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# Astronomical Aspects of Interstellar Communication

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**Abstract—Astronomical Aspects of Interstellar Communication.**
*Habitable Planets*

Planets of other stars are too faint, and too close to their star, for any direct observation. According to modern theories, planets are formed together with the star, being the rule and not the exception. Nine conditions needed for life result in about 1 per cent of all stars having a planet able to develop higher life. Our Galaxy then probably contains about 2000 million habitable planets. The nearest ones are 15 light-years distant, too far for travel but close enough for communication.

If life and intelligence actually form on each habitable planet, going once through a technological period limited to 100,000 years, say, then our Galaxy contains 40,000 technological civilizations, with 500 light-years between neighbors. Communication is still possible.

*Astronomical observations*

Organic molecules have been observed in interstellar space, making the origin of life less improbable. During all 'normal' observations one should watch out for any sign of life. But so far, all suspicious objects have later been explained by natural causes.

Advanced technological civilizations might utilize all of their star's energy, and their waste energy should be observable around 10 μm wavelength. Infrared stars have been observed, but are again explained by natural causes.

*Where is Everybody?*

Technologically highly advanced civilizations could do many things visible to astronomers. Why, then, is nothing seen? Four possibilities are discussed:

(a) Life and intelligence are very rare. (b) Technology is exciting only during a short period, being surpassed by other activities. (c) Science and technology cause severe crises (population explosion, self-destruction, genetic degeneration). Maybe all surviving civilizations must have developed much regimentation and stabilization, and there is a possibility of irreversible stagnation. (d) Maybe there *are* many signs of life which we have not looked for or not understood.

*Translated abstracts appear at the end of this article.*

## Introduction

ON A CLEAR night, we see about 3000 stars with the naked eye; our stellar system, the Galaxy or Milky Way, contains about 200,000 millions of stars, and with our best telescopes we can observe over 1000 millions of other, similar galaxies. It would be a clear case of megalomania, an extreme delusion of greatness, to assume that we on Earth were the only intelligent beings in the universe. *Nothing is unique*, and most probably we are about average (just as our Sun is only an average star) with a huge number of other civilizations around us, about half of them more advanced than we are.

But *nothing lasts forever*, and it would be equally presumptuous to assume that our present state of mind is the only and final goal of all evolution. Most probably our present strong dominance of science and technology is just one link in a long chain, to be surpassed by other (now unpredictable) interests. However, a technical communication is possible only among technical civilizations, and this constraint yields a strong reduction for the number of our possible partners for CETI, the communication with extra-terrestrial intelligence.

Any large specific effort for CETI will need, for proper planning, an estimate concerning the number of possible partners and the distance to the nearest ones. And the astronomical aspect of this question then concerns the number and distance of habitable

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[1] Operated by Associated Universities, Inc. under contract with the National Science Foundation.

planets.

In addition to any specific CETI projects, it is important that also during all 'normal' astronomical observations the astronomer watches out for any sign of life, for example, any odd, artificial-looking feature that cannot be explained by natural causes but could be explained by the activity of intelligent beings, an activity which may have nothing to do with communication.

Finally, since no such sign of life has yet been observed, we are left with the rather serious question: 'Where is everybody?' This question is not specifically astronomical; but we might try, and astronomers have a remarkable tradition of drawing conclusions from observation as well as from their absence.

## 1. How Frequent are Habitable Planets?

### 1. *Observation is impossible*

Even if every single star in the sky had a planetary system exactly as ours, we still could not observe any of all these planets directly, nor could we obtain any indirect observational evidence for their presence. Thus, the lack of such observations, the statement that 'we have yet to detect a second planetary system' [10] *cannot* be used as an argument against their presence.

From the distance of the nearest stars, about 4 light years, our Sun is seen as a rather bright star. But the Earth is 1500 million times (23 magnitudes) fainter, and only 1 sec of arc away; and even Jupiter, the largest planet, is 12 million times (18 mag) fainter than the Sun and only 5 arcsec away. All our planets are much too faint and too close to the bright Sun for being detectable over distances of some light years with the best terrestrial telescopes.

What about indirect evidence? More than half of all stars are double, both companions orbiting about their common center of gravity. Sometimes it happens that one component is too faint for observation, while the orbital motion of the brighter component is still observable as a small but regular wiggle of its path. But this wiggle is the smaller the less massive and less distant the faint companion is; and if the companion is not a second star but only a planet the size and distance of Jupiter, then the wiggle of the Sun's path is only 0.005 arcsec as seen from the nearest stars, again too small for being observable.

Only if some day we could put a fairly large optical telescope in space or on the Moon, of about 100 in. dia., we may become able to observe other planetary systems, directly and indirectly. For the present and the near future, however, observation is impossible and we depend on theory and analogy.

### 2. *Theory of planet formation*

Our theories about the formation of planets have their origin already 200–300 years ago, see Refs. [1], [2] and [3]. There are mainly two types: tidal and nebular theories. The tidal theories assume that the Sun once suffered a close approach of another star (or of a large comet) whereby tidal forces threw out some solar material which later on formed the planets. In this case, planetary systems would be seldom, only about 100 systems per galaxy, as can be shown. But the tidal theories have been convincingly disproved meanwhile: ejected solar material would be much too hot, and would thus escape from the range of solar gravity.

