Civilizations Out in Space

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From the beginning, men have looked into the starry sky and asked, "Are we alone in this vastness?" Scientific knowledge now enables us to outline an answer to this question, and that will be our purpose here. Some interesting implications of the answer may come to mind as we proceed.

As a logical prerequisite even to asking the question, one must conceive of the stars as other suns and of the Earth as a planet in the solar system. The first of these ideas was held by some thinkers far back in history (among them several ancient Greek scholars) even though it has been accepted by most people only in the last few centuries. The second, although proven only in 1727 (by Bradley's measurement of the aberration of starlight), was also accepted long ago by some scientists.

Among the early records of extensive scientific thinking about the possibility of other civilizations is a fascinating little book published by Christiaan Huygens, a physicist, near the end of the 1600's (1). He wrote:

> Why then shall we not . . . conclude, that our star has no better attendance than the others? So that what we allow'd the planets, upon the account of our enjoying it, we must likewise grant to all those planets that surround that prodigious number of suns. They must have their plants and animals, nay and their rational ones too, and those as great admirers, and as diligent observers of the heavens as ourselves; and must consequently enjoy whatsoever is subservient to and requisite for such knowledge.

Since then other scholars have speculated about civilizations outside the Earth, but these have generally been only the most

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adventurous thinkers. In fact, many individuals and groups have strongly opposed the notion. The interesting ideas of the Book of Moses (2), dating from 1830, were therefore quite advanced, especially in view of their theological setting. In that book, Joseph Smith not only remarked on the existence of other worlds (3), but he attributed these ideas to divine revelation, wherein God said:

> And worlds without number have I created; and I also created them for mine own purpose; and by the Son I created them, which is mine Only Begotten. And the first man of all men have I called Adam, which is many. But only an account of this earth, and the inhabitants thereof, give I unto you. For behold, there are many worlds that have passed away by the word of my power. And there are many that now stand, and innumerable are they unto man; . . .

Two scientific achievements of the 1950's changed our intellectual climate and brought renewed interest in possible galactic civilizations: the development of radio astronomy provided a means of communicating with other societies, and the dramatic launching of the first Sputnik by Russia in 1958 showed that man was ready to step out into space. Several articles and books about extraterrestrial civilizations by scientists and writers appeared (4), (5), (6). A whole new branch of science—exobiology—was born. Some of what had been written, often with considerable knowledge and imagination, as "science fiction" began to appear much more plausible.

ARE THERE CIVILIZATIONS OUTSIDE THE EARTH?

Where do we now stand? What can be said from the viewpoint of science about the chances for extraterrestrial life? Are there other civilizations outside the Earth? Is there a chance to communicate with, or visit, such civilizations if they exist?

Let us first remind ourselves of the nature of our universe (7). Our Earth is one of many planets (nine major ones) which, along with comets and meteors, revolve about an ordinary star called the Sun. The Sun is one of about 100 billion (10^{11}) stars of various brightnesses, sizes, temperatures, compositions, and ages which make up the Milky Way galaxy. (On occasion we will need some large numbers here—much larger than we can understand from daily experience; therefore, we will use superscript numbers to eliminate using large numbers

of zeros.) A galaxy is a major grouping of stars, and galaxies span a considerable range in size, form, and brightness. Galaxies in turn are grouped into clusters, and clusters are grouped into superclusters. This hierarchy may continue up to the size of the entire universe. In any case, the universe contains at least a few billion galaxies altogether. There is some tentative evidence that the universe stretches out to a distance of perhaps 10 billion (10^{10}) light years (a light year is the distance light travels in a year—about 6×10^{12} miles) and has an age of 10 or 15 billion years.

Of the 10^{20} to 10^{24} stars in all the galaxies in the universe, it would be fantastic if only our star had a planet which supported a civilization!

