денным выше: $\Lambda_h = 128\pi^2\hbar^6\beta^2/27\sigma^4 m^3$, $a_h = 16\pi\hbar^2\beta/3\sigma^2 m$. При $\gamma \gg 1$, что отвечает $R \gg \Lambda$, кривая *1* (зависимость $\Lambda/a_h(\gamma)$) выходит на асимптоту $3\gamma/64 = (a_0 a_h)^{-1}$ (a_0 — эффективный радиус экситона), а кривая *2* ($a/a_h(\gamma)$) и зависимость $\Lambda/\Lambda_h(\gamma)$ — на значения, указанные выше. Немонотонность зависимости $\Lambda/a_h(\gamma)$ объясняется тем, что при $A^{-1} > \alpha^{-1}$ росту эффективного радиуса экситона с уменьшением R препятствует деформация решетки, в которой локализован экситон. Поскольку для отыскания высоты барьера использован вариационный принцип, представленные на рисунке результаты являются верхней оценкой величины Λ/Λ_h (величина Λ_h оценена с большей точностью, чем Λ). Изображенная область значений параметра γ отвечает интервалу изменения R/Λ от нескольких сотых до нескольких сотен. Как видим, почти во всем этом интервале Λ заметно меньше Λ_h. Можно поэтому думать, что в ксеноне дырка либо вовсе не локализуется, либо барьер автолокализации настолько высок, что вероятность туннелирования значительно меньше вероятности захвата ею электрона с образованием экситона или какого-либо иного процесса.

Иная интерпретация этого эксперимента возможна на основе [5], где различие в высоте барьеров экситона и дырки связывается с эффектом Яна—Теллера.

Отметим в заключение, что указанный механизм может играть определенную роль в стабилизации многочастичных комплексов.

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K. K. REBANE

SIGNALLING BETWEEN CIVILIZATIONS AND PROTECTING THE ENVIRONMENT*

K. K. REBANE. TSIVILISATSIOONIDEVAHELISED SIGNAALID JA ELUKESKKONNA KAITSE

К. К. РЕБАНЕ. СИГНАЛИЗАЦИЯ МЕЖДУ ЦИВИЛИЗАЦИЯМИ И ОХРАНА СРЕДЫ ОБИТАНИЯ

Recently Troitsky showed that to send (or detect) isotropic signals to (from) other worlds far in the space by means of radiotelescopes requires

* Symmary of contributed paper presented at the symposium SETI (Search of Extraterrestrial Intelligence) held in Tallinn, Estonian SSR, USSR, December 8—11, 1981.

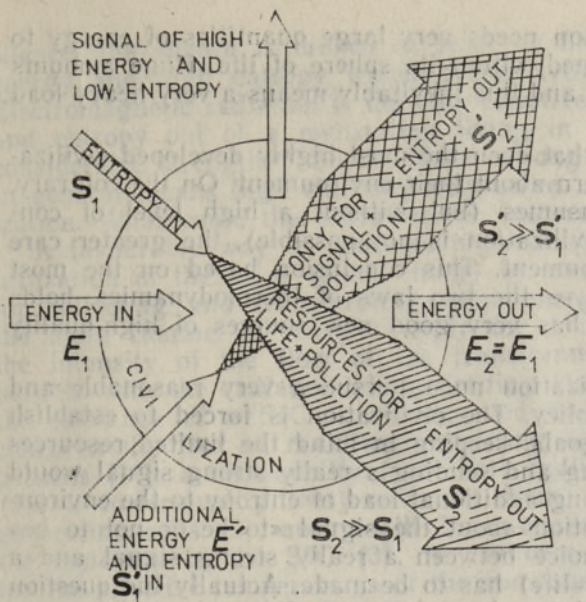

Fig. 1. The entropy balance of a civilization. The preparation of a really strong signal brings along a really large increase of entropy and a lot of pollution of the environment but gives nothing for better life.

such a lot of materials, so much energy and so much time for the transportation of materials that to build an antenna big enough and far enough from the residence of the civilization is impossible even for a very well advanced civilization [1]. Actually Troitsky has estimated for a model how energy and environmental considerations (the temperature of the environment must be kept within certain limits) lead to quite strong restrictions.

The first law of thermodynamics (conservation of energy) and the second law of thermodynamics (increase of entropy) allow us to draw some quite general conclusions about what are the problems with energy and environment for every civilization and what difficulties arise when a really strong signal is to be delivered [2,3].

1. Let us consider a civilization as a strongly non-equilibrium thermodynamical system which is being kept far from the state of thermodynamical equilibrium and which is preserving its high-order subtle structure owing to the energy and entropy flows through the system (input and output of energy E_1, E_2 and entropy S_1, S_2). We know from the first law that the energy is conserved $E_1 = E_2$, and from the second law that the entropy has to increase $S_2 > S_1$. Actually S_2 has to be very much larger than S_1, $S_2 \gg S_1$ (Fig. 1). All resources for the life of the civilization are provided in the course of the growth of entropy in its environment. The civilization must not only have the sources of energy of a high quality (fuels, nuclear and solar power, etc.) but the effective ways to get rid of the low-grade used energy as well. The amount of the energy to be got rid of must be equal to the amount of energy generated by the civilization.

