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EXOGENOUS FACTORS IN THE EVOLUTION OF THE EARTH. ASTROPHYSICS AND THE WEAK FORM OF THE HYPOTHESIS OF PANSPERMIA[1]

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Abstract. We search for interrelation of events in the biosphere and geospheres of the Earth from comparison of the data on mass extinctions and impacts and the data on geological activity for the same period (Phanerozoic). In addition, we examine the data on Phanerozoic climate change, which include data on the glacial periods. The role of comets is important not only in the formation of the Earth, but throughout its evolution. Results of spectral, wavelet, and correlation analysis of the data series representing these processes are given. We conclude that most of them are cyclic, some of the periods are present in all the processes. The mechanisms of the influence of the Galaxy on the processes occurring on the Earth are discussed.

Introduction

The paper consists of two sections linked by a key role of cometary bodies.

I. The problems of the origin of the Earth and life are fundamental in the modern science. Relying on the data of recent years, we consider a new course of research in this old problem. On the basis of astrophysical data obtained during the last 30–50 years, recent results of the study of small bodies in the Solar System (comets in particular), theoretical and laboratory data on the Earth evolution, it is possible to combine the old idea about panspermia in a broadened sense and the search of the fundamentals of life on the early Earth.

Hypotheses about panspermia go back to times of Anaxagoras from Clazomenae (5th century B.C.) – his "nothing is born from nothing" and ideas about "life seeds". The problem of panspermia, delivery of life on the Earth from space was discussed beginning from the times of Berzelius, Helmholtz, and Kelvin. The second hypothesis about autonomous origin of life on the Earth appeared after the hypothesis of academician Oparin about the primordial soup and the famous experiments by Miller. The last fifty years allow us to look at these hypotheses from a new point of view [1].

By now, solid argumentation has been obtained in favor of the Solar System origin in a dense star association with the presence of massive stars. We discuss the consequences of such combined birth of planetary systems for our Solar System.

[1] Talk presented at the Interdisciplinatory Colloquium on Cosmic Factors of Evolution of the Biosphere and Geosphere, Moscow, May 21–23, 2014.

Most likely, the Sun and a gas-dust disk surrounding it were created in a Giant molecular cloud near young giants—blue OB-stars, whose ultraviolet radiation generated a weak chirality (to 15% of EEs) in organics of interstellar dust. A part of interstellar dust beyond orbits larger than 3–4 AU remained cold and then entered into the first planetesimals. The organics, after melting of the interiors of the first planetesimals due to heating by short-living ^{26}Al and ^{60}Fe, sank, in the form of kerogens, into the planetesimal cores, where formation of the first complex organic compounds began. This occurred in the first 3–4 Ma after the formation of CAI. Apparently, it is necessary to look for anaerobic life in comets.

II. The role of comets is important not only in the formation of the Earth, but also throughout all its evolution. Various aspects of the Earth as an open system were considered for a long time: the radiation fluxes from the Sun and the solar wind, galactic cosmic rays, impacts of large cosmic bodies and fluxes of meteorite material on the Earth, the internal energy of the Earth partially absorbed by the biosphere and lost in the form of infrared radiation, a loss of atmospheric gases and the interaction of magnetic fields of the Earth and the Sun.

In many areas of Earth sciences the researches on the detection of cyclicity in the processes occurring on the Earth and in space and the correlations between some of them are conducted to determine the possible evolutionary tracks of the supersystem by the name of the Earth. Now we can say that two main trends have determined the evolution of the entire Earth, and the Earth's crust in particular, the directionality, the irreversibility of evolution in general, and multiordinal cyclicity, expressed in a temporary partial reversibility of this evolution and its periodic changes in rate and intensity over time.

Geological cycles are the largest unit of rhythm installed on the Earth. They are reflected in the changing modes of sedimentation, magmatism, and volcanism; periods of formation of weathering crusts, paleoclimate changes on the Earth and the content of main atmospheric gases, CO_2 and O_2; in the alternation of glacial periods, changing in the face of the Earth, and they left their marks in paleontological findings.

