Physics – Uspekhi **62** (4) 378 – 404 (2019)

FROM THE CURRENT LITERATURE

PACS numbers: 96.12.Kz, 96.30.Ea, **96.90.+c**

Hypothetical signs of life on Venus: revising results of 1975 – 1982 TV experiments

L V Ksanfomality, L M Zelenyi, V N Parmon, V N Snytnikov

DOI: https://doi.org/10.3367/UFNe.2018.12.038507

Contents

Abstract. **Extraterrestrial life may presumably be discovered not in worlds separated from Earth by tens of parsecs but on the surface of Earth's nearest planet neighbor in the Solar System, Venus. This conclusion follows from the newly processed archive data of the TV experiment that was performed in 1975 and 1982 on Venus's surface by the VENERA Soviet spacecraft missions. One of the main experiments, pioneering in situ TV scanning of the planet surface, has never been repeated by any other space mission. The unique archive data have been reprocessed using state-of-the-art technologies that enabled image details to be substantially improved. The new analysis of the VENERA television images has identified up to 18 hypothetical living objects that feature a complex regular structure and presumably are capable of very slow motion. The objects, whose dimensions are significant, may be indicative of the existence of life on a planet whose physical environment is crucially different from Earth's. Water, which is terrestrial life's basis, cannot exist in the liquid phase at temperatures of about 460 °C characteristic of the spacecraft landing sites. Water content in the gaseous state is also negligible (about 2×10^{-5}). Both water and oxygen are virtually absent in Venus's atmosphere. Therefore, the question is: what matter may life on the planet be built on? We consider chemical compounds stable at high temperatures that may be a base for hypothetical Venusian life. We conclude that to explore Venus's hypothetical life, a new dedicated mission, much more advanced than the VENERA missions, should be sent to the planet.**

Keywords: Venera missions, TV experiments, astrobiology, amisadas

L V Ksanfomality (1 *), **L M Zelenyi** (1, 2, †),
V N Parmon (3, 4, ‡), **V N Snytnikov** (3, 4, ♯)
(1) Space Research Institute, Russian Academy of Sciences,
ul. Profsoyuznaya 84/32, 117997 Moscow, Russian Federation
(2) Moscow Institute of Physics and Technology (State University),
Institutskii per. 9, 141700 Dolgoprudnyi, Moscow region,
Russian Federation
(3) Boreskov Institute of Catalysis, Siberian Branch
of the Russian Academy of Sciences,
prosp. Akademika Lavrent'eva 5, 630090 Novosibirsk,
Russian Federation
(4) Novosibirsk State University,
ul. Pirogova 1, 630090 Novosibirsk, Russian Federation
E-mail: * ksanf@iki.rssi.ru, * leksanf@gmail.com,
† lzelenyi@iki.rssi.ru, ‡ parmon@catalysis. ru,
♯ snyt@catalysis.ru, ♯ valsnyt@gmail.com

Received 31 August 2018, revised 29 December 2018
Uspekhi Fizicheskikh Nauk **189** (4) 403 – 432 (2019)
DOI: https://doi.org/10.3367/UFNr.2018.12.038507
Translated by M Sapozhnikov

1. Introduction

Beginning with the time of philosophers of antiquity, the development of science and scientific knowledge has been explicitly or implicitly related to the search for extraterrestrial life, the search for habitable worlds. Attempts to understand the surrounding world always started from the stellar sky over our heads. Nowadays, when the knowledge accumulated for centuries allows us to answer many questions, when new astrophysical methods make possible investigations of space up to the Universe horizon, this search has several facets. First, this is fundamental knowledge about the origin of the world where we are living. Second, these are new concepts about the evolution of our planet, whose nature is far from having ceased development and is not so unambiguous and stable as has been assumed before. And, finally, these are conditions required for the appearance and development of life. However, is life in amino-nucleic acid form — the only one known to us, which appeared at some point in time, evolved, and exists on our planet — unique?

In the mid-1980s, when numerous missions to planets and other bodies of the Solar System became the normal method for investigating and searching for extra-terrestrial life forms, the leading scientific schools raised the questions of what namely should be searched for and how this search could be related to the question of the Search for Extra-Terrestrial Intelligence (SETI). In 1988, seven years before the discovery of the first solar-like 51 Peg planetary system, Carl Sagan organized and held the Planetary SETI Conference in Toronto where, along with the search for extraterrestrial intelligence, the conditions for life's origin and existence, including intelligent life, were discussed. In 1989, the National Academy of Sciences of the United States of America published a special edition, *The Search for Life's Origins* [1], devoted to the problems of terrestrial and hypothetical extraterrestrial planetary biology. The number of such issues rapidly increased. Certain attention was devoted to this problem in Russia as well. In 2003, a special program, Biosphere's Origin and Evolution, of the Presidium of the RAS was created. As a result, large collections of papers by Russian authors were published [2, 3]. In 2009, a peculiar summary of discussions in the Russian scientific community was presented in the collection of papers, "Problems of Life's Origin," published by Rozanov et al. (Institute of Paleontology, RAS) [4], where the most contentious problems of the origin of living forms were considered.

In searching for signs of life, researchers commonly use the facts known about terrestrial life. Therefore, it is assumed that extraterrestrial life should also be based on carbon and liquid water and should not significantly differ from our life (and can even be intelligent). Physical conditions should also be similar to terrestrial conditions and temperatures near the planet surface should be comfortable for us. Therefore, the search for 'habitable zones' in extrasolar planetary systems is based on the postulate of the habitable zone with 'normal' physical conditions, i.e., pressure, temperature, and possibly an atmosphere composition that should contain oxygen. Note that the last condition is directly indicated in spectroscopic searches of exoplanets as a probable habitability sign. One can easily see that in this way we are searching outside Earth for... ourselves. However, should we not consider such an approach as 'Earth chauvinism'? The crusaders undertook crusades because they were sure that they and their faith were the best in the world, whereas all the rest is heresy.

In fact, the requirements presented above are based on a fanatic faith in accepted postulates that are perceived as a 'holy cow', although they are far from being obvious. So it is, for example, with the postulated necessity for atmospheric oxygen. Oxygen is virtually absent in the atmosphere of Venus. However, it was not always present in our atmosphere either. Geologically documented data about the appearance and evolution of oxygen in Earth's atmosphere have been discussed in many papers (see, for example, [5]). According to Rozanov's paleontological data, oxygen was absent in Earth's atmosphere only for the first 600–700 million years, while after 1 billion years its content reached 1% of the present day content (Fig. 1). There is no complete consensus on the evolution of the oxygen content. Thus, it was asserted in [6, 7] that terrestrial life existed virtually without oxygen for the first 2 billion years after its origin. Then, in the Phanerozoic, during the last 600 million years, the oxygen content in the atmosphere has been about 20%, with variations from 14 to 35%. The reasons the atmospheric oxygen content as the product of Earth's biota has changed in the Phanerozoic remain a subject of discussion. However, what is important is that the statement about the necessity of the presence of oxygen in an exoplanet's atmosphere as a criterion for habitability is not indisputable at all.

The temperature at the middle level of Venus's surface is 460 °C. It is well known that chemical reactions are drastically accelerated with increasing temperature. In addition, new reactions appear which do not proceed under normal conditions and produce substances stable only at high temperatures [8]. Many sea fauna species live near hot bottom sources at high temperatures and extremely high pressures. Thus, the restrictions mentioned above (including that on orbital parameters for searching for habitable exoplanets only in the 'comfortable zone', which is also called the Goldilocks zone) have no sound physical grounds. Many researchers take into account this circumstance and believe that the search for extraterrestrial life should also include other physical conditions different from 'normal' conditions. In his book, *Life in the Solar System and Outside* [9], Jones mainly considers life in its terrestrial, amino-nucleic acid form, but points out: "Our approaches should not be directly based on the terrestrial life form involving RNA, DNA (carbon and liquid water), and a certain group of proteins.... Following some variants of the search, we could find life based on a completely different chemical composition (without carbon and water)."

Moreover, an analysis of problems related to the concept of 'life' shows that the most important sign of life taken in a separate biocenosis and in the whole biosphere is the presence of molecular carriers of biological information. These carriers should be matched with a mutagenic autocatalytic system of chemical transformations inside a phase-separated object. This should provide the possibility of adaptive natural selection [10–12]. DNA and RNA appeared in terrestrial biocenoses as molecular carriers of biological information due to a number of factors, first of all, the presence of liquid water and the chemical composition of the prebiotic soup and atmosphere containing numerous reactive and sufficiently energy-saturated compounds like CH_2O, C_2H_2, HCN, NH_3, and CO (see, for example, [10, 11, 13]). At the same time, at high temperatures, the DNA molecules cannot fulfill their functions of molecular carriers of biological information because of the rapid decay of very specific and weak ($E_{\mathrm{fr}} < 40$ kJ mol^{-1}) hydrogen bonds determining the spatial structure of DNA molecules and providing the possibility of formation of double DNA helixes.

The biophysicist A Azimov considered the chemical makeup of life forms existing at high temperatures and indicated nucleic acids and proteins that can be based on nitrogen rather than carbon. It is the synthesis of such compounds that V N Snytnikov discussed based on the concept of astrocatalysis as the life origin process in the Solar System [14, 15]. In 2008, the *New Scientist* magazine

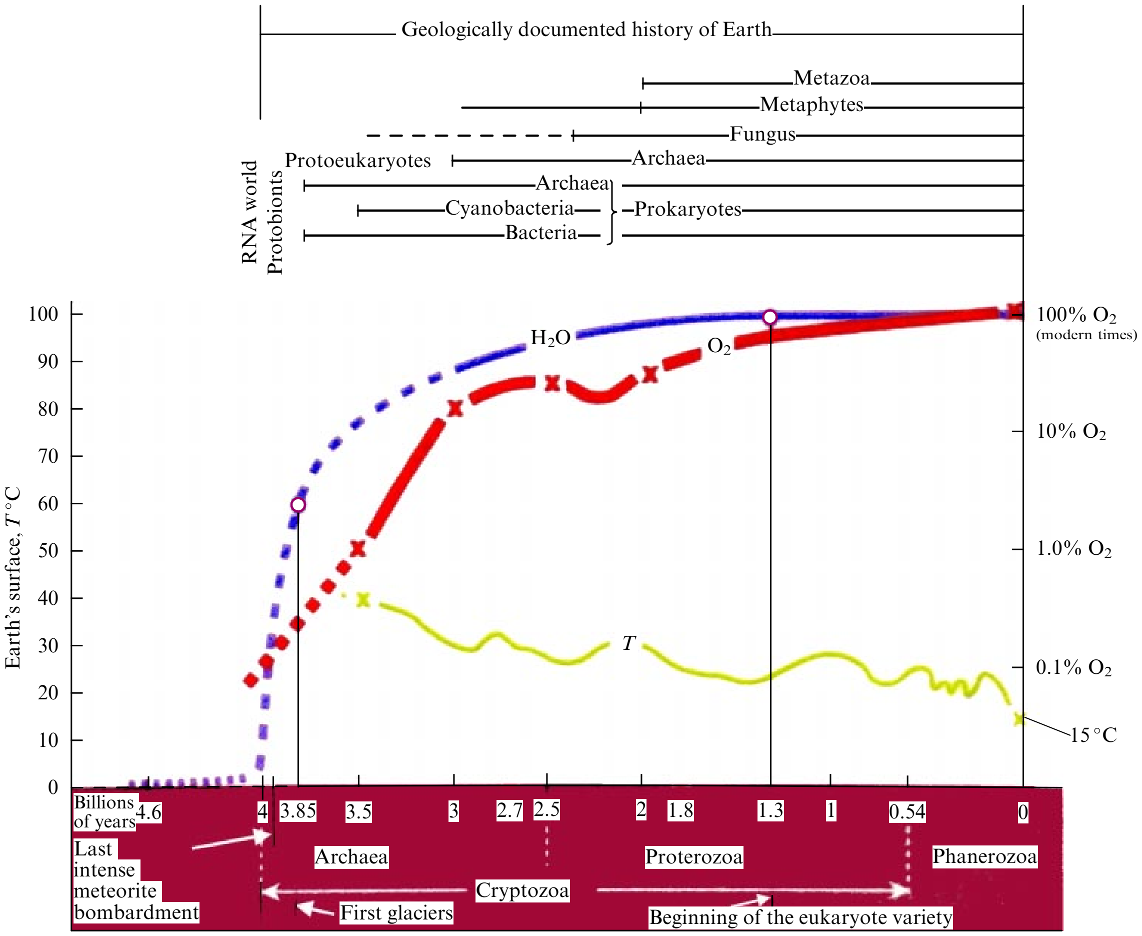

Figure 1. (Color online.) Evolution of the oxygen content in Earth's atmosphere for 4 billion years with respect to the present day-level, taken to be 100%. (Adapted figure from collection [4, p. 196]). The red curve is the estimated oxygen level; the green curve is the estimated temperature on Earth's surface. The present-day oxygen content in the atmosphere is 20.95%.

published a thematic issue devoted to possible extraterrestrial life forms. After publication of the first reports about the hypothetical discovery of life on Venus, A S Spirin commented on the possibility of life on Venus as follows: "As a molecular biologist... I have found nothing that would principally contradict the possibility of existing living organisms under conditions on Venus..." [16].

A few dozen of the first discoveries of exoplanets have already shown that physical conditions on some of them should be close to Venusian [17]. Therefore, the planet Venus, with its thick, hot (735 K), nonoxidizing CO_2 atmosphere and high (9.2 MPa) pressure on the surface could be a natural laboratory for such studies. Due to the absence of new landing missions to Venus, we again studied in this work the TV panoramas transmitted by the Soviet Venera spacecraft in 1975 and 1982 from the surface of Earth's nearest planet, including images that had not been processed before. The TV panoramas were processed again using modern codes, resulting in a considerable increase in their resolution and detail. The analysis has revealed approximately 18 comparatively large objects with sizes from 1 dm to 1 m and unusual morphology. Some of them moved or changed their shape. Some objects were observed in some images but were absent in others. We have failed to explain the appearance of such objects as communication line noise. Physical conditions on the planet are supercritical concerning the basic components of Venus's atmosphere: carbon dioxide and nitrogen. Because the surface temperature in the landing places was measured to be 735 K on average and the thermodynamic properties of the medium are known, the results obtained require a critical analysis of the known strict restrictions on the origin of biocenoses with their living organisms if the latter are considered hypothetical objects of flora and fauna of the planet.

2. Hypotheses about possible life in the cloud layer of Venus

The cloud layer of Venus forms micrometer high-concentration sulfuric acid drops. The dynamics of the permanent cloud layer are well observed in the near-UV region at a wavelength of 370 nm (Fig. 2). Assumptions about the possible existence of life in the lower part of Venus's cloud layer, which have been proposed many times, are related to the fact that pressure (about 100 GPa) and temperature (about 330 K) at heights in the interval between 47.5 and 50.5 km are close to these under 'normal' terrestrial conditions.

