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Scaling law of the biological evolution and the hypothesis of the self-consistent Galaxy origin of life

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Abstract

It is supposed that the sequence of the Earth's biospheric revolutions obeys the scaling law. An estimation of the duration of the prebiological chemical evolution as $(5–7) \times 10^9$ years is obtained by an extrapolation of the scaling law of the biospheric evolution. The expected scale of time of interstellar prebiological panspermia ($\sim 0.2 \times 10^9$ yr) is much shorter then the estimated duration of the prebiological chemical evolution. The hypothesis of the long prebiological chemical evolution implies that: (a) the prebiological evolution and the origin of life may be a self-consistent Galaxy process and not a process localized on single planets and (b) life has the same chemical base and the same chirality everywhere in the Galaxy.

Keywords: Biological evolution; Prebiological chemical evolution; Scaling law; Panspermia

1. Scaling law of the Earth's biospheric evolution

Life must be originated in a process of a natural chemical prebiological evolution – maybe on the Earth, maybe in some other place, and then brought to the Earth by the panspermia process. Nobody can estimate now the duration of the prebiological evolution from the 'first principles' or from experiment. In the first part of the present paper, we will show that it is possible to obtain an independent phenomenological estimation of the duration of the prebiological chemical evolution on the basis of the phenomenon of *scaling law of the Earth's biospheric evolution.* This estimation should be considered as a *hypothesis*.

The history of life on the Earth was started with arising of the biosphere about 4×10^9 years ago (Orgel, 1998) and was continued by the history of the intelligence after arising of Homo about 4.4×10^6 years ago (Wood, 1992). There are many common features in the mechanisms of evolution of the biosphere itself and the humankind (Snooks, 1996, 2003; Nazaretian, 2003; Nazaretian et al., 2004). We will speak about the evolution of biosphere in the generalized sense. We consider the evolution of the biosphere itself and then the history of humankind to be united continuous process. Similarly, the term 'biosphere' is understood in the generalized sense. Biosphere includes the civilization at the latest stages of its history.

The evolution of the Earth's biosphere passed through a sequence of phases with *phase transitions* between them – *biospheric revolutions*. The complete set of biospheric revolutions will be used in the following analysis. There is no exact method to select biospheric revolutions, therefore the following list of them should be considered as a hypothesis and a proposal for further discussion. To collect the events that may be qualified as biospheric revolutions we use a number of signs of them as proposed by Nazaretian (2003), Nazaretian et al. (2004) and estimations of some well-established

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biospheric or historical events that are presented in the literature. The events of biospheric evolution were chosen in the accordance with literature on bacterial and classic paleontology (see hereinafter), the events of the history of humankind correspond to the periodization adopted by Diakonov (1994) and Kapitza (1996). It is important that the aim of Diakonov and Kapiza was to study a very long period of history from a general united point of view, and that it is possible to find many common features in biological and social evolution (Nazaretian, 2003; Nazaretian et al., 2004; Snooks, 1996, 2003). The sequence of biospheric revolutions is listed below with numeration starting from zero. The dates of events in the list are presented very approximately, but high accuracy of dates is not needed in the following analysis. Each date may be safely moved to the past or future up to 30% relative to the present time.

