COMMISSION 51: BIOASTRONOMY: SEARCH FOR EXTRATERRESTRIAL LIFE

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1. Introduction

The past three years have been extraordinarily productive for the Bioastronomy community. In particular, the detection of extrasolar planets and the possible evidence for fossil life on Mars have given substance to the concept of life elsewhere in the universe, and reinforced the connection between life on Earth and its cosmic origin. The structure of this report follows the agenda from the highly successful IAU Colloquium 161 on Bioastronomy, organized by Cristiano Cosmovici and Stuart Bowyer on the island of Capri in July 1996. The content has been provided by attendees of that Colloquium. Given the breadth of the subject matter covered by this Commission, this report could not have been generated any other way, and I am most grateful to all the contributors.

J. C. Tarter

2. Astronomical Origins: T. Owen

2.1. ISM

Perhaps the most significant advance in studies of the ISM is coming from the observations by ISO, the Infrared Space Observatory launched by ESA on 17 November 1995. This facility allows unrestricted coverage of the near infrared spectrum and has already led to the discovery of new interstellar absorption features. While anticipation continues to run high, there are no convincing identifications of PAHs yet. A preliminary report is given in ESA Bulletin 86 (May 1996). More detailed discussions are being presented at conferences such as COSPAR (Birmingham, England, July 1996) and topical meetings. A review of pre-ISO data on ISM abundances was given by Van Dishoeck et al. (1993).

2.2. METEORITES AND CATASTROPHIC IMPACTS

The last three years have seen growing certainty that the SNC meteorites actually come from Mars. A review of the evidence was given by McSween (1994). The most recent development was the discovery by McKay et al. (1996) of organic compounds (PAHs), mono-mineralic crystals of magnetite and sulfate, carbonate globules and possible microfossils in close proximity inside the Mars meteorite known as ALH 84001. McKay et al. (1996) suggest this could be evidence of biological activity on early Mars. Even if it isn't, this existing discovery demonstrates that organic material from the first billion years of the planet's history is indeed preserved in its oldest rocks. This provides us with a record we can use in studies of the origin of life on Earth, which was occurring at just this time.

On 22 July 1994, fragments of Comet Shoemaker-Levy 9 crashed into Jupiter, an event that had been predicted and was well observed both from Earth and from the Galileo Spacecraft (Spencer and Mitton 1995; West and Bohnhardt 1995). The results from this catastrophic event are still being analyzed, a notable feature was the formation of copious HCN in Jupiter's atmosphere.

2.3. COMETS

Comet 1996b (Hyakutake) made a spectacular appearance in terrestrial skies in the spring of 1996. Besides being a beautiful object for millions to admire, this comet yielded some important secrets. For the first time in any comet, Mumma et al. (1996) were able to detect C_2H_6 and CH_4, and Brooke et al. (1996)

I. Appenzeller (ed.), Reports on Astronomy, Vol. XXIIIA, 251–262.

found C_2H_2. These symmetrical molecules cannot be detected at radio wavelengths and this was the first comet to be so well-observed in the infrared. At radio frequencies, Irvine et al. (1996) made the important discovery of HNC, found for the first time in any comet, suggesting the possibility that compounds of cometary ices come directly from the ISM, where HNC exists together with its more stable isomer HCN. There are prospects for more exciting discoveries when Comet Hale-Bopp reaches maximum brightness in the spring of 1997.

2.4. PLANETARY ATMOSPHERES

The entry of the Galileo Probe into Jupiter's atmosphere on December 7, 1995 provided the first in situ measurements of conditions in a giant planet's atmosphere (see Science, 10 May 1996 (Vol. 272, pp. 781-920) for a collection of articles describing preliminary results). Unfortunately for students of cloud physics on Jupiter, the probe entered a region on the planet called a "5-micron hot spot". These regions, well-known from Earth based studies, are places where radiation from the planet's interior escapes into space because there are almost no clouds to impede its progress. The probe verified this by finding only a thin haze of ammonia cirrus and a second thin cloud possibly composed of NH_4SH. There was no sign of the widely anticipated thick water clouds. Indeed water vapor was very deficient in the upper part of the probe trajectory. No trace of complex organic compounds was found, although the probe did succeed in detecting the abundant isotopes of xenon, representing a mixing ratio of 10-11. The analysis of these results is still in its early stages.

2.5. SPACE MISSIONS TO PLANETS

This three-year period has seen the completion of the Magellan mission for the radar mapping of Venus and the initiation of the exploration of the Jupiter system by the Galileo Spacecraft. For bioastronomy purposes, one of the most important goals of the Galileo orbiter is the careful mapping of the satellite Europa, which many scientists think may have a deep ocean of water underneath its icy crust. Could there be biologically interesting organic chemistry taking place in that ocean? First we need to know there's an ocean, and Galileo may tell us.