Origin of cometary nuclei and cometary subnuclei

Primary comet nuclei – a kind of "ice asteroids" – formed in the zone of the giant planets. In the framework of the standard model of the Solar System (SS) formation (see, e.g., [2–4]), it is believed that 4.6 billion years ago, a gas-dust disk with a mass of 0.03–0.07 $M_\odot$ ($M_\odot$ is the mass of the Sun) existed around the young Sun. After turbulence damping and settling of dust onto the median plane a dust subdisk was formed. Upon reaching the critical density in it, about double "smeared" density of the Sun at given distance R from the Sun ($\rho_{\rm cr} \geq 6M_\odot/4\pi R^3$), the gravitational instability develops and its break-up into gas-dust clusters occurs. The characteristic dimensions of primary clusters were of the order of hundreds of kilometers, their densities were an order of magnitude greater than $\rho_{\rm cr}$ ($\delta_0 \sim 10^{-5}$ g/cm^3 for the Earth zone and ($\delta_0 \sim 10^{-7}$ g/cm^3 for the Jupiter zone). It is believed that in a relatively short time (of the order of hundreds of thousands of years [2], and, perhaps, millions of years [3, 5]), the system of colliding, coalescing, and disintegrating clusters evolved to a system of bodies with asteroid sizes, which then, in times of tens of million years, has evolved into the system of planets of SS. There is no doubt that the largest bodies of the asteroid belt, the nuclei of modern comets in the Kuiper belt and the Oort cloud are preserved remnants of protoplanetary bodies.

With the growth of massive bodies in the zone of the giant planets the relative velocities of the bodies increased, and the eccentricities and inclinations of their orbits reached critical values of $\sim 1/3$, which, along with the passage of stars near the forming Solar System, led to the ejection of the bodies to the periphery of SS, i.e., to the formation of the Oort cloud.

The origin and evolution of cometary nuclei (CN) have been studied in a number of papers [4, 6, 7]. Nevertheless the composition and inner structure of CN seem unclear at the moment. Traditionally only the thermal history of a single ice body separated from an ensemble of similar bodies is investigated. Attention is focused on the influence of the composition and structure of ice and refractory admixture, values of heat conductivity coefficients, and radioactive U, Th, ^{40}K, ^{26}Al abundances.

Vityazev A.V. [8] studied the combined effects of collisions between CN, heating and cooling processes, and possible mass transfer in CN interiors. Here our object was to testify the possibility of sufficient heating and redistribution of impurities during the formation of dust subnuclei.

It should be stressed that the CN cannot avoid collisions while forming. CN that have sizes $r > r_{\rm cr}$ can grow, others with $r < r_{\rm cr}$ undergo catastrophic disruption and supply material for the surviving ones. Critical radius $r_{\rm cr}$ is determined by the sizes of the maximal bodies (protoplanets) in the zone of accumulation $r_{\rm max}$ [3].

Calculations [3] showed that for bodies of size $r \sim 100$ km and moderate values of the dust admixture concentration, $c \approx 0.2$–0.5, and usually adopted U, Th, ^{40}K abundances the temperature of CN interiors reaches temperature of ice melting $T_{\rm m}$ after $t \sim 10^8$ years.

The situation changes radically in the case of fresh ^{26}Al or very low heat conductivity λ such as for amorphous ice $\lambda_{\rm a}$, which is 4–5 orders less [9] than the usually adopted values of λ_0. In the presence of fresh ^{26}Al even for CN of radius $r \geq 1$ km the temperature $T \approx T_{\rm m}$ is possible. Low contents of radioactive sources for CN material and small initial temperatures in the outer zone of the SS have been compensated by low values of ice melting temperature $T_{\rm m}$. The formation of liquid phase in CN interiors appeared possible due to sufficiently thick thermo-insulating shells. Heating and differentiation of large ($\sim$ 100 km) ice-dust planetesimals can occur even in the Kuiper belt and the Oort cloud during the first 10^8 years after their formation [8]

On the role of comets in the origin of life and its evolution

I. Already for half a century searches for polyatomic molecules in molecular complexes proceed. Not only fullerenes are found, but also a number of more complex $C_nH_nN_n$, forming the objects of terrestrial biosphere. The molecules including CHNOSP and entering into the composition of a preplanetary cloud (except areas close to the Sun) have kept their structure.