0. *The origin of life* – 4×10^9 years ago (Orgel, 1998). The biosphere after it's appearance was represented by nucleusless procaryotes and existed the first 2–2.5 billion years without any great shocks.
1. *Neoproterozoic revolution (Oxygen crisis)* – 1.5×10^9 years ago (Rozanov, 2003; Zavarzin, 2003). Cyanobacteria had enriched the atmosphere by oxygen that was a strong poison for anaerobic procaryotes. Anaerobic procaryotes started to die out and anaerobic procaryote fauna was changed by an aerobic eucaryote and multicellular one.
2. *Cambrian explosion (The beginning of Paleozoic era)* – 570×10^6 years ago (Carrol, 1988, V1; Paleozoic, 1975a). All the modern phyla of metazoa (including vertebrates) appeared during a few of tens of million years. During the Paleozoic era the terra firma was populated by life.
3. *Reptiles revolution (The beginning of Mesozoic era)* – 235×10^6 years ago (Paleozoic, 1975b; Mesozoic, 1975, Carrol, 1988, V1,V2). Almost all paleozoic Amphibia died out. Reptiles became the leader of the evolution on the terra firma.
4. *Mammalia revolution (The beginning of the Cenozoic era)* – 66×10^6 years ago (Mesozoic, 1975; Cenozoic, 1975; Carrol, 1988, V2,V3). Dinosaurs died out. Mammalia animals became the leader of the evolution on the terra firma.
5. *Hominoid revolution (The beginning of the Neogene period)* – 24×10^6 years ago (Cenozoic, 1975; Begun, 2003; Carrol, 1988, V3). A big evolution explosion of Hominoidae (apes). There were 14 genera of hominoidae between 22 and 17 millions years ago – much more than now (Begun, 2003). The flora and fauna became contemporary.
6. *The beginning of Quaternary period (Anthropogene)* – $(4–5) \times 10^6$ years ago (Wood, 1992; Jones, 1994). The first primitive Homo genus (hominidae) separated from hominoidae.
7. *Palaeolithic revolution* – $(2–1.5) \times 10^6$ years ago (Jones, 1994). Homo habilis, the first stone implements.
8. *The beginning of Chelles period* – 0.7×10^6 years ago (Jones, 1994). Fire, Homo erectus.
9. *The beginning of Acheulean period*– 0.4×10^6 years ago (Jones, 1994). Standardized symmetric stone implements.
10. *The culture revolution of neanderthaler (Mustier culture)* – $(150–100) \times 10^3$ years ago (Jones, 1994). Homo sapiens neandertalensis. Fine stone implements, burial of deadmen (a sign of primitive religions).
11. *The Upper Palaeolithic revolution* – 40×10^3 years ago (Jones, 1994). *Homo sapiens sapiens* became the leader of cultural evolution. Development of advanced hunter instruments – spears, snares. Imitative art is widespread.
12. *Neolithic revolution* – $(12–9) \times 10^3$ years ago (Diakonov, 1994; Nazaretian, 2003). Appropriative economy had been replaced by productive economy.
13. *Urban revolution (the beginning of the Ancient world)* – 4000–3000 B.C. (Diakonov, 1994; Nazaretian, 2003). Appearance of state formations, written language and the first legal documents.
14. *Imperial antiquity, Iron age, the revolution of the Axial time* – 750 B.C. (Diakonov, 1994; Nazaretian, 2003; Jaspers et al., 1955). The appearance of a new type of state formations – empires, and a culture revolution. New kinds of thinkers such as Zaratushtra, Socrates, Budda, and others.
15. *The beginning of the Middle ages* – 500 A.D. (Diakonov, 1994). Disintegration of Western Roman Empire, widespread Christianity and Islam, domination of feudal economy.
16. *The beginning of the New Time, the first industrial revolution* – 1500 A.D. (Diakonov, 1994; Nazaretian, 2003). Appearing of manufacture, printing of books, the New time culture revolution etc.
17. *The second industrial revolution (steam and electricity)* – 1830 (Diakonov, 1994). Appearance of mechanized industry, the beginning of globalization in the information field (telegraph was invented in 1831), etc.
18. *Information revolution, the beginning of the postindustrial epoch* – 1950 (Diakonov, 1994). The main part of population of industrial countries work in the field of information production and utilization or in the service field, not in the material production.

It is easy to see that the duration of the phases of biospheric evolution reduces from the past to the present. It is a manifestation of the well known 'acceleration of the evolution time' phenomenon ('accelerating pace of life'

Snooks, 1996, p. 92). Moreover, the sequence of biospheric phase transitions in some approximation has a property of scale invariance (Snooks, 1996, 2003; Kapitza, 1996). It means that the sequence of corresponding time points is a simple geometrical progression and different parts of this sequence may be obtained from each other by scale transformation.

An ideal scale invariant sequence of points may be written as

$$t_n = t^* - T/\alpha^n. \quad (1)$$

In Eq. (1) the coefficient $\alpha > 1$ is a coefficient of reduction of the duration of each subsequent evolution phase comparing with the corresponding preceding one. T is a duration of the whole period of time under consideration, n is a number of phase transition, and t^* is the limit of the geometrical progression $\{t_n\}$ and t^* may be called as 'singularity of the evolution'.