These hypotheses are related to the results of searching for microbiological life in the upper layers of Earth's atmosphere [20, 21] and to hypotheses about life on Solar System planets and their satellites. The problem concerns discussions of

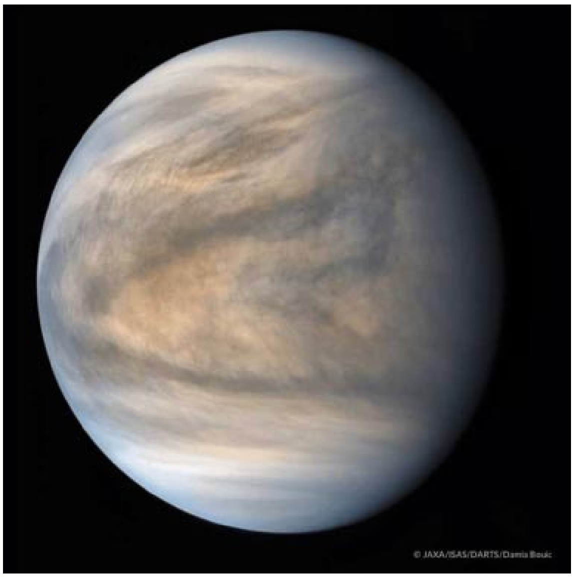

Figure 2. (Color online.) Venus's persistent cloud layer consisting of micrometric concentrated sulfuric acid drops is located at altitudes of 48–70 km. The photograph was taken in the UV range with the Japanese Akatzuki spacecraft, JAXA/ISAS/DARTS (Japan Aerospace Exploration Agency/Institute Space and Astronautical Science/Data ARchive and Transmission System), in 2018.

numerous recent and planned space missions [22–25]. It is known that the most probable candidates on which the discovery of extraterrestrial life forms is expected are Mars [26–28] and possibly some satellites of Jupiter and Saturn [29–31]. The absence of positive results on numerous spacecraft missions to Mars is a separate problem. As for Venus, the possibility of existing microbiological forms on this planet was discussed in papers [32–34], but the cloud layer of Venus's atmosphere was assumed to be the habitable medium. It seems that Carl Sagan was the first to propose this hypothesis in 1967 [35]. However, the hypothesis about life on Venus's surface was first proposed only in 1975 as a comment on the TV image of Venera 9 in the book by L V Ksanfomality [36]. The microbiological habitability of clouds was discussed in numerous papers. Cockell [33] concluded that conditions in the above-mentioned interval of heights are compatible even with terrestrial biology, although microforms are frozen at large heights. In the following papers, the properties of a medium favorable to bioforms were indicated, including the physicochemical properties of a carbon dioxide medium with sulfur components. Such conclusions may seem paradoxical; however, a number of discoveries made in recent decades have demonstrated the habitability of some places on Earth with extremal physicochemical conditions. Thus, microorganisms were found capable of enduring and (or) maintaining active life activity at high pressures (a few hundred MPa) [37], at low and high temperatures [38–40], in concentrated acid solutions [41] and solutions with a very low pH [42], in supercritical CO_2 [43], under hard radiation exposure [44], in an anhydrous dry medium [45], at large depths under Earth's surface [46, 47], and in the atmosphere at heights up to 77 km. The survival of a number of extremophiles under space vacuum conditions [48] and the preservation of their viability in the latent state were also demonstrated. Until recently, the red-hot and virtually anhydrous (about 20 ppm of water in the near-surface atmosphere) Venusian surface itself was completely ruled out as a possible habitable medium for any life forms [33]. The surface temperature is 460 °C on average and pressure is 9.2 MPa (down to 4.5 MPa in mountainous regions), which is incompatible with terrestrial life forms. The problem of survival of living microforms in the cloud medium of Venus consisting of micrometer sulfuric acid (about 75%) drops, which is common to all the above-mentioned hypotheses, also remains.

The leading role in the studies of Venus historically belongs to the Soviet Union. The Venera spacecraft missions were quite informative [49–51]. The rather high near-surface pressure and temperature of Venus's atmosphere proved to be unexpected. The Venera spacecraft provided data on the chemical composition of the atmosphere. The elemental composition of the soil was spectrometrically studied, the near-surface wind velocity was measured [52], and electric discharges (lightning) were discovered in the atmosphere [53]. Direct photographs of the surface were taken for the first time. Radiolocation mapping of the planet was performed from the orbit of an artificial Venusian satellite. The data obtained indicated probable volcanic activity on Venus, whose manifestations were earlier presented in [54]. Numerous hypotheses and discussions concerning the possibility of existing life on Venus are presented in [24, 32–34, 55–59]. The authors of [60] assume that Venus at the early stages of the Solar System's evolution had more favorable conditions for life than Earth. Based on topographical data of the Magellan mission, climatic conditions on Venus were simulated for a period up to 2.9 billion years into the past [61]. It was assumed that life in the Solar System could have first appeared namely on Venus, and the panspermic model of the transport of microbiota from Venus to Earth was proposed in [62].

The recent discovery of extremophiles and spores in the upper layers of Earth's atmosphere [58] is also considered to be an argument confirming the possibility of existing analogous life forms in Venus's atmosphere [32–34, 55–59] in the medium containing H_2S, SO_2, COS, and a small amount of water vapor, comparable to that in the driest regions on Earth [63]. It was also pointed out that an ozone layer was discovered in Venus's atmosphere in 2011 [64], which weakened the action of solar UV radiation on microorganisms. The authors of [56] considered a possible protective mechanism of phototrophic organisms based on the action of sulfur allotropes contained in Venus's atmosphere. Among recent studies on the possible existence of microbiological forms in the cloud layer of Venus, we point out a detailed theoretical study published by L Sanjai and coworkers [65].

Note, however, that, as a whole, the survival of living microforms in Venus's cloud medium consisting of micrometer 75% sulfuric acid drops seems problematic.

3. Venera spacecraft TV experiments

Direct TV studies of Venus's surface remain a unique experiment. In 1975, two Soviet Venera series spacecraft, Venera 9 and Venera 10, landed on Venus's surface. The first TV experiment on studying the planet surface was one of the most important. After seven years, in 1982, the more sophisticated Venera 13 and Venera 14 TV experiments were performed. The TV image communication is a popular modern method for studying celestial bodies and searching for life or its traces on Solar System bodies. This method is extensively used at present to study another planet, Mars.

In 2018, six spacecraft, including Exomars, were operating in Mars's orbit. The spacecraft transfer detailed TV images of Mars, while the study of the planet's surface is presented by Mars rover TV photos. At the same time, already more than 40 years ago Venera spacecraft studied Venus's surface using the TV method, when TV photos of the planet surface were obtained for the first time. Note that none of the world's space agencies has repeated these experiments so far, mainly because of their extreme technological complexity. The 1980s were the peak of Soviet investigations of this nearest planet by space means. Venera spacecraft performed complex experiments, descending into the planet's atmosphere, which was so dense that the first Venera 4 spacecraft probing the atmosphere (1967) was crushed by the atmosphere already at a pressure of 0.72 MPa at the height of about 25 km over the planet's surface. The next Venera 5 and Venera 6 spacecraft (1969) withstood a pressure of 2.7 MPa (the last measurements were performed at a height of about 17 km) and were also crushed by the atmosphere. Venera 7 (1970) and Venera 8 (1972) were the first spacecraft to land in the operation state. The first photos of the surface were sent by Venera 9 and Venera 10 in the fall of 1975. At an atmospheric pressure exceeding that on Earth 92 times and a temperature 460 °C, they operated for almost 1 hour until their destruction. All these spacecraft, created by a group of constructors at the Lavochkin Research and Production Association [66], were equipped with special TV cameras [67, 68]. The images obtained were black and white, not very detailed but sharp (Fig. 3). More complex experiments were performed on the Venera 11 and Venera 12 spacecraft in 1978. The optical windows of the TV cameras had special lids to protect them during landing, which had to be dropped with a special device after landing. However, the experiment was unsuccessful, because the spacecraft design neglected some specific features of Venusian conditions and the lids were not detached. For more than an hour, cameras sent to Earth only the image of the inner surface of the lids, whereas the appearance of the landing surface remained unknown.

TASS reported other spacecraft experiments, for example, the discovery of atmospheric electric discharges (thunderstorms) on Venus [53]; however, the unsuccessful TV experiment was not mentioned. Later, when the 'secrecy' was lifted, problems with Venera 9 and Venera 10 were also revealed: only one lid opened on each of the cameras in each spacecraft.

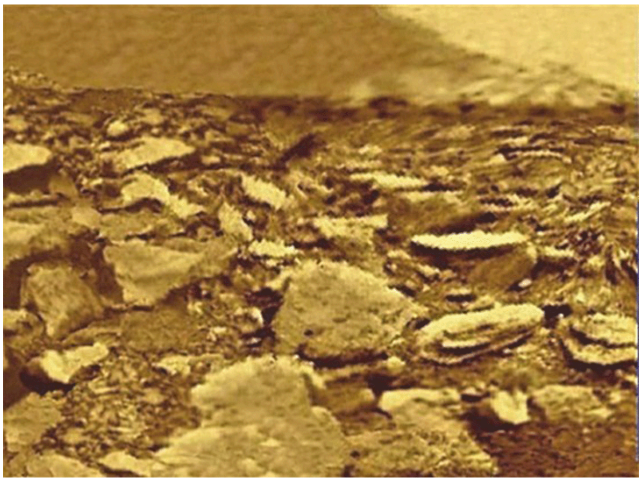

Figure 3. (Color online.) Venus's surface. The image is constructed based on a portion of the panorama sent in 1975 from the Venera 9 landing site. Geometrical distortions are corrected.

Figure 4. (Color online.) The Venera 13 spacecraft during laboratory tests. The TV camera entrance closed with a lid is located at the top of a spherical body over the inscription CCCP. A spiral omnidirectional transmission antenna is located over a round shield decelerating the spacecraft's descent in the dense atmosphere of the planet. The landing buffer below absorbed the shock energy during landing. The ring to the right over the landing buffer is the antenna of the Groza instrument which detected electric discharges in Venus's atmosphere. The spacecraft height up to the circular parachute shield is 1 m.

Venera 13 (Fig. 4) and Venera 14 became the complete triumph of researchers. Detailed color images of the 'panorama' of Venus's surface sent by these spacecraft in March 1982 were reproduced in many of the world's publications. The scientific aspect of TV experiments was reported in numerous publications, but the means providing the observation of Venus's surface remained poorly known to readers.

The optomechanical TV cameras for spacecraft were developed by a group of researchers headed by A S Selivanov and Yu M Gektin at the Research Institute of Space Instrument Making [67–69]. M Ya Marov recalls that, during the discussion of the report about experiments performed on Venera 7 (1970), the president of the Academy of Sciences of the USSR, M V Keldysh, proposed for the first time to obtain TV images of Venus's surface. This work was commissioned to A S Selivanov's group, who had already built TV cameras for moon rovers and landing spacecraft for studies of Mars.

The TV cameras developed by this group had an unusual design. CCD arrays, which are now used in electronic cameras and telephones, were absent at that time. In the 1960s–1970s, moon and Mars spacecraft were equipped with film cameras with automatic devices for chemical developing and subsequent electronic scan and radio-line image transfer. However, the temperature in the TV cameras aboard Venera spacecraft continuously increased, and it was impossible to use the photoprocess.

The use of transmitting TV tubes, which are not suitable for operation at high temperatures, not only was more risky but also required a considerable memory volume. Because of this, an FEU-114 photomultiplier, developed by a group of researchers headed by G S Vil'dgrube, was used as a photodetector. The spectral characteristic of the FEU-14 photocathode corresponds to the multialkali type (Fig. 5a). The maximum sensitivity was achieved at a wavelength of 550 nm, while at wavelengths of 400 and 760 nm the sensitivity was 0.2 of its maximum value. The TV camera was technically complex and its operation voltage was about −1500 V.

An opaque screen with an aperture of 11 min. of angle was mounted in front of the PM cathode. An objective produced an image on the screen, and the image element falling on the aperture was the transmitted point of the image. A mirror mounted in front of the objective reflected the spacecraft landing site and rocked within about 40°, one oscillation taking 0.78 s for the cameras on Venera 13 and Venera 14 and 3.5 s for those on Venera 9 and Venera 10. In this way, one image line was produced whose elements ran by turn through the aperture. Unlike the line of a usual TV image, this line was oriented vertically, and at the end of each line a special mechanism turned the mirror at an angle corresponding to the aperture size in the plane perpendicular to the rocking direction. In this way, the next line of the image was drawn. To remove the camera from thermal radiation penetrating inside, a periscope system was used with the camera in its lower part and a scanning mirror in the upper part. For Venera 13 and Venera 14, the entire image consisted of 1000 lines, each line containing 211 pixels and 41 service information pixels.

The optical axis of the objective was directed downwards at an angle of 40° to the vertical, and the panorama covered a band from horizon to horizon. A newly processed portion of the image sent by Venera 9 is presented in Fig. 3. Cameras on Venera 13 and Venera 14 transmitted, along with black and white, color-divided images in red, green, and blue filters (Fig. 5b), but blue panoramas proved to be virtually useless because of the almost complete absorption of blue radiation in the atmosphere. The scan of one complete image took 13 minutes. Cameras on Venera 13 and Venera 14, with a guaranteed operation time of 30 min, continuously operated for more than 2 hours and sent many full and partial panoramas. The images and service data were coded in a 10 bit system (1024 levels altogether, 512 of them in the image) and were sent via an omnidirectional antenna from the spacecraft transmitter (see the helix at the top of Fig. 4) to the orbital spacecraft.

The entrance of the optical system was located at a height of 82 cm for Venera 9 and Venera 10 and 90 cm for Venera 13 and Venera 14 over the plane of the landing buffer. Compared to the optical resolution of Venera 13 and Venera 14 cameras, the resolution on more modest panoramas sent by Venera 9 and Venera 10 was lower by almost a factor of two: 517 vertical lines in the 189° panorama, 115 pixels in each line, and the complete image was obtained for about 30 min. The angular resolution (single pixel) was $21'$ [7]. Venera 9 and Venera 10 cameras sent only black and white images. Each Venera spacecraft (see Fig. 4) had two cameras mounted on its opposite sides. The panorama sent by Venera 9 encompassed 174°, the exposure time (with simultaneous transmission) was 29.3 min. Then, a photograph of the right part of the panorama within 124° was taken.

Venera 9 and Venera 10 spacecraft operated on Venus's surface for 50 and 44.5 min, respectively. The panorama scope of Venera 10 was 184°, then two 63° and 17° portions at the beginning and end of the image were again sent. The images were coded in a 6 bit system (64 levels), sent via the omnidirectional antenna from the spacecraft transmitter to the orbital spacecraft (a satellite on a 40-hour orbit) and were retranslated in real time to Earth via highly directional antenna.

