ON THE INEVITABILITY AND THE POSSIBLE STRUCTURES OF SUPERCIVILIZATIONS

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ABSTRACT. Since civilizations face always problems that require continuously greater activity, it is likely that supercivilizations will undertake activities and construct structures of a very large scale. Properties and means of detections of such superstructures and activities are discussed. We also examine six possible scenarios on the evolution of civilizations.

1. WHAT ARE WE SEARCHING FOR?

At present the most important aspect of the problem of searching for extraterrestrial civilizations seems to be the need for a logically consistent agreement on what is it that we are searching for. Unfortunately, such an agreement has not yet been reached. Most experimental searches for extraterrestrial civilizations proceed from a position of "Terrestrial Chauvinism". Thus, in spite of criticism that the probability of finding a civilization at our level of development and - moreover - among the nearest stars is in fact close to zero, the search for Earth-type civilizations is continuing. The solution of the problem has not and will not be advanced until the initial concepts and therefore the search strategies are changed. This is where the situation stands today. No long-term search program has yet been started, and no attempts to search for signals can be regarded as substantial. Extraterrestrial civilizations have not yet been found, because in effect they have not yet been searched for.

Obviously the state-of-the-art of the problem is the result of the extreme difficulty we have in predicting the development of civilizations over astronomical spans of time. All predictions of this kind seem like science fiction very far from reality. Specific calculations seem possible only for civilizations at a technological stage similar to ours.

Nevertheless it is necessary to develop some imaginative models for supercivilizations by starting from the present scientific and technological level and keeping in mind the well-known laws of Nature, which have been reliably verified by astronomical observations over

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tremendous expanses of space and time. Probably more fundamental laws of Nature are to be discovered in the future, but they will not abolish the laws we already know.

Let us now consider two assumptions, which in our opinion must be made in order to build plausible models for supercivilizations:

I. The scales of activity of any civilization are restricted only by natural and scientific factors. This assertion implies that all processes observed in Nature (from phenomena in the microcosmos to those in the macrocosmos and all the way to the whole Universe) may in time be utilized by civilizations, be reproduced or even somewhat changed, though of course always in accordance with the laws of Nature.

II. Civilizations have no inner, inherent limitations on the scales of their activities. This implies that presumptions of a possible self-destruction of a civilization, or of a certain restrictions on the level of its development are not factual. Actually social conflicts may in fact be resolved, while civilizations will always face problems that demand larger scales of activity. It is this approach to the problem that seems most consistent with our current concepts.

To prove the above two assumptions, some method similar to that of mathematical induction could be used. Let a certain activity in which a civilization is involved be described by the parameters, M = the mass of constructions, P = the power consumed, I = the information volume which describes the program activity and memory, and so on. Then, whatever the degree of specification, recommendations may be given on how to organize an activity with parameters 2M, 2P, 2I, etc. The point is that the physical parameters of the objects observed in the Universe may assume values that span a tremendously large range.

The main consequence of the assumptions made for the search for extraterrestrial civilizations, is the assertion that among the astronomical objects observed there should be some that are characteristic of intelligent activity. Most probably, these objects would have a very large mass, a large energy potential and a high information volume. They also would tend to exist over cosmological spans of time, i.e., billions of years, and be compact enough for a rapid exchanged of information among them.

2. TECHNOLOGICAL STRUCTURES OF ASTRONOMICAL DIMENSIONS

Obviously one of the basic forms of matter in which a civilization may exist is the solid state, which is the optimal state for a high degree of organization. This state, however, has been very poorly studied in the Universe. Astronomers engaged in studying physical processes are most frequently dealing with plasmas. One may guess that, in fact, all possible states of matter may be put to use with the active intervention of intelligence. A direct proof for the artificial origin of an object would be the discovery of immensely huge solid-state structures.

A great number of such major cosmic projects have been discussed in references (1) to (9). F. Dyson, for instance, has shown that it is possible to build astroengineering structures (Dyson Spheres) several AU in size, using as building material the matter of the planets (3). The

possibility of an artificial explosion of a star has also been discussed. Possible ways for changing the orbit of the Sun or of other stars in our Galaxy could be suggested, as well as the use of star collisions to gain mass and energy (3). I think astronomers may find many ways of doing such projects, because there are many similar processes in Nature. Giant molecular clouds (with masses of millions of solar masses) constitute also a great potential for astroengineering. The restructuring of entire galaxies may open up even greater opportunities.