There are three free parameters α, t^*, T that can be obtained by the best fitting of scale invariant sequence Eq. (1) to the actual (experimental) sequence of the biosphere revolutions – it is a simple mathematical procedure. To understand what is the quality of the approximation it is suitable to rewrite Eq. (1) as

$$\lg(t^* - t_n) = \lg T - n \lg \alpha.$$

It is seen that the dependence of the distance from the point of transition t_n to the singular point t^* in the logarithmic scale from the transition number n must be approximately a straight line.

The result of such kind of analysis is shown on Fig. 1. It is seen that the sequence of the biospheric revolutions satisfies the scaling law in a good approximation. It is possible to say that there exists an scale invariant attractor of the evolution (straight line in Fig. 1). The actual

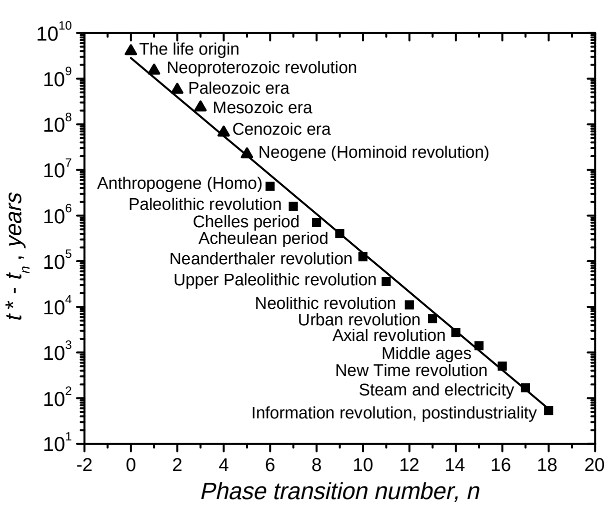

Fig. 1. The scale invariance of the distribution of the biospheric phase transitions in time. Triangles – pure biospheric transitions, squares – transitions of the social history. Straight line – the scale invariant attractor of the evolution on the Earth.

evolution follows this attractor with relatively small fluctuations. Since the scale invariant attractor exists, the parameters α and t^* become meaning. The analysis produces the values:

$$\alpha = 2.67 \pm 0.15; \quad t^* = (2004 \pm 15) \text{ year}. \quad (2)$$

It is funny to note that $\alpha \approx e = 2.718\ldots$ Note also that since $t^* = 2004$ year, one can conclude that we live near the final point of the cycle of the scale invariant evolution with duration four billion years.

Note that Eq. (1) does not represent a 'theory of evolution' but it is a phenomenological description of some experimental facts only. Such a description can not be used for any serious prediction of evolution into far future or its retrodiction into very distant past, but the observed phenomenological regularity is sufficient to propose and discuss some interesting hypotheses. One such hypothesis is proposed in Section 2.

While our description of evolution should be considered as pure phenomenological one, there exists a dynamical theory that explains the accelerating pace of life and humankind. This is the *dynamic-strategy theory* of Snooks (1996, 2003). The main point is that both genetic change and technological change involve processes in which the outputs of one paradigm become the inputs of the next paradigm. This theory is an 'explanation' or an 'existential' type and not a deductive quantitative theory, but it supports our phenomenological results.

It should be noted that Snooks, when analysing the transformation of the biosphere, in 1996 proposed the value $\alpha = 3$ for the factor of the acceleration of life (biomass) generated by biological and technological change Snooks, 1996, pp. 79–82, 92–95, 401–405. This value is close to our estimation Eq. (2). Diakonov (1994, pp. 352–353) pointed out in 1994 the exponential acceleration of social evolution (without explicit estimation of α) from the Neolithic revolution up to present days and pointed out that the character of acceleration implies the existence of the point of 'singularity of history' somewhere in nearest future. Kapitza (1996) proposed the acceleration factor $\alpha = 2.5$–3.0 for evolution of humankind from the beginning of Anthropogene ((4–5) $\times 10^6$ years ago) up to now. The author's Eq. (2) confirms the earlier calculations for biological and social evolution – now called the Snooks-Panov Algorithm – and provides a greater degree of precision.