4. Physicochemical properties of the atmosphere and surface in Venera 13 and Venera 14 landing sites

The main results of the Venera 13 and Venera 14 missions and the properties of these spacecraft are presented in the special issue of *Space Research* [70]. The coordinates of the landing site of Venera 13 (1 March 1982) were 7.5°S and 303.5°E, the height of the place over the nominal radius level of 6051 km was 1.9 km. The temperature was 735 K (462 °C) and pressure was 8.87 MPa, corresponding to a gas density of 59.5 $\mathrm{kg\,m^{-3}}$. The local time was 10 am and the solar zenith angle was 37°. The illumination by scattered solar light was 3–3.5 klx. The Venera 14 lander (5 March 1982) also landed in the equatorial zone (13°S, 310°E), the height of the landing place being 1.3 km over the 6051-km level (the average radius of the surface). Here, the physical conditions were measured to be: temperature 738 K, pressure 9.47 MPa, and atmospheric

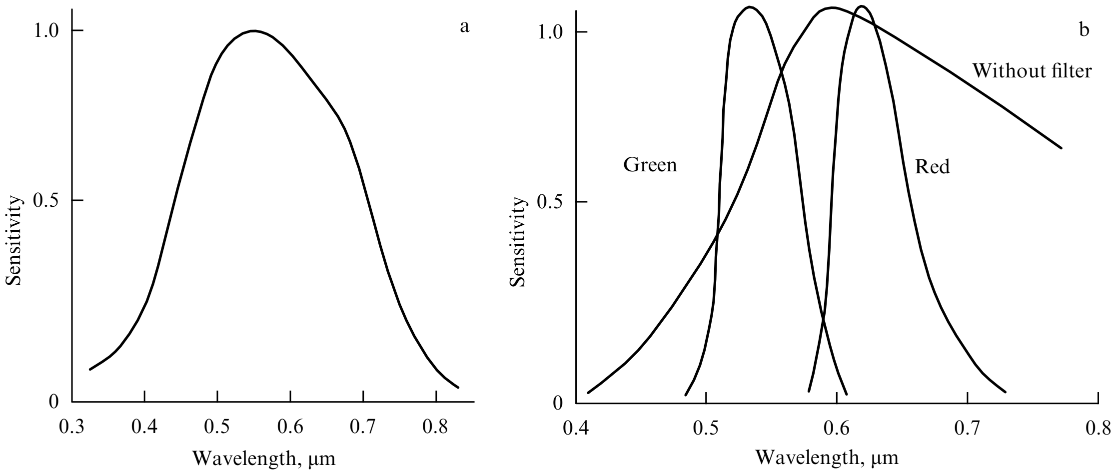

Figure 5. Spectral characteristics of optical detectors on Venera 9 and Venera 10 (a) and optical detectors and light filters on Venera 13 and Venera 14 (b).

density about 65 kg m^{-3}. Gas analyzers indicated that the atmosphere consisted almost completely of CO_2 and N_2 ($\sim 0.965\,CO_2$ and $\sim 0.035\,N_2$). The atmosphere near the surface includes the following small components: 1.5×10^{-4} SO_2, 2×10^{-5} H_2O, about 2×10^{-5} O_2, up to 3.0×10^{-4} COS (carbonyl sulfide) and H_2S, chlorides (0.4×10^{-6} HCl), and fluorides [66–68]. The local time was about 10 am and the solar zenith angle was 36°. The illumination of the scene also reached 3.5 klx [68, 71]. On 1 and 5 March 1982, Venera 13 and Venera 14 sent 37 TV panoramas (or portions) of their landing site on Venus's surface.

Venus's atmosphere at heights of 0–49 km contains a small amount of aerosols, and its transparency is mainly limited by Rayleigh scattering. The high, although inhomogeneous, transparency of Venus's atmosphere near its surface was demonstrated in all in situ experiments. In the years of extensive Venera and Pioner–Venera studies of Venus, a few important papers were published devoted to the cycles of thermochemical interactions of Venus's atmosphere and surface, which is much more greatly (7–20 times) enriched by sulfur than Earth's surface. Because of the huge mass of the atmosphere, the specific feature of its dynamics and the absence of seasonal phenomena (the polar axis is almost normal to the orbital plane), local temperature variations near Venus's surface are insignificant and are close to the natural thermostat. The physical conditions on the planet rule out any rainfall (containing water).

After the end of the Venera 9 and Venera 10 missions, the co-authors of the TV experiments, Yu M Gektin and A S Panfilov, considered models of thermochemical equilibrium of gaseous components of the atmosphere in the interval of heights from the surface to 30 km [72]. They discussed more than 180 equilibrium chemical reactions between small components of the atmosphere, including NO, NO_2, SO_2, SO_3, COS, H_2S, CS_2, NH_3, CN, and C_2N_2. Another earlier Russian publication is the book by V P Volkov, *Chemistry of Venus's Atmosphere and Surface* [73], where the features of the chemistry of many natural processes on Venus are formulated based on the data on the atmosphere and surface composition and physical conditions on the planet. Volkov pointed out that the near-surface part of the Venusian troposphere is in high-temperature chemical equilibrium with surface rocks, the reduction–oxidation regime of the surface being determined by a solid pyrite–anhydride–magnetite mineral buffer operating independently of the local content of magnesium, silicon, aluminum, and iron in the rock. The main variants of chemical atmosphere–high-temperature surface interactions were proposed, in particular, the reaction

$$3\,FeMgSiO_4 + CO_2 = 3\,MgSiO_3 + Fe_3O_4 + CO$$

(olivine + carbon dioxide = enstatite + magnetite + carbon monoxide), as well as other variants.

In the same period, a number of studies by other authors were published in which possible variants of the atmosphere–surface interaction were also considered [74–76]. In [76], the weathering of rocks was considered, in particular, the reaction of the fayalite mineral Fe_2SiO_4 with a small atmospheric component COS:

$$Fe_2SiO_4 + 4\,COS \Leftrightarrow 2\,FeS_2 + SiO_2 + 2\,CO_2 + 2\,CO\,,$$

which leads to the formation of pyrite FeS_2 on the surface and in the granular soil, the reaction shifting to the right at less high temperatures. In other words, pyrite FeS_2 proves to be stable in mountainous regions. Obviously, it would be naive to expect that all the basic chemical chains could be established at such an early stage of investigations. The authors of the papers mentioned above (and following papers) failed to reach any conclusions about possible phase transitions in compounds formed near the surface at 735 K.

Eight years after the completion of the Venera 13 and Venera 15 missions, the Magellan mission was started [77], which mapped almost the entire surface of Venus by radiolocation methods. In 1995, regions with high reflectivity were found in mountainous areas of the Lakshmi Planum and on the slopes of the tallest mountain on Venus, Maxwell Montes (the only masculine gender name on Venus). The study of these regions resulted in a hypothesis about sediments precipitated in mountainous regions (the heights correspond to the temperature interval 650–700 K). It is known that high radio reflectivity is inherent both in soils with high permittivity and electric conduction and in highly granulated soils [78, 79]. However, the hypothesis about sediments was the most theoretically developed. It is assumed that pyrite, tellurium, and metal sulfides, in particular, lead and bismuth sulfides, can change their phase state at the temperatures mentioned above [80–82]. However, no assumptions about media possessing phase transitions at the 'zero' level of Venus's surface were made.

The chemical composition of the soil at the landing site of Venera 14 was investigated in experiment [83], with the results presented in Table 1. According to the interpretation of the authors of [83], the soil composition is close to terrestrial tholeiitic basalts.

In the upper part of the cloud layer (58–70 km), possible reactions between SO_2 and NH_3 can produce ammonium pyrosulfate $(NH_4)_2S_2O_3$ aerosol [84]. However, the formation of this aerosol in the lower atmospheric layers is excluded.

More detailed data about possible compounds contained on the Venusian surface and their phase composition in the supercritical state of the Venusian atmosphere are absent in the literature.

5. Images of Venus's surface

The image processing means available in 1982–1984 were rapidly exhausted, and the results obtained based on them

Table 1. Composition of Venus's surface [83].* Chemical composition of the ground at the Venera 14 landing site.

Oxides	Content, Venera 14, %	Content, toleit basalt, %
SiO_2	48.7 ± 3.6	50.6
TiO_2	1.25 ± 0.41	1.2
Al_2O_3	17.9 ± 2.6	16.3
FeO	8.8 ± 1.8	8.8
MnO	0.16 ± 0.08	0.2
MgO	8.1 ± 3.3	8.5
CaO	10.3 ± 10.2	12.0
Na_2O	2.4 ± 0.4	2.4
K_2O	0.2 ± 0.07	0.1
S	0.35 ± 0.28	0.07 ± 0.01
Cl	< 0.4	0.01

* Data were not confirmed.

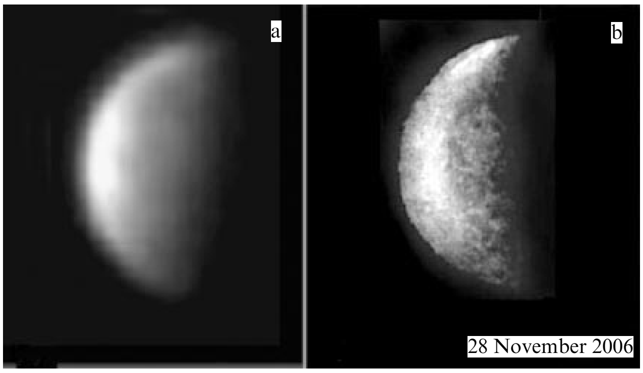

Figure 6. Progress in image processing (1999–2006) [85]. Views of the planet Mercury in the best usual terrestrial photo (a) and after image processing by new methods (b). (Electron photos and image processing by L V Ksanfomality).

were published in [67–69] and other numerous papers. Although the panoramas of Venus's surface were obtained more than 40 years ago, none of the world's space agencies has repeated this experiment so far. At the same time, progress in the development of image processing means and in the experience in this field considerably improved the quality of the panoramas obtained.

An important role belongs to the experience accumulated during the processing of electronic images of Mercury [85] obtained by ground-based means. The usual 'classical' image of Mercury is presented in Fig. 6a. Figure 6b shows the result of processing of an array of electron images obtained at the same phase of the planet. Above the equator, on the right, a 1000-km 'sea', the Caloris Basin, is seen. These results already allow us to compare the ground-based photos of Mercury with space photos.

Figure 7 presents full panoramas obtained by Venera 9 and Venera 10 initially processed in 1976–1998. These images were already suitable for preliminary geological analysis [86]; however, their present-day processing considerably improved the image resolution and discernibility of small details, which allowed us later to find the objects described below. The images have the following geometrical properties. The bending of initial images is explained by the inclined position of the optical axis of the objective directed by a scanning mirror downwards at an angle of 50° to the vertical. The horizontal straight line, which can be drawn through the panorama center, corresponds to the intersection of the surface by a plane in which the optical axis of the objective lies. The amplitude of scanning from the central line was from ±19° to ±20° along the line (along the vertical in the panorama). During successive turns of the mirror axis from the panorama center, successively increasing geometric distances from the surface got into each next line.

Figure 7. Venera 9 and Venera 10 panoramas initially processed in 1976–1985.

Figure 8 shows a newly processed Venera 9 panorama. If the scan geometry is taken into account, the shape of this corrected panorama is related only to the upper half of the image located over the horizontal line passing through the panorama center in Fig. 7. Corrections to the geometry of the lower half should bend its image in the opposite direction, although to a lesser degree, because the central line plane is inclined by 50° to the vertical. In this way, a photographic map is constructed in which all elements have the same scale [see Figs 30 and 31 in the Appendix (Section 9)].

To obtain a perspective image, image correction was performed in [87] so that the image acquired an arc shape. We also used this processing method. In this case, the central lower part of the panorama is inevitably distorted so that the shape of a toroidal landing buffer, which looks like an arc in Fig. 7, becomes a straight line. These distortions should be taken into account in the analysis of images.

As mentioned above, the resolution of the Venera 13 and Venera 14 cameras exceeded that of the Venera 9 and Venera 10 cameras 4-fold. Venera 13 and Venera 14 panoramas initially processed in 1976–1998 are presented in Fig. 9. Four complete

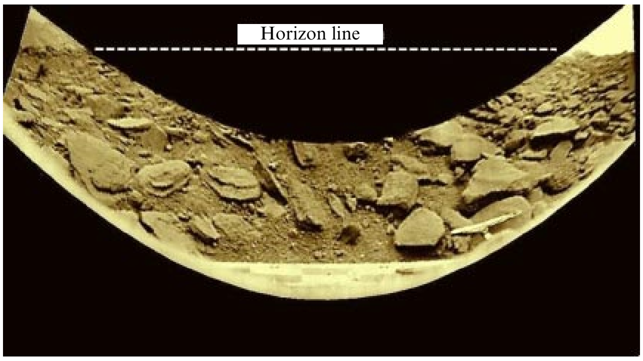

Figure 8. (Color online.) Newly processed Venera 9 panorama.

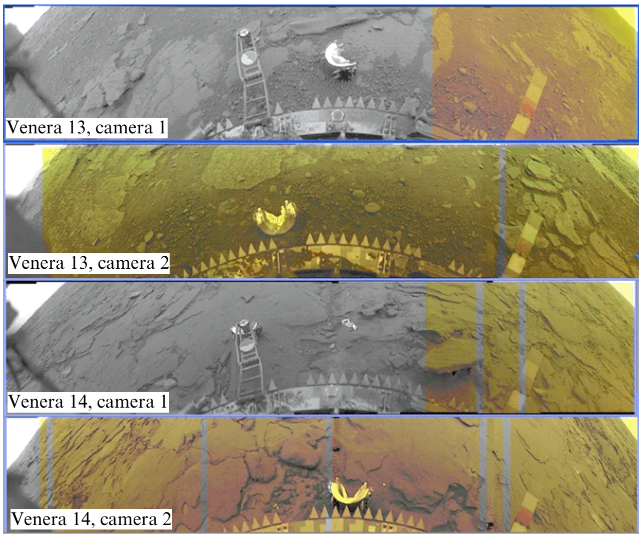

Figure 9. (Color online.) Venera 13 and Venera 14 panoramas processed in 1982–1998.

