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LIFE AND INTELLIGENCE IN THE UNIVERSE - A COSMIC PERSPECTIVE

by

Michael D. Papagiannis
Department of Astronomy
Boston University
Boston, Massachusetts

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Michael D. Papagiannis
Department of Astronomy
Boston University
Boston, Mass. 02215, USA

ABSTRACT

The relatively high abundances in the Cosmos of the chemical elements hydrogen (H), Oxygen (O), Carbon (C), and Nitrogen (N) that are the basis of life, the existence of several physical laws that assure long lives for stars and for planets with life around them, and the presence of life on earth with its long evolutionary history, indicate that the universe, with its 10^{20} or more stars, is favorably predisposed for the origin of life and its subsequent long evolution to higher intelligence. Advanced technological civilizations are likely to reach rapidly their physical limits of growth and will either perish, or they will redirect their growth toward more intellectual and spiritual objectives. It is conceivable, therefore, that the whole process of cosmic evolution, that started with the Big Bang about 15 billion years ago, might indeed have as its ultimate goal to populate the whole universe with intelligent being that will live in harmony with the creator of the universe. Bioastronomy is a new, interdisciplinary branch of astronomy that is now actively searching for life and intelligence in the universe. The results of these searches may ultimately enlighten us on the entire process of cosmic evolution and may also affect profoundly the future of our civilization.

1. Chemical Abundances and Chemical Evolution

The development of spectroscopy made it possible in this century to study the chemical composition of our sun, as well as the compositions of other stars and galaxies. These studies have shown that the whole universe is made of the same 92 chemical elements, which obey the same laws of physics everywhere in the cosmos. Hydrogen (H) and Helium (He), which are the first two chemical elements of the Periodic Table and therefore the two simplest, were formed in the Big Bang with which our universe started about 15 billion years ago, and account for about 98% of all the matter of the universe. All the others, which collectively are called Heavy Elements, were formed later on in supernovae, i.e., in the cataclysmic explosions with which the more massive stars end their lives. The relative abundances by weight of the most common of the heavy elements in our solar system and in the universe are given in Table 1.

TABLE 1

RELATIVE ABUNDANCES OF THE HEAVY ELEMENTS

Heavy Elements		% By Weight
Oxygen	(O)	46.4
Carbon	(C)	19.1
Neon	(Ne)	9.4
Nitrogen	(N)	7.1
Iron	(Fe)	6.3
Silicon	(Si)	3.8
Magnesium	(Mg)	3.5
Sulfur	(S)	2.2
Argon	(Ar)	0.6
All others		1.6

It is interesting to compare these cosmic abundances with those of the chemical elements that make up the biomass of the earth, i.e., the bodies of all the living organisms on our planet which are given in Table 2.

TABLE 2

RELATIVE ABUNDANCES IN THE BIOMASS OF THE EARTH

Heavy Elements		% By Weight
Oxygen	(O)	69.0
Carbon	(C)	15.0
Hydrogen	(H)	10.0
Nitrogen	(N)	4.0
Phosphorus	(P)	0.5
Calcium	(Ca)	0.5
Sulfur	(S)	0.5
All Others		0.5

A comparison of Tables 1 and 2 shows that the chemistry of life is in obvious harmony with the chemical composition of the universe. The 6 most common chemical elements of the universe are: Hydrogen (75%), Helium (23%), Oxygen (0.9%), Carbon (0.4%), Neon (0.2%), and Nitrogen (0.15%), which account for about 99.65% of the total. Leaving aside the two noble gases Helium and Neon, which are chemically inert and therefore are not involved in the chemistry of life, the other four (H,O,C,N) account for about 98% of the biomass of the earth. It is also interesting that that hydrogen which is the most common of all the chemical elements, and oxygen which is the most common of the heavy elements, have a great affinity for each other and unite with a great release of energy to form water (H_2O). As a result, with the exception of H_2, water must be the most common molecule in the universe, and it is also the basis of the chemistry of life on earth. As a matter of fact, about 70% of the biomass of the earth is water, as are also our own bodies.