Nebular theories assume that the Sun and its planets were formed more or less simultaneously, out of the same primordial gaseous nebula. This was promoted from Descartes (1644), over Kant (1755) and Laplace (1796), to von Weizsäcker (1944), Kuiper (1950) and others. A problem which showed up some decades ago is the need for chemical segregation: Sun, stars and interstellar matter consist of about 29% of helium, and only 1% of all heavier elements together, whereas our planets have much higher a fraction of the heavy elements.

Present theories [3–6] yield the following picture. Stars are formed in stellar clusters or associations, from large gas clouds, by a repeated process of alternating contraction and fragmentation. This process is stopped, as has been shown, with fragments of about one solar mass average, and with a size of about Jupiter's orbit. These fragments or 'protostars' lose angular momentum slower than energy, and thus must contract to a flat gaseous disc rotating in its own potential. Its inner parts move to the center, via turbulent friction, forming the Sun or star. The planets are formed within the disc, either by condensation, or, more probably, by accretion where small particles collide and stick together, yielding fewer and larger particles, growing finally into planets. This accretion favors dust particles, consisting of heavier elements. In both cases, condensation or accretion, the forming planet evaporates much of the lighter elements and retains most of the heavier ones. The smaller the planet and the closer to the Sun, the less of the lighter elements are retained by its gravity.

According to this nebular theory, planetary systems should be the general rule and nothing special. This may be wrong, of course, but at present it is the opinion of most who work in this field. However, since this is a crucial point, we will give, on a broader base, some additional reasons for assuming the general occurrence of planetary systems.

First, the only star where planets could be observed actually has planets (the Sun). In principle, there is nothing wrong with doing statistics with $n = 1$. This yields an estimator for the average (us). However, $n = 1$ does not yield an estimator for the mean error. Furthermore, there is a bias, because this question can have been asked only on an existing planet; it could not have been asked where there are no planets. From statistics only, the assumption that most stars have planets thus has the highest possibility of being right, but we have not the slightest idea of how wrong it may be (regarding both the statistical and the systematical error).

Second, the only planetary system we know has not just one, but *nine* planets, plus hundreds of comets, thousands of asteroids, and millions of small solid particles as shown in Fig. 1.

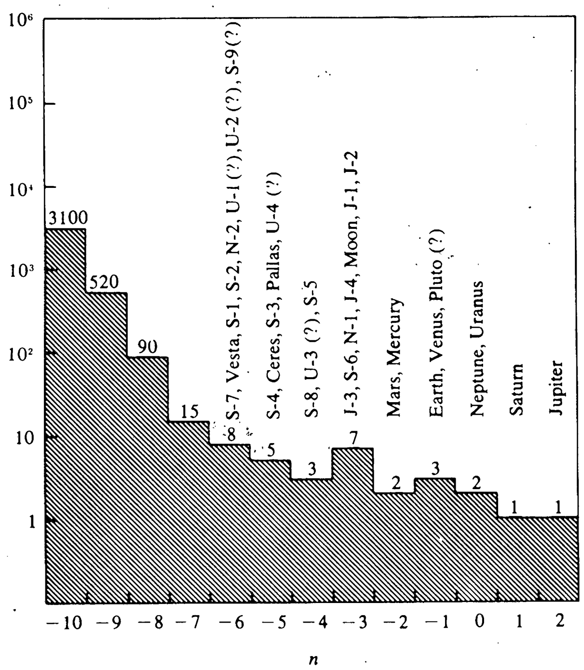

FIG. 1. Mass distribution in the solar system [Ref. 9].

Third, six of these nine planets have satellites of their own, up to 12 for Jupiter and 5 in the average. This, of course, is only an analogy, but it includes even the mass ratios: the log of the mass ratio Sun/planet ranges from 3.0 to 6.8 with a median of 5.5; and from 1.9 to 7.2 with a median of 6.0 for the mass ratio planet/satellite.

Fourth, binary (or multiple) stars are more frequent than single stars, with a wide range of mass ratios, almost down to planetary masses for the secondary. The formation processes of binaries and of planets may be different, but still it shows that single objects are seldom and not the rule.

The following estimates thus will assume a probability close to one that some planets were formed together with any given star.

### 3. *Habitable planets*

Suppose a star has planets. What, then, is the probability that at least one of them is habitable, a planet where life and intelligence could develop? Su-Shu Huang estimated in 1959 [7] that about 5 per cent of all stars may have habitable planets, and similar estimates are given in Cameron's book *Interstellar Communication* [8]. The most detailed and careful estimates were done by Stephen H. Dole, filling a whole book called *Habitable Planets for Man* [9]. Here, I can only give a short summary.

Only under certain conditions can organic life develop. The average temperature must be within a limited range, somewhat above the freezing point of water and well below its boiling point, which means the planet must be neither too far nor too close to the star, within its so-called 'ecosphere' or life-zone. The temperature must also be fairly stable and should have only small daily and yearly fluctuations. The planet should have water and an atmosphere. Finally, the planet must be old enough, about 3000 million years or more.