In the fall of 1996, we anticipate three launches to Mars, one from Russia and two from the US. The Russian mission is called Mars 96 and consists of a heavily instrumented orbiter that carries a small lander and two penetrators. One US launch consists of a lander (Pathfinder) that carries a small rover with a camera and an alpha back-scatter device for elemental analysis of rocks. The second launch carries an orbiter (Mars Global Surveyor) that will accommodate part of the payload lost from the failure of Mars Observer to go into orbit in 1993. If successful, these spacecraft will achieve the first return to Mars after a 20 year lapse since Viking reached the red planet in July 1976.

REFERENCES

Brooke, T. Y. Tokunaga, A. T., Weaver, H. A., Crovisier, J., Bockele-Morvan, D. and Crisp, D. (1996), "Detection of acetylene in the infrared spectrum of Comet Hyakutake," Nature (in press).

Irvine, W. and nine co-authors (1996), "Interstellar ices incorporated into Comet Hyakutake (1996 B2)," Nature (in press).

McKay, D. S. and eight co-authors (1996), "Search for past life on Mars: Possible relic biogenic activity in Martian meteorite ALH 840001," Science 273, pp. 924-930.

McSween, H. Y. (1994), "What we have learned about Mars from SNC meteorites," Meteoritics 29, pp. 757-779.

Mumma, M. J. and six co-authors (1996), "Detection of abundance ethane and methane, along with carbon monoxide and water in comet C/1996 B2 Hyakutake: Evidence for interstellar origin," Science 272, pp. 1310-1314 . Spencer, J. R. and Mitton, J. (eds) (1995), The Great Comet Crash (Cambridge U. Press, Cambridge).

van Dishoeck, E. F., Blake, G. A., Draine, B. T. and Lunine, J. I. (1993), "The chemical evolution of protostellar and protoplanetary matter," Protostars and Planets III, E. H. Levy and J. I. Lunine (eds) (U. of Arizona Press, Tucson), pp. 163-244.

West, R. and Bohnhardt, H. (eds) (1995), European SL-9/Jupiter Workshop (Feb 13-15, 1995) (ESO Conference and Workshop Proceedings No. 52).

3. The Search for Extrasolar Planets: J. C. Tarter

Since the unexpected first discovery by Mayor and Queloz (1995) and the rapid confirmation by Marcy and Butler (1995) of a massive planetary companion with a 4.4 day period orbiting the star 51 Pegasus, our knowledge of other planetary systems has literally exploded. Today there are more planets known outside the solar system than within; 9 if we limit ourselves to stellar hosts and 12 if we include the three small planets orbiting pulsar 1957+12 (Wolszczan and Frail, 1992), with additional announcements being promised for future scientific meetings! To be sure, most of these systems are quite different from our own, and some scientists caution that the sin(i) ambiguity in the mass determination from radial velocity measurements might mean that we are dealing with Brown Dwarfs or stellar companions (Black, 1996). However, theorists are now attempting to extend and improve models of our own solar system formation in order to accommodate these "hot Jupiters". As time goes by, and the groundbased precision radial velocity and astrometric techniques begin to sample longer orbital periods, we can hope to discover other systems having "Jupiters" in the familiar place. "Earths" will have to wait for space missions. The disks in which these planets form are just now beginning to be mapped and probed by mm interferometers, and imaged by HST.

The table below presents the latest statistics and is taken from a review by Beckwith and Sargent (1996) and Black (1996). By the time this publication appears, it will be far out of date. For an up to date accounting, the reader should access an active site on the Word Wide Web, e.g. the San Francisco State University Planet Search Project at http://cannon.sfsu.edu/~williams/planetsearch/planetsearch.html

Host Star	Spectral Type	Planet Mass×sin(i)	Orbit Radius in AU	Period in years	Method
51 Peg	G2-3V	0.6 MJup	0.05	0.012	radial velocity
47 Uma	G0V	2.4 MJup	2.1	3	radial velocity
55 Can	G8V	0.8 MJup	0.11	0.04	radial velocity
Tau Boo		3.8 MJup			radial velocity
Ups And		0.68 MJup			radial velocity
70 Vir	G5V	6.6 MJup	0.43 (e=0.38)	0.32	radial velocity
HD114762	F9V	10 MJup	0.34 (e=.035)	0.23	radial velocity
Lalande 21185	M2V	1.1 MJup	11	≈30	astrometry
		0.9 MJup	2.2	≈6	astrometry
PSR 1257+12	Pulsar	4.7 exp -5 MJup	0.19	0.064	radial velocity
		.011 MJup	0.36 (e=0.02)	0.18	radial velocity
		0.0088 MJup	0.47 (e=0.03)	0.26	radial velocity

References:

Beckwith, S.V.W. and Sargent, A.I. (1996), *Nature* **383**, p.139.
Black, D.C. (1996), *Sky and Telecope* **96**, No.2, p. 20.
Marcy, G.W. and Butler, R.P. (1996), *Astrophysical Journal* **464**, pp. L147-L151.
Mayor, M. and Queloz, D. (1995), *Nature* **378**, pp. 355-359.
Wolszczan, A. and Frail, D.A. (1992), *Nature* **355**, p. 145.