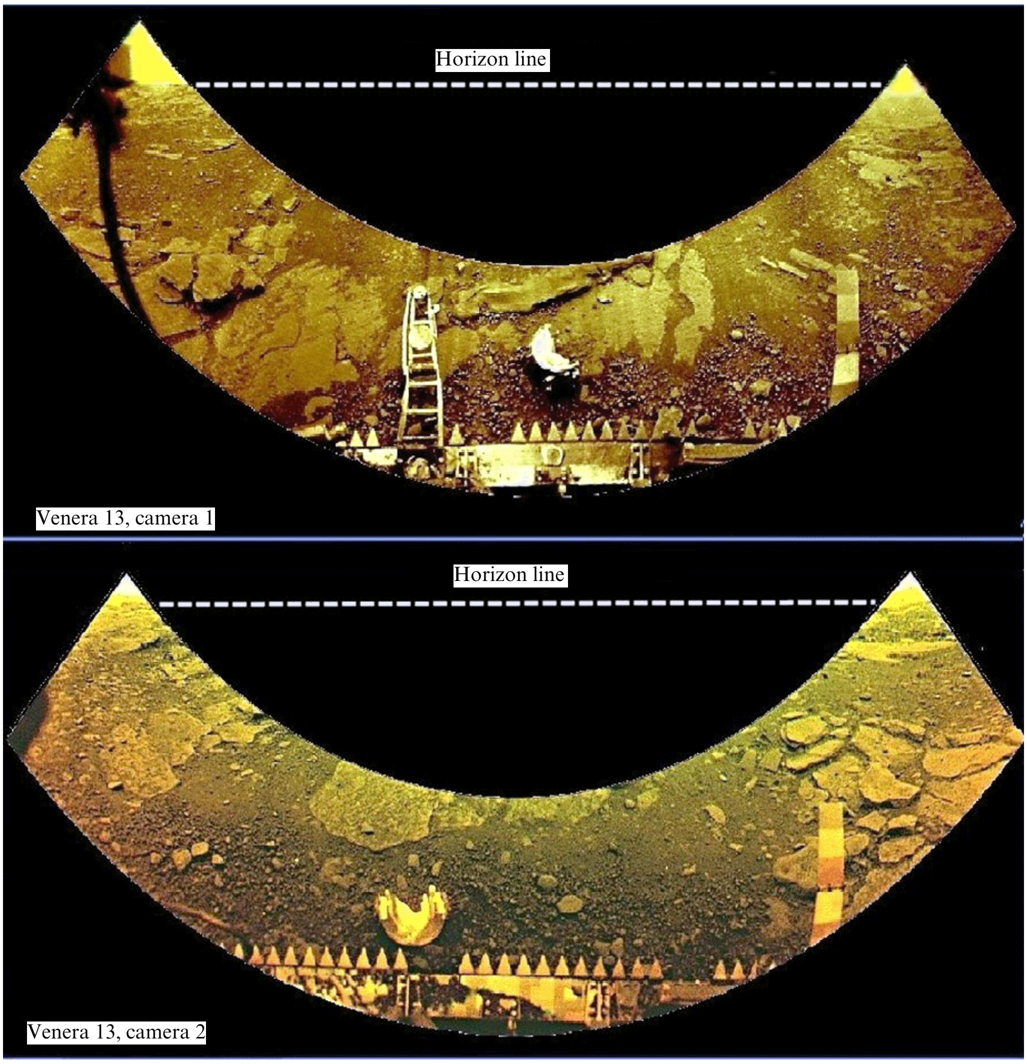

Figure 10. (Color online.) Two processed Venera 13 images. Views of Venus's surface on both sides of the lander. Geometrical distortions are partially corrected (see the text). The details of the images are seen over the toothed landing buffer: a bracket of the device for measuring the ground density, a dropped half-cylindrical TV camera lid, and a panel for controlling the color reproduction. The scale is illustrated by the tooth step of a vortex generator in the landing buffer equal to 5 cm. The size (diameter) of the half-cylindrical lid is 20 cm.

panoramas constructed from numerous primary images are shown. Telemetric insets were removed in the initial processing. Papers in the period from 1983 to 2011 in which Venera panoramas and portions thereof were presented used the images shown in Fig. 9.

5.1 Newly processed Venera 13 and Venera 14 panoramas

A new, time-consuming processing used all 37 images obtained by Venera 13 and Venera 14 and four Venera 9 and Venera 10 images. The processing of the initial images completely ruled out their retouching, filling-in, additions, or corrections. The contrast and brightness of the images were corrected. If the image structure allowed, a 'sharpness enhancement' operation was applied together with a low 'spread' level of standard Microsoft Office Windows programs.

Up to 16 different codes were used, including special programs developed for processing images of Mercury. As shown in Fig. 9, complete color panoramas were sent by cameras 2, while the color part of images sent by camera 2 covered only 30% of the image area. During processing, the averaged shade of the color part of the panoramas was extended to the entire image of cameras 1. A small area of the sky in the right-hand part of all panoramas has a yellow color inherent in the Venusian sky. However, in the left-hand part of the camera 2 panoramas, only a small triangular part is yellow, because the complete part is absent in the color-divided panorama. In color images sent by camera 1, the averaged color shade of the sky in the right-hand part of the panoramas is also assigned to the sky portions in the left-hand part. All the other details of the newly processed images in Figs 10 and 11 completely correspond to the initial panoramas.

A pair of processed images in Fig. 10 presents a view of Venus's surface on both sides of the Venera 13 spacecraft. If we turn the upper panorama and make its ends coincident with the lower panorama, the relief of the end of the right-hand part of the upper panorama joins with the left-hand part of the lower panorama and vice versa. Geometrical distortions are partially corrected, as mentioned above. One can see from a comparison with Fig. 9 that the discernibility of details considerably improved.

The same can be said about Fig. 11, where two processed Venera 14 images present a surface formed by rugged layered plates (sedimentary or volcanic origin). The region is a plain,

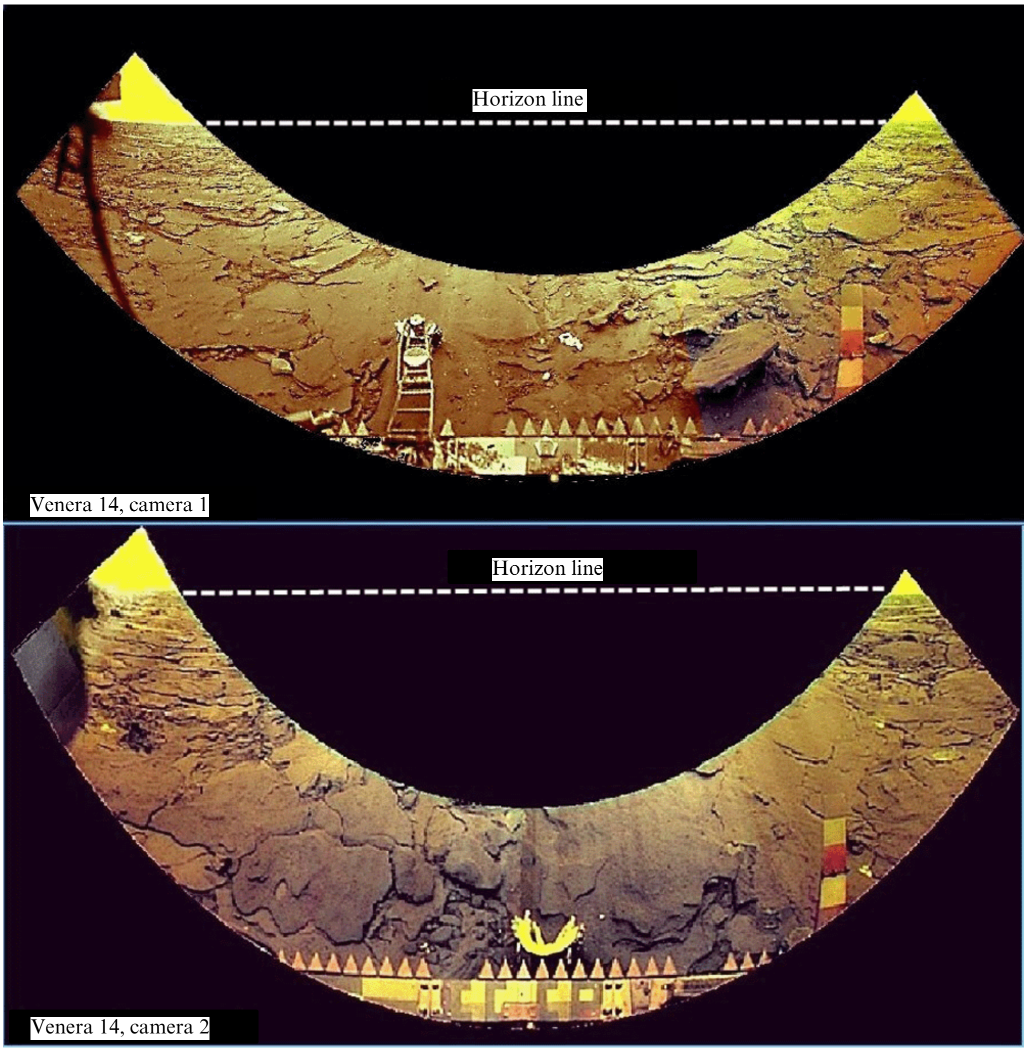

Figure 11. (Color online.) Views of the surface on both sides of Venera 14; two processed images. Unlike the porous ground in Fig. 10, the surface consists of durable layered plates of sedimentary or volcanic origin. The region is characterized by a geometrically even horizon line. For the objective height of 90 cm over the even surface, the horizon line on Venus is located at a distance of 3.5 km.

as follows from the geometrically flat horizon line. The surface on the right-hand side of the upper panorama in Fig. 11 exhibits a bright spot of light, which is difficult to explain, because it is assumed that the daylight is scattered by an extended cloud layer and the Sun disk is not seen from the surface. The position and shape of the images in Figs 10 and 11 somewhat differ because of the different accidental slope of the landers.

5.2 Tentative living objects

The updated image processing considerably improved the image details. The aim of new papers [19, 88–98] was to find any differences in new or successively recorded initial panoramas (the appearance or disappearance of image details or a change in their shape) and to explain why (for example, due to the wind). Another feature of the required objects is the peculiarities of their morphology distinguishing their shape from that of usual geological formations, for example, the presence of shape symmetry.

Analyses of the details of surface images allowed us to distinguish a few objects satisfying formulated criteria. In 2012–2013, parts of images were presented that were tentatively assigned to living forms [19, 93, 96]. By 2018, the number of hypothetical living objects found in Venera 9–Venera 14 panoramas reached 18. Calculations showed that the probability of the accidental appearance of images of ordered structures caused by radio line noise is vanishingly small. The features and details of some of them are considered in the Appendix (Section 9).

As examples of the objects found, a moving object called ‘scorpion’ (Fig. 12) and an object called ‘stem’ (Fig. 13) are presented. (Note that all the names of the objects considered are of purely conditional and in no way correspond to their terrestrial analogs). Before the appearance of ‘scorpion’, the Venera 13 lander had already operated for more than 1 hour 27 min (the onset of the 6BW image scan). Therefore, the first assumption was that this regular structure is the product of the destruction of some part of the lander itself. However, the lander continued to operate for another hour, demonstrating that it had not deteriorated up to that point; otherwise all its devices would have failed to operate due to catastrophic overheating. All the external operations (for example, the drop of lids, drilling machine operation) were completed less than 30 min after landing.

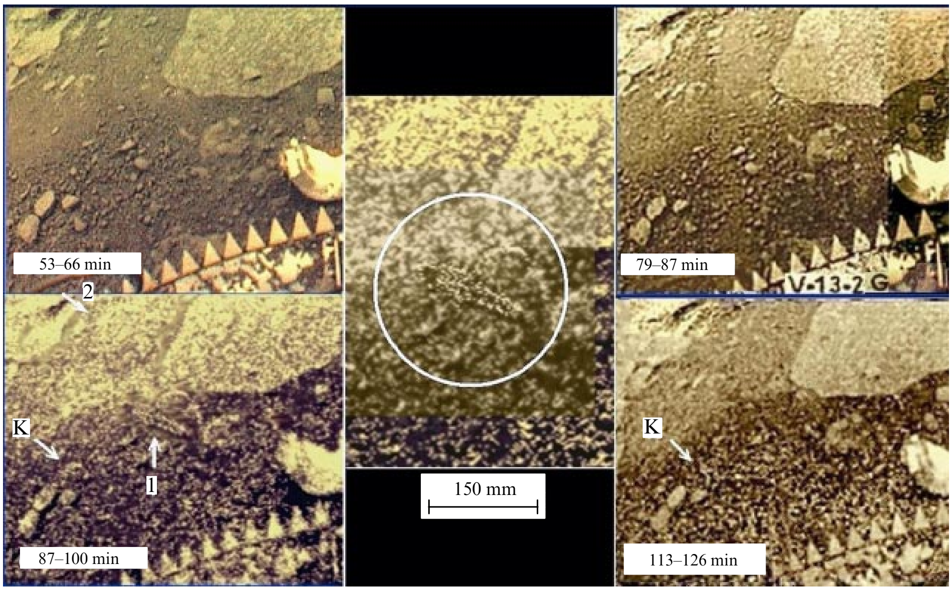

Figure 12. (Color online.) The moving object, scorpion, that appeared in the 6BW Venera 13 panorama obtained in the time interval from 87 to 100 min. The object is absent in images obtained before 87 min and after 113 min. Scorpion's size is indicted at the central part of the figure.

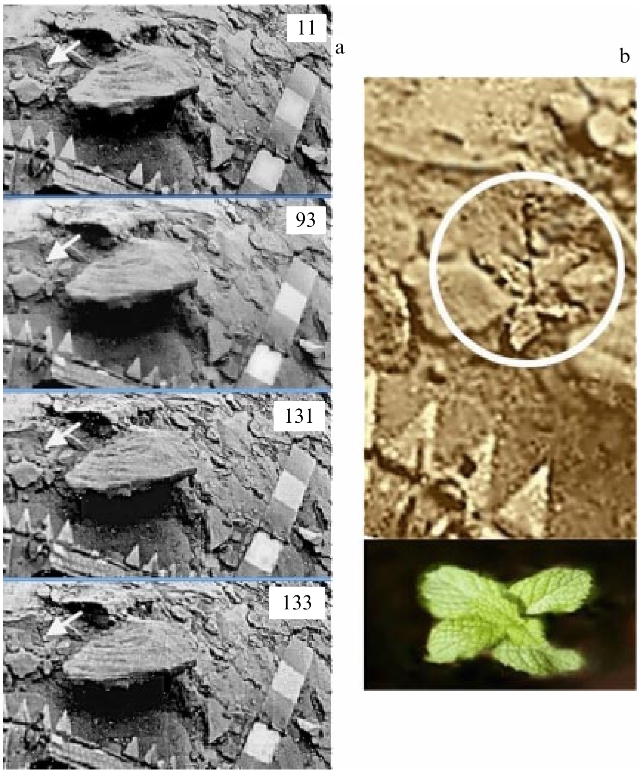

Figure 13. (Color online.) (a) Portions of four processed images. The arrow shows a thin inclined black line — the object resembling a repeating defect. (b) Details of the object shown by arrows in Fig. 13a as a hypothetical plant on Venus with a four-leaf at the base and a 'bud' at the top. Top view, about 60° to the horizon. The inset at the bottom shows a sample of terrestrial cruciferous plants with a similar leaf structure.

The assumption about the detached part also contradicts the fact that the object is absent in the next images. It was assumed, in particular, that the object could have been displaced by the wind, whose velocity near the surface was measured by the Venera landers. For the lander velocity at the landing point of 0.45 m s^{-1} [52, 99] and the atmosphere density of about 64 kg m^{-1}, the wind velocity thrust $F = \rho S v^2/2$ on the 'scorpion' cross section area $S = 0.012\ \mathrm{m}^2$ gives a pressure of about 0.08 N, which is insufficient for the displacement of scorpion by the wind.

One hypothesis explains the late appearance of scorpion as follows. The vertical velocity of the landing spacecraft found by the dynamic method was 7.6 m s^{-1} and the side velocity was within the method error. It is natural to expect that the side velocity of the lander was approximately the same as the measured wind velocity (0.3–0.5 m s^{-1}). The landing shock was $50g$ of Venus. The lander damaged the ground and threw it out in the direction of the side motion. The buffer and surface dust in the panoramas is mainly observed on the one side of the lander, where scorpion was found. The places where scorpion appeared were investigated in all the available panoramas. Scorpion is absent in the thrown out ground in the first image (53–66 min), being possibly buried with the soil. In its place, a hollow elongated groove about 100 mm in length is seen. In the second image (79–87 min), the sides of the groove are uplifted and its length increased to approximately 150 mm. The groove orientation is the same as that of scorpion. In the 87–100-min image, a regular scorpion structure appeared from the groove. It seems that by minute 93 (the panorama center), scorpion has already completely come out of the soil that covered it, a layer that probably did not exceed a few centimeters. Thus, the object rescue operation required about 1.5 hours. We can assume that this demonstrates its slowness and (or) limited physical capability. In the 113–126-min panorama, scorpion is already absent.