What does all this mean in astronomical terms? The stellar surrounding does not matter much; only in the extremely dense and small central nucleus of some galaxies will stars come so close as to disturb each others planetary systems, but normally there is no intereference. Only the properties of star and planet matter.

First, the mass of the star must be between 0.72 and 1.43 solar masses, which holds for 25 per cent of all stars. Smaller stars are so faint that their ecosphere is so close that the tidal friction would remove the rotation of the planet, yielding extreme temperature fluctuations. And larger stars evolve too fast and cannot be old enough. Second, stars within this mass range may be old enough, but will actually be so with an average probability of about 60 per cent. See Fig. 2.

Third, in order to yield a stable planetary orbit, we must either have a single star, about 30 per cent of all stars; or, in case of a binary, the two components must be either very close together, less than $\frac{1}{3}$ the planet's orbit, or very far apart, more than 3 times the orbit, see Fig. 3. But the observed distances between binaries cover an extremely wide range, from $\frac{1}{100}$ the Earth's orbit up to 100 times this orbit; this is a range of four powers of ten, of which only one power of ten is excluded, leaving roughly 75 per cent of all orbits in the stable regions. Together with the single stars,

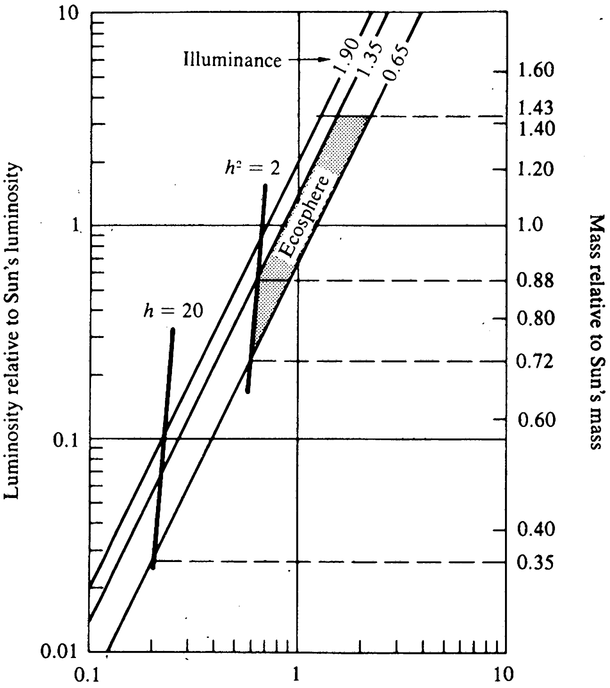

FIG. 2. The boundaries of ecospheres [Ref. 9].

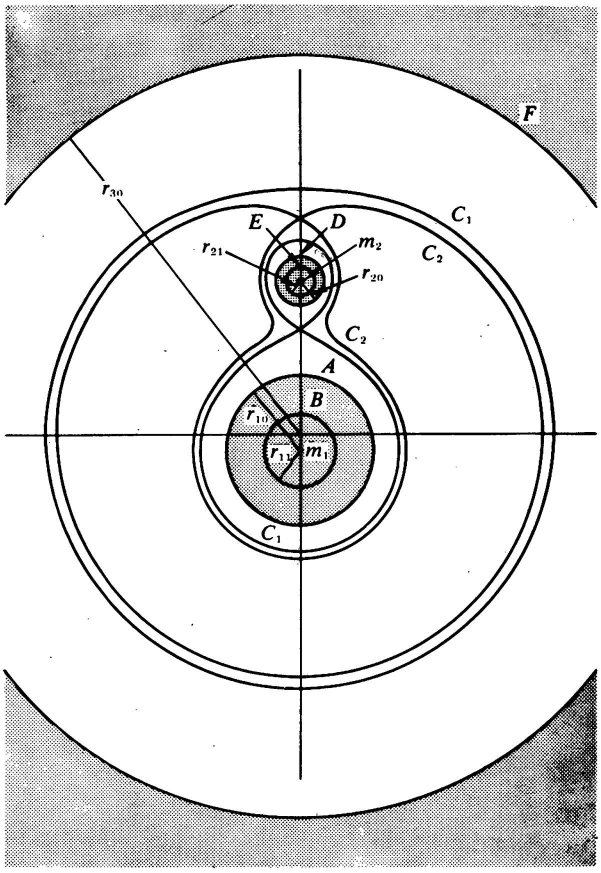

FIG. 3. Regions within which stable, direct, near-circular planetary orbits can exist, $\mu = m_2/(m_1 + m_2) = 0.1$ [Ref. 9].

we find that 82 per cent of all orbits are stable.

Fourth, in planetary systems similar to ours there is a chance of 35 per cent for a planet being within the star's ecosphere, giving the right average temperature. Fifth, we have 94 per cent chance for about-circular orbits, needed for constant temperature.