4. Origin and Evolution of Life: Andre Brack

Primitive terrestrial life probably resulted from the chemical processing of reduced organic molecules by liquid water. Until recently, the dominant model referred to prebiotic organic building blocks produced from small molecules formed in a primitive reducing terrestrial atmosphere dominated by methane. This hypothesis was strengthened by Miller's stimulating experiments. Geochemists now favor a less reducing atmosphere dominated by carbon dioxide. In such an atmosphere, very few building blocks are formed under prebiotic conditions and other sources of prebiotic organic molecules are searched for.

Wachtershauser suggested that life started from carbon dioxide. The chemical energy required to reduce carbon dioxide was provided by the formation of pyrite from iron sulfide and hydrogen sulfide. Pyrite has positive surface charges and absorbs the products of carbon dioxide reduction giving rise to a two dimensional reaction system, a surface metabolism. Experiments are currently under way to validate this new and interesting hypothesis.

Deep-sea hydrothermal systems may also represent likely environments for the synthesis of prebiotic organic molecules. Experiments have been carried out in order to test whether amino acids can be formed under conditions simulating hydrothermally altered oceanic crust. The variety of amino acids that have been obtained corresponds roughly to that reported for electric discharges in reducing gas mixtures.

Increasingly, the importance of extraterrestrial organic molecules is being recognized. Comets, for instance, show substantial organic material. Comet Halley contains 14dominated by light elements C, H, O, N and 35% are close in composition to carbonaceous chondrites. Among the molecules identified in comets are hydrogen cyanide and formaldehyde, two molecules known to lead to biotic building blocks under simple conditions. The Rosetta mission designed for in situ analysis of both cometary nucleus and dust will help clarify the part played by comets in providing a source of complex organic molecules to Earth.

The study of meteorites, particularly the carbonaceous chondrites that contain up to 5% by weight of organic matter, has allowed close examination of extraterrestrial organic material. Eight proteinaceous amino acids have been identified in the Murchison meteorite among more than 70 amino acids. Engel reported that L-alanine was 18% more abundant that D-alanine in the Murchison meteorite. This rather surprising result has been recently confirmed by Cronin (1996). The latter found a racemic composition (equal mixture of L and D enantiomers) for norvaline and a-amino-n-butyric acid which can racemize by abstraction of the Ca hydrogen atom. However, Cronin found enantiomeric excesses of about 10% for isovaline, a-methyl norvaline and a-methyl isoleucine which cannot racemize by proton abstraction. The enantiomeric excesses found in the Murchison meteorite may help us to understand the emergence of a primitive homochiral life. Indeed, the homochiralty of present-day life (all biomolecules are of one hand, all L amino acids and all D sugars) is now believed to be not just a consequence of life but also a prerequisite for life because stereoregular polymers such as b-sheet polypeptides do not form with racemic mixtures of amino acids. The chiral (one handedness) amino acids found in Murchison meteorite may result from the processing of the organic mantles of interstellar grains by circularly polarized synchrotron radiation from a neutron star remnant of a supernova.

A large collection of micrometeorites has been recently extracted from Antarctic old blue ice and analyzed by Maurette. A constant high percentage of unmelted chondritic micrometeorites from 50 to 100 mm in size has been observed, indicating that a large fraction crossed the terrestrial atmosphere without drastic thermal treatment. In this size range, the carbonaceous micrometeorites represent 80% of the samples and contain 7% of carbon. They might have brought about 1020 g of carbon over a period of 300 million years corresponding to the late terrestrial bombardment phase. This delivery represents more carbon than that incorporated into biomass, i.e. about 1018 g. Amino acids such as a-amino isobutyric acid, have been recently identified in these Antarctic micrometeorites which may have functioned as tiny chondritic chemical reactors upon reaching oceanic water.