The length of scorpion is about 15–17 cm (see Fig. 12). Close to it, on the right, is located a semicircle formation, which turns by 90° in the next photos.

The example of how subtle objects (stems) can be found in well processed panoramas is presented in Fig. 13. The hypothetical stem in the processed images resembles a subtle defect, a thin black inclined line repeated in all the camera 1 images of Venera 14 in the same place. The arrows in Fig. 13 show its repeating position. After additional group image processing, an object resembling terrestrial plants becomes visible in this place (Fig. 13b, in the circle). A 'Four Leaf' near the stem base on the surface resembles terrestrial Cruciferae (inset at the bottom of Fig. 13b), but has only one 'leaf' layer.

Some objects of hypothetical living forms on Venus are presented in the Appendix (Section 9). The authors of this paper follow the system proposed in Ksanfomality's papers, where the objects found are classified by the biocenosis form (like terrestrial analogs) using the corresponding terminology. Of course, the classification of Venusian biocenoses, if they are real, can considerably differ from that of terrestrial ones.

6. Hypothetical photosynthesis

It is important to find out what energy sources can be used by the hypothetical fauna on Venus, with its almost oxygen-free, dry, and hot atmosphere. If this is autotrophic flora, samples, stems, indeed have been found. However, these 'fauna objects' [88] have a fairly large size, not being microorganisms. It is reasonable to assume that Venus's fauna, or at least some of it, like terrestrial fauna, is heterotrophic, and the source of its existence should be hypothetical autotrophic flora. The most probable assumed energy source is photosynthesis. As a rule, direct solar rays do not reach Venus's surface; however, the scattered light intensity there is sufficient for terrestrial-like photosynthesis. Note another feature of the hypothetical biosphere of Venus: the duration of the day and night amounts to 58.4 terrestrial days. In the case of terrestrial flora, a scattered light intensity of 0.5–7 klx is normal for photosynthesis, even in the thick forest depths. The scattered light intensity on Venus was measured to be of the same order of magnitude, from 0.4 to 9 klx.

Obviously, high-temperature synthesis in the nonoxidizing atmosphere should be based on completely different, unknown biophysical mechanisms.

Solar radiation spectra studied in experiments [100] are shown in Fig. 14a for different altitudes over Venus's surface. The solar radiation spectrum on the Venusian surface has a complicated shape (Fig. 14b), which is discussed below. Differences in the spectra are obvious. The properties of the environment are also different.

According to paleontological data [4], the evolution of terrestrial flora began at the end of the Silurian — beginning of the Devonian (periods 444–419 and 419–359 million years ago, respectively), when the oxygen content in Earth's atmosphere approximately corresponded to its present day content (see Fig. 1).

Despite the huge difference in present-day physical conditions on Earth and Venus, one of the hypotheses about the gradual change in physical conditions on Venus assumes that these conditions were once similar to those on the earlier Earth, and, in the absence of water bodies [79], Venus's biosphere gradually evolved to that existing under present day physical conditions to which all its mechanisms, including photosynthesis, have adapted for a few billion years. As mentioned above, the illumination of Venus's surface presently corresponds to that required for terrestrial photosynthesis.

Photosynthesis is the only process providing energy for almost all the terrestrial biota (except chemotrophic microorganisms). In fact, this is continuous global chemical production. Photosynthesis on Earth produces about 2×10^{14} kg of bound carbon per year, 80% of the product being attributable to oceanic plankton. The existence of photosynthesis is one of the most important characteristics of a habitable planet.

By comparing conditions for photosynthesis on Earth and for tentative photosynthesis on Venus, it is important to point

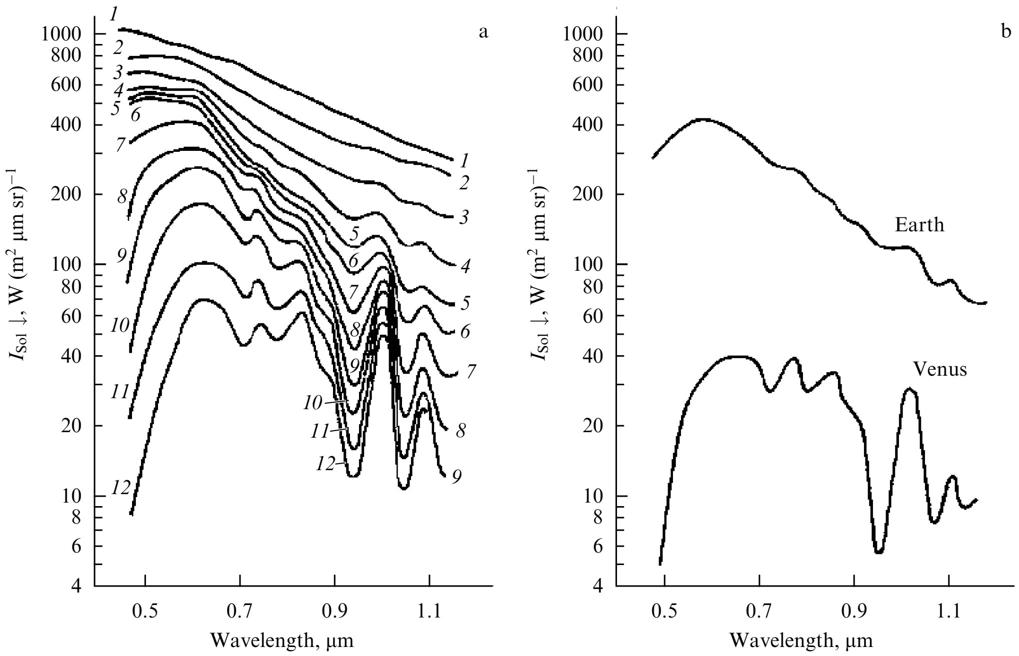

Figure 14. (a) Incident and scattered radiation spectra on Venus at various altitudes over its surface: (*1*) over clouds, at heights (km) of (*2*) 62, (*3*) 55, (*4*) 52, (*5*) 49 (*6*) 40, (*7*) 25, (*8*) 16.5, (*9*) 10, (*10*) 4.5, (*11*) 1 and (*12*) 0. Spectra were recorded with a Venera 14 spectrometer [100]. (b) Incident solar radiation spectra on Earth (for a clear sky) and Venus.

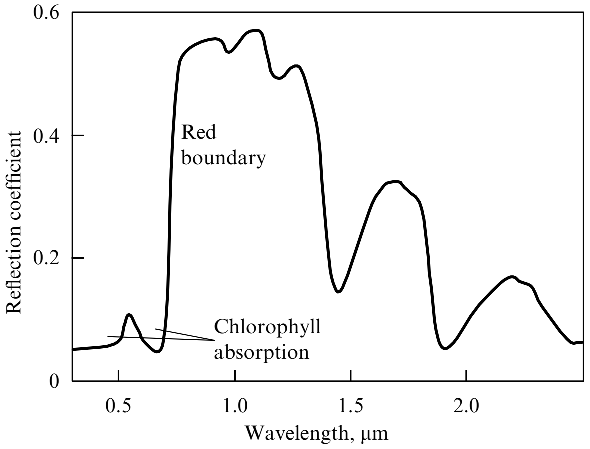

Figure 15. Reflection spectra of green leaves.

out the following circumstances. The absorption of light on Earth in photosynthesis followed by the formation of chemical substances with the release of oxygen occurs via a universal mechanism using green pigment chlorophyll [101]. This mechanism is critical with respect to the absorbed photon energy $h\nu$ and the radiation spectrum. Chlorophyll a with the molecular mass of about 890 is a component of chloroplasts, cellular organelles similar to mitochondria in their structure. Aside from chlorophyll, plants on Earth also use other pigments, for example, carotene. Photosynthetic reactions can be written in the simplified form as

$$CO_2 + H_2O + h\nu \rightarrow [CH_2O] + O_2 .$$

Thus, the initial components are present on Venus as well; although the amount of water vapor near Venus's surface is very small, about 20 ppm, this amount in mass is the same as in arid regions on Earth. The energy $h\nu$ required to produce one conditional $[CH_2O]$ molecule is 5.1 eV, but instead of the corresponding UV emission with a wavelength of about 240 nm, the photosynthetic mechanism uses the total energy of a few photons with wavelengths up to 680 nm (1.8 eV). More specifically, terrestrial photosynthesis in green plants is based on multiphoton processes and uses two spectral ranges, from 640 to 680 nm and from 410 to 450 nm, involving two systems of pigments. Note that this mechanism operates only if the incident radiation is present simultaneously in both these spectral ranges. Finally, the energy is accumulated in adenosine triphosphate (ATP). Photosynthesis is blocked for radiation with a wavelength shorter than 300 nm and is considerably complicated in the presence of IR radiation, for example, the IR radiation of xenon arc lamps in greenhouses.

A comparison of the spectra for Earth and Venus presented in Figs 14 and 15 shows that the requirements of terrestrial photosynthesis for radiation are satisfied near Venus's surface in the red and near-IR ranges; however, radiation in the wavelength interval from 410 to 450 nm is absorbed in the atmosphere. The hypothetical Venusian flora for photosynthesis has only the spectral interval 520–910 nm restricted on both sides (1.36–2.38 eV) by the additional 980–1025-nm IR band (1.21–1.27 eV). However, illumination of Venus's surface corresponds to the requirements of terrestrial photosynthesis. Therefore, getting away from the huge differences in physical conditions, there are no physical thermodynamic restrictions on the existence of biocenoses on Venus, and its flora can be chemically no less rich than terrestrial flora.

7. Possible nature of living forms on Venus

Information on terrestrial biocenoses accumulated for the last centuries has been obtained, as a rule, for 'normal' atmospheric pressure and temperature on Earth's surface. The biochemical and chemical data were mainly obtained at pressures two orders of magnitude lower and an absolute temperature approximately 0.4 times these parameters on Venus. For a few billion years of its evolution, life on Earth has optimized its properties with respect to the physical and geological conditions on Earth over the totality of biochemical and geochemical reactions. However, for other planets with cardinally different conditions on the surface, it is reasonable to search for absolutely different physicochemical foundations of life. Obviously, fundamental physical laws, in particular, the laws of conservation of energy and nonequilibrium thermodynamics in open systems, must be fulfilled for any foundations.

From the point of view of the physics of evolving systems, both Venus and Earth are, as a whole, energetically open systems exporting entropy to space by thermal radiation [12]. The entropy flux in the atmosphere and on the surface of Venus and Earth depends on numerous factors, in particular, chemical and photochemical nonequilibrium processes.

The hypothesis of the existence of a biosphere on Venus requires first of all answers to the following questions related to megabiology, according to G A Zavarzin's terminology [102]:

(1) *From what chemical compounds can Venus's living objects be constructed*? Is modern chemistry aware of suitable polymers that are stable in a CO_2 and N_2 atmosphere to high pressures and temperatures near Venus's surface?

(2) Terrestrial life uses in its biocenoses a unique solvent — water. *Which of the known chemical compounds can replace water in Venusian biocenoses*?

(3) *What are the geochemical processes on which life on Venus can be based*?

(4) Based on the data obtained from the Venusian surface in 1975–1982, we can assume that Venus's biocenoses, if they exist, can resemble in their phenotypic manifestations the biocenoses of terrestrial dry deserts. *Which of the terrestrial biocenoses could be used as a model object for preparing experiments on a new Venus mission to study biogeochemical processes of hypothetical Venusian life*?

Questions related to the organization of a genetic code and the cellular structure of separate micro- and macroorganisms should be considered at the next stages of the development of a hypothesis about Venus's biosphere.

7.1 Chemical compounds from which hypothetical living objects on Venus can be constructed

To answer the first of the questions presented above, let us recall that the physics and chemistry at high pressures up to a few tens of thousands and millions of atmospheres (with diamond anvils [103]) have been considerably developed in recent decades. In a chemical reaction, where the volume decreases on passing from initial substances to products, the equilibrium position depends on the pressure of gases. According to Le Chatelier's principle, as pressure is increased, the equilibrium shifts to the side of decreasing total number of moles of gasses, and vice versa. A classic example is the synthesis of ammonia from nitrogen and hydrogen on catalysts containing iron. The synthesis is performed at high pressures (a few dozen MPa). As a whole, conditions on Venus's surface are thermodynamically favorable for bonding nitrogen and carbon dioxide, and many chemical reactions proceed at high rates in the presence of catalysts. High-pressure chemistry is related to the synthesis of compounds that are unstable or metastable at normal pressures. In recent years, a number of substances with an absolutely unexpected stoichiometry and structure have been synthesized at high pressures. Among them are Na_xCl_y [104], polymeric $(NH)_x$ [105, 106], diborane (BH) [107], H_6O [108], $(CN)_x$ [109, 11], polymeric nitrogen [101], and a number of other compounds [102, 103]. It is interesting that nitrogen exhibits the greatest chemical variety of unstable, metastable, and high-energy compounds at high pressures: nitrogen polymers, polynitrogen heterocycles, carbon nitrides, cyano- and isocyano acetylenes, hydrozines, organic polynitro compounds, etc. [114–120]. It is important to note that the synthesis of many metastable nitrogen compounds requires, aside from high pressures, a broad range of high temperatures (up to 7000 K). Under conditions on Venus, nitrogen can serve as the basic component of monomers to synthesize polymers. It was assumed that, in this sense, life on Venus can be based on nitrogen as an alternative to carbon life [123]. It has been shown in many publications that nitrogen chemistry at high pressures can be no less diverse than carbon chemistry [105–113, 115–118, 123, 125–127]. Under conditions on Venus, nitrogen is activated. At the same time, it is unlikely that the chemistry of the near-surface medium on Venus will be predominantly based on nitrogen. This is the region where carbon, nitrogen, oxygen, and sulfur are active, while hydrogen bonds are broken.

At present, a number of nitrogen-containing polymer compounds are known which are highly stable at temperatures of about 500 °C and are capable of withstanding short-term heating up to 1500 °C. They are polyimines, polyamides, polyaldazines, polymer pyrazoles and thiazoles, polymer amidrazone chelate metal complexes, polyesterimides, etc. [121, 122]. Recently, a number of hypotheses have been proposed about the important role of unstable polynitrogen compounds for extraterrestrial chemistry, in particular, for planets with high pressures [66, 124]. Cyanopolyacetylenes were found in Titan's atmosphere and in the interstellar space [124]. Silane polymers are thermally stable at temperatures above 500 °C, and they have been extensively developed recently [125]. Of interest is the class of polyphenylene sulfides, for example, with the composition $(-S-C_6H_4-)_n$, in which benzene rings are bonded via sulfur. These polymers are thermally stable in the nitrogen atmosphere at terrestrial pressures at temperatures up to 600 °C [125], and they can be stable in Venus's atmosphere. Other carbo- and heterocyclic polymers such as polybenzimidazole, polybenzoxazole, polyimides, and malenimide are also thermally stable. However, the well-known polyamides nylon and capron are not thermally stable. At the same time, one of the polyamides, terlone, with the composition $-C_6H_4-$ containing the benzene group $(-HN-C_6H_4-NH-CO-C_6H_4-CO-)_n$ has the melting temperature of 600 °C.