Sixth, the planet itself must be in the mass range between 0.4 and 2.4 Earth masses for having the proper type of atmosphere and water, which means about 20 per cent of all planets. Seventh, the planet must have enough rotation for constant temperature, about 90 per cent.

Table 1. *Fourteen Stars Most Likely To Have Habitable Planets, in Order of Distance from Earth* [*Ref.* 9].

| Star | Distance from Earth (light-years) | Probability ($P_{HP}$) | |
|---|---|---|---|
| Alpha Centauri A | 4.3 | 0.054 | 0.107 |
| Alpha Centauri B | 4.3 | 0.057 | |
| Epsilon Eridani | 10.8 | 0.033 | |
| Tau Ceti | 12.2 | 0.036 | |
| 70 Ophiuchi A | 17.3 | 0.057 | |
| Eta Cassiopeiae A | 18.0 | 0.057 | |
| Sigma Draconis | 18.2 | 0.036 | |
| 36 Ophiuchi A | 18.2 | 0.023 | 0.042 |
| 36 Ophiuchi B | 18.2 | 0.020 | |
| HR 7703 A | 18.6 | 0.020 | |
| Delta Pavonis | 19.2 | 0.057 | |
| 82 Eridani | 20.9 | 0.057 | |
| Beta Hydri | 21.3 | 0.037 | |
| HR 8832 | 21.4 | 0.011 | |
| | | $\Sigma = 0.55$; $P = 0.43$ | |

In summary, we find that about 1 per cent of all stars should have habitable planets. Our stellar system, the Galaxy, then has about 2000 million habitable planets, quite a large number. Table 1 shows 14 of the most likely candidates among our nearby stars, together with their individual probability of having a habitable planet. In total, there is a chance of 43 per cent that at least one of these 14 stars has a habitable planet.

## 4. *Distances*

The distance between neighboring stars is about $D_0 = 3$ light years. Selecting 1 per cent of all stars with habitable planets, our nearest such neighbors then are expected at a distance of $D_h = D_0(0.01)^{-\frac{1}{3}} = 15$ light-years. Interstellar distances, of several light-years, can certainly be bridged by signals, even with the means of our own present technology, although the waiting time for an answer then would be 30 years in our case. But interstellar space travel, although feasible according to F. Dyson [17], would take about 1000 years and does not look very promising [8, 16, 22].

However, even if life and intelligence would develop on each habitable planet, we should not assume to find always a technical civilization like ours, where science and technology play a dominant and crucial role and attract a good deal of individual genius and of public big money. Other ways of development may bypass this state of technical dominance; and even if it would always be attained, we should never assume that it lasts forever. There will come a change of interest, whereafter technology is just used to keep things going, but the main effort goes somewhere else. Furthermore, technology has its great dangers, to be discussed later.

In any case, we should assume a finite longevity $L$ for the technical state of mind. If intelligence began $T$ years ago at the oldest stars, then roughly speaking the distance to the nearest technical civilizations is $D_t = D_h(T/L)^{\frac{1}{3}}$. For example, estimating $T = 5000$ million years and assuming $L = 100{,}000$ years, we obtain a distance of $D_t = 500$ light-years. This is still feasible for communication, but the waiting time for answers is 1000 years which means that civilizations talk to each other and not individuals. Our Galaxy then would contain about 40,000 technical civilizations.

Of course, these numbers are very uncertain since a longevity of 100,000 years was just a free guess (without even having $n = 1$ for an estimator). But the uncertainty enters only with the power $\frac{1}{3}$, and $L$ must be wrong by a factor 1000 before $D$ gets wrong by 10.

Most probably, half of all civilizations are more advanced than we are, and probably they have established communication networks already long ago. But just in case that we are among the first ones who want to establish contact, we can give a fairly accurate estimate regarding the distance to be covered and the minimum duration needed for a trial to have success. If, on the fraction $q$ of all habitable planets, a civilization emits strong signals (and listens, too) during a trial of duration $t$, then the distance between simultaneously trying ones is $D_s = D_h(T/qt)^{\frac{1}{3}}$, while success means receiving an answer which takes a minimum waiting time $t = 2D_s/c$. Both equations together then yield $D_s = D_h^{\frac{3}{4}}(cT/2q)^{\frac{1}{4}}$, see [22]. Here, our ignorance enters only with the power $\frac{1}{4}$. Assuming $q = 0.1$, for example, yields a distance of 3000 light-years, and a minimum duration for this trial of 6000 years. The nice thing is that this same estimate can be made by anybody else in the Galaxy as well, with the same result.

## 2. Astronomical Observations

1. *Organic molecules*

Interstellar space, the space inbetween the stars, is almost empty but not quite. It contains gas, of the same chemical composition as our Sun and all stars, in the forms of atoms and molecules. The first optical absorption spectra of interstellar molecules were found in 1937; these were simple diatomic molecules, with two atoms only. Radio astronomers found in 1963 the spectral lines of hydroxyl, OH, at 18 cm wavelength. This again is diatomic, and actually nothing more complicated was expected.

