, 1982
4. Cocconi G., Morrison P.: Nature 1959, 184, 884.
5. Drake F. D.: Cosmic Search 1975, 1, No. 1, 11.
6. Shklovski I. S., Sagan C.: Intelligent Life in the Universe, Dell Publ Co 1966.1966.
7. Sagan C.: Communications with Extraterrestrial Intelligence (CETI) MIT Press 1973.
8. Hart M. H.: Q. Jl R. Astr. Soc. 1975, 16, 128.
9. Hart M. H., Zuckerman B.: Extraterrestrials, Where are They? Pergamon Press 1982.
10. Papagiannis M. D.: Q. Jl R. Astr. Soc. 1978, 19, 277.
11. Papagiannis M. D.: (Editor), Strategies for the Search for life in the Universe, D. Reidel Publ Co 1980.
12. Papagiannis M. D.: J. B. I. S. 1983, 36, 305.
13. Field G.: Astronomy and Astrophysics in the 1980's, Nat. Ac. Press, Washington DC 1982.
14. Sagan C.: (letter), Science, 1982, 218, 429.
15. Papagiannis, M. D.: (Editor) IAU Symposium 112: The Search for Extraterrestrial life - Recent Developments, D. Reidel Publ Co, 1985
16. Papagiannis M. D.: Nature 1985, No 6042, 135.
17. Papagiannis M. D.: J. B. I. S. 1988, 41, 534.
18. Marx G.: IAU Colloquium 99 - Bioastronomy: The Next Steps, D. Reidel Publ Co 1988.
19. Papagiannis M. D.: p. 281, IAU Colloquium 99 Bioastronomy - The Next Steps, ed. G. Marx, D. Reidel Publ Co 1988.
20. Tarter J.: p. 271, IAU Symposium 112, ed. M. D. Papagiannis, D. Reidel Publ. Co, 1985.
21. Sullivan W. T. III; Brown S., Wetherill C.:

Science 1978, 199, 377.

22. Sullivan W. T. III, Knowles S. H.: p. 327, IAU Symposium 112, ed. M. D. Papagiannis, D. Reidel Publ Co 1985.
23. Knowles S. H.: p. 335, IAU Symposium 112, ed. M. D .Papagiannis, D. Reidel Publ Co 1985.
24. Cohen N., Malkan M., Dickey J.: Icarus 1980, 41, 198
25. Werthimer D., Tarter J., Bowyer S.: p. 421, IAU Symposium 112, ed. M. D. Papagiannis, D. Reidel Publ Co 1985.
26. Werthimer D., Brady R., Berezin A., Bowyer A.: Contr. 244, Space Sci. Lab, U. of California-Berkeley 1987.
27. Papagiannis M. D.: p. 505, IAU Symposium 112, ed. M. D. Papagiannis, D. Reidel Publ. Co 1985.
28. Dixon R. S.: p 305, IAU Symposium 112, ed. M. D. Papagiannis 1985, D. Reidel Publ. Co.
29. Horowitz P., Forster J., Linscott I.: p. 361, IAU Symposium 112, ed. M. D. Papagiannis, D. Reidel Publ. Co 1985.
30. Peterson A. M., Chen K. S., Linscott I. R.: p. 373, IAU Symposium 112, ed. M. D. Papagiannis, D. Reidel Publ Co 1985.
31. Seeger C. L., Wolfe J. H.: p. 391, IAU Symposium 112, ed. M. D. Papagiannis, D. Reidel Publ. Co 1985.
32. Klein M. J., Gulkis S.: p. 397, IAU Symposium 112, ed. M. D. Papagiannis, D. Reidel Publ. Co 1985.

Symposium 112, ed. M. D. Papagiannis, D. Reidel Publ Co 1985.