II. Since Pasteur it is known about chirality of amino acids and sugars in the terrestrial biosphere. Vernadsky wrote about it, addressing to outstanding scientists of the time, and since 1950s researches on chirality of terrestrial biosubstance have begun. Searches of chirality in star clouds have begun actually from article [10]. Last year a big work under the direction of Douglas Whittet, director of Institute of Astrobiology, Troy (USA), on the research of star formation in giant molecular clouds has come to the end. In the article of Fukue T. with 9 coauthors [11] it has been informed about chirality measured in the area of the Orion Trapezium. Along with detection of weak chirality in carbonaceous meteorites, we have a thread (so far thin) helping to understand how the building blocks of future life have got to the Earth.

In the circumsolar gas-dust disk first planetesimals are formed (within the first 1–5 Ma). Their number is 10^{12}–10^{15}, depending on their sizes (1–10 km) and the mass of the primary cloud. In their interiors ice melting occurred due to heating by short-lived ^{26}Al and ^{60}Fe.

Temperatures depending on the frequency of planetesimal collisions are between −100°C and 2000°C. Sea temperatures were 0–150°C, Ph = 7 ± 2, there are metals and montmorillonite. Ketones could increase the chirality to 100%.

Endogenous and exogenous factors in the history of the Earth

In the geosciences, various data banks have been obtained, such as data on the endogenous activity of the Earth, mass extinctions of life and changes in biodiversity, impacts of cosmic bodies, the inversion of the magnetic field, climate change, world ocean level, etc. From these data banks time series can be obtained, reflecting one or another process. Due to measurement errors or the nature of the majority of geophysical phenomena the time series are sequences of quasi-random values, so useful information should be extracted from them by the methods of statistical processing.

The paper presents the results of statistical analysis of some of the above-mentioned series by different methods; multi-ordinal cyclicity and connectedness of processes are discussed [12].

Endogenous activity of the Earth

We estimate the periodic feature of the development of endogenous processes. This feature of the development of the Earth's crust and tectonosphere generally finds its most complete reflection in the cut of sedimentary strata. Almost exclusively in sedimentary sequences it is possible to detect the entire range of cycles from the very large ones with duration of hundreds of millions of years to very short annual periods (band clay), a total of 8 orders of magnitude.

Geological cyclicity has a various origin. The most long-period cycles are associated with deep processes, and the most short-period cycles have an astronomical basis—classic Milankovitch cycles and possibly some of the longer cycles of endogenous activity.

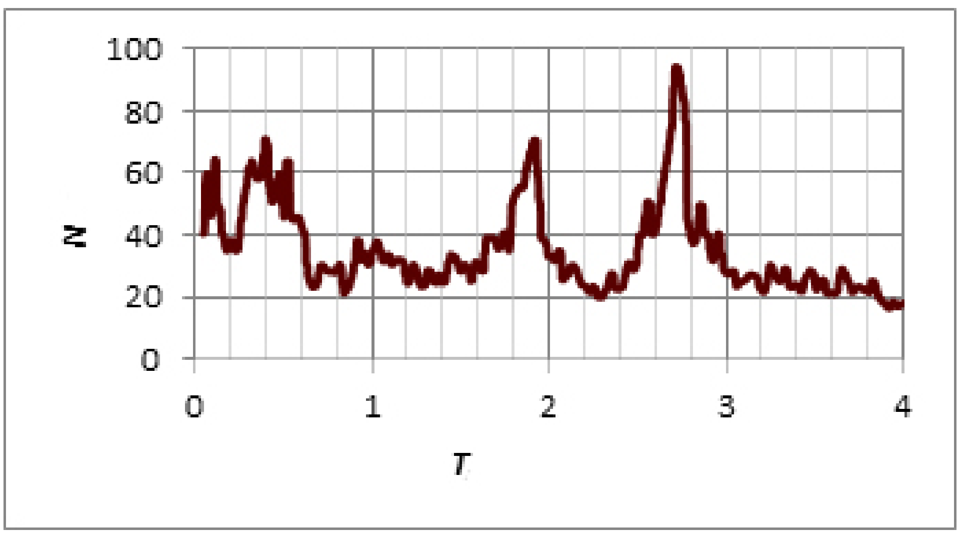

Figure 1: Graph representing the statistical analysis of a fundamental data bank (over 12,000 of dating) on the mantle and crustal rocks that covers almost the entire interval of the evolution of the Earth [13]. The graph shows the peaks of total maximum endogenous intensification against the background of relatively calm periods (age T is in billions of years; N is the number of datings).