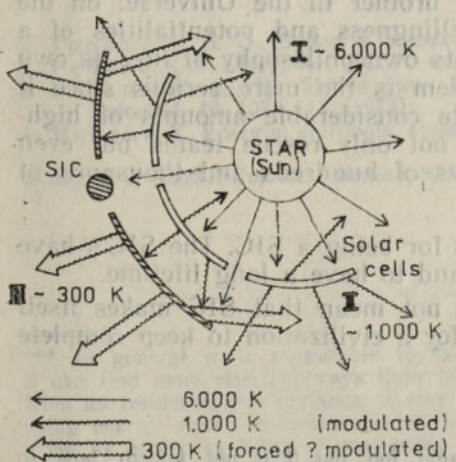

Fig. 2. If the main channel of energy supply is star (solar) energy and the amount of generated energy is really large (e. g. ten per cent of the total radiative energy of the star), the radiation from the system (star + solar battaries + the residence of the civilization) should consist of three characteristic components. If the civilization desires to broadcast, the simplest way is to modulate flow II or (and) III.

A highly developed civilization needs very large quantities of energy to be transferred and transformed within its sphere of life. Huge amounts of entropy are being created, and this inevitably means a very heavy load to the environment.

So we have to conclude that even the most highly developed civilizations are not free from concern about their environment. On the contrary, the more a civilization consumes (but without a high level of consumption a high level of civilization is not possible), the greater care it has to take of its environment. This conclusion based on the most fundamental laws of nature — the two laws of thermodynamics, holds even for a civilization that has very good new sources of high-quality energy at its disposal.

A highly developed civilization must pursue a very reasonable and economical environmental policy. The civilization is forced to establish a hierarchy of values and goals, keeping in mind the limited resources of the environment. Preparing and sending a really strong signal would inevitably mean a really strong additional load of entropy to the environment (Fig. 1) and the question about the signal «to be or not to be» has to be answered, the choice between a really strong signal and a much better environment (=life) has to be made. Actually the question is transferred out from physics and astronomy and transformed into the most important question of estimating (human) values and goals — what material and spiritual values are really valuable? In what order should these values and goals be ranged? It is not obvious at all that the signalling to other civilizations should occupy the very first positions in such an order. We should rather be inclined to think (being nowadays well exposed to rising prices for fuel and raw materials, and to the mounting environmental problems) that reasonable and economical civilizations which consider signalling very exciting but regard a more healthy and interesting life as much more important, have more chances to reach a high level of development and keep it for a long time. It is quite possible that the better part (if not all) of the highly developed civilizations are silent civilizations (SIC). That could be one of the good reasons why the Universe is not overcrowded by signals.

2. Even if a civilization is very well provided with sources of energy, if it has worked out very effective ways of getting rid of the excess of entropy and has therefore no major environmental problems, there might be another reason for being reluctant to send signals and information to other worlds. The civilization may consider it unwise and ethically doubtful to deliver information to his brother in the Universe: on the long-term scale it may retard the willingness and potentialities of a dependent civilization in working out its own philosophy of life, its own science and technology [4]. The problem is the more serious since it is impossible «in real time» to donate considerable amounts of high-quality energy or materials, to send not only rescue teams but even «rescue information» over the distances of hundreds and thousands of light-years.

3. Well, there are at least two reasons for being a SIC. The SIC's have good chances to survive, to go ahead and to have a long lifetime.

Most fortunately, being silent does not mean that SIC makes itself entirely undetectable. It is impossible for a civilization to keep complete

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** In principle the neutrinos can do the same job, but it is not known how to control the neutrino flows in a proper way.

silence: the silence is broken at least by the flows of the low-quality energy and high entropy which every civilization has to get rid of. Electromagnetic radiation is the only effective carrier to take the energy and entropy out of a civilization living in a gravitational field of a considerable strength.** So the flows of long-wave radiation (long-wave in general means high entropy) may serve as an indication of a civilization. What could the characteristic features of such flows be?

A favourable way to generate high-quality energy seems to be the utilization of the solar (star) energy by means of fields of solar cells for collecting and transforming solar energy into electricity. If it is the main channel of energy supply for a really well developed SIC, the intensity of the flow of the transformed energy should be comparable with the radiation of the feeding star (Fig. 2). In such a case the existence of a SIC is accompanied and may be detected by the characteristic flux of radiation consisting of the following three components [2,3]: a high-quality (very hot) radiation from the feeding star (1); a lower-quality (hot) radiation from the fields of the electricity generating cells (2); and a still lower-quality (warm) radiation from the residence of the SIC (3). In the case of our Sun the estimates for the effective temperatures of the components might be: $T_1=6000$ K; $T_2=1000$ K; $T_3=300$ K (Fig. 2).

To clean up the environment, SIC may force flow III to be much more intense than it should be for a black body at T_3. Quite effective ways for that kind of activities should exist, because thermodynamically the task is to pump heat and to do it in the direction from the higher temperature T_3 to the lower temperature of the space (with effective temperature of the relic radiation $T_r=3$ K).

If a civilization desires to broad-cast (Talkative Civilization (TAC)), the ecologically most reasonable way seems to be to modulate flows III or (and) II.***

4. It is not a bad feeling that there do exist quite a number of silent civilizations in the space and that the talkative ones are few (if any at all).

It is most important to get evidence that a really well developed civilization does exist: it will strongly support our confidence that we are able to get over our own global problems and crises including the environmental ones and that we still have good chances to advance.

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*** In general it is reasonable to suppose that if a TAC wants to communicate, it can find more effective ways than isotropic signals of tremendous intensity directly from its residence. For instance, it may try to display rather far from the its residence using energy stored in metastable matter in the space processes which may be understood by others as being of man-made origin (e. g. movements apparently faster than velocity of light) or try to get and detect non-linear reflections of a coherent laser beam from another coherent beam sent by another TAC.