We can conclude that modern polymer chemistry offers a virtually inexhaustible variety of possible organic polymers from which organisms of the hypothetical flora and fauna on Venus can be constructed.

7.2 Agent that can play the functional role of water in Venusian biocenoses

In answering the second question, we emphasize the following circumstance. In the terrestrial biosphere, water is contained inside all organisms, including unicellular ones. The exchange of water between organisms inside biocenoses occurs either via food, in the condensed water medium, or via atmospheric moisture. The last variant is typical for dry arid ecosystems. At the same time, physical conditions on Venus's surface are supercritical for carbon dioxide (Fig. 16), as for nitrogen.

These conditions in the phase diagram correspond to the high-temperature region behind the critical values of the basic components of Venus's atmosphere: carbon dioxide and nitrogen (critical points: 7.38 MPa and 304 K (31 °C) for CO_2, and 3.35 MPa and 126 K (−147 °C) for N_2), greatly exceeding the critical temperature. This region in Fig. 16 is denoted as 'supercritical fluid', which can be called the fourth phase state of carbon dioxide. Unfortunately, data on the chemistry of organic compounds at Venusian pressures and temperatures under conditions of a catalytically active solid phase of Venus's ground are virtually absent. All that can be said at present is based on the extrapolation of information on supercritical media in the region of Venusian parameters.

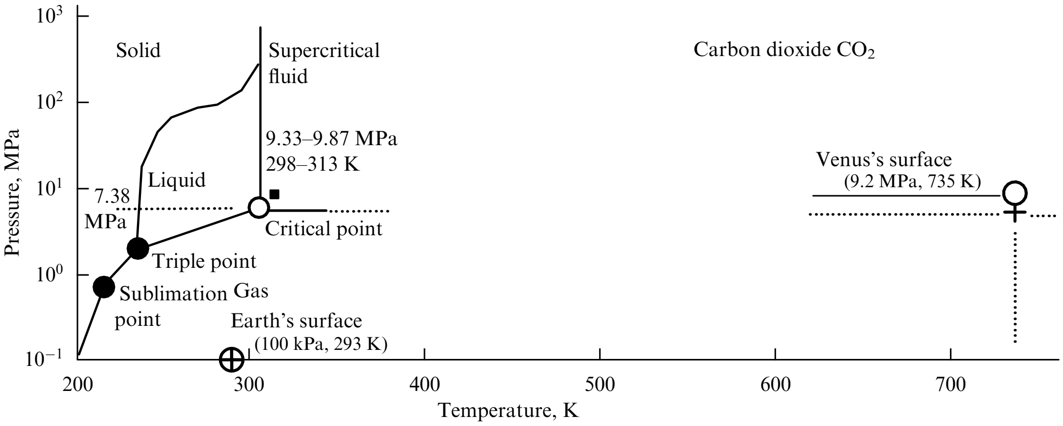

Figure 16. Phase diagram of carbon dioxide. The region of physical conditions near Venus's surface corresponds to its supercritical state. Shown are the positions of physical conditions on Earth and Venus (figure from [126] with additions).

Studies of supercritical media, including supercritical (SC) CO_2 fluids (SC CO_2), were initiated comparatively recently [127]. Such media have the following features: (a) a combination of gas (low viscosity, high diffusion coefficient) and liquid (high dissolving ability) properties; (b) intense mass transfer because of the low viscosity and high diffusion; and (c) the absence of interphase tension. As a result, supercritical fluids, together with compounds dissolved in them, can penetrate into microporous media, in particular, through cellular membranes, more easily than liquids. At the same time, it was shown that enzymes remain active in SC CO_2 at relatively low temperatures [128]. The dissolving ability of SC CO_2 is highly sensitive to changes in the chemical composition of the medium, making it possible to separate SC fluids from the substances dissolved in them. The unique properties of SC CO_2 as a solvent find wide industrial applications for the extraction and separation of components [128]. In SC media, molecules with various sizes, molecular masses, and polarities can be dissolved. The SC CO_2 medium has a greater mole volume than that of liquid CO_2, which can facilitate the formation of clusters and unstable complexes [126–128].

Most of the monomers used are soluble in SC CO_2. In polymer chemistry, SC CO_2 is used as a medium for efficient purification from impurities. A nonreacted monomer and a polymerization initiator are extracted with the help of SC CO_2. Because of its extremely high diffusion properties, this fluid can easily penetrate into a polymer [128]. In this case, there is no need for great amounts of organic solvents, which, as a rule, are difficult to remove from a polymer mass. It is known that polymers readily swell when permeated with a fluid, absorbing it with a considerable increase (up to 30%) in their volume [129].

Supercritical CO_2 is used to introduce stabilizers and various modifiers into a polymer mass. Thus, copper complexes introduced into polyarylate form metal copper after their reduction. As a result, this polymer containing uniformly distributed copper represents a composition possessing high durability [129]. For example, polysiloxanes and fluorinated polyhydrocarbons are dissolved in SC CO_2 at a temperature close to 100 °C and a pressure of 30 MPa. This fact allows using SC CO_2 as a medium for polymerization of usual monomers for manufacturing shells and nanometer covers [128, 129].

It should be expected that at a surface temperature of about 735 K, carbon dioxide and nitrogen molecules will have additional excited energy levels compared to levels at moderate temperatures. Therefore, carbon dioxide and nitrogen will be chemically more active in the high-temperature region, while carbon dioxide, being the main component of the atmosphere, can be both a reagent and a solvent on Venus. *Thus, high-temperature* CO_2*, being a fluid on Venus's surface, is a promising candidate for fulfilling many functions of water in biocenoses on Venus.*

7.3 Some chemical atmosphere–surface interaction processes on Venus

To answer the third question, we consider briefly some chemical atmosphere–Venusian surface interaction reactions based on data on catalytic processes.

The absolute content of water in the near-surface layer of Venus's atmosphere is only about 20 ppm H_2O. However, due to the high density of the atmosphere, it is comparable with the water content in arid places on Earth (0.1 g m^{-3}). Near Venus's surface and up to an altitude of about 20 km, the atmosphere contains, along with water vapor, noticeable amounts of COS, H_2S, and SO_2, up to approximately 180 ppm [130], but this estimate seems overstated.

The basic process in the terrestrial biosphere is the synthesis of organic $[CH_2O]$ compounds from water and CO_2, for which formaldehyde CH_2O serves as a monomer according to the reaction

$$H_2O + CO_2 \leftrightarrow [CH_2O] + O_2\,.$$

Data on the composition of the near-surface Venusian atmosphere and ground suggest that the basic process on Venus, similar to the terrestrial synthesis of organic compounds, is the synthesis of organic compounds, for which [COS] serves as an intermediate product on a catalyst or is desorbed in the COS form to the atmosphere in the reaction

$$H_2S + CO_2 \leftrightarrow [COS] + H_2O\,.$$

This reaction is weakly endothermal under terrestrial conditions. The logarithm of the equilibrium constant for this reaction is $\lg K_r = 2.02$ at a temperature of 740 K [131]. All the components of this process are found in Venus's atmosphere. Hydrogen sulfide in terrestrial biochemistry is known as an energy source during its oxidation. Taking into account that the H_2S concentration is approximately constant in the interval of heights from the surface up to ~ 20 km and then rapidly decreases, we can assume that a long-term source of hydrogen sulfide H_2S may be Venus's interior.

The main source of hydrogen for reducing CO_2 in this process is the reaction of interaction of hydrogen sulfide with iron sulfide proceeding at temperatures above 100 °C [132],

$$H_2S + FeS \rightarrow FeS_2 + 2\,[H]\,,$$

in which iron sulfide transforms into pyrite and hydrogen atoms are adsorbed by its surface. Then, pyrite FeS_2 again transforms into catalytically active iron sulfide in the reaction

$$FeS_2 + CO_2 \rightarrow FeS + [COS] + [O]\,,$$

while oxygen on the catalytically active surface of granules of the Venusian ground then also interacts with hydrogen, producing water:

$$2\,[H] + [O] \rightarrow H_2O\,.$$

Finally, the processes considered above give the COS synthesis reaction with the oxidation–reduction of iron ions.

The sulfidizing of the surface layers of iron oxide particles on oxide catalysts Fe_2O_3/SiO_2 and Fe_2O_3/Al_2O_3, i.e., with components that are abundant on Venus's surface, was demonstrated in [133]. Reactive mixtures used in experiments contained an inert gas, hydrogen sulfide, oxygen, and, of necessity, water vapor. Without water in experiments, hydrogen sulfide was oxidized on iron oxide to sulfur. The presence of water in the mixture facilitated the formation of FeS_2 on the surface of Fe_2O_3/SiO_2 and Fe_2O_3/Al_2O_3 catalysts, resulting in a change to the oxidizing path and the appearance of SO_2 in products. Oxygen on the catalyst surface is wasted in the reaction with the formation of sulfur dioxide:

$$[S] + 2[O] \rightarrow SO_2\,.$$

In this case, SO_2 becomes the main product. Recall that water and sulfur dioxide SO_2 play an important role in the formation of Venus's sulfuric acid clouds [79].

Note that one of the hydrogen sources on Venus's surface may be simple hydrocarbons. For one of them, ethane, found in Venus's atmosphere, a temperature of 550 °C is the boundary of starting gas-phase pyrolysis reactions initiated by IR radiation [134]. Transition metal oxides contained in Venus's ground serve at these temperatures and atmospheric pressure as catalysts of hydrocarbon, degrading with the formation of acetylene, aromatic compounds, coke on the surface, and hydrogen. For the surface conditions on Venus, the catalytic degrading of hydrocarbons may have special features, which should be elucidated experimentally.

Hydrogen atoms on the iron sulfide catalyzer can reduce CO_2 with the synthesis, for example, of methyl sulfide (methyl mercaptan) with the active SH-thiol group,

$$CO_2 + 4\,H_2S + 3\,FeS \to [CH_3SH] + 3\,FeS_2 + 2\,H_2O\,.$$

According to one hypothesis [135], the synthesis of methyl sulfide CH_3SH involving iron is one of the most ancient methods of CO_2 fixing, which is the most efficient in media with a low water content. In addition, ground with an $Fe-SiO_2-Al_2O_3-MgO-CaO-K_2O$ composition with reduced iron is by its composition a typical catalyst for ammonia synthesis from nitrogen and hydrogen. This catalyst was studied in chemical technology in numerous papers [136]. Its composition was optimized for industrial production in the pressure range from 10 to 30 MPa and the temperature range from 300 to 550 °C with the transformation degree falling in the range 10–16% per transit. On the catalyst, the activated adsorption of nitrogen on Fe active centers occurs with the formation of iron nitrides Fe_xN. Hydrogen then interacts with iron nitrides with the formation of intermediate complexes Fe_xNH and Fe_xNH_2. The presence of sulfur above 0.1% in the catalyst drastically reduces its activity with respect to the ammonia yield. On Venus, with its supercritical conditions for CO_2-N_2, nitrogen activation on reduced Fe can be expected with the formation of at least the Fe_xNH complex involved in further syntheses of organic compounds and polymers. Under these conditions, the reaction

$$N_2 + H_2S + Fe \to 2\,[NH] + FeS\,,$$

in which active iron sulfide appears, is not ruled out either.

The presence of other metals in the ground can strongly change the catalytic activity of Venusian ground. Thus, it is known that at moderate temperatures and relatively low pressures, catalysts containing metal ruthenium on magnesium oxide are very active in the ammonia synthesis [137]. Catalysts using magnesium oxide with sodium and potassium additions as a carrier are the most active, the replacement of MgO by aluminum oxide or carbon materials resulting in a drastic decrease in ruthenium activity [138].

Finally, in the CO_2 atmosphere on the surface of Venus's ground, particles containing iron and other metals in the presence of sulfur, metal carbonyl groups $M(CO)_n$, in particular, with iron can be produced. Carbonyl iron compounds possess a high catalytic activity in chemical organic synthesis reactions (see review in [139]).

All the compounds mentioned above, as well as other organic compounds such as [COS] and $[CH_2O]$, $[CH_3SH]$ thiols, and nitrogen compounds [NH], initiate on the catalyst surface the chains of all further syntheses of substances. These substances can also contain other elements, for example, silicon, iron, magnesium, nickel, zinc, and other components of the Venusian soil. Among all the possible compounds in the presence of high-temperature CO_2 fluid and nitrogen, stable compounds, including some synthesized polymers, remain. The participation of carbonyl sulfide in the polymerization reaction with oxides was experimentally shown in [139], where [COS] reacted with propylene oxide at a temperature of 25 °C, even in the absence of metal-containing catalysts.

Thus, data on heterogeneous catalytic processes under conditions typical of Venus's atmosphere and ground composition allow us to assume the possibility of an existing geochemical 'iron–sulfur world' as a hypothesis about the basis of life on Venus. Note that such an iron–sulfur world on Venus differs from the iron–sulfur world of underwater volcanos with 'black smokers' [140]. Underwater volcanos act in liquid water with subcritical parameters at relatively low temperatures of dissolved and suspended reagents.

7.4 Terrestrial model object of the hypothetical Venusian biocenosis for preparing a new mission to Venus

Are there terrestrial analogs of hypothetical Venusian biocenosis? Could they be used as a model for experiments on a new Venus mission for studying biogeochemical processes in hypothetical life on the planet? Of course, it would be naive to search on Earth for direct analogs of high-temperature macroforms of Venus's hypothetical flora and fauna. However, some close analogs can be found among terrestrial biocenoses. High pressures, temperatures exceeding 100 °C, the minimal amount of water — such conditions in combination are virtually absent on Earth. In our opinion, such conditions are closest to underground microbe biocenoses. These biocenoses were studied earlier in superdeep wells, the Kolvin (5900 m) and Tyumen (6820 m) wells. The kern and stratum fluid samples obtained from these wells contained viable thermophilic microflora. E A Bonch-Osmolovskaya analyzed the data on studies of the underground biosphere [141] and found that high-temperature horizons under the oceanic crust in regions of present day underwater volcanic activity are of the most interest from the point of view of existing isolated thermal communities of microorganisms. Rocks under oceanic bottoms contain only stratum water with dissolved salts, and sunlight is completely absorbed in the upper layers of ocean water.

Rich microbial life was discovered recently at depths of 1626 m under the sea floor level inhabited by various thermophilic archaebacteria [140]. The drilling was performed near Newfoundland's shores. The ocean depth at the drilling place was 4500 m.

Japanese researchers found bacterial biocenosis in liquid CO_2 in a medium consisting of 86–92% CO_2 with dissolved H_2S, CH_4, and water. This biocenosis was at a depth of 1400 m at the ambient temperature of 3.8 °C near the arc hydrothermal Izena Hole system of the Mid-Okinawa Trough [142].

In these bacterial biocenoses at moderate terrestrial temperatures, $H_2O + CO_2 \leftrightarrow [CH_2O] + O_2$ should be performed as chemosynthesis. Chemosynthetic bacteria are the only organisms on Earth not using solar energy. For example, sulfur bacteria (*Desulfuromonas, Desulfobacter, Beggiatoa*) oxidize hydrogen sulfide to molecular sulfur or to sulfuric acid salts. These sulfur bacteria can live at high pressures near breaks in Earth's crust, where hydrogen sulfide enters the water. Thionic bacteria (*Thiobacillus, Acidithiobacillus*) exist by oxidizing thiosulfates, sulfides, and molecular sulfur to sulfuric acid at a low pH of the liquid medium. Some of the thionic bacteria are capable of multiplication at a solution pH up to 2. They also can withstand high concentrations of heavy metals.