We also know that all the active elements form simple molecules with other active elements and especially with hydrogen and oxygen, both of which are very active. Typical examples are water (H_2O), ammonia (NH_3), methane (CH_4), hydrogen sulfide (H_2S), phosphene (PH_3), carbon monoxide (CO), and carbon dioxide (CO_2). Under the effects of different sources of energy, such as the ultraviolet radiation of the stars, electric discharges in planetary atmospheres, radioactivity on newly formed planets, etc., these simple molecules can combine to form much more complex organic compounds, such as amino acids that are the building blocks of all proteins, and sugars that are essential compounds for all living organisms.

These chemical processes have been confirmed both through laboratory experiments starting with the famous experiment of Miller and Urey in 1953, as well as from astronomical observations of interstellar molecules, and from our recent close encounters with Halley's comet. Table 3 gives the long list of organic compounds that have so far been detected outside the earth. This is a list that is steadily growing both in the number and in the complexity of the molecules it contains. We have also found highly complex organic compounds in carbonaceous meteorites, which are pieces of carbon-rich asteroids, that occasionally fall on earth. The organic compounds found in them include many of the 20 alpha amino acids that are the building blocks of the proteins of all living organisms, and in recent studies Cyril Ponnamperuma (1986) and his group believe that in samples of the Murchison meteorite that fell in 1969 in Australia, they have detected all five nucleic acids (Adenine, Guanine, Thymine, Uracil, and Cytosine) that are the key componentss of DNA and RNA.

In summary, our astronomical observations and the results of our space program show convincingly that the abundances of the different chemical

TABLE 3

Interstellar and Cometary Molecules, Radicals and Ions

	(2 Atoms)
H_2	Hydrogen molecule
OH	Hydroxyl radical*
OH^+	Hydroxyl radical ion*
C_2	Diatomic carbon*
CH	Methylidyne radical*
CH^+	Methylidyne radical ion*
CO	Carbon monoxide*
CO^+	Carbon monoxide ion**
CN	Cyanogen radical*
CN^+	Cyanogen radical ion**
CS	Carbon monosulfide*
N_2^+	Nitrogen molecule ion
NH	Imino radical**
NO	Nitric oxide
NS	Nitrogen sulfide radical
S_2	Sulfur molecule**
SO	Sulfur monoxide
SiS	Silicon monosulfide
SiO	Silicon monoxide
HCl	Hydrogen chloride
	(3 Atoms)
O_3	Ozone
H_2O	Water*
H_2O^+	Water ion**
C_3	Triatomic carbon
C_2H	Ethynyl radical
CO_2^+	Carbon dioxide ion**
HCO	Formyl radical
HCO^+	Formyl ion
HOC^+	Isoformyl ion
N_2H^+	Diazenylium ion
NH_2	Amide**
HCN	Hydrogen cyanide*
HNC	Hydrogen icocyanide
HNO	Nitroxyl acid
H_2S	Hydrogen sulfide
H_2S^+	Hydrogen sulfide ion**
SO_2	Sulfur dioxide
HCS^+	Thioformyl ion
OCS	Carbonyl sulfide
SiC_2	Silcyclopropyne
NaOH	Sodium hydroxide (Uncertain)
	(4 Atoms)
C_2H_2	Acetylene
C_3H	Propynylidyne radical
C_3O	Tricarbon monoxide
H_2CO	Formaldehyde*
$HOCO^+$	Protonated carbon dioxide
NH_3	Ammonia*
C_2CN	Cyonoacetylene radical
$HCNH^+$	Protonated hydrogen cyanide
HNCO	Isocyanic acid
H_2CS	Thioformaldehyde
HNCS	Isothiocyanic acid
	(5 Atoms)
CH_4	Methane
C_3H_2	Cyclopropenylidene (ring)
C_4H	Butadiynyl radical
HCOOH	Formic acid
CH_2CO	Ketene
HC_2CN	Cyanoacetylene*
CH_2NH	Methanimine
NH_2CN	Cyanamide
CH_3CN	Methylcyanide*
SiH_4	Silane
	(6 Atoms)
C_2H_4	Ethylene
CH_3OH	Methyl alcohol
$HCONH_2$	Formamide
CH_3CN	Acetonitrile
CH_3SH	Methyl mercaptan
	(7 Atoms)
CH_3CCH	Methylacetylene
CH_3CHO	Acetaldehyde
CH_3NH_2	Methylamine
CH_2CHCN	Vinyl cyanide
HC_4CN	Cyanodiacetylene
	(8 Atoms)
$HCOOCH_3$	Methyl formate
CH_3C_2CN	Methyl cyanoacetylene
	(9 Atoms)
CH_3CH_2CN	Ethyl cyanide
CH_3C_4H	Methyl diacetylene
CH_3CH_2OH	Ethyl alcohol
CH_3OCH_3	Dimethyl ether
HC_6CN	Cyanotriacetylene
	(11 Atoms)
HC_8CN	Cyanotetracetylene
	(13 Atoms)
$HC_{10}CN$	Cyanopentacetylene