Tectonic, wider – tectonic and magmatic cyclicity, is reflected in cyclicity of almost all other geological processes, both endogenous and exogenous. This applies to the behavior of the Earth's magnetic field, to fluctuations in the global sea level, changes in the organic world—the biosphere, in particular, to the phenomena of mass extinctions and regenerations of fauna and flora, to changes in the scale of production of various minerals and the change of sedimentary formations at all.

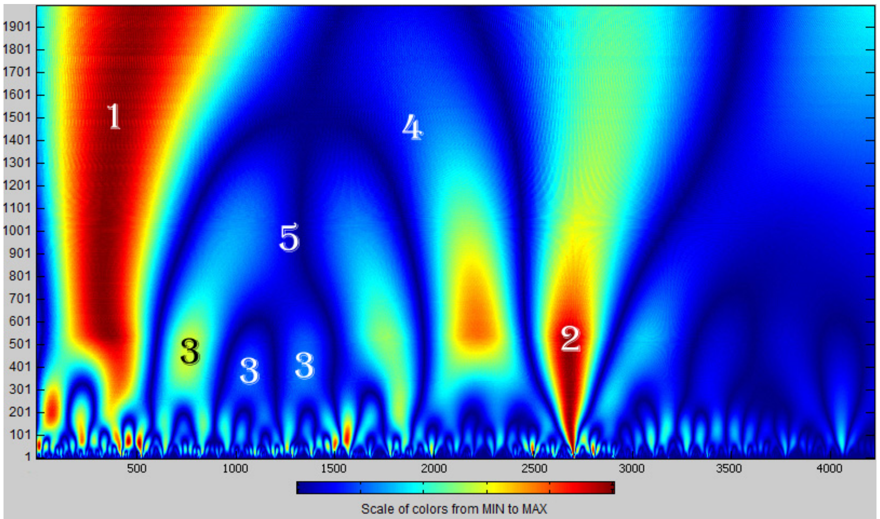

Figure 2: Wavelet spectrum of the total endogenous activity of the upper mantle and crust in the entire interval of geological time. One of the main advantages of the wavelet analysis is the possibility of determining the time of appearance of harmonics and clear visibility of other temporary features in the spectrum of the signal.

"Hot" region "1" on the wavelet spectra of the endogenous activity is related to the fact that relatively young rocks are now well preserved, while the old ones were destroyed. Region "2" is known as a period of strong growth of the continental crust. However, in Fig. 2 a peculiarity in the positions of areas "5" and "4"is observed with a duration of approximately 1.3 billion years, and the distance between the areas of "3" in Fig. 2 is 330 Ma.

Extinction of marine biota

Extinction is a phenomenon in biology and ecology consisting in the disappearance of all members of a particular biological species or taxa.

Phanerozoic history contains all extinction events of the "Big Five" (major extinction events [16]: End Cretaceous (65.5 Ma), End Triassic (205 Ma), End Permian (251 Ma), End Devonian (360–375 Ma), and End Ordovician (440–450 Ma).

The brightest region in Fig. 4 corresponds to a phenomenon called the Cambrian explosion (in the region of 500–540 million years ago). This phenomenon is truly interesting [17].

The statistical analysis shows the presence of a stable periodicity in the processes of endogenous activity: 20–35, 50, 100, 120, 135, 160, 175, 195, 220, 270 ... Ma.

The statistical analysis of the series of intensity of extinctions of marine biota shows periods extending to 16, 18, 25–40, 45, 63, 75, 87, 107, 136 Ma. It can be seen that some of the periods are by their duration close to periodicities in the endogenous activity.