For many decades, it was believed that primitive life emerged as a cell, thus requiring boundary molecules like phospholipids, catalytic molecules like protein enzymes and informative molecules like nucleic acids. Vesicle forming fatty acids have been identified in the Murchison meteorite. Primitive membranes could also have initially been formed by simple terpenoids. Selective condensation of amino acids controlled by liquid water has been experimentally documented (Luisi and Deamer, 1996). When hydrophobic and hydrophilic amino acids coexist within the same polypeptide chain, the duality generates interesting topologies such as stereoselective and thermostable b-sheet structures. Short peptides have also been shown to exhibit catalytic properties. When nucleotide chemists have been unable to demonstrate that accumulation of large quantities of natural nucleotides, the building blocks of RNA, was a plausible chemical event on the primitive Earth, thus weakening the cellular origin of life hypothesis. Intense experimental work is presently run on RNA analogs, such as pyranosyl-RNA, in Eschenmoser's laboratory. Since RNAs have been shown to be able to act simultaneously as informative and catalytic molecules, they are often viewed as the first living systems on the primitive Earth (RNA world). One should, however, remember that their synthesis under prebiotic conditions remains an unsolved challenge. Many chemists are now tempted to consider that primitive life was supported by simpler informative molecules and large efforts are devoted to studying autocatalytic systems including simple organic molecules and micelles.

A good picture of the common microbial ancestor would also help to understand the different steps of early life. Recent advances in molecular phylogeny suggest that the first microorganisms were hyperthermophilic prokaryotes, but arguments have also been provided suggesting that prokaryotes and eukaryotes emerged simultaneously from the same mesophilic common ancestor.

The isotopic signatures of the organic carbon of the Greenland metasediments bring indirect evidence that life may be 3.9 billion years old. The isotopic signatures are fully consistent with a biological origin and the remarkable diversity of the Warrawoona microflora reported by Schopf.

The clues which may help chemists to understand the emergence of life on Earth about 4 billion years ago have been erased by the Earth's turbulent geological history, the permanent presence of liquid water, and by life itself, when it conquered the whole planet. We remain ignorant of the true historical facts on Earth from the time when life started. Titan, the largest satellite of Saturn, offers a nice control planetary laboratory probably not modified by "living" systems. Titan's organic chemistry is believed to have remained almost unchanged over geological periods. Its active atmospheric chemistry will be studied by the Huygens probe of the Cassini mission.

The early histories of Mars and Earth clearly show similarities. Geological observations collected from Martian orbiters suggest that liquid water was once stable on the surface of Mars, attesting the presence of an atmosphere capable of decelerating C-rich micrometeorites. Therefore, primitive life may have developed on Mars as well. Liquid water seems to have disappeared from the surface of Martian soil. However, this does not preclude the existence of organic molecules and fossils of micro-organisms which developed on early Mars before liquid water disappeared. Martian sub-surface keeps perhaps a freeze-frame of Martian life focused on its very early stages.

REFERENCES

Luisi, P. L. and Deamer, D., 1996, "Self-reproducing Vesicles as Models for Prebiotic Protocellular Structures", paper S3-11 presented at 5th International Conference on Bioastronomy, IAU Colloquium No. 161, Capri, Italy, July 1-5. To be published in book of proceedings.

Cronin, J. R. and Pizzarello, S., 1996, "The Organic Chemistry of Carbonaceous Chondrites", paper S1-08 presented at 5th International Conference on Bioastronomy, IAU Colloquium No. 161, Capri, Italy, July 1-5. To be published in book of proceedings.

5. Evolution of Life and Intelligence: Lori Marino

Since the 1993 Bioastronomy Symposium there have been four major areas in which significant advances in our understanding of behavior and, in particular, intelligence, have taken place. First, neurobiological research, combined with statistical analysis, is revealing striking regularities and commonalities in brain development across highly divergent mammalian groups and is also providing further evidence for the relation between brain size and intelligence. Finlay and Darlington's (1995) paper "Linked regularities in the development and evolution of mammalian brains," is an excellent example of the former. Finlay and Darlington (1995) found that, across 131 mammal species, the sizes of brain components are highly predictable from absolute brain size by a nonlinear function and that the sequence of neurogenesis in all of these species is essentially the same. Brain structures that are large are generated late in neurological development in all the species examined. Their results have three important implications: 1) that there is a great deal of conservatism in mammalian brain evolution, 2) that selection on specific brain areas seems to necessitate an overall brain size increase, and 3) because of the correlated overall increase in brain size, selection on one specific trait may open up an extensive array of behavioral capacities in addition to that trait. Another study, Andreasen et al. (1993) "Intelligence and Brain Structure in Normal Individuals," is important because it demonstrates the connection between brain size and intelligence (as measured by full-scale IQ). They found that IQ was modestly, but significantly, correlated with the volume of a number of brain structures (measured from magnetic resonance imaging scans). This study is also important from a technical point of view because increasing sophistication in brain imaging methods is offering us the opportunity to make more accurate and precise structural, as well as functional, assessments.