2. Time scale of prebiological chemical evolution

Galimov (2001, Chapters 2–3) proposed a theory, where prebiological chemical evolution, origin of life, and subsequent evolution of biosphere was considered and described as a united continuous process. This theory deals with selection, disproportioning of entropy, transferability and evolution conservatism in the thermodynamic no-equilibrium systems near the state of equilibrium, and this paradigm is used for periods before and after origin of life by the same manner. This theory is thoroughly elaborated and it covers many fine details of origin of life and further evolution of biosphere, but it is impossible to obtain an unambiguous estimation of the duration of prebiological chemical evolution within this theory. The private opinion of Galimov (2001, p. 129) is that the prebiological evolution may be a process short in the geological scale of time (a few millions years).

But another logic is possible too. We see (Section 1) that the higher the organization of the biosphere, the higher the speed of its evolution. Since (a) any prebiological system is organized lower than any biological system, and (b) the prebiological chemical evolution and the biological evolution may be considered as a united process, then one can suppose that the speed of the prebiological evolution should be slower than the speed of subsequent evolution of a biosphere. Moreover, being an united process with evolution of life, one can *suppose* that prebiological evolution lies in the same scale invariant attractor of evolution as evolution of a biosphere. We can estimate the duration of the prebiological chemical evolution by extrapolation of this scale back in time. Of course, it is a simple induction and one must consider such estimation as a *hypothesis*. Using the estimated value of α as in Eq. (2) and the duration of the first step of the biological evolution $4.0 \times 10^9 - 1.5 \times 10^9 = 2.5 \times 10^9$ years (it is the distance between the origin of life and the Neoproterozoic revolution) one can obtain the estimation for the duration of the prebiological chemical evolution: $\tau_{\text{chem}} = 2.5 \times 10^9 \times 2.67 \approx 6.7 \times 10^9$ years. A more rigorous technique is to extrapolate directly the optimal scale invariant attractor. This method produces the value $\tau_{\text{chem}} \approx 5.5 \times 10^9$ years. One can conclude that the extrapolated value of the duration of the prebiological chemical evolution is $\tau_{\text{chem}} = (5-7) \times 10^9$ years.

The value $\tau_{\text{chem}} \approx 6 \times 10^9$ years is very long. At the same time it is argued that the duration of the prebiological chemical evolution on the Earth actually was very short: shorter than 0.2×10^9 years (Orgel, 1998) (from 4.1 to 3.9 billion years ago). The actual duration of the prebiological evolution on the Earth is not only unexpectedly short. Moreover, it is in a deep contradiction with subsequent scale invariance of the biological evolution. It is seen a sharp anomaly if one draws the point of the beginning of the prebiological evolution on the Earth together with the biological phase transitions (“hockey stick”, see Fig. 2). A resolution of this contradiction may be the following. The duration of the prebiological evolution is *in fact* about 6 billion years, but it took place not on the Earth but on the other Earthlike planets near the stars much older then the Sun. And life could be brought to the Earth by the panspermia process (Crick and Orgel, 1973). The idea of panspermia was supported by discovering the meteorites from the surface of Mars and other planets (McKay et al., 1996).

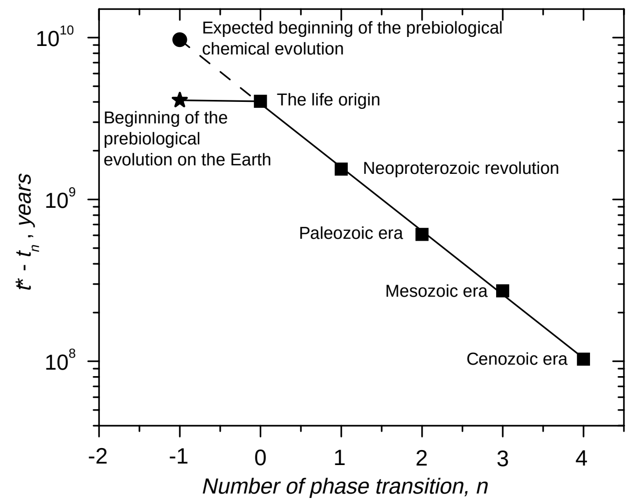

Fig. 2. Extremely short time of the prebiological chemical evolution on the Earth produces an anomaly ‘hockey stick’ in the exponential scale of time of the evolution.