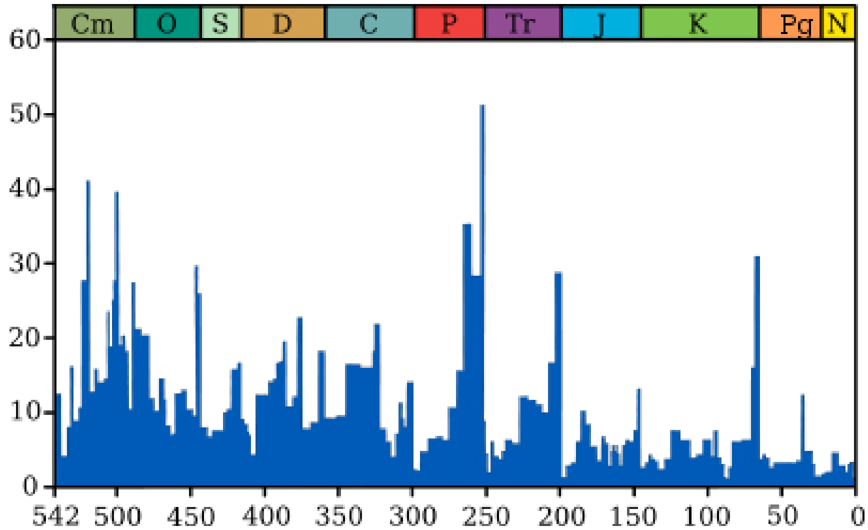

Figure 3: Proportion (not the absolute number) of marine animal genera becoming extinct during some given time interval (millions of years). It is plotted on the principle of the presence of traces of biological remains to a certain time and lack of them after. Data are taken from [14] and based on [15].

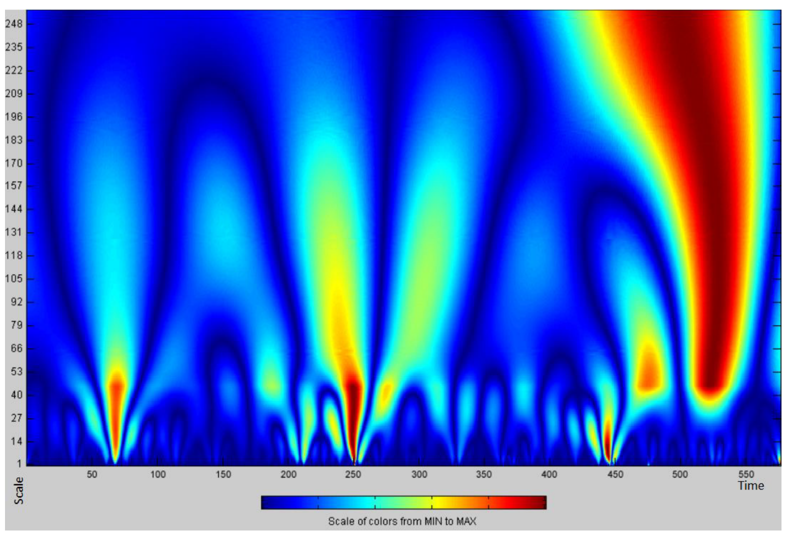

Figure 4: Wavelet spectrum of the time series of the intensity of marine biota extinctions.

Table 1 listing multiscale cycles can tell us about possible causes of cycles that long. Of course, the table is not exhaustive and is meant to show the ordinal scale of periodic phenomena and their reasons.

Thus, a possible cause for some of the cycles is associated with the processes of galactic nature. But then, what is the mechanism of the effect of the Galaxy on the running processes on the Earth? An unambiguous answer is not here. So it remains an open question about the causes of the other cycles.

Table 1:

Variations (periods)	Source	Description
600 Ma	The Earth (interiors)	Wilson cycles
225–250 Ma	The orbit of the Solar system in the Galaxy	Galactic year
150–200 Ma	The Earth (interiors)	Bertrand cycles
50 Ma	Galaxy	The period of revolution of the spiral structure
36 Ma	The Earth (interiors)	Stille cycles
15–18 Ma	Galaxy	Circulation period of the bridge
93,000 years	Earth as a planet	Milankovitch cycle – variations in eccentricity
41,000 years	Earth as a planet	Milankovitch cycle – long-period nutation
25,750 years	Earth as a planet	Milankovitch cycle – precession
2300 years	The Sun	Hallstatt cycle
210 years	The Sun	Swiss cycle and cycle De Vrayes
87 years	The Sun	Gleißberg cycle
22 years	The Sun	Hale cycle
18.6 years	Earth as a planet	Nutation
11 years	The Sun	Schwabe cycle – sunspots
1 year	Earth as a planet	One revolution of the Earth around the Sun
1 day	Earth as a planet	One revolution of the Earth around its axis.

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References

1. Vityazev A.V, Pechernikova G.V. Astrophysics and a weak form of panspermia hypothesis // Biosphere Origin and Evolution (Part 2) / Ed. E.M. Galimov. Moscow: URSS, 2012. P. 93–102.