A breakthrough came in 1968 and 1969 with the discovery of the lines of water (3 atoms) and ammonia (4 atoms) at about $1\frac{1}{2}$ cm wavelength. Since then, over two dozens of more and more complicated molecules were observed, up to 7 atoms at present. And many of these are what we call 'organic' molecules, like for example formaldehyde, methyl alcohol, or methyl-acetylene, see Table 2. The wavelengths are mostly in the range of very short radio waves, of some millimeters to centimeters. As to the origin of these molecules, it seems most likely that they are formed on the surface of dust grains and then released.

Another source of information are meteorites. Here, it is very difficult to distinguish between the original contents, and contaminations which may come from the atmosphere, the soil, or from human hands. But in several cases it seems to be certain that some small traces of organic matter were originally contained in the meteorite. Most interesting was the discovery of several amino acids, the building blocks of organic life [11].

What are the implications for CETI? We certainly do not think that these 'organic' molecules are the left-overs from organic life. But they show that rather complicated molecules can be formed even in the almost empty interstellar space. Which then should be a lot easier in the dense atmospheres of planets, thus making the origin of life less difficult and less improbable.

2. *Regular astronomical observations*

Whenever we use our large optical or radio telescopes for some regular astronomical observations, we should always look out for anything suspicious which might be some sign of life. Some activities of advanced civilizations may be observable, activities which may have nothing to do with communication [15].

Several astronomical discoveries looked quite suspicious for a while, but then found 'natural' explanations. For example: the sudden outburst of a new brilliant star, a so-called nova; or the fact that

Table 2. *Molecules Found in the Interstellar Medium* [9].

| Year | Molecule | Symbol | Wavelength | Telescope | Reference |
|---|---|---|---|---|---|
| 1937 | | $CH$ | 4300 Å | Mt Wilson 100 in | Dunham |
| 1940 | Cyanogen | $CN$ | 3875 Å | Mt Wilson 100 in. | Adams |
| 1941 | | $CH^+$ | 3745–4233 Å | Mt Wilson 100 in. | Adams |
| 1963 | Hydroxyl | $OH$ | 18, 6.3, 5.0, and 2.2 cm | Lincoln Lab 84 ft. | Weinreb *et al.*, 1963 |
| 1968 | Ammonia | $NH_3$ | 1.3 cm | Hat Creek 20 ft | Cheung *et al.*, 1968 |
| 1968 | Water | $H_2O$ | 1.4 cm | Hat Creek 20 ft | Cheung *et al.*, 1969 |
| 1969 | Formaldehyde | $H_2CO$ | 6.2, 2.1, 1 cm<br>2.1, 2.0 mm | NRAO 140 ft | Snyder *et al.*, 1969 |
| 1970 | Carbon Monoxide | $CO$ | 2.6 mm | NRAO 36 ft | Wilson *et al.*, 1970 |
| 1970 | Cyanogen | $CN$ | 2.6 mm | NRAO 36 ft | Jefferts *et al.*, 1970 |
| 1970 | Hydrogen | $H_2$ | 1100 Å | UV Rocket Camera | Carruthers, 1970 |
| 1970 | Hydrogen Cyanide | $HCN$ | 3.4 mm | NRAO 36 ft | Snyder and Buhl, 1971 |
| 1970 | X-ogen | ? | 3.4 mm | NRAO 36 ft | Buhl and Snyder, 1970 |
| 1970 | Cyano-acetylene | $HC_3N$ | 3.3 cm | NRAO 140 ft | Turner, 1970 |
| 1970 | Methyl Alcohol | $CH_3OH$ | 36 cm | NRAO 140 ft | Ball *et al.*, 1970 |
| 1970 | Formic Acid | $CHOOH$ | 18 cm | NRAO 140 ft | Zuckerman *et al.*, 1971 |
| 1971 | Carbon Mono-Sulphide | $CS$ | 2.0 mm | NRAO 36 ft | Bell Labs |
| 1971 | Formamide | $NH_2CHO$ | 6.5 cm | NRAO 140 ft | U. of Illinois |
| 1971 | Silicon Oxide | $SiO$ | 2.3 mm | NRAO 36 ft | Bell Labs |
| 1971 | Carbonyl Sulphide | $OCS$ | 2.5 mm | NRAO 36 ft | Bell Labs |
| 1971 | Acetonitrile | $CH_3CN$ | 2.7 mm | NRAO 36 ft | Bell Labs |
| 1971 | Isocyanic Acid | $HNCO$ | 3.4 mm<br>1.4 cm | NRAO 36 ft | U Va/NRAO |
| 1971 | Hydrogen Iso-Cyanide | $HNC$ | 3.3 mm | NRAO 36 ft | U Va/NRAO |
| 1971 | Methyl-acetylene | $CH_3C_2H$ | 3.5 mm | NRAO 36 ft | U Va/NRAO |
| 1971 | Acetaldehyde | $CH_3CHO$ | 28 cm | NRAO 140 ft | Harvard |
| 1971 | Thioformaldehyde | $H_2CS$ | 9.5 cm | Parkes 210 ft | CSIRO Australia |

some radio source seemed to have regular variations, like the quasar CTA 102; or the discovery of the pulsars which emit radio pulses with extremely high regularity, but which are explained as rotating neutron stars.