It is interesting that the extrapolated beginning of the prebiological evolution $4 \times 10^9 + 6 \times 10^9 = 10 \times 10^9$ years ago almost coincides with the time of the formation of the Galaxy disk (Rocha-Pinto and Maciel, 1997). The Galaxy disk is the subsystem of our Galaxy that contains the stars with a high fraction of heavy chemical elements. Just such stars are needed to produce Earthlike planets. Therefore to have time for the origin of life on the Earth the prebiological evolution must have started on the very first Earthlike planets in the Galaxy simultaneously with the Galaxy disk formation. This implies that the evolution on the Earth may be near to the front of the total evolution in the Galaxy.

3. Self-consistent Galaxy origin of life

In Section 2 it was argued that the short prebiological chemical evolution on the Earth may actually mean the possibility of the panspermia process and a long prebiological evolution on other Earthlike planets (but not on the Earth). But if we suppose the possibility of the biological panspermia, then we should suppose the possibility of prebiological panspermia as well, because the products of a prebiological evolution must be less sensitive to the difficulties of a cosmic travel than any biological systems. One can expect the time scale of the Galaxy panspermia process to be about 200 million years – the scale of one Galaxy year. Any matter (prebiological or biological systems and other) emitted from the surface of any planet will be spread upon the volume of almost the whole Galaxy disk for about one Galaxy year due to the differential rotation of the Galaxy disk. Therefore we have two time scales: one is a long scale, $\tau_{chem} \approx 6 \times 10^9$ years, this is the scale of the natural prebiological chemical evolution; and one is a short scale, $\tau_{pan} \sim 0.2 \times 10^9$ years – the scale of the panspermia process. The existence of these two scales of time implies that the prebiological chemical evolution on different Earthlike planets would not be independent from each other.

Let suppose, some good (in some sense) prebiological system (for example, a stable autocatalytic chain) appears on some Earthlike planet at the stage of the prebiological evolution of the Galaxy (before life originates in the Galaxy for the first time). This is quite a random event. Then during a short time of order τ_{pan} this good prebiological system will be spread by the panspermia process on all Earthlike planets which are also at the stage of chemical evolution. This progressive system must dislodge less efficient prebiological systems of the host planet by selection process and move the evolution forward with the new chemical system. This is a selection process in the scale of the whole Galaxy. Due to the condition $\tau_{pan} \ll \tau_{chem}$ this process must synchronize prebiological chemical evolution in the volume of the whole Galaxy and implicates the appearance of life almost simultaneously in all the planets that have suitable conditions for life hosting, and on the same chemical base and with the same chirality. This event is like a no-equilibrium phase transition of the Galaxy. The prebiological chemical evolution and the origin of life may be a self-consistent Galaxy process and not a process localized on single planets as is usually supposed – this is the formulation of *the hypothesis of self-consistent Galaxy origin of life*. This hypothesis is the implication of the *supposition* that the natural prebiological chemical evolution belongs to the same exponential scale of time as the evolution of the life on the Earth. If the hypothesis of self-consistent Galaxy life origin is valid, then after the transition of the whole Galaxy to the era of life, the life does not originate by a process of 'natural' chemical evolution. Natural evolution can not concurrent with the much faster process of biological panspermia.

Note, that if life may exist on planets with conditions which are sharply different from the Earth's, then life in the Galaxy may exist in a number of different phases corresponding the classification of the conditions on planets – without any competition between different phases. But in the present stage of the study of the problem this note may be considered as unimportant. The existence of the common chemical base and chirality of life in the Galaxy is an experimental critical test of the hypothesis of self-consistent Galaxy origin of life.

4. Conclusions

If the duration of the prebiological chemical evolution is very long (billion years) then the chemical evolution can not be localized on different single planets due to the prebiological panspermia, and the origin of life is expected to be a self-consistent Galaxy process. The scale invariant attractor of the biospheric evolution on the Earth hints that the duration of the prebiological chemical evolution actually may be very long.