Thus, microbial life under the sea floor level at depths of more than 1 km in regions of underwater volcanic activity can be considered a model subject for experiments on a new Venus mission for studying biogeochemical processes of hypothetical life on Venus.

7.5 Possible nature of living forms on Venus. Conclusions and necessary experiments

Available data suggest the existence of stable solid polymers on Venus's surface from which Venusian organisms can consist. Microorganisms living at depths of more than 1 km under the sea floor can be considered to be relatively close subjects for comparing with the microbial biosphere on Venus, if it exists.

Supercritical carbon dioxide and nitrogen can serve as a substrate (a solvent similar to water on Earth) on Venus. By considering the possibility of life existing at high pressures, the authors of this paper compared the data in the literature about the variety in nitrogen chemistry at high pressures and about stable and metastable polymeric and high-energy nitrogen-containing compounds. We assume that the existence of living forms on Venus can be based on a modified biochemistry with highly nitrogen-enriched components with [COS] synthesis,

$$H_2S + CO_2 \leftrightarrow [COS] + H_2O\,,$$

and, possibly, with photosynthesis,

$$H_2O + CO_2 \leftrightarrow [CH_2O] + O_2\,,$$

while a mixture of supercritical CO_2 and nitrogen serves as a solvent.

The conclusions and hypotheses presented above are based on the extrapolation of our knowledge in catalytic chemistry and photochemistry to conditions on Venus's surface. To obtain more substantiated data and prepare new missions to Venus, it is necessary to perform extensive studies of catalytic processes in reactors under conditions simulating conditions on Venus's surface. These studies should give information on the chemical interaction of N–C–O–S organic compounds at pressures and temperatures on Venus with reagents contained in Venus's atmosphere in the presence of a catalytically active solid phase simulating Venus's ground depending on its composition, dispersion, and morphology. The first experiments to perform may be COS synthesis from CO_2 and H_2S in the presence of N_2 on finely divided Fe_2O_3/SiO_2 oxides and on nanometer Fe/SiO_2 and Fe/Al_2O_3 particles with single Fe ions on their surface. These experiments should give quantitative data on the yield of COS, SO_2, H_2O, and other key products for these comparatively simple catalysts. In addition, data are required on the chemical stability of a number of promising polymers subjected to the prolonged action of a medium simulating Venusian conditions. These studies should work out special experiments and determine the equipment required for new missions intended to answer the question about the chemical foundations of as yet hypothetical life on Venus.

One of the necessary investigations for the next mission to Venus is the construction of a chromatograph with polycapillary columns for operation on Venus's surface and the development of corresponding methods for chromatographic analysis of organic compounds. Based on the Venera 13 and Venera 14 experiments, it is necessary to determine with the help of a chromatograph and other analytic instruments the sets of catalytic synthesis products that can appear on Venus's surface.

8. Conclusions

By generalizing experimental and theoretical results based on revised Venera TV experiments, we recall that the TV image method is widely used at present to study celestial bodies and, in particular, to search for traces of life on Mars. However, already 44 years ago, Venera landers studied Venus's surface by the TV method, and these experiments remain unrepeated to date. The aim of these experiments was to obtain general information on Venus's surface. To search for traces of life on a planet with an oxygen-free carbon dioxide atmosphere, a pressure of 9.2 MPa, and temperature of 735 K near the surface — nobody could have imagined this in the 1980s–1990s. At the same time, TV photos of Venus's surface taken 44 and 37 years ago and processed anew using modern computer codes indicate the possible presence of flora and fauna on this planet. Numerous objects having a complex regular structure and probably demonstrating very slow motion at velocities of about 1 mm s^{-1} were found. Their study allows us to assume that hypothetical objects of Venus's flora and fauna have been found. From 2012 to 2018, about fifty papers devoted to approximately 18 strange objects observed in Venusian panoramas were published in Russian and foreign scientific papers.

Experimental data on the tentative habitability of Venus were obtained *for the first time*, while physical conditions on Venus contradict the accepted paradigm about conditions assumed to be comfortable for life. The paradigm is commonly accepted and nobody wants to discard it. For this reason, concerning hypothetical life on Venus, the scientific community, as a rule, follows the Schopenhauer principle: "All truth passes through three stages: first, it is ridiculed, then it is violently opposed, and finally it is accepted as being self-evident." [1]

Terramorphism of hypothetical flora and fauna objects on Venus has often been mentioned in publications. The repeatability of forms of living objects on various planets with radically different physical conditions is a serious challenge to the natural sciences. We can assume that terramorphism will in the future attract the attention of zoologists and biophysicists.

Along with the discussion of hypothetical living forms, we considered in this paper data in the literature about the features of the chemistry of carbon dioxide and nitrogen at high (supercritical) pressures and temperatures and of stable and metastable polymers and other high-energy nitrogen-containing compounds produced, which can tentatively provide the appearance of life at high pressures and high temperatures. We conclude that living forms on Venus can be based on special high-temperature biochemistry. Note that

---

[1] "Jede Wahrheit durchläuft drei Phasen: In der ersten wird sie verlacht, in der zweiten wird sie wild bekämpft, und in der dritten wird sie als Selbstverständlichkeit akzeptiert." Arthur Schopenhauer (1788 – 1860).

knowledge developments and investigations in this field are extremely important for studying not only the astrobiology of the Solar System and exoplanets, but also high-pressure organic space chemistry, i.e., in a new scientific field that had not attracted the attention of researchers earlier.

The importance of the results obtained is obvious. However, to confirm them, a new mission to study Venus's surface is required. Investigations of Venus continue. In 2005, the Venus Express mission of the European Space Agency (ESA) obtained new data on Venus, including spectrometric results suggesting probable volcanic activity on the planet confirming conclusions made in [54]. However, the urgent undertaking of a new mission to study life signs on Venus's surface has now become the most important. This expedition should be special and considerably more sophisticated than the previous Venera missions. The Russian Venera D mission is planned in cooperation with NASA, USA, in 2020–2030. The scientific tasks of the mission include investigations of Venus's atmosphere and surface [146, 147] with the help of a Venera lander operating for a long time on Venus's surface [148]. It is assumed to accomplish this, in particular, by using new electronic components developed at NASA for operating under the physical conditions on Venus [149, 150]. An electric wind generator should be used as a long-term energy source. Aside from necessary laboratory studies of the chemical foundations of hypothetical life on Venus, the new mission should be equipped with high-resolution spectral cameras with a frame of no less than 10 Mbit and a resolution of 0.1 mm near the objective to 10 cm at a distance of 10 m with 10 bit coding and serial imaging. Taking into account the small size of modern CCD cameras, their required thermal protection and prolonged operation on Venus's surface can be ensured [150]. The directional communication of data to an orbital spacecraft over the reference signal was already discussed during the preparation for the Venera D mission. This increases many times the volume of information communicated. The new mission should be rather complex. Nevertheless, the progress in science and technology achieved in the 40 years since the Venera missions makes the solution of such a problem quite realistic, and the results of this mission will allow us to talk about life on Venus as a confirmed fact.

Acknowledgments

This work was partially supported by Programs P28 and P17 of the Presidium of RAS.

9. Appendix. Discovery of hypothetical living forms on Venus

9.1 'Flora' [2]

Forty-four years ago, the Venera spacecraft performed TV studies of Venus's surface, and these experiments remain unrepeated to date. Their aim was to obtain general information on Venus's surface. After examining panoramas, initially processing them, and publishing the corresponding papers and collections in 1975–1989, interest in these images gradually disappeared. Nevertheless, the work was continued at the Space Research Institute, RAS, and new image processing methods revealed in 2010–2011 much more detail in the panoramas. The aim of the new studies [19, 88–98] was, as mentioned in Section 5.2, to find any differences among initial or earlier unused panoramas. The problem of searching for traces of life on a planet with an oxygen-free carbon dioxide atmosphere, a pressure of 9.2 MPa and a temperature of 735 K near the surface was not posed in 1980–1990. Nevertheless, the TV images of Venus's surface obtained 37 and 44 years ago and processed anew with advanced software indicate the possible presence of flora and fauna on this planet. In the period from 2012 to 2018, about fifty papers were published in Russian and foreign journals which were devoted to 18 strange objects found in the Venusian panoramas. By analyzing details of surface images, it is possible to distinguish several objects satisfying criteria formulated. Let us consider them below.

9.1.1 'Mushroom'. In the central part of the Venera 13 panorama, at the front at a distance of approximately 15–20 cm from the lander buffer, a small light object having a regular conic shape is located (shown circled in Fig. 17). By comparing the brightness of the object with the light periphery of the figure, one should take into account that the object is located in the shadow from the parachute shield of the lander. Recall that the color image is composed of primary panoramas, black-and-white and color-divided red and green. The color of the images presented approximately corresponds to the spectrum of sunlight illuminating Venus's surface.

All the initial panoramas exhibit a radial folded structure of an object with a tent shape. The object size is comparable to that of terrestrial mushrooms and the object looks namely like folded-shaped mushrooms (Fig. 17, frame 3). Its diameter is about 8 cm and it is raised approximately 3 cm over the surface. However, no foundation supporting this object is observed.

It seems that the object is not part of Venus's 'fauna'. We did not observe any signs of its motion for 1.5 hour. All six successive images, including panoramas that were not used earlier, were processed by the correlational stacking method [85]. Three black-and-white versions of resulting images, 01,

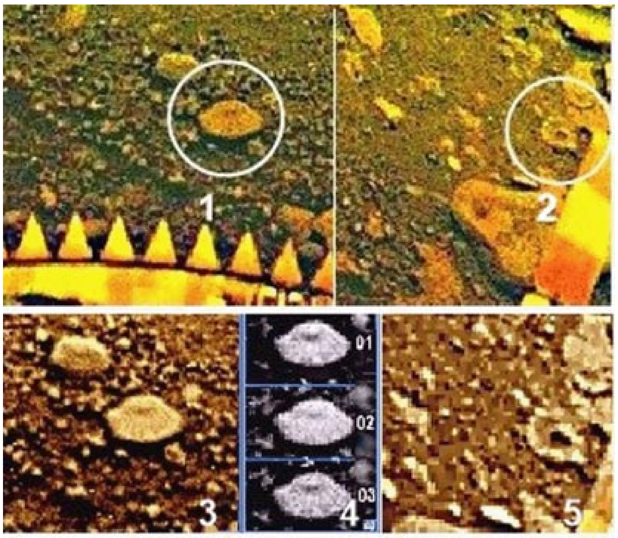

Figure 17. (Color online.) Parts of the Venera 13 panorama. Circles show objects resembling a folded terrestrial mushroom cap (1) and tree fungus (2). Processing results are shown in frames 3–5. The sizes of objects 1 and 2 are about 8 and 6 cm, respectively.

---

[2] All the names of objects considered here are purely conditional and in no way is it claimed that they have properties of analogs on Earth.

02, and 03, are shown in Fig. 17 (frame 4). The 'classic' shape of a tent is seen in each of the images. The 'mushroom' is clearly visible in all the successive Venera 13 panoramas.

Due to its fortunate close location to the camera, the details of the 'mushroom' structure are clear, allowing us to assign its properties to the features of terramorphism, indicating again yet unknown biophysical laws. The size of the 'mushroom' is small, and therefore other similar objects located at large distances from the camera are difficult to find. An exception may be an object in the same panorama having special shape (see Fig. 17, frame 2 (circled) and frame 5). It looks like terrestrial tree fungus that sometimes grows on tree trunks. Its size is about 6 cm, but it is located at a greater distance from the objective and so details are not seen.

9.1.2 'Stem'. The first 'stem' found also resembles terrestrial plants (Fig. 13). The 'stem' itself is a vertically oriented, thin, possibly knotty 'plant' trunk 0.3–0.5 cm in thickness with four leaves located on the ground near the stem base. Each of the elements ('leaves') of the four leaves is 5–10 cm in length and has some visible radial structure. Yu G Simakov concluded that the four leaves near the 'plant' base on the ground resemble terrestrial cruciferae (see the image in the lower part of Fig. 13b), but have only one leaf tier. The 'stem' is located at a distance of about 40 cm from the Venera 14 landing buffer. Its size (height and other dimensions) was determined using a photographic map and geometrical relations (Fig. 13). The photographic map (not presented here) was needed because distances between the details of images in the original panoramas are distorted by the projection. The entrance of the optical system was located at a height of 90 cm, the distance from the entrance projection to the 'plant' was 40 cm, and its top was projected on the surface at a distance of 75 cm. The object is seen from above at an angle of about 50°, and its height seems smaller than the real value. If the 'stem' is located vertically, then it follows from a rectangular triangle that its height is 42 cm. The surface is uneven and therefore an error of about 25% is possible in the estimate of distances and sizes.

9.1.3 'Flowers'. Later, other 'plants', also with four leaves near their base, were discovered. Their stems in color panoramas look black. The trunk of the 'plant' or 'stem' of the first object discovered (Fig. 13b) has a large thickening ('bud') at the top with a light center. Other 'plants' of the hypothetical flora on Venus (shown below) possess a similar structure, including open 'buds'. For convenience, the general name 'stems' was proposed for all hypothetical flora on Venus.

In the Venera 13 landing place, one or two similar objects were found with stem bases located, as in Fig. 13b, in stone cracks. No stems were found on the granulated ground. The part shown in Fig. 18 has eight distinct successive images, allowing group processing. The arrow indicates a repeating element, which looks in initial images like a triad of bright points located at the top of the 'stem' (Fig. 18), the triad position changing somewhat in successive frames.

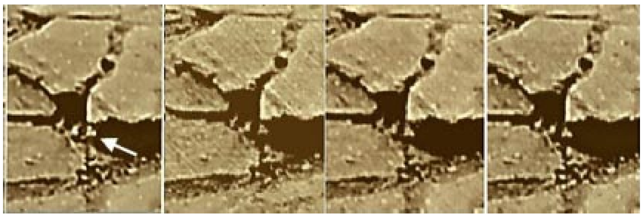

Figure 18. (Color online.) Four successive images of a small stem in fissure of stones in Venera 13 panoramas obtained for 1 h. The position of a triad (shown by the arrow in the extreme left photo) with respect to a stone in successive frames changes somewhat probably under wind action.

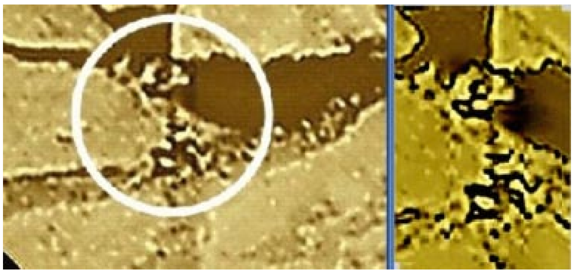

Figure 19. (Color online.) Group processing of successive images presented in Fig. 18 with decreasing contrast shows that the triad is a part of the object similar to terrestrial flowers. The small white spot at the center and surrounding details recall a pistil and petals of terrestrial flowers.