(no *) Observed only in interstellar space.
(one *) Observed both in interstellar space and in comets.
(two **) Observed only in comets.

elements, as well as the process of prebiotic chemistry in the interstellar space, in comets, in the asteroids, on Titan, etc., favor the building of complex organic compounds. Under favorable conditions, namely the availability of liquid water, these complex compounds seem to be able to start life, as the case of the earth clearly suggests where life got started very soon after our planet got settled down.

2. The Physical Laws of the Universe

A study of the physical laws of Nature shows that the universe is favorably predisposed toward the origin and the evolution of life. To start with, the universe could have been much simpler, having for example only one kind of particles and only one kind of force, such as only neutrons and gravity. Such a simple universe would have also formed galaxies, stars, planets, etc., but would have not been able to start life, because life is a phenomenon that requires a high degree of complexity that such a simple universe would have not been able to provide, while our universe that has four different forces (nuclear, electromagnetic, weak interaction, and gravity) and a rather wide variety of elementary particles, does provide.

What is also amazing is that these four forces have been given the strengths that can help life get started and to slowly evolve toward more advanced forms. Dicke (1962) has shown, e.g., that the luminosity of the stars is proportional to G^7, while their life spans are proportional to G^{-5}. Thus by doubling the value of the gravitational constant would reduce the lives of the stars by a factor of 32, while by reducing it to half would reduce their luminosities by a factor of 128, making it also very difficult for massive stars to form. It is interesting to remember that the force of gravity is $10^{39} = 2^{130}$ times smaller than the electromagnetic force, and that if this ratio was 2^{129} or 2^{131} it would have played havoc with life because the stars would have not been able to provide the long, steady radiation required for the slow evolution of life to higher intelligence.

Essential is also the role of the electromagnetic force because it controls the make-up of the atoms and of the molecules which are the building blocks of life, as well as the radiation emitted by the stars and hence the radiation received by life on near-by planets. It also regulates the opacity of the layers that surround the cores of the stars where the nuclear energy is produced. If, e.g., these surrounding layers were totally transparent, the superhot core would radiate away all of its heat and would freeze out into a dead star in just one day.

The weak interaction force controls the conversion of protons to neutrons in the cores of the stars and hence regulates the rate at which nuclear energy is released through the burning of H into He. Increasing or decreasing it would change drastically the rate at which stars produce energy, with obvious repercussions on their life-spans and hence on the evolution of life on their nearby planets.

The nuclear force is also very critical in all of these cosmic processes. It is interesting, e.g., that the electromagnetic repulsion between 2 protons is just 2% stronger than their nuclear attraction at close range. As a result 2 protons can not combine to form He-2 and need the presence of neutrons, which provide the added nuclear forces to keep them together. If He-2 were possible, probably most of the hydrogen of the universe would have been converted into helium at the early moments of the big bang, which would have eliminated the possibility of life. One of the reasons is that helium is an inert gas and therefore can not replace hydrogen in the chemistry of life (without hydrogen there wouldn't even be water). An other reason is that without hydrogen stars would be deprived of their slow, hydrogen burning period when life manages to get started and to slowly evolve, and would have jumped directly to the helium burning stage with its short life-span and its harsh for life ultraviolet radiation.

Another peculiarity of the nuclear force is the high instability of Beryllium-8, which has a half-life of only $2.6x10^{-16}$ sec. This is very odd, because Be-8 consists of 4 protons and 4 neutrons, i.e., of 2 alpha particles (helium nuclei), and therefore it ought to have been very stable since He-4, C-12, O-16, Ne-20, Mg-24, Si-28 and S-32, which respectively consist of 1, 3, 4, 5, 6, 7, and 8 alpha particles, are all very stable. Actually the only stable isotope of Beryllium is Be-9 with an extra neutron, which is difficult to make and therefore exists only in very small amounts. The surprisingly high instability of Be-8 prevented the synthesis of the heavy elements in the early moments of the big bang and therefore they had to be synthesized in much smaller amounts later on in the supernova explosions of the more massive stars. If seems likely that a higher abundance of heavy elements would have produced far more massive planets at closer distances to the stars, which would have retained much denser atmospheres with potentially detrimental results for life due to intence greenhouse effects.