As an example we will consider now a possible, but very large structure. The assumption is made that a civilization has at its disposal a power L and solid matter with mass M. A rigid structure of astronomical scale, which will include all the instrumentation and facilities required and which will be resistant against the gravitational force, may be made in the form of a disk spinning with a constant angular velocity Ω, which corresponds to the motion of particles along circular orbits due to the body's own gravity (Figure 1). If we assume that the disk has a constant density ρ, then in order to maintain a constant angular velocity Ω, the thickness of the disk must be $h = h_o(1-r^2/R^2)^{1/2}$ where h_o is the thickness of the disk at the center, r is a given radius, and R is the radius to the outer edge of the disk. From this it follows that the total mass M of the disk is,

$$M = 2\pi R^2 h_o \rho/3 \qquad (1)$$

Let us now suppose that the surface of the disk converts a power L into thermal radiation at a temperature T. We then have,

$$L = 2\pi R^2 \sigma T^4 \qquad (2)$$

where $\sigma = 5.67 \cdot 10^{-5}$ is the Stefan-Boltzmann constant. By combining (1) and (2) we obtain, $R = (L/2\pi\sigma T^4)^{1/2}$, and $h_o = 3M\sigma T^4/\rho L$. Using now values for L and M that are appropriate for supercivilizations controlling an entire galaxy, namely, $L = 10^{12} L_\odot$, $M = 10^{12} M_\odot$, T = 300 K, and ρ = 8 g/cm^3, we get R = 12 pc, h_o = 860 m, and a disk rotation period of $P = 4R^{3/2}(\pi/3GM)^{1/2} \sim 2{,}600$ years.

The thermal radiation emitted by such a disk should have its maximum near λ = 20 μm. At a distance therefore D = 10^3 Mpc, its flux would be $F_\nu = 2\pi kTR^2/\lambda^2 D^2$ = 1 Jansky. This example is a good illustration of situations that we may face in our search program. If a thorough analysis of such structures were to be carried out, several possible approaches to their construction may be outlined, since similar in terms of mass and power formations may develop in Nature.

3. ASTRONOMICAL OBJECTS AND SEARCH PROCEDURES

What astronomical objects could then be regarded as potential candidates for dwellings of supercivilizations? Obvious possibilities are the vicinities of galactic nuclei and quasars. It is also possible that infrared investigations may discover some yet-unknown objects of very