Can we estimate how many civilizations there are? Consider first the prerequisites of life. All life on Earth (and that includes all known life in the universe) is based on the chemistry of carbon, an element which is quite abundant throughout the cosmos. All living organisms need water in the liquid state. A supply of oxygen is needed. Plants (on which all life depends) require a source of heat or light in the correct amount and at the proper wavelengths. Since the rates of some physical processes depend on it, gravity of a proper value is needed. Finally, poisonous substances must not be present. We therefore concentrate our search for life on those parts of the universe where these prerequisites are met. It has been suggested that these limits might be extended if life elsewhere were based on a different system of chemical compounds, such as those of silicon, or if ammonia or alcohol could replace water or sulfur replace oxygen. While this speculation is interesting, it seems highly improbable that an organism as complex as the human body could be so constructed. Therefore, although we cannot exclude the possibility that living matter elsewhere might be based on some exotic chemistry, we restrict our speculations to life as we know it on Earth.

With this assumption most of the universe can quickly be excluded as a habitat for any sort of life. The surface (and the interior) of the stars are much too hot for complex molecules to form. The space between the stars, on the other hand, is generally much too cold for any life to exist. Surrounding each star is a certain zone where the temperature may permit life. A planet, like Earth, orbiting within this "life-zone" would

be the most obvious—probably the only—spot to fulfill the conditions for life.

CIVILIZATIONS IN THIS GALAXY

Can we estimate quantitatively the number of civilizations in the galaxy? Even more specifically, can we estimate the number of communicative civilizations out there. This number can be written as the product of several factors, each specifying the rate or probability of one event. There are several valid formulations of the equations, one of which is (8)

$$N = R_* f_p n_e f_l f_i f_c L.$$

Here N is the estimated number of communicative societies in the galaxy at any time; R_*, the rate of star formation; f_p, the fraction of stars forming planets; n_e, the number of planets per star with environment suitable for life; f_l, the fraction of suitable planets upon which life develops; f_i, the fraction of life-bearing planets upon which intelligence appears; f_c, the fraction of intelligent cultures communicating in an interstellar sense; and L is the time spent in a communicating state. (This particular equation was used at the informal meeting of eleven scientists in November 1961 at the National Radio Astronomy Observatory, Greenbank, West Virginia to discuss the prospects of communicating with possible civilizations outside the Earth.) Some of the factors involved in the calculation of N must come from astrophysics, some from biology, and some from sociology. Several will be barely more than guesses, but at least we can set some limits on the probable number of communicative societies. Any answer different from $N = 1$ would be exciting!

The rate of star formation (R_*) can be estimated only approximately. If there are 10^{11} stars in our galaxy and it is 10^{10} years old, stars formed at the average rate of 10 yer year. However, we must not count the earliest stars; for, if all elements heavier than hydrogen and helium have been produced by nuclear reactions in the centers of stars, any planets formed with these early stars probably were too deficient in carbon, nitrogen and oxygen to support life. Furthermore, if the evolution of life on Earth is a guide, life would not have to develop around stars which evolve quickly (the brightest and most

massive) (7), (9). On the other hand, most of the stars may have formed during a few epochs in the past, and we may be underestimating by a factor of 10-1000. A value of $R_* = 10$ stars/year seems reasonable.

What fraction of stars have planets? We have directly seen only those planets which circle our own star and it would be extremely difficult to observe planets of other stars directly. However, a slight wobble in the motion of certain nearby stars must be due to the existence of small, dark companions. For stars whose distance is known and whose mass can be estimated, it is even possible to deduce the mass of the unseen partner from the amount of wobble. Some of these masses are too small to correspond to real stars and begin to approach planets. The most extreme example is Barnard's star, which yields a possible pair of Jupiter-sized planets (10). Current theories of star formation from the collapse of massive clouds of gas and dust make it appear likely that planetary systems would often form along with the star. On the other hand, it may be more common to form one large planet (almost a small star) rather than several small ones, which would greatly reduce the fraction of stars with small, life-supporting planets (11). In addition, about half of the stars we see are not single, but are members of double or triple star systems, and stable planetary orbits in the life-zone of such systems are unlikely, though not impossible. As a final compromise, let $f_p = 1/10$.

How many planets per star have environments suitable for life? Since the mechanism of star and planet formation is not understood quantitatively, this cannot be calculated theoretically. Observationally, from our solar system, we know that Earth sits comfortably in the life-zone of the Sun. Very simple forms of life (like virus or bacteria) might be possible on Venus and Mars at the edges of the life-zone, but higher life is out of the question. Any life on the other planets seems quite improbable. No trace of any organic compounds was found in the "moon rocks" brought back by Apollo XI and XII. We choose $n_e = 1$.