Another critical physical property of the universe is the strength of the big bang. Had it been much weaker, the universe would have stopped expanding and would have collapsed back in a relatively short period without giving the opportunity to life to evolve into advanced civilizations. On the other hand, if the big bang were much stronger and the expansion rate much faster, it is possible that galaxies and even stars might have had difficulties forming. This would be especially true for later generation (Population I) stars like our sun, which have a higher percentage (~2%) of heavy elements thanks to earlier supernova explosions of Population II stars and the subsequent mixing of gases inside a stable galaxy. Without population I stars, most probably there would have been no life either.

One more interesting point is the following. Nature favors the increase of entropy (disorder), while life with its high molecular organization favors the decrease of entropy (increase of order). Life, therefore, appears to be a phenomenon that goes against the wishes of Nature. With its continuous expansion, however, the universe has set up an intriguing thermodynamic system that favors the appearance of life. Hot stars ($T \sim 6{,}000^{o}K$) radiate away large amounts of high quality (low entropy) energy, which is received by the surrounding cooler planets ($T \sim 300^{o}K$) that use it to get things organized. Life is the best means to increase order, as in the case of photosynthesis where living organisms with the help of solar energy combine water and carbon dioxide to form sugars and oxygen.

The planets, however, must also radiate away the energy they receive from the sun so as to maintain a stable temperature. They do it, though, at a much lower temperature ($T \sim 300^{o}K$) and therefore they radiate away energy of much lower quality (higher entropy). This is possible because the cosmic background, thanks to the continuous expansion of the universe, is at a much lower temperature ($T \sim 3^{o}K$) and therefore an excellent dumping depot for the low quality energy of the planets. Thus the universe, with its three temperature levels, the hot stars, the cooler planets, and the very cold cosmic background, provides an ideal thermodynamic system to build order at the intermediate stage, i.e., at the planets. Since life is the ideal way to increase order at the planetary level, it is clear that the thermodynamic set-up of the universe favors the appearance of life on planets.

From all of the above it is quite evident that the physical properties of the universe (Papagiannis, 1978, 1986) are all favorably predisposed for the emergence and the subsequent long evolution of life to advanced civilizations. This observation is often called the Anthropic Principle (Davies, 1981) which simply sais that our mere presence here defines the initial properties of the universe. This might sound a little too far fetched, but in reality it is not very different from a statement by a meteorologist who would say: "Since it is snowing this morning, the conditions in the atmosphere last night must have been such and such."

3. Astrophysical and Planetary Results

Astronomical observations have shown us that our sun is a star of intermediate mass, located in the suburbia of the disk of our spiral galaxy, the Milky Way, which consist of more than 200 billion stars (suns), at least a billion of which must be quite similar to our sun. We also have found that in the visible universe there are 10^{10} - 10^{11} galaxies, each one with an average of 10^{10} - 10^{11} stars, i.e., a total of at least 10^{20} stars and therefore something like 10^{18} stars with physical properties (mass, chemical composition, radiation spectrum, life-span, etc.) similar to those of our sun. Given the universality of the chemistry we discussed above, it is evident that the universe with its huge number of sun-like stars is well prepared to face any odds that may be involved in the origin and in the subsequent long evolution of life. It would be very unlikely, therefore, that our planet would be the only place in universe where life managed to get started and to evolve into an advanced civilization.

How rare a planet like the Earth might be is still an unanswered question. Theoretical studies (Hart 1978, 1979) indicate that the habitable zone, or the ecosphere as it is also called, i.e., the range of distances around a star where a planet with liquid water may exist for billions of years, is limited to only a few percent of the distance from the Earth to the sun. Part of the reason is that the luminosities of the stars keep increasing with time (our own sun was about 25% dimmer when life started on earth 3.5 - 4.0 billion years ago), and as a result the limits of the habitable zone keep shifting farther out as the star ages. Therefore, in order to remain in the habitable zone during the long stretch of the biological evolution, the planet initially must be near the outer limit of the habitable zone so as to continue to be in it as the habitable zone would drift farther out after several billion years.

Besides the distance from the star, there are also several other factors that must be satisfied for a planet to be able to hold life on it. These include the mass of the planet (if too small, e.g., the planet will not be able to retain an atmosphere and hence liquid water on its surface), the spinning rate (if too slow, there will be very large temperature differences around the planet), the obliquity of its axis, the eccentricity of its orbit around the star, the presence of large moon(s), etc., all of which, as well as the ranges of their cyclical variations, affect the temperature and hence the living conditions on a planet (Papagiannis, 1983).

The search for planets around other stars is a very difficult task because of the colossal distances that separate us. The distance from the earth to the sun when seen from the nearest stars looks like two points just a few millimeters apart seen from a distance of one kilometer. In addition the sun is several billion times brighter than the earth and therefore to a far away observer the earth next to the sun is like a fire-fly sitting at the edge of a powerful search light, which completely overpowers it. Still a variety of techniques are being developed to search for planets around nearby stars and significant progress has been made in this field in the last 10 years. Actually we can anticipate that in the next decades we will be able to deploy the appropriate instruments in space that will allow us to gather the proper statistics about the distances and the masses of planets around other stars, and to hopefully identify other stars that have earth-like planets around them. Further on, we also hope to conduct spectroscopic studies of the atmospheres of these planets and from the data to infer the presence of life on these planets (Burke, 1986a, 1986b). This would be the case, e.g., if we were to detect an oxygen rich atmosphere on such a planet, because the highly reactive oxygen can exist free and in large quantities only if it is continuously replenished by a biological process such as photosynthesis.

4. The Evolution of Advanced Civilizations

The emergence of an advanced technological civilization is an extremely fast event, because technology accelerates immensely all aspects of development. Even if we were to place the beginning of our civilization at the emergence of the austrolopithecus about 3-4 million years ago, still this long background of mankind would represent only one thousanth of the history of life on Earth. If we were to start counting only about 4,000 years ago with the appearance of writing and metallurgy, this would represent only one millionth of the presence of life on earth, and if we were to start from the harnessing of nuclear energy or from the advent of the space era, we would have an interval equal to only 10^{-8} of history of life on our planet.

The development of technology allows the rapid accumulation and dissemination of knowledge (written documents, books, photographs, telecommunications, computers, etc.). It also enhances immensely the ability to exploit the resources of the earth through mining, agriculture, production of energy, transportation, etc. The results, however, can also be frightening because this rapid progress can easily get out of hand (Papagiannis, 1984) as seen from of the following serious problems:

I. Overpopulation

About 2,000 years ago the earth had only around 100 million people and the population was growing only at 0.05% per year. Now it has 5 billion people, i.e., 50 times more, and the population is growing at about 1.7% per year, i.e. 30-40 times faster, doubling in just 40 years.

II. Depletion of Resources

Oil and natural gas, that account for about 65% of our current energy resources, are expected to get almost fully depleted by the middle of next century. So will also several other critical materials such as aluminum. Meanwhile our energy consumption is increasing at a rate of 3% per year, doubling in only 23 years.

III. Diminishing Food Supplies

We are already cultivating more than half (the best half) of the available agricultural land on earth. The continuous increase of the population takes over part of this valuable land, thus reducing continuously the land available for agriculture, while the need for food keeps steadily increasing.

IV. Pollution and Destruction of the Environment

Acid rain and chemicals such as Mercury, Lead, DDT, Dioxin, etc, are polluting our waters and our land. The disposal of nuclear wastes is a serious problem too. We are also reducing the ozone layer and increasing the greenhouse effect, both with potentially serious long-term effects.

V. The Danger of Nuclear Destruction

The Nuclear arsenals of the superpowers have now grown to a total power of about 14,000 Megatons of TNT. This is the equivalent of one million Hiroshima bombs, which had a power of only 14 kilotons of TNT, but still managed to kill about 100,000 people when it was dropped on Hiroshima on August 6, 1945. The danger, therefore, of self-destruction from a nuclear holocaust is indeed very real.

VI. Thermal Pollution

People tend to think that the discovery of new forms of energy, such as the harnessing of controlled nuclear fusion, will solve all the problems of mankind. Actually, almost all of the energy used is converted into waste heat (the law of entropy), which increases the temperature of the environment. It is estimated that in about 100 years the amount of waste heat being released will reach about 1% of the heat that the earth receives from the sun, which will have very serious long term effects on the climate of our planet.

From all of the above, it becomes obvious that our own civilization is rapidly approaching the limits of growth of our planet (Meadows, et al, 1975; Barney, 1980), and therefore it is now entering a major crisis that may threaten its own survival.

The expansion of an advanced civilization to the whole space of their solar system is a very realistic possibility (O'Neil 1977), but if they were to continue their old habits of overpopulation, energy consumption, etc., they would rapidly reach again the limits of growth for their entire solar system. The present energy consumption on earth is about 10^{14} kWh per year, i.e., about 1.2×10^{20} erg/sec, while the total energy output of the sun is 4×10^{33}, i.e., about 3.3×10^{13} which makes it 2^{45} times bigger. However, at a growing rate of 3% per year, which implies a doubling period of 23 years, 45 doublings would occur in only 23x45 = 1,035 years, and therefore in just about 1,000 years they would be needing the entire energy output of the sun to keep their energy hungry civilization going. This, however, is the ultimate limit and therefore if we were to keep our current trends for an other 1,000 years, which cosmically is an insignificantly short period, we would reach our ultimate limits of growth.

The same would be true with the growth of the population. With a doubling period of 40 years, in 1,035 years we will have 26 doublings, i.e., our present population of $5x10^9$ will increase by a factor of $2^{26} = 6.7x10^7$ to a total of $(5x10^9)x(6.7x10^7) = 3.4x10^{17}$ people. Assuming now an average weight of about 100 lb ($4.5x10^4$ gm) per person, we see that the total mass of mankind would be $(3.4x10^{17}) \times (4.5x10^4) = 1.5x10^{22}$ gm. Since carbon represents about 15% of the biomass, it follows that we will be incorporating into human bodies about $2.3x10^{21}$ gm of carbon, which is more than all the carbon we can extract from the whole crust of the earth and from all of the asteroids in the asteroid belt.

Interstellar travel and interstellar colonization are realistic possibilities, but will not be able to help the overpopulation problem, or the depletion of the natural resources of a solar system. The reason is that the cost to ship people to another solar system exceeds by far the cost of providing for them for life in their own solar system. Interstellar commerce is also out of the question because the energy cost would be colossal, not to mention shipping times of the order of centuries. Even at an interstellar speed V equal to 10% of the speed of light, i.e., at $V = 0.1c$, and at an optimically low value of 100 to 1 for the mass M of the spaceship and the fuel to the mass m of the useful cargo, i.e., for $M = 100m$, since the interstellar probe must first accelerate to the cruising speed of $V = 0.1c$

and then to decelerate back to zero at its final destination, the total energy required would be:

$$E = 2(^1/_2MV^2) = MV^2 = (100m)x(0.1c)^2 = (100m)x(0.01c^2) = mc^2$$

This, however, is the theoretical limit for converting energy to matter, and therefore every gram of matter carried over from an other star would cost the equivalent of $9x10^{20}$ ergs, or of $2.5x10^7$ kWh. At present energy prices, this is equal to about 1 million dollars, while a gram of gold costs now only about $14, i.e., about 70,000 times less.

From the above it becomes obvious that advanced technological civilizations will be rapidly faced with a major crisis imposed by the limits of growth of their own planet, or of their own solar system, and that they cannot obtain material help from the outside. For them, therefore, the only solution would be to reform, to stop their frenzied growth and redirect their interests from materialistic pursuits to intellectual and spiritual goals. Those that will succeed in making this change will probably be able to extend their peaceful existence for millions of years, while those that will continue with their materialistic traits are destined to self destruct in a very short period. Hence if we would ever make contact with other advanced civilizations in our galaxy, the overwhelming probability is that they would be peaceful, intellectual, altruistic, and spiritual civilizations whith a practically zero rate of physical growth. The reason is that even if their energy consumption were to keep growing at rate of 0.003% per year, i.e., 1,000 times slower than our present rate, in about a million years they too would have had 45 doublings of their energy consumption and thus they too would have reached their ultimate limit of growth requiring the entire energy output of their star for their needs.

5. The Search for Extraterrestrial Intelligence

The question of whether life and especially life with intelligence does exist in other planets of our solar system as well as in other stars, is indeed a very old one, but it was only in our days that the development of technology made it possible to undertake real searches. The advent of the space era made it possible to explore our solar system, to land men on the moon, to land space probes on Venus and on Mars, and to have a close encounter with Halley's comet. The results so far have been negative, though we have found places, such as on Titan the large moon of Saturn, where prebiotic chemistry is still actively producing biologically important compounds.

Also we have undertaken radio searches for signals from other advanced civilizations starting with Project Ozma of Frank Drake, who in the spring of 1960 carried out the first search for radio signals from two nearby stars, Epsilon Eridani and Tau Ceti. By now we have carried out more than 50 such SETI (Search for Extra-Terrestrial Intelligence) projects, and have devoted to then more than 150,000 hours using the radio telescopes of most of the technologically advanced countries (USA, USSR, Australia, Canada, France, Germany, Holland, England, Argentina and Japan).

Furthermore, we have two facilities that are fully dedicated to SETI. The older one, that has been in operation since 1973, is the Ohio SETI Program under the direction of J. Kraus and R. Dixon. It has been using the large radio telescope of the Ohio State University near Columbus, Ohio, that has a collective area of 2,200 m^2, the equivalent of a parabolic dish 53m in diameter. The more recent one, which has been in operation since 1983, is Project Sentinel which in 1985 became Project META, that is under the direction of P. Horowitz and has been using the Harvard/Smithsonian 26m parabolic radio telescope near Boston. Both of these facilities are fully automated and operate on a continuous basis, 24 hours a day, 365 days a year. As a result each one of them accumulates more than 8,500 SETI hours per year.

In addition S. Bawyer, D. Werthimer and V. Lindsay of the University of California, Berkeley, have developed a piggyback equipment which they call SERENDIP. They use it with different radio telescopes while they are carrying out other radio astronomical projects. This equipment, in a parasitic mode but also in real time, does a SETI analysis of the data obtained by the radio telescope for other purposes. This equipment is now connected to the NRAO 100m radio telescope at Green Bank, W. Virginia, and it too is accumulating several thousand hours of SETI work per year. Thus just these three projects are now piling up close to 20,000 SETI hours per year.

In the nearly 30 years since the first search by Frank Drake, we have carried out many searches, including some at optical and at infrared wavelengths, but unfortunately without any positive results. Actually most of these searches, including those carried out at the two SETI dedicated facilities, have been conducted at the hydrogen line around 1.4 GHz (21 cm), in the hope that since this must be a universally known frequency, civilizations would select it, at least to make the first contact, as Cocconi and Morrison (1959) proposed nearly 30 years ago. Actually some searches have been conducted at other special frequencies too, such as at the lines of hydroxyl (OH) at 18cm, and the line of carbon monoxide (CO) at 2.6 mm, but no searches have been made as yet that would cover a wide range of the radio spectrum.

This is now the goal of a far more ambitious program that will be undertaken by NASA. It is called the NASA SETI Program and is under the direction of Dr. Bernard M. Oliver. It will consist of two parts, the

"Targeted Search" and "The Sky Survey". The Targeted Search will use the largest available radio telescopes and will focus on 800 - 1000 targets including 773 sun-like stars up to a distance of 82 light years, and several other interesting object such as stars with peculiar spectra and whole galaxies. It will have a high spectral resolution of about 1 Hz and will cover the frequency range from about 1.2 GHZ to about 2.0 GHz. This range of the radio spectrum is called "the water hole" because it is bracketed by the lines of hydrogen (H) around 1.4 GHz and of hydroxyl (OH) around 1.7 GHz, which together form water (H_2O).

The Sky Survey will have a lower frequency resolution of about 32 Hz and will use medium size telescopes, but will search the whole sky and will cover the entire microwave window from about 1 GHz to about 10 GHz. The search over a wide range of frequencies has become possible thanks to the development of a new search instrument called a Multi-Channel Spectrum Analyzer (MCSA). The MCSA is essentially an electronic, high-resolution radio spectrometer that can study simultaneously the signals received at millions of adjacent frequencies. The NASA MCSA, which is expected to have more than 8 million channels, is now being constructed by Stanford University. The NASA SETI program is expected to get under way in the early to mid 1990's and to last for about 10 years. It will represent a huge step forward in our search for extraterrestrial civilizations.

Characteristic of the colossal technological progress that has been made in the last 30 years is the following comparisson. The 200 hours that Frank Drake spent in 1960 with the 85 ft Tatel radio telescope and his primitive superheterodyne receiver (the state of the art in 1960) in the first SETI project, NASA's new MCSA working in conjunction with the huge 1,000 ft Arecibo radio telescope, will be able to do it a billion times faster,i.e., in just a thousanth of a second.

It is appropriate to mention also that the International Astronomical Union (IAU), the prestigious international organization that represents all the astronomers of the world, established in 1982 a new Commission to coordinate the work on the search for extraterrestrial life. I was elected to serve as the first President of this new Commission for the 3-year period 1982-1985, and was succeeded by Frank Drake who became its President in 1985, 25 years after his Project OSMA, for the period 1985-1988. Following my official recommendation, the IAU endorsed the new term "Bioastronomy" to represent this new interdisciplinary branch of Astronomy. The new Commission, therefore, now has the official title: IAU Commission 51 - Bioastronomy: Search for Extraterrestrial Life. In 1982 we held in Boston our first international IAU Symposium on Bioastronomy, the proceedings of which were published by Reidel (Papagiannis, 1985a). Also the prestigeous science journal NATURE, invited me to write a technical review article on this new field (Papagiannis, 1985b). In 1987 we had our second international meeting on Bioastronomy, this time in Hungary, and the Commission now has over 300 members. Thus Bioastronomy is now an internationally sanctioned scientific undertaking with a broad participation of astronomers and other scientists from all around the world.

6. Summary and Conclusions

From the times of the ancient Greeks there was the intuitive feeling that there must be life and intelligence in many other places of the universe. Metrodorus of Chios, e.g. in his book On Nature around 400 B.C. 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." Only in our century, however, did science and technology advance enough to allow us to scientifically justify this belief. They also made it possible for us to undertake sophisticated scientific searches for primitive life in our solar system and for advanced civilizations in other solar systems. As seend in sections 1 and 2, the universe seems to be very favorably predisposed for the emergence of life and for its subsequent evolution to higher intelligence. Since we do know of at least one such case, our own, it seems extremely improbable that this will be the only one in the whole universe.

Given the physical and chemical properties of the universe, one is tempted to believe that life must have started in many solar systems of our galaxy. Whether it would manage to complete its painfully slow evolution to an advanced civilization, and whether this civilization would be able to overcome the major crisis that seems to follow the development of technology, are questions that still need to be answered. It is immensely exciting, however, that we happen to live now and be part of the effort to answer these profound questions.

Making contact with other advanced civilizations in our galaxy, which most likely would have already established contacts with each other and must have formed something like a galactic society, will certainly be a unique achievement. It will also be a great intellectual and spiritual uplift for our civilization, because as we discussed in section 4, all these long established stellar civilization must have already reached a level of serene maturity and spirituality. On the other hand, if after an extensive and comprehensive search we were to conclude that we must be one of very few if not the only advanced civilization in our galaxy, this too would be a very important result, because it would make us realize how cosmically important this little speck of intelligence is, and how universally essential it is to preserve it, in the hope that some day in the future our descendants may become the ones that will carry the flame of intelligence to all the hospitable stars of our galaxy.

If advanced life with high intelligence, but also with high moral and spiritual standards, is bound to finally populate the entire universe, then it seems justified to argue that the universe cannot be a cosmic accident without a purpose. Hence there must be a superintelligence behind the whole creation that established the laws of nature in such a way as to assure a successful cosmic evolution from the big bang to a universe populated by mature civilizations. With our current searches for extraterrestrial life and for extraterrestrial intelligence, the long advancements we have made in the physical and in the biological sciences are finally coming to a climax.

If our searches were to prove successful, we will gain a far broader understanding of the whole creation that will unify all the disciplines into a global unit. This unified knowledge will bring together the physical evolution of the universe from the big bang to planets with liquid water, the biological evolution from procaryotic bacteria to an advanced civilization, and the evolution of social, ethical and religious principles from the desire of physical possessions and dominance over others to the joy of loving, of giving and of higher intellectual and spiritual pursuits. This then would be a purposeful cosmic evolution that started as a totally amorphous mass and is destined to lead to a network of stellar civilizations with high spiritual standards, that live in harmony with the creator of this cosmic miracle.

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