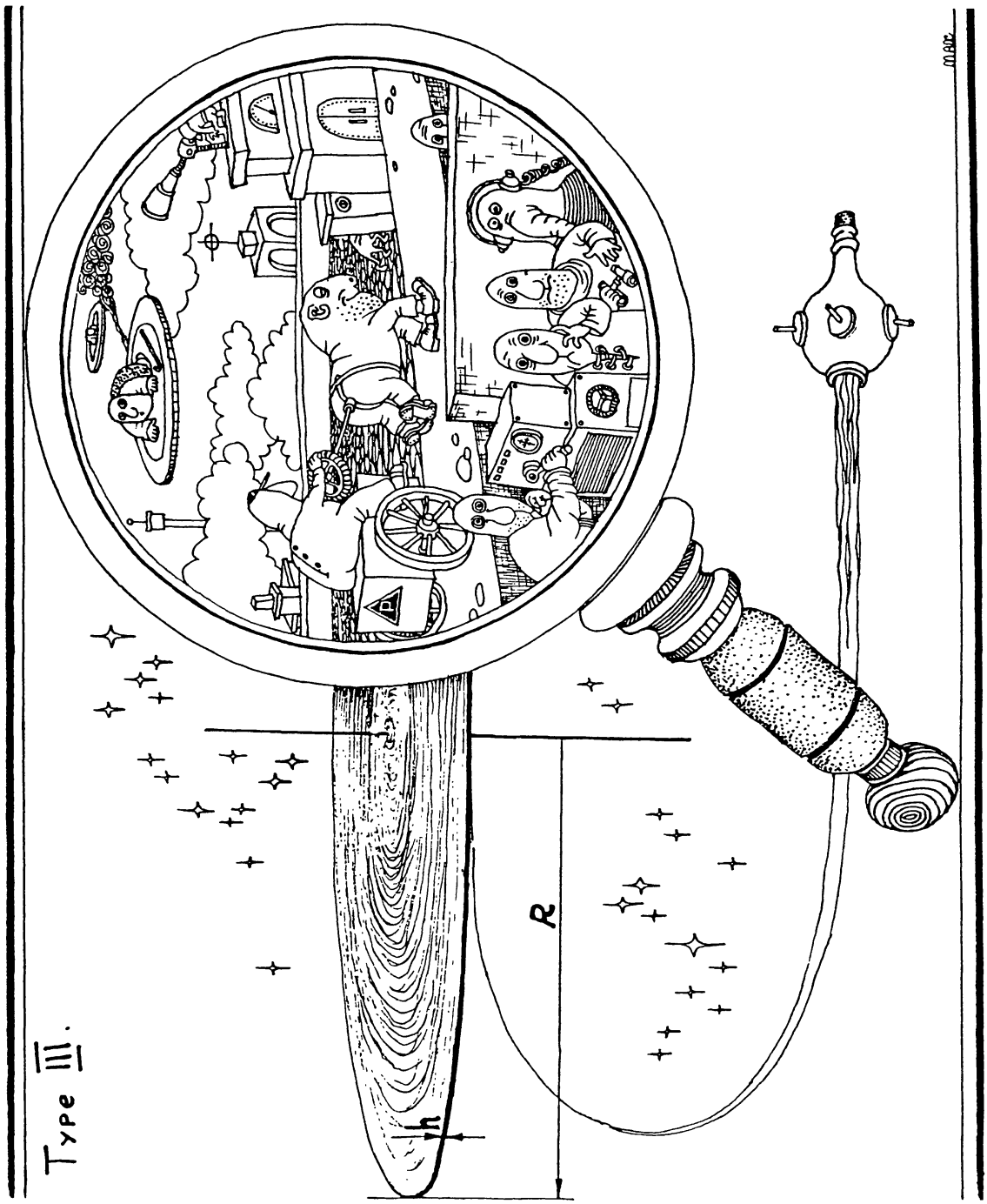

FIGURE 1. A general view of a Type III Supercivilization (cartoon by I. Maximov).

large power and mass. From the viewpoint of evolution, the first supercivilizations and the first quasars could have originated almost simultaneously - in the first billion years of the expansion of the Universe. Some types of objects related to civilizations may be identified among galactic nuclei and quasars. This type of objects should be characterized by intense infrared radiation with an almost thermal spectrum from astroengineering structures. The temperature of that radiation may vary from 3 to 1000 K, depending on the particular model of technological activity associated with the use of solid-state structures. Hence we should search for radiation from such structures in the wavelength range from a few microns to a few millimeters.

In some cases an anomalously strong infrared radiation has already been recorded from extragalactic objects. This radiation is obviously caused by interstellar dust particles. The main difference between the radiation from large structures and from dust particles is due to the fact that the former are much larger while the latter are much smaller than the wavelength. Consequently, the long wavelength portion of the dust spectrum would show a much steeper dependence on the wavelength as compared to the spectrum of large-size bodies ($\sim\lambda^{-2}$). Large structures may also be identified by their screening or reflection effects on radiation. Radio interferometry observations, which provide the highest possible angular resolution for astronomical studies, may also permit the identification of such structures from to their unusual configurations.

Another important aspect in developing a strategy for the search for civilizations is the problem of special-purpose radio transmissions. For an isotropically emitting transmitter the optimal wavelength is about 21 cm, but it is near 1.5 mm for a strongly collimated beam (8). It is assumed that a supercivilization and its related objects do not produce any radio interference in the same range that would limit transmission capabilities. Under the assumption of highly developed supercivilizations we may expect a collimated toward the Solar System or our Galaxy information-bearing radiation.

It is conceivable that our civilization has been discovered since long ago by the telescopes of supercivilizations which could be analogous to their very-large-size structures. If a present-day telescope 1 m in diameter on a 300 km-orbit can photograph the landscape of the Earth with a resolution of only a fraction of a meter, in order to get similar results from a distance of 10 kpc (say from near the center of the Galaxy) one would need a reflector 0.1 light years in diameter. The problem of making such reflectors is undoubtedly even farther from being solved than the problem of the existence of supercivilizations. However if science and technology in such a supercivilization are assumed to be highly developed, it is to be expected that Cosmic Ethnography, a new branch of science, would be well developed. Planetary systems, primitive forms of life, and civilizations, may first be remotely sensed with large telescopes.

More thorough studies, however, would required sending dedicated probes. Search for such probes in our Solar System is also one of the SETI alternatives. Here the already known problems will be further enhanced by ethical and legal matters up to and after the contact. For

instance sending a probe with an active program may be regarded inadmissible. This may be one of the explanations why the Earth (10) has never been colonized.

4. POSSIBLE SCENARIOS ON THE EVOLUTION OF CIVILIZATIONS

Two factors may be regarded as fundamental in the evolution of civilizations, the natural evolution and the evolution due to contacts with other civilizations.