Kardashev [13] introduced the idea of three types of higher advanced civilizations, regarding their energy consumption. A type 1 civilization uses all energy sources available on their planet (where the rate of consumption then is limited by thermal considerations), a state which we will have reached in a few decades. Type 2 civilizations have learned to harness the energy production of their star, and type 3 may use the energy produced by all stars in their whole galaxy. Although we do not know what to look for, something of all this activity should be observable for us.

Freeman Dyson [14, 15] made an interesting suggestion. He says a type 2 civilization would like to consume the maximum amount of energy, populate the largest possible area, and use for these aims whatever matter is available. In our case, for example, this would mean to take the largest (and otherwise rather useless) planet Jupiter apart, and to build from its matter around the Sun a spherical shell somewhat larger than the Earth's orbit. The energy produced by the Sun and consumed by the population must finally be radiated away at the outside of the sphere, at a temperature of about 300°K, which means at a spectral maximum of about 10 μm wavelength. Thus, Dyson suggests looking out for 'infrared stars' as possible seats of advanced civilizations. But again: the dozen or so of infrared stars which have actually been observed have found a natural explanation; they seem to be an early state during the formation of a new star. So far, we really have no observational evidence for life somewhere else.

## 3. Where is Everybody?

1. *The question*

If we are average, and if half of all habitable planets carry a higher advanced civilization, using the energy production of a whole star, then we should expect to see some sign of all this. Energy cannot be 'used up', it can only be converted from a higher form into a lower one, and finally into heat; the energy thus may be observable for us even after it has been used. Furthermore, activities on a stellar or even galactic scale are certainly possible, they do not violate any laws of physics; they just need determination and time. Finally, as Dyson argues, whatever can be done (within the laws of physics, given enough mass and energy) actually will be done, somewhere and sometimes (given enough space and time). This I would like to call the 'ergodic principle' of civilizations; it has a strong convincing power.

Why, then, do we not see any sign of life, not with our largest telescopes, not among the millions of stars and of galaxies which we observe? This indeed is a very serious question.

2. *Some possible answers.*

Now, it could be that the 'Zoo Hypothesis' of John Ball is right [in press], where we are set aside in a wilderness area or a perfect zoo, that is, a zoo in which the animals do not know it and do not see their waiters. Or it could well be that we actually do see a lot of activity but don't recognize it as such because it is beyond our 'mental horizon'. But I think that the most probable explanations are the following, single or in combination.

First, the *rarity of life* (and/or intelligence). As I said already, expecting plenty of advanced civilizations has the highest probability of being right, but we have no idea how wrong it may be. Somehow we feel that we should never expect to be something special, but maybe we are. On the other side, similar ideas in our past have always turned out to be wrong: China was not the center of the Earth, the Earth not the center of the universe, and barbarians did not just babble but had a language of their own.

Second, a *change of interest,* as I suggested when we discussed distances. Maybe the change comes not after 100,000 years but much sooner, before the ability for interstellar activities has been developed. This could well be, I would think.

Third, a need for *stabilization.* It seems that our type of technical intelligence leads of necessity into several severe crises which I will discuss briefly in the next section. If this is true, then the surviving civilizations must have developed very efficient means of stabilization against all possible crises and accidents. Also, they must have shifted the emphasis more and more from emotion to reason; and most motivations for interstellar activities are more on the emotional side, like conquest of space, being the first one, the challenge of the difficult, and so on. It could well be that any surviving civilization is, of necessity, so much stabilized and sober that no desire for any great enterprise is left or allowed.

Our question is 'Why don't we see any sign of life, no interstellar activity?' And I mentioned three possible reasons: rarity of life, change of interest, and need for stabilization. All three could be combined, of course, and for my personal feeling it is a combination of the latter two which is probably right: a stabilization on the technical side, combined with a change of interest to other (now unpredictable) activities, and both most probably triggered or even enforced by a series of crises. Therefore, I should also give here a brief summary of some crises [22].

3. *Crises of development*

I will mention four crises: population explosion and self-destruction, the two crises we just have entered; then biological degeneration, which must come later; and finally stagnation which may come eventually

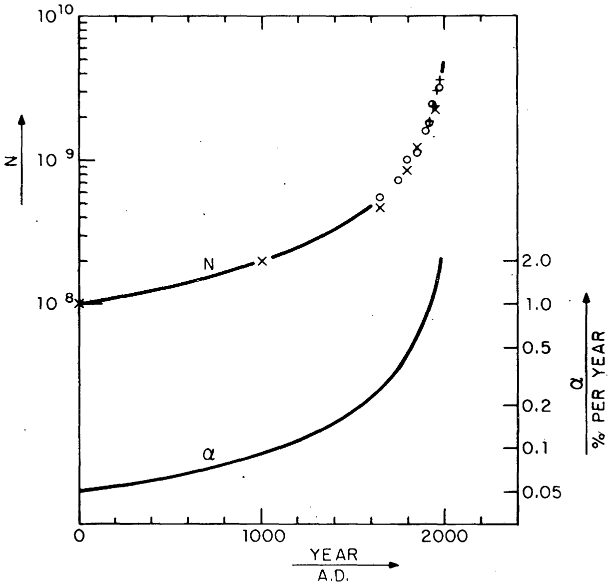

FIG. 4. World population $N$, and its growth rate $\alpha$ [Ref. 22].