The second major area of advancement is in our increased sophistication in molecular genetics and especially the application of molecular genetics to quantitative behavioral genetic studies. This has opened up a rapidly advancing area of study into the genetic basis of complex human behaviors (personality, intelligence, psychopathology). Linkages between specific genes and a number of complex behaviors (e.g., violence, paranoid schizophrenia, alcoholism) that were previously thought to be too complex to genetically disentangle are now being clarified. The implications are far-ranging. However, one of the most important outcomes of this research for Bioastronomy is our improved understanding of the relative contributions of genetics and experience in behavior, including intelligence. This will, in turn, increase our understanding of the parameters within which natural selection acts during brain evolution. (See the June 17 issue of Science, 1994, vol. 264 for a special section on these new advances in behavioral genetics).

Third, two papers from evolutionary biology have revealed important parameters about the evolution of the eye. In Quiring et al. (1994) the authors announced evidence from embryology that the eyes of species as different as fruit flies, mice, and humans may have common evolutionary beginnings. Previously, it was thought that the eye evolved independently many times over in the animal kingdom. This new evidence, however, suggests that this did not happen and that we may have to revise our estimate of the probability of a complex sensory organ evolving repeatedly in different organisms. The other paper, Nilsson and Pelger (1994) is actually quite optimistic for Bioastronomy because the authors used a very conservative (or "pessimistic") set of assumptions about the time required for optical structures of the eye to evolve and found, through modeling, that a light-sensitive patch of cells can evolve into a focused lens in only a few hundred thousand years. This is of obvious importance to Bioastronomy because of its suggestion that complexity can arise in a short period of geological time. Finally, behavioral work on nonhuman primates has recently confirmed that some nonhuman species possess the rudiments of many abilities previously thought to be uniquely human, including numerical competence, syntactic comprehension, and deception. One important example is Frans de Waal's publication of his recent book Good Natured: The Origins of Right and Wrong in Humans and other Animals (1996) in which he brings together years of observational evidence that nonhuman primates, and especially chimpanzees, share some behavioral and psychological features with us that we consider part of our moral and ethical make-up. Although the data for this conclusion derive from research that has been conducted for decades, the newer aspect of this is that de Waal has recently brought his observations together into a conceptual framework that allows for comparisons across primate species, including humans. As a result, the range of characteristics that we share with other species continues to widen and now includes what has previously been taken for granted as uniquely human, that is, morality and social ethics. These kinds of results force us to further examine the place of our species among other animals and may offer insights which will improve our hypotheses about what some intelligent extraterrestrial organisms would be like.

REFERENCES

Andreasen, N.C., Flaum, M., Swayze II, V., O'Leary, D.S., Alliger, R., Cohen, G., Ehrhardt, J., & Yuy, W.T.C. (1993). *Intelligence and Brain Structure in Normal Individuals. American Journal of Psychiatry*, vol. 150(1), 130 - 134.

De Waal, F. (1996). Good Natured: The Origins of Right and Wrong in Humans and other Animals. Cambridge: Harvard University Press. Finlay, B, L., Darlington, R.B. (1995). Linked Regularities in the Development and Evolution of Mammalian Brains. Science, vol. 268, 1578 - 1583.

Nilsson, D.E., & Pelger, S. (1994). A Pessimistic Estimate of the Time Required for an Eye to Evolve. Proceedings of the Royal Society of London, April, 53 - 56.

Quiring, R., Walldorf, U., Kloter, U., Gehring, W.J. (1994). Homology of the "eyeless" Gene of Drosophila to the "Small eye" Gene in Mice and Aniridia in Humans. Science, vol. 265, 785-788.

6. The Search for ExtraTerrestrial Intelligence - SETI: Jill Tarter

The most significant occurrence in this field since the last triennial report was political, rather than scientific. In October of 1993, the United States Congress terminated the funding for NASA's observational SETI program, the High Resolution Microwave Survey. Fortunately, this did not end exploratory scientific research in this area, but it did negatively impact almost all SETI projects on telescopes or on the drawing board at that time. The most obvious victim was the HRMS Sky Survey that had been in operation for less than a year, and had to be discontinued because of its reliance on the telescopes of NASA's Deep Space Network. Within the US, private philanthropy and corporate contributions have permitted the continuation of most SETI projects. The exception to this is the Ohio State University Radio Observatory Sky Survey, the longest running SETI observational program. In operation since 1977 with the help of a volunteer organization, the telescope will be demolished at the end of 1997 because the University has sold the land on which it stands to a real estate developer. Within the former Soviet

Union, the crisis of scientific funding has adversely affected SETI programs there along with every other research program. Nevertheless, there have been a number of new SETI observing programs that have been conducted over the last three years, they are listed below in tabular format.