Various models of one- and two-sided contacts are possible. In our view, most probable are the models which would best promote the progress of science, technology, and culture for the two sides in contact. In this approach, the process of unifying civilizations and concentrating them in a small number of compact regions in the Universe is a basic factor in their evolution. We shall call this assumption the "Urbanization Hypothesis" of the Universe.

In Table I that follows, we present six scenarios on the evolution of civilizations, which deserve a more detailed treatment. The third column in this Table is the author's subjective estimate of the probability of the implementation of these scenarios.

In closing, we will present a subjective estimate of the Confidence Level of the arguments given here. It is most probable that cosmic supercivilizations may be discovered near the most powerful and compact astronomical objects, but search procedures must also be revised, placing more emphasis on the detection of large-size solid structures. To this end, a class of specific objects should be identified to be studied more thoroughly. For these objects it is necessary to consider again the problem of the optimal range for information transmission, taking into account their continuum emission spectrum of natural origin, the directivity or isotropy of a transmitter, and other specific features.

It is obvious that these scenarios should be regarded merely as tools that may help in solving the problem of the search. Each of the scenarios may actually exist, but it should be verified by some specific experiment.

TABLE I

Possible Scenarios for the Evolution of ETI

No.	Evolution Scenario & Level of Urbanization.	Subjective Probability.	Objects for Study and Search Procedures.	Scenarios for the Evolution of our Civilization after Contact.
I.	Intensive unification of civilizations at a scale of 1 to 10 billion light years, with concentration into one compact object.	60%	Most powerful quasars and galaxies. Search for new extraterrestrial objects with the radiation power>10^{45} erg/s in the range 10μ - 1 cm, and in other spectral regions as well. Search for astroengineering structures. Search for beamed signals at 1.5 mm and for omnidirectional at 21 cm*.	Sharp increase in the growth rates in all areas. Large-scale social economic and cultural changes in preparation to join the higher civilization. Establishment of an ethnographic conservation Center on Earth.
II.	Unification at a scale of large clusters of galaxies.	20%	Investigations of the nucleus of the Virgo cluster (galaxy M87?) and of other large clusters. The same procedures as in I*.	Same as in I.
III.	Unification at a scale of large galaxies.	10%	Investigations of the nucleus of our Galaxy and the nuclei of the nearest big galaxies (M31, M33, etc.). Same procedures as in I*.	Same as in I.
IV.	Complete colonization of space.	0%	"They" should have been on Earth, but there is no evidence for it.	Same as in I.
V.	Self destruction of planetary civilizations before contact.	10%	Artifacts of late civilizations may be found in the vicinity of the nearest stars.	No development by definition.

VI.	We are the first and we are still alone.	0%	Proceed with studies in exobiology. There are data which seem to exclude this scenario: First micro-organism formed at least 3.5 billion years ago, i.e., immediately after large masses of meteorites stopped falling on Earth.	Possible contacts some time in the future. Evolution then may follow any of the above 5 scenarios.

REFERENCES

1. Dyson, F.J., Search for Artificial Stellar Sources of Infrared Radiation, in Interstellar Communication (A.G.W. Cameron ed.), W.A. Benjamin, New York, 1963, pp. 111-114; Science, 1960, **131**, 1667-8.
2. Dyson, F.J., Gravitational Machines, in Interstellar Communication (A.G.W. Cameron, ed.), W.A. Benjamin, New York, 1963, pp. 115-120.
3. Dyson, F.J., The search for extraterrestrial technology. Prospects of Modern Physics, (Marshak R.E., ed.), Wiley, New York, 1966, **N.4**, 641-655).
4. Astroengineering Activity: The Possibility of ETI in Present Astrophysical Phenomena. Discussion in: Communication with Extraterrestrial Intelligence, (Sagan, C, ed.), MIT Press, Cambridge, MA, 1973, 188-229,371-389.
5. Sagan, C., Walver R.G. The Infrared Detectability of Dyson Civilizations, Ap.J., 1966, **144**, N 3, 1216-1218.
6. Kardashev, N.S., Transmission of Information by Extraterrestrial Civilizations. Astronomicheskii Zh., **41**, 282, 1964. (English translation in Soviet Astronomy, **8**, 217.).
7. Kardashev, N.S., Acta Astronautica, 1979, **6**,33-46.
8. Kardashev, N.S., Optimal wavelength region for communication with extraterrestrial intelligence: λ = 1.5 mm, Nature, 1979, **278**, 28-30.
9. O'Neill, G., Space Colonization and SETI - Cosmic Search, 1979, **1**, 16-24 (interview by J. Kraus).
10. Ball, J.A., The Zoo Hypothesis, Icarus, 1973, **19**, N3, 347-349.