5. Note added in proof

While this paper was being prepared for publication, an English article by E.M. Galimov was issued (Galimov, 2004).

References

Begun, D.R. Planet of the apes. Scientific American 289 (2), 64–73, 2003.

Carrol, R.L. Vertebrate Paleontology and Evolution. W.H. Freeman and Company, New York, 1988.

A.P., Cenozoic era, in: The New Encyclopedia Britanica, 15th ed., vol. 3, Encyclopedia Britanica, Inc., Chicago/London/Toronto/Geneva/Sydney/Tokyo/Manila/Seoul/Johannesburg, pp. 1079–1083, 1975.

Crick, F.H., Orgel, L.E. Directed panspermia. Icarus 19, 341–346, 1973.

Diakonov, I.M. The Ways of Hysory. From the Ancient Man to Our Days. Eastern Literature, Moscow, 1994 (in Russian).

Galimov, E.M. The Phenomenon of Life: between Balance and Nolinearity. URSS, Moscow, 2001 (in Russian).

Galimov, E.M. Phenomenon of life: between equilibrium and nonlinearity. Origins of Life and Evolution of the Biosphere 34, 599–613, 2004.

Jaspers, K., Von Ursprung und Ziel der Geschichte, Fisher Bucherei, Frankfurt/Main, Hamburg, 1955.

Jones, S. (Ed.). The Cambridge Encyclopedia of Human Evolution. Cambridge University Press, Cambridge, 1994.

Kapitza, S.P. The phenomenological theory of world population growth. Physics – Uspekhi 39 (1), 57–71, 1996.

McKay, D.S., Gibson, E.K., Thomas-Kepra, K.L., Vali, H., Romanek, C.S., Clemmet, S.L., Chiller, X.D.F., Maechling, C.R., Zare, R.N. Search for past life on Mars: possible relic biogenic activity in martian meteorite ALH 84001. Science 273, 924–930, 1996.

A.H., Mesozoic era, in: The New Encyclopedia Britanica, 15th ed., vol. 11, Encyclopedia Britanica, Inc. Chicago/London/Toronto/Geneva/Sydney/Tokyo/Manila/Seoul/Johannesburg, pp. 1013–1017, 1975.

Nazaretian, A.P., Civilization crises within the context of Big history. Self-organization, psychology and futurology, Mir, Moscow, 2004 (in Russian).

Nazaretian, A.P. Power and wisdom: toward a history of social behavior. Journal of the Theory of Social Behaviour 33 (4), 405–425, 2003.

Orgel, L.E. The origin of life – How long did it take?. Origins of Life and Evolution of the Biosphere 28, 91–96, 1998.

T.K., Paleozoic era, lower, in: The New Encyclopedia Britanica, 15th ed., vol. 13, Encyclopedia Britanica, Inc. Chicago/London/Toronto/Geneva/Sydney/Tokyo/Manila/Seoul/Johannesburg, pp. 916–920, 1975.

J.B.W., Paleozoic era, upper, in: The New Encyclopedia Britanica, 15th ed., vol. 13, Encyclopedia Britanica, Inc., Chicago/London/Toronto/Geneva/Sydney/Tokyo/Manila/Seoul/Johannesburg, pp. 921–930, 1975.

Rocha-Pinto, H.J., Maciel, W.J. History of the star formation in the local disk from the G dwarf metallicity distribution. Monthly Notices of the Royal Astronomical Society 289 (4), 882–888, 1997.

Rozanov, A.Y. Unearthed bacteria, sedimentogenesis, and the early stages of the biospheric evolution. Palaeontological Journal N6, 41–49, 2003 (in Russian).

Snooks, G.D. The Dynamic Society. Exploring the Source of Global Change. Routledge, London and New York, 1996.

Snooks, G.D. The Collapse of Darwinism or the Rise of a Realist Theory of Life. Lexington Books, 2003.

Wood, B. Origin and evolution of the genus *homo*. Nature 355, 783–790, 1992.

Zavarzin, G.A. Formation of the system of biogeochemical cycles. Palaeontological Journal N6, 16–24, 2003 (in Russian).