DATE: 1993
OBSERVERS: Steffes and DeBoer
SITE: NRAO/Tucson
INSTRUMENT SIZE: 12m
SEARCH FREQUENCY: 203 GHz
FREQUENCY RESOLUTION: 32 Hz
OBJECTS: 40 stars and 3 locations near Galactic Center
FLUX LIMITS: 2.3x10-19 W/m2
TOTAL HOURS: 25
REFERENCE: Steffes and DeBoer (1994)1
COMMENTS: Search for artificial signals at the positronium hyperfine line (analog of 21 cm HI line)

DATE: 1993
OBSERVERS: Jugaku, Noguchi and Nishimura
SITE: IR telescope at the Institute of Space and Astronautical Sciences and IR telescope at the Xinglong Station of the Beijing Astronomical Observatory
INSTRUMENT SIZE: 1.3 m and 1.26 m
SEARCH FREQUENCY: K-band (2.2 microns) and IRAS 12 micron flux
FREQUENCY RESOLUTION:
OBJECTS: 180 solar-type stars
FLUX LIMITS:
TOTAL HOURS:
REFERENCE: Jugaku et al. (1995)2
COMMENTS: Searched for 12 micron excess radiation from IRAS catalog stars by using K-[12] color index. Excess of 1 magnitude or more would have been suggestive of presence of a Dyson Sphere. None found.

DATE: 1993-1995
OBSERVERS: Lemarchand et al. (META II)
SITE: Instituto Argentino de Radioastronomia
INSTRUMENT SIZE: 30m
SEARCH FREQUENCY: 1420 MHz
FREQUENCY RESOLUTION: 0.05 Hz
OBJECTS: 80 solar-type stars south of -10^0 declination
FLUX LIMITS: 1x10-24 W/m2
TOTAL HOURS: 290
REFERENCE: Lemarchand (1996)3
COMMENTS: META II system used for a targeted search of nearby solar-type stars in southern hemisphere

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DATE: 1994
OBSERVERS: Mauersberger, Wilson, Rood, Bania, Hein, and Linhart
SITE: IRAM/ Pico Veleta
INSTRUMENT SIZE: 30 m
SEARCH FREQUENCY: 203 GHz
FREQUENCY RESOLUTION: 1 MHz and 9.7 kHz

OBJECTS: 16 stars and Galactic Center
FLUX LIMITS: transmitters with 0.2-20 x1015 W EIRP
TOTAL HOURS: 5 hours
REFERENCE: Mauersberger et al (1996)4
COMMENTS: Search at the positronium line towards nearby stars with IR excesses that might be Dyson Spheres.

DATE: 1995
OBSERVERS: Gray
SITE: NRAO/VLA
INSTRUMENT SIZE: 27-element array of 26m antennas
SEARCH FREQUENCY: 1420 MHz
FREQUENCY RESOLUTION: 6104 Hz over 781 kHz and 381 Hz over 195 kHz
OBJECTS: OSU "Wow" signal coordinates
FLUX LIMITS: 10 and x10-29 W/m2/Hz/beam/channel
TOTAL HOURS: 4hours
REFERENCE:
COMMENTS: Search of "Wow" signal location on sky with 4 arcsec synthesized beam

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DATE: 1995
OBSERVERS: SETI Institute Project Phoenix
SITE: ATNF/ Parkes and Mopra
INSTRUMENT SIZE: 64m and 22m
SEARCH FREQUENCY: 1200 to 3000 MHz
FREQUENCY RESOLUTION: 1 Hz
OBJECTS: 206 solar-type stars, 1220-1750 MHz
105 solar-type stars, 1750-3000 MHz
FLUX LIMITS: 1.32x10-25 W/m2 for half of the 1750-3000 MHz observatons, 1.82x10-25 W/m2 for all other observations
TOTAL HOURS: 2600
REFERENCE: Tarter (1996)5
COMMENTS: First use of two-site pseudo-interferometric technique to discriminate against RFI during targeted search. Targets were solar-type stars visible only from southern hemisphere.

DATE: 1995
OBSERVERS: te Lintel Hekkert and Tarter (Phoenix Cooperative Science)
SITE: ATNF/Parkes and Mopra
INSTRUMENT SIZE: 64m and 22m
SEARCH FREQUENCY: 1200 to 3000 MHz
FREQUENCY RESOLUTION: 1 Hz
OBJECTS: 4 potential Dyson Spheres
FLUX LIMITS: 1.9 x 10-25 W/m2
TOTAL HOURS: 48
REFERENCE:
COMMENTS: Candidate Dyson Sphere selection criteria: IRAS PSC sources with temperatures from 300-500K, that were not identified in OH/IR or CO(1-0) surveys, and had galactic latitudes $> 5^0$.