The *population crisis* is much more serious than most of us think. Even our voices of warning and alarm [21] talk always of 'exponential growth' and its dangers, whereas in reality the growth is much steeper. Figure 4 shows the population of the Earth, of the last 2000 years, plotted over time, both in logarithmic scale. Exponential growth then would mean a straight line for $N(t)$, and a constant growth rate $\alpha$. Both is clearly not the case. Actually, $\alpha$ increased in proportion with $N$; but if that is so, then the number goes as $N(t) = \text{const}/(t_\infty - t)$, which means the population goes to infinity after a finite time. This formula is checked in Fig. 5, where the fit is alarmingly good, without the slightest indication yet of any turnover or stabilization. We find: the best-fitting curve for the past 2000 years extrapolated into the

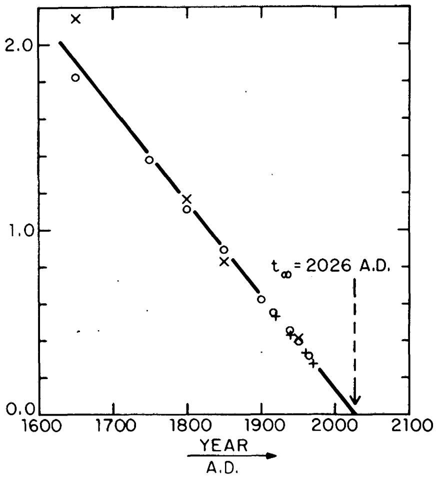

FIG. 5. Same data as Fig. 2 (last 300 years), but $1/N$ plotted over $t$. The straight line represents $N \sim 1(t_\infty - t)$. Up to 1970, there is no indication of any beginning saturation [Ref. 22].

future, predicts an infinite number of people after only 54 years. Some drastic change must be achieved by us with great effort, or it will happen to us with great suffering. And that is not all. Population control needs a government regimentation; because, if left to the understanding and reason of the individual, a voluntary control leads to the genetic self-elimination of reason [19].

The second crises we just have entered is *self-destruction.* The big nations on Earth spend 10 per cent of their gross national product on the arms race. At present all our nuclear bombs have a destructive power of 10 tons of TNT per person; which is equivalent to a round ball of dynamite, 7 ft or 2 m in diameter, one such ball for everyone on Earth, grandmothers, babies and all. Or, 10 tons of TNT have the energy to lift a whole apartment house (10,000 tons, say) to a height of 500 m, and let it fall down on you, again, one such house for each person. This illustrates the kind of powder keg on which we sit.

And this type of peace we have, the so-called balance of power, is stable only under some conditions but not under others; there is a very educational computer study about this question [20]. Weapon systems get obsolete every, say, seven years or so, and the new situation may be unstable; or even on the way to a stable next situation, there might be an unstable transition region where war becomes likely. Thus, even if every single transition has only a small chance of yielding war, the probabilities accumulate, and after several transitions war becomes more probable than peace. For example, if we estimate that the single transition has a 10 per cent chance for war, then war becomes more likely than peace after 46 years.

Another note of warning. Many people think that 'egoism plus intelligence' is all we need; but that is completely wrong, because *my* egoism unfolds best if everybody else sticks to a moral code except me.

*Genetic degeneration* must become a serious problem, after some thousand years or so. When a species develops intelligence and medicine, then not only the fittest can survive but almost everybody else. This means that the frequency of hereditary diseases will increase. Medicine diminishes contagious diseases but increases hereditary ones.

Second, medicine eliminates natural selection to a high degree, while mutations still go on, almost all mutations being bad ones. This means that our genetic stock goes down in value. Both things mean that after a while we must introduce artificial or at least guided breeding.

Third, who or what is going to decide which kind of breed is desirable, which of the present human types is 'not to be continued', which personal traits and desires are to be eliminated? Wrong decisions may lead to irreversible mistakes.

Finally, if the survival of the race would get an absolute priority, this could lead to an absolute *stagnation*, so-to-say the 'crisis to end all crises' [22]. After a while, most material progress becomes impossible; as for example with regard to the population number, to energy consumption, and to exploitation of natural resources and to pollution; all these things must find a saturation or stagnation. But in the very long run, each kind of progress has some element of danger, and if survival is all that matters, then stagnation is maybe the answer. Together with artificial or guided breeding, this could even lead to irreversible stagnation.

## 4. *The role of communication*

It could well be that interstellar communication plays the most crucial role in the development of civilizations. Just like speech and writing are crucial factors in the development of the individual. Furthermore, interstellar communication gives all the advantages of competition (it counteracts stagnation), but without the dangers of competition: we may beat, but cannot kill, each other. Finally, survival of the race loses some of its priority, since survival of the culture and spirit is now what matters. Interstellar expansion, then, would be mental, not physical. Maybe this is why we have not seen it yet?