2. Safronov V.S. Evolution of the Protoplanetary Cloud and the Formation of the Earth and Planets (in Russian), Moscow: Nauka, 1969. 244 p. [NASA Tech. Transl. F-677, Washington, D.C., 1972.

3. Vityazev A.V., G.V. Pechernikova and V.S. Safronov. The Terrestrial Planets: Origin and Early Evolution (in Russian), Moscow: Nauka, 1990. 296 p.

4. Protostars and Planets I, II, III (Ed. T. Gehrels, vol. I, 1978; eds. D. Black and M. Matthews; vol. II, 1985; eds. E.N. Levy and J.I. Lunine J.I., vol. III, 1993), Tucson, Arizona: The University of Arizona Press.

5. Pechernikova G.V., Vityazev A.V. Evolution of gas-dust clusters in the protoplanetary disk // Soviet Astron. **65**, 58–72 (1988).

6. Wilkening L.L. (Ed.), Comets. Tucson, Arizona: The University of Arizona Press, 1982.

7. Rickman H., The thermal history and structure of cometary nuclei // Comets in the Post-Halley Era (Eds. Newburn Jr., Mengebayer M. and Rahe J.) Kluwer: Academic, 1991. P. 733–760.

8. Vityazev A.V. Formation of cometary subnuclei // Planet. Space Sci. **44**, No. 9, 967–971 (1996).

9. Kouchi A., Greenberg J.M., Yamamoto T. and Mukai T. Extremely low thermal conductivity of amorphous ice: relevance to comet evolution // Astrophys. J. **388**, L73–L76 (1992).

10. Bailey J., Chrysostomou A., Hough J.H., Gledhill T.M., McCall A., Clark S., Menard F., Tamura M. Circular polarization in star-formation regions: implications for biomolecular homochirality //Science **281**, 672–674 (1998).

11. Fukue T., Tamura M., Kandori R., Kusakabe N., Hough J.H., Bailey J., Whittet D.C.B., Lucas P.W., Nakajima Y. Hashimoto J. Extended High Circular Polarization in the Orion Massive Star Forming Region: Implications for the Origin of Homochirality in the Solar System // Orig. Life Evol. Biosph. **40**(3), 335–346 (2010).

12. Глазачев Д.О., Печерникова Г.В., Витязев А.В. Активность взаимодействующих коры, мантии, ядра и гео-биологическая эволюция // Геофизика межгеосферных взаимодействий / Под ред. В.В. Адушкина – Москва: ГЕОС, 2008. С. 105–119.

13. Balashov Y.A. Time concept in a geological history of the Earth // Geology and minerals of the Kola Peninsula. V. 3. New ideas and approaches to studying of geological formations. Apatity: Polygraph, 2002. P. 51-75.

14. Rohde R.A., Muller R.A. Cycles in fossil diversity. Nature **434**, 209–210 (2005).

15. Sepkoski, J. A Compendium of Fossil Marine Animal Genera // Eds. Jablonski, D. & Foote, M. Bull. Am. Paleontol. No. 363. Paleontological Research Institution, Ithaca, NY, 2002.

16. Raup, D. & Sepkoski, J. (1982). Mass extinctions in the marine fossil record. Science **215**, 1501–1503; DOI:10.1126/science.215.4539.1501.

17. Yochelson E.L., Fedonkin M.A. Paleobiology of Climactich-nites, an enigmatic Late Cambrian fossil // Smithson. Contrib. Paleobiol. 1993. No. 74. 74 p.

Экзогенные факторы в эволюции Земли. Астрофизика и слабая форма гипотезы панспермии

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Резюме. Проведен поиск взаимосвязи между событиями в биосфере и геосферах Земли и импактных событий на основании сравнения данных о массовых вымираниях с данными о геологической активности в тот же период (фанерозой). Рассмотрены данные по изменениям климата в фанерозое, в том числе по ледниковым периодам. Кометы играют важную роль не только в возникновении жизни на Земле, но и в течение всей её эволюции. Приведены результаты спектрального, вейвлет и корреляционного анализа рядов данных, представляющих эти процессы. Сделан вывод о цикличности большинства процессов, некоторые периоды присутствуют во всех процессах. Обсуждаются механизмы влияния Галактики на процессы, происходящие на Земле.