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DATE: 1995
OBSERVERS: Shostak, Ekers, and Vaile (Phoenix Cooperative Science)
SITE: ATNF/Parkes
INSTRUMENT SIZE: 64m
SEARCH FREQUENCY: 1200-1750 MHz
FREQUENCY RESOLUTION: 1 Hz
OBJECTS: 3 fields in the SMC,
FLUX LIMITS: 1.9 x10-25 W/m2
TOTAL HOURS: 24 hours
REFERENCE: Shostak, Ekers, and Vaile (1996)6
COMMENTS: Search of > 107 stars contained within the three fields of the SMC. Limit on detectable transmitters of 1.5x1018 W EIRP.

DATE: 1995
OBSERVERS: Sullivan, Wellington, Shostak, Backus, and Cordes (Phoenix Cooperative Science)
SITE: ATNF/Parkes
INSTRUMENT SIZE: 64 m
SEARCH FREQUENCY: 1420 +/- 5 MHz
FREQUENCY RESOLUTION: 1 Hz
OBJECTS: Galactic Center and 5^0 high strip +/-15^0 longitude along Galactic Plane
FLUX LIMITS: 1.5 - 10 x 10-25 W/m2
TOTAL HOURS: 48 hours
REFERENCE: W.T. Sullivan III et al.7
COMMENTS: Multiple 30-second observations of strip along galactic plane and the Galactic Center, looking for repetitive signals.

DATE: 1995
OBSERVERS: Norris (Phoenix Cooperative Science)
SITE: ATNF/Parkes and Mopra
INSTRUMENT SIZE: 64 m and 22 m
SEARCH FREQUENCY: 1200 to 3000 MHz
FREQUENCY RESOLUTION: 1 Hz
OBJECTS: Galactic Center
FLUX LIMITS: 1.3 x 10-25 W/m2
TOTAL HOURS: 24
REFERENCE:
COMMENTS: Galactic Center searched for beacon.

DATE: 1995
OBSERVERS: Zadnik et al. (Phoenix Cooperative Science)
SITE: ATNF/Parkes
INSTRUMENT SIZE: 64m
SEARCH FREQUENCY: 4462, 4532, 8295, 8393, 8666 MHz
FREQUENCY RESOLUTION: 1 Hz
OBJECTS: 49 stars closer than 11.5 pc
FLUX LIMITS: 3.5 and 5.0 Jy
TOTAL HOURS: 48 hours
REFERENCE: M.G. Zadnik et al.8
COMMENTS: "Magic Frequency" search at P*HI, e*OH, 2P*HI, e*(OH + H), 3He

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DATE: 1995 and on
OBSERVERS: Horowitz et al (BETA)
SITE: Oak Ridge Observatory
INSTRUMENT SIZE: 26m
SEARCH FREQUENCY: 1400 to 1720 MHz
FREQUENCY RESOLUTION: 0.5 Hz
OBJECTS: sky survey from -30^0 to +60^0 declination
FLUX LIMITS:
TOTAL HOURS: ongoing
REFERENCE: LePage (1996)9
COMMENTS: Waterhole search, using dual-beams and omni antenna to discriminate against RFI. Project BETA is follow-on to META.

DATE: 1995 and on
OBSERVERS: Kingsley
SITE: Columbus Optical SETI Observatory
INSTRUMENT SIZE: 10 inch
SEARCH FREQUENCY: 0.55 microns
FREQUENCY RESOLUTION:
OBJECTS: nearby solar-type stars
FLUX LIMITS: transmitters with peak instantaneous power > 1018 W
TOTAL HOURS: ongoing
REFERENCE: Kingsley (1996)
COMMENTS: Broadband optical search for short pulses (≈ 1 nanosecond) that instantaneously outshine the host star.

DATE: 1996 and on
OBSERVERS: Tilgner, Heinrichsen, Kruger, Pacher, Walker, Wolstencroft
SITE: ISO (Infrared Space Observatory) satellite, ISOPHOT photopolarimeter
INSTRUMENT SIZE: 0.6 m
SEARCH FREQUENCY: 3 - 100 microns
FREQUENCY RESOLUTION: 0.2 microns (3 micron filter band) 51 microns (90 micron filter band)
OBJECTS: 6 solar-type stars and 1 infrared-excess target star
FLUX LIMITS: approximately 30 - 90 x10-29 W/m2/Hz (S/N = 10)
TOTAL HOURS: 1.3 hours (guaranteed schedule)
REFERENCE: Tilgner and Heinrichsen (1995)10
COMMENTS: Search for astro-engineering products like Dyson spheres and rings by separation of their infrared spectra from that of the host star.