Images in all the initial parts in Fig. 18 have too high a contrast. After decreasing the contrast, the image quality considerably improved. One can see now that the stem top is crowned with an object more complicated than a triad (or a 'bud' in Fig. 13b) and that the triad is a part of a formation similar to flowers on Earth (Fig. 19, in the white circle). Animation constructed from successive images confirmed the assumption about the object's motion caused by the wind: the 'stem' and 'flower' sway with respect to motionless stones. The wind velocity at the Venus 13 operation site was about 0.45 m s^{-1} [52, 99], which is equivalent to 8 m s^{-1} on Earth.

The same animation also demonstrates several smaller details with the same motion. The stem height found by the position in the photographic map is only about 20–30 cm. Near its base, in a crack between stones, a group of four light formations is seen. They are similar to the four leaves shown in Fig. 13b and are probably also related to the stem.

It was assumed that the complex structure of the stem top is an open 'flower'. The processing of images strongly decreasing their contrast and performing gamma-correction confirmed this assumption and allowed us to see the whole 'flower' of a regular shape (see Fig. 19) with a white spot (pistil) at the center and petals surrounding it. The flower consists of six or eight light petals, their right, brighter part forming a regular triad, shown in Fig. 19 as a part of the opened flower. The size of the 'flower' is approximately the same as that of the four leaves at the base of its stem (about 8 cm). The Venera 13 panorama was organized so that the figure gives only a black-and-white image, and thus the color of the 'petals' remains unknown.

Another small light four-leaf configuration was found at the center of a Venera 14 panorama in a pit near the landing buffer (see frame *1* in Fig. 20). This object of tentative flora has the same stem shape as in Fig. 13b, but the stem is much smaller and hardly noticeable because it is masked by a dark background in a fissure in the stones.

The stem in initial panoramas is difficult to observe; it was distinguished using gamma correction and is shown in frame *2* in Fig. 20. Its 'leaves', unlike those in Fig. 13b, are very light, being only slightly darker than the dropped white lid of the TV camera. One of the leaves is darker than the others, because it is located in the shadow of a stone. The size

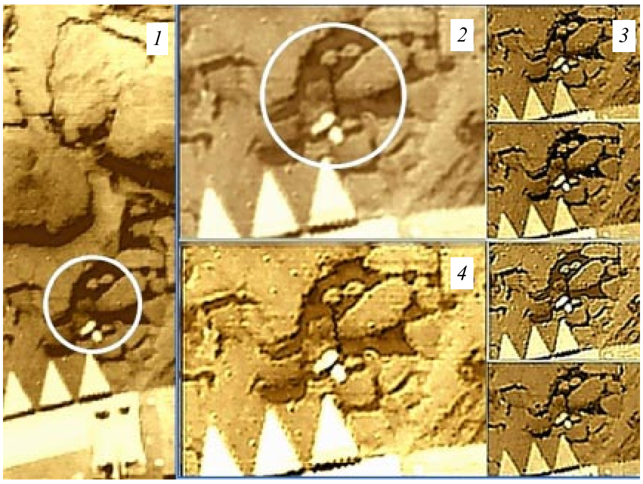

Figure 20. (Color online.) Very light small group of 4 leaves with a 'stem' and a 'flower' (frame *1*, the initial image in the circle) repeats in all Venera 14 panoramas. The object located near the spacecraft landing buffer was separated by gamma correction (*2*). Processed successive images (*3*) demonstrate a 'stem', 'flower', and 4 leaves presented in the final form in frame *4*. It seems that another similar 'flower' is located behind the stone.

of the leaves is small, only 1–2 cm, but the similarity of the object with Fig. 13b is obvious. The stem height, also observed from above, does not exceed 12 cm. The processed successive images (frames *3* in Fig. 20) demonstrate the stem top with an open bud or 'flower' no more than 2 cm in size (see frame *4* in Fig. 20). The stem rises from a pit. To the right of it, another similar 'flower' is seen whose stem is obviously located behind a stone.

Figure 21 generalizes three 'plants with flowers' found: one of them is found in Venera 13 panoramas and two are found in Venera 14 panoramas. As was mentioned, the Venera 13 spacecraft landed in the equatorial zone of Venus at the 7.5°S, 303.5°E point to the east of the Phoebe region, while Venera 14 also landed in the equatorial zone at the 13°S, 310°E point. The distance between the landing sites of the spacecraft was 970 km. Taking into account this considerable distance, we see that Venusian flora of this type with single and vertical stems are quite abundant. In all cases, stem bases are located in cracks or pits between stones.

Near the Venera 9 landing site, an object is also seen, which may be a thick 'stem' (Fig. 22). It has a light spotted top. The object's height and its stem thickness are approximately estimated as 0.5 m and 5–8 cm, respectively. The Venera 9 landing site is located at a distance of 4500 km from the site of the objects shown in Fig. 21. No other 'stems' were found in the Venera 9 panorama.

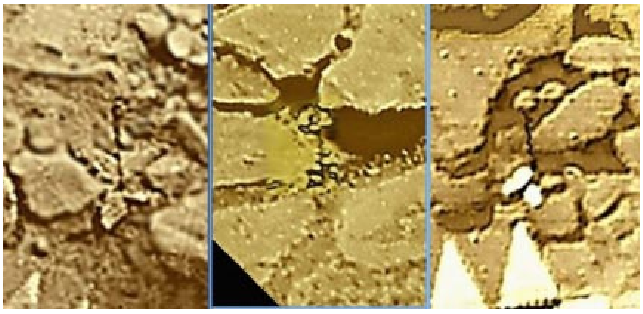

Figure 21. (Color online.) 'Stems', 'flowers', and 'buds' on Venus. Regions where three 'stems with flowers' were found are separated by distances of almost 1000 km.

Figure 22. (Color online.) Vertical dark object at the center of the Venera 9 panorama can be a thickened stem with a light top.

Thus, several vertically oriented linear objects resembling terrestrial plant stems were found near the Venera 13 and Venera 14 landers. If the tops of the 'stems' are really buds and flowers, we should attempt to understand their role. The flowers of terrestrial plants serve for pollination and multiplication. Plants are pollinated by both insects and the wind. Signs of the wind near Venus's surface were presented in [52, 99] and other studies. Wind-pollinated plants do not need flowers, in principle, as, for example, in the case of poplar down. Flowers attract insects to carry out pollination. Do the tops of the stems in Fig. 22 indicate at least indirectly the presence of such probable participants in the pollination process on Venus?

The 'flowers' with their petals in Figs 20 and 21 are new objects with surprisingly repeated stem shapes on different planets with radically different physical conditions. We can assume that their repeatability will attract the attention of botanists, zoologists, and biophysicists in the future.

9.2 'Fauna'

Most of the objects found on Venus's surface resembling living forms by morphology and behavior are static. However, the experimental method could not be used to study the dynamics of objects, because each panorama was got and simultaneously transmitted over the radioline for a long time: 30 min for Venera 9 and Venera 10 and 13 min for Venera 13 and Venera 14. By comparing the successively obtained panoramas as instant photographs, we can observe in some cases a noticeable displacement of the objects found or their movement outside the field observed. Some of them leave obvious displacement tracks, suggesting their ability to move and even allowing us to estimate the velocity of their motion.

Terrestrial life is based on a water medium. However, the typical Venusian landscape is a waterless red hot stony or porous surface, sometimes with mountains or rarely volcanos. Liquid water cannot exist here. High in the atmosphere, at a level of 47–49 km, is located the lower boundary of a dome of the extended layer of sulfuric acid clouds. At a temperature of about 460 °C at the landing site, water is in an overheated vapor gaseous state and (or) is bound to surface minerals. The proportion of water in the gaseous state is about 2×10^{-5}, and that of oxygen is approximately the same.

What substances could be used by nature to create life on Venus? At present, we have only the assumptions considered in Section 7. The rate of chemical reactions at such high temperatures is known to be very high. Temperatures of about 735 K near Venus's surface are detrimental to terrestrial life forms; however, from the thermodynamic point of view, they are no worse than terrestrial conditions. The media and acting chemical agents are unknown exactly, but nobody has searched for them, whereas initial materials on Venus do not substantially differ from those on Earth. Photosynthesis for a number of prokaryotes is based on a reaction in which hydrogen sulfide H_2S instead of water is an electron donor. Some of the autotrophic prokaryotes living underground use chemosynthesis instead of photosynthesis. There are no physical prohibitions on life at high temperatures, and anaerobic mechanisms are well known.

Why in all the cases when the displacement of objects of Venus's possible fauna was observed, was their velocity surprisingly small, about 1 mm s^{-1}? The medium forming hypothetical living organisms on Venus should have some unusual properties. One of the assumptions is that this is related to some energy restrictions inherent in Venus's fauna. At the same time, another even more probable reason is possible, which is determined by the properties of substances consisting the bodies of Venus's fauna. Because the existence of liquid water on Venus's surface is ruled out, such organisms should consist of other substances, for example, polymers (see Section 7). Some polymers have a delayed plasticity. We can assume that a body constructed of such a viscous medium requires a noticeable time to change its shape, and the properties of the viscous medium determine the slowness of Venus's fauna.

Below, we present a brief description of six samples of hypothetical Venusian fauna of 18 objects found directly near the Venera landers.

9.2.1 'Amisadas'. The high density of the hypothetical habitability of Venus's surface suggests that it resembles more the bottom of terrestrial shallow water than the terrestrial surface. In this section, we present several tentative living forms found on Venus's surface. We discussed above the possible energy sources that could be used by the hypothetical fauna on the planet. It is unlikely that rather rare 'stems' can solve the fauna nutrition problem. Their number is small, whereas smaller vegetation like grass or moss are indiscernible in the photographs. Indirect evidence of the fact that the 'stems' do not exhaust the variety of small-scale flora of the planet is demonstrated by 'amisadas' in Venera 14 panoramas, hypothetical objects of Venus's fauna resembling terrestrial reptiles. The conditional name 'amisada' is an abbreviation of the name of the Babylonian king of Mesopotamia Ammisaduqa (16th century BC), during whose reign ancient astronomers registered the morning and evening Venusion elongations on clay tablets. The moving amisada looks as if it is examining the surface of a stone on which it is half-mounted (Fig. 23b). Possibly, this is the process of searching for plant food with much smaller dimensions than stems and indiscernible to the TV cameras.

An amisada was found in the Venera 14 panorama in 2013 [91, 92] near the landing buffer of the spacecraft close to the 'stem' shown in Fig. 13b. It resembles somewhat in shape a terrestrial lizard. Its size is 12–15 cm. The amisada was located very close to the TV objective.

Figure 23a shows the single image of an amisada obtained at the 30th minute of Venera 14's TV camera operation. Figure 23b presents the averaged view of six initial images, and Fig. 23c shows the appearance of the slow Australian lizard, the shingleback, resembling an amisada in size (10–15 cm), shape, and the position of its limbs. According to the shape and position in the figure, the amisada is climbing on a stone 5–8 cm in height. We will assume that its upper part in the figure is the front part, which seems to be demonstrated by its motions, although we have no other signs. Of course, it is not ruled out that the amisada is descending from the stone rather than climbing it. The amisada is also of interest because, due to the low noise of the Venera 14 TV photos, we can see small and extremely slow displacements of amisada's parts. As shown below, the 'slowness' is inherent as a whole in the part of the hypothetical Venusian fauna revealing the ability to move.

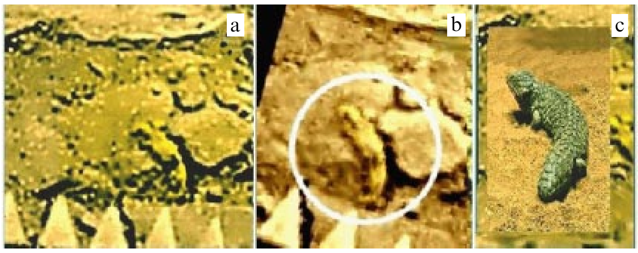

Figure 23. (Color online.) (a) Amisada climbing on a stone. (b) Combination of the six initial parts of Venera 14 panoramas. (c) Australian shingleback lizard resembling amisada in its size, shape, and slowness.

The processed amisada images allow us to show the motions of its front part as a sequence of its six positions shown by the direction of the arrows in Fig. 24, where parts of six panoramas are presented. The order of frames *1*–*6* is chronological, the intervals between them being about 13 min. on average.

In Fig. 24 (frame *1*), the upper extreme portion of the amisada is directed to the left (the 9 o'clock direction), while the shadow under it is almost invisible. Recall that in the case of scattered natural light on Venus, shadows appear only when an object is located at a small height over the surface comparable to its size. The absence of shadow shows that the portion is uplifted over the surface.

The extreme amisada part in frame *2* in Fig. 24 has moved in the 7 o'clock direction and a shadow is also absent. Finally, the direction of the extreme portion in frame *3* is at approximately 8 o'clock with a dense shadow under it (the object on the surface). Further changes are shown by the

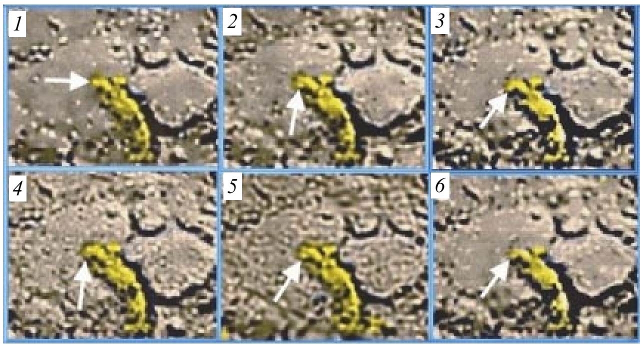

Figure 24. (Color online.) Amisada near the Venera 14 landing buffer. Nonaveraged processed parts of six initial panoramas. The arrows show the sequence of positions of the front part of the amisada, resembling in its size and motions a human finger.

sequence of frames *4–6*. The portion corresponds in size and motion approximately to a human finger, and its displacement is 1–2 cm for 1.5 h. Also noticeable is the displacement of two symmetrically located organs in the first part of the object, resembling its limbs. The animation constructed from frames *1–6* demonstrates the displacement of the entire object, which is also noticeable by the changing distance between the amisada and the stone to the right of it in Fig. 24.

As mentioned in [91], one or two objects were also found near the amisada and 'stem', which are similar to them in size and displacements. One of them, a 'fat man', is shown in Fig. 25. The size of the part at the fore is about 50 cm. The 'fat man' is located near the part, in a small alcove close to the left boundary of the figure and was observed at an angle of about 60° to the horizon (Fig. 25a, in the circle). It represents an elongated volume body about 12 cm in size (without the protruding front part). The front (left) part is ended by a regular structure protruding 2–3 cm and formed by an inclined 'crown' — a half circle consisting of separate elements. The 'crown' slope changes in successive images, whereas the 'fat man' moves along its axis. The 'fat man' is a clearly discernible body resembling in shape a fish when observed from above, but with supporting (and possibly moving) organs, as reptiles have. The more detailed 'fat man' image is shown in Fig. 25b. The structure and function of the organ resembling a crown ending the front (or rear?) side of the 'fat man' are unclear. The 'fat man' also reveals signs of motion, very slow, as with other Venusian objects. On the right, the 'fat man' body has a short narrow 'tail'. It seems that the 'fat man' rests on the perturbing parts of the body.