The history of a civilization, then, might look as follows. First comes the great upheaval, the highly competitive and exciting but rather hectic development which we are in, and which leads into crises and catastrophes if left unbridled. Many civilizations may terminate here. For the survivors comes a transition and decision period where interstellar communication may or may not be taken up. If not, stagnation will follow. If yes, the own planetary culture merges into a much more advanced interstellar one of galactic dimension.

Question: if a civilization tries to avoid crises and catastrophies, and by doing so approaches the temptation of eternal life via irreversible stagnation, is there enough time in between to establish interstellar contact? This needs already some stability, just enough to perform a project lasting some thousand years, but it still needs a good deal of enthusiasm and of zest for progress, just enough to get it started.

We do not know the answer, but let us give it a try. And let me finish with Frank Drake's famous question: 'Is there intelligent life on Earth?'

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**Résumé—Aspects astrominaux de communications interstellaires.**

*Planètes habitables.*

Les planètes des autres étoiles sont trop faibles et trop proches de leur étoile pour toute observation directe. Selon les théories modernes, les planètes sont formées avec les étoiles, étant la règle et non l'exception. Neuf conditions nécessaires à la vie résultent en 1% environ de toutes les étoiles ayant une planète capable de développer une vie plus élevée. Notre galaxie contient donc environ 2000 millions de planètes habitables. Les plus proches sont à 15 années lumière, trop loin pour être atteintes mais suffisamment proches pour communication.

Si la vie et l'intelligence se forment sur chaque planète habitable, en traversant une fois une période technologique limitée à 100.000 ans, notre galaxie contient 40.000 civilisations technologiques avec 500 années lumière entre voisins. Les communications demeurent possibles.

*Observations astronomiques.*

Des molécules organiques ont été observées dans l'espace interstellaire, ce qui rend l'origine de vie moins improbable. Pendant toutes les observations "normales" il faut surveiller tout signe de vie. Jusqu'à présent, tous les objets suspects ont été éventuellement expliqués par causes naturelles.

Les civilisations technologiques avancées pourraient utiliser toute l'énergie de leur étoile, et les déchets d'énergie devraient être observables autour d'une longueur d'onde de 10 microns. Des étoiles infra-rouges ont été observées mais là encore il existe une explication par cause naturelle.

*Où est tout le monde?*

Les civilisations technologiques très avancées pourraient faire beaucoup de choses visibles aux astronomes. Pourquoi alors n'est-il rien vu? Quatre possibilités sont discutées: (a) La vie et l'intelligence sont très rares. (b) La technologie n'est intéressante que pendant une courte période, d'autres activités devenant plus importantes. (c) La science et la technologie sont la cause de crises sérieuses (explosion de population, auto-destruction, dégénération génétique). Il est possible que toute civilisation survivante a développé une grande régimentation et une grande stabilisation et la possibilité d'une stagnation irréversible. (d) Il est possible que de nombreux signes de vie existent mais que nous n'avons pas regardé ou pas compris.

## Резюме—Астрономические аспекты коммуникаций в межзвездном пространстве.

*Годные для жилья планеты*

Планеты других звезд очень слабо видны, и находятся слишком близко к своим звездам для непосредственного наблюдения. Согласно современным теориям, планеты образуются вместе со звездой — это является правилом, а не исключением. Девять условий требующихся для жизни ведут к тому, что один процент всех звездных планет в состоянии развить высшую форму жизни. Поэтому, наша Галактика, вероятно, содержит около 2000 млн. годных для жилья планет. Самые близкие находятся на расстоянии 15 световых лет — слишком далеко для поездки, но достаточно близко для коммуникации.

Если жизнь и интеллект действительно возникили на каждой годной для жизни планете, и, скажем, прошли через период технологического развития в пределах 1000000 лет, то наша Галактика содержит 40000 технологических цивилизаций с промежутками 500 световых лет между соседями. Коммуникация все таки возможна.

*Астрономические наблюдения*

В межзвездном пространстве заметили органические молекулы, что делает возникновение жизни менее невероятным. Во время всех «нормальных» наблюдений необходимо замечать малейшие намеки на жизнь. Но до сих пор все подозрительные объекты были позднее объяснены естественными явлениями.

Передовые технологические цивилизации возможно используют всю энергию своей звезды, а отходы их энергии можно, вероятно, исследовать на примерно 10-микронной длине волны. Замечались инфракрасные звезды, но они также были объяснены естественными причинами.

*Где все?*

Технологически высокопрогрессивные цивилизации могут проводить много действий, видимых астрономам. Почему же ничего не видно? Обсуждаются четыре возможности. (а) Жизнь и интеллект встречаются чрезвычайно редко. (б) Существование технологии очень коротковременное, позднее она замещается другой деятельностью. (в) Наука и технология являются причиной серьезных кризисов (перенаселение, самоуничтожение и генетическое вырождение). Может быть все выжившие цивилизации развили палочную дисциплину и стаблизацию, а может быть безвозвратный застой. (г) Может быть *имеется* много признаков жизни, которые мы не замечаем или не понимаем.