DATE: 1996
OBSERVERS: Biraud and Airieau
SITE: Nancay Observatory
INSTRUMENT SIZE: 40 m x 240 m
SEARCH FREQUENCY: 1420 +/- 0.3 MHz and 1660 +/- 2.2 MHz
FREQUENCY RESOLUTION: 50 Hz
OBJECTS: 4 stars with giant planets (51 Peg, 47 UMa, 70 Vir, Gl 229)
FLUX LIMITS: 1 x 10-24 W/m2

TOTAL HOURS: 40 hours
REFERENCE:
COMMENTS: Search of newly discovered extrasolar planetary systems using observing protocol from Biraud and Tarter 1981-1988 SETI program at Nancay.

DATE: 1996 and on
OBSERVERS: Shuch et al (Project Argus)
SITE: multiple sites world-wide (currently 3)
INSTRUMENT SIZE: 2 m (satellite TV dishes)
SEARCH FREQUENCY: 1420 - 1720 MHz (in 12 kHz steps)
FREQUENCY RESOLUTION: 1 Hz
OBJECTS: all sky
FLUX LIMITS: 7 x 10-22 W/m2
TOTAL HOURS: ongoing
REFERENCE:
COMMENTS: Hope to organize up to 5000 radio amateurs to provide continuous sky coverage with systems that can be bought and built by individuals.

DATE: 1996 and on
OBSERVERS: Werthimer et al. (SERENDIP IV)
SITE: Arecibo
INSTRUMENT SIZE: 305 m
SEARCH FREQUENCY: 1420 +/- 50 MHz
FREQUENCY RESOLUTION: 0.6 Hz
OBJECTS: Survey of 30FLUX LIMITS: 5 x10-24 W/m2
TOTAL HOURS: ongoing
REFERENCE: Werthimer et al.11
COMMENTS: Commensal search occurring at twice sidereal rate in backwards direction while radio astronomers track targets using Gregorian system.

REFERENCES

1. Steffes, P.G., and DeBoer, D.R. (1994), "A SETI Search of Nearby Solar-Type Stars at the 203 GHz Positronium Hyperfine Resonance." Icarus 107, pp. 215-218.

2. Jugaku, J., Noguchi, K., and Nishimura, S. (1995), "A Search for Dyson Spheres Around Late-Type Stars in the Solar Neighborhood." Progress in the Search for Extraterrestrial Life, ASP Conference Series Vol. 74, ed. G.S. Shostak, pp. 381-385.

3. Lemarchand, G.A. (1996), "SETI From the Southern Hemisphere: Project META II." SETI Quest Vol. II, No. 2, pp. 13-18.

4. Maurersberger, R., Wilson, T.L., Rood, R.T., Bania, T.M., Hein, H., and Linhart, A. (1996), "SETI at the Spin-Flip Line Frequency of Positronium." Astron. Astrophys. 306, pp. 141-144.

5. Tarter, J.C., "Project Phoenix: The Australian Deployment." Proceedings of SPIE Optical meeting, San Jose, Calif. January 31, 1996.

6. Shostak, S., Ekers, R., and Vaile, R. (1996),"A Search for Artificial Signals from the Small Magellanic Cloud", A.J. 112, pp 164-166.

7. Sullivan, III, W.T., Wellington, K.J., Shostak, G.S., Backus, P.R., and Cordes, J.M. (1996), "A Galactic Center Search for Extraterrestrial Intelligent Signals." Poster paper# P4-17 presented at 5th International Conference on Bioastronomy, IAU Colloquium No. 161, Capri, Italy (July 1-5).

8. Zadnik, M.G., Winterflood, J., Williams, A.J., Wellington, K.J., Vaile, R. Tarter, J., Norris, R., Heiligman, G., Blair, D.G., and Backus, P. (1996), "Interstellar Communication Channel Search of Solar-

Type Targets Closer than 11 pc." Poster paper # P4-21 presented at 5th International Conference on Bioastronomy, IAU Colloquium No. 161, Capri, Italy (July 1-5).

9. LePage, A.J. (1996), "Project BETA." SETI Quest, Vol. II, No. 3, pp. 1-8.

10. Tilgner, C.N. and Heinrichsen, I. (1995), "A Program to Search for Dyson Spheres With the Infrared Space Observatory," paper # IAA-95-IAA.9.1.11, IAF Congress, Oslo, Norway (October).

11. Werthimer, D., Bowyer, S., Ng, D., Donnelly, C., Cobb, J., Lampton, M., and Airieau, S. (1996), "The Berkeley SETI Program: SERENDIP IV Instrumentation." Poster paper # P4-20 presented at 5th International Conference on Bioastronomy, IAU Colloquium No. 161, Capri, Italy (July 1-5).