What are the chances that life will appear on a favorable planet? From experience on Earth we know that life is very tough; it survives under surprisingly extreme conditions. From observations of the vigor of life, we assume that if conditions are such that life can survive, it certainly will, and optimistically set $f_l = 1$.

What is the probability that life will produce an intelligent civilization? (Our questions are becoming more difficult and the answers less certain.) Again by analogy, we might argue that the evolution of life on other worlds will not have been greatly different from what has occurred here on Earth, and intelligent creatures will probably appear as they have here. Although it has been suggested that other creatures such as the dolphin may have a sort of culture, here only man has produced an intelligent civilization (if not intelligent, our civilization is at least technologically advanced). Yet the alternatives in evolution are so numerous that every world may be different. Perhaps, then, an optimistic guess is that of those planets which support life, 1 out of 10 will produce a civilization.

HOW MANY CIVILIZATIONS ARE COMMUNICATIVE?

What fraction of the intelligent civilizations are communicative? The technological history of the Earth is complicated and one can easily imagine rather different results from slightly different events along the way. Conceivably a civilization might be quite successful without our technology (perhaps better off). For the sake of this discussion, we shall assume that all civilizations have the desire and ability to communicate and set $f_c = 1$.

This is a good time to consider our progress in calculating N, the number of (communicating) civilizations. Substituting our estimates into the equation, we get

$$N = 10 \times (1/10) \times 1 \times 1 \times (1/10) \times 1 \times L = (1/10)L.$$

None of the factors are likely to be wrong by large amounts. Clearly, our answer for N depends largely upon L, the lifetime of a civilization (in years). Other scientists have made estimates ranging from $(1/100)L$ to 100L (5), (8), (12).

HOW LONG DO CIVILIZATIONS LAST?

How long then, do civilizations last? On this question—perhaps the most important factor—we can hardly even guess. By definitions based on such technological accomplishments as transmission of radio signals, or the discovery of nuclear fission, civilization on Earth is less than a century old. Whether it will continue as long as the planet remains a suitable habitat

is not known. Is civilization, like life, tough and durable, or is it a fragile thing? No one knows. Many agents for ending civilization are known: war, especially thermonuclear or bio-chemical; disease, due perhaps to a new bacterial or viral mu-tation; pollution of the air or water; an atrophy of man's abili-ties due to exposure to drugs or radiation. On the other hand, man may overcome these dangers and continue (even improve) civilization indefinitely.

Values of L in the literature range from a thousand to a billion years depending largely on the writer's optimism. If civilizations last a million years, there are about 100 thousand in the Milky Way galaxy. If they last only a thousand years, there are only 100 or so, and if they last a billion years, there are some 100 million civilizations. Here the problem of calcu-lating the number of other civilizations stands, with little chance of significant improvement since the result depends so strongly on the unknown lifetime of a civilization.

Despite the uncertainties, one important conclusion emerges clearly: *it seems very likely that there are many civilizations in the galaxy around us.* Furthermore, since there are billions of galaxies in the universe, the total number of civilizations might be about 10^{15} (a million billion); the total number of intelli-gent beings, 10^{24}!

WHAT KIND OF BEINGS INHABIT OTHER WORLDS?

What kind of beings are they who have created these numberless civilizations out in space? One can find a wide range of educated speculation, much of it by writers of science fiction. Some have argued that evolution of living things on Earth has followed such a tortuous path, with so many other alternatives open at every step, that perhaps no being exactly like man will have appeared anywhere else (13). Perhaps we should not be too surprised if members of other civilizations are giant "something-or-others," cybernetic organisms (cy-borgs), (14), or little green men. On the other hand, since Homo Sapiens have prospered on Earth, it seems plausible that similar beings (with paired limbs, a head, two eyes, hands, etc.) might succeed on other planets, too. The teachings of the pro-phets also imply that extraterrestrial beings are man-like since they must also be children of God and created in His image. How fascinating to meet one!

We cannot help wondering about the religions of these other intelligent beings. Do they also have their gods and devils? If they worship a Supreme Being, is He the same as our God? Do they also need or claim a Savior? Are they behind us or ahead of us in their spiritual knowledge and righteous living?

Although we cannot even guess what life must be like in other worlds, it is fun to speculate, and many writers have. It is similar to predicting what life on Earth will be like in the year 2000 A.D. or 10,000, or 100,000. (We must remember that our civilization is a mere baby among those in the galaxy.) Even the most casual observer must be amazed at the dazzling technological progress during his own lifetime in transportation, medicine, power, communication, genetics, and electronics. Given a hundred or a thousand more years, man may continue such remarkable progress and create a truly incredible civilization. In a similar way, these other civilizations may be technically advanced beyond our wildest imaginings.

Technical progress of a civilization is not the same as benevolence (love of God and love of fellow man) and the two may not necessarily occur together. The technologically advanced man can be proud, make war, be immoral, or take advantage of his fellow man just as the cave man did. Among these other civilizations, there may be some which are evil as well as some which are good; they may war or they may work together. If the members of any of these advanced civilizations have raised themselves to a high level of goodness as well as a high level of technology, we would probably regard them as gods.

POSSIBILITIES OF COMMUNICATION

What are the prospects of communicating with any of these civilizations? The answer depends largely on their separation from us, which depends on the number of civilizations scattered about the galaxy. If there are as few as 1000 civilizations in our galaxy, the average distance between them must be on the order of 1000 light years, while if the number of civilizations is on the order of 100 million, then the average distance is on the order of a few tens of light years. Because of the enormous distances involved, electromagnetic radiation (light, radio waves, X-rays, etc.) alone travels sufficiently fast for signifi-

cant communication with these civilizations. At best it will be a slow process, for even the nearest stars are several light years away.

Two different kinds of electromagnetic radiation have been suggested for interstellar communication: radio waves (15) and lasers (16). Radio communication at or near the strong spectral line of neutral hydrogen at 21 centimeters has been suggested because of the lack of background interference of other celestial sources and the belief that all civilizations must have radio telescopes (large radio antennas) equipped to detect radiation at that frequency. If other civilizations have radio transmitters as powerful as ours, it would be possible even now for us to detect transmissions from planets of a few nearby stars. The other suggestion is that we might be able to communicate with lasers in the visible part of the spectrum. At the moment our lasers are not sufficiently powerful to communicate with near stars, but the development of more powerful lasers is probably just a matter of time.

Due to the high cost and demand for use of telescopes on other projects, no attempt has been made at transmission to other civilizations, but Project Ozma (1960) was an attempt at detection of possible signals. A radio telescope at the National Radio Astronomy Observatory was guided on two stars—Tau Ceti and Epsilon Eridani—to listen for any signals (15). None were detected from these near, sun-like stars, although it would have been a fantastic coincidence had something been found on the first try. In the meantime several papers have been written on the problems of deciphering communication and understanding languages of other civilizations. The first communication may well be dots and dashes which can be arranged to form a picture. It is, of course, possible that many of these other civilizations are already engaged in frequent communication with one another (14).

Many articles, both scientific and fictional, have been written about the prospects of traveling to other civilizations or of receiving visitations from them, but with present spacecraft, it is hopelessly out of the question. Rockets which use photons for propulsion and travel near the velocity of light are conceivable, but trips to the stars would still take decades or centuries—hardly the job for present humans. Although gains can be made by deep-freezing (as in "2001—A Space Odys-

sey") or by the Einsteinian relativistic time dilation (the clock on the space craft and hence the biological processes of the astronauts slow as one nears the speed of light), the problems are still insurmountable to our technology. Visitations to the Earth by representatives of other civilizations in the past have also been suggested (15), and it is possible that some artifact of such a visit may someday be unearthed or a record may be found in ancient writings.

In summary, although we have proven nothing, the knowledge of modern science makes it probable that there are a great many other civilizations in our galaxy, and there are billions of other galaxies. With this fantastic number of civilizations, it is very likely that many are far beyond us in every way. We may not communicate with them in our lifetime, or even within the next millenium, but if we do, it will be one of the most exciting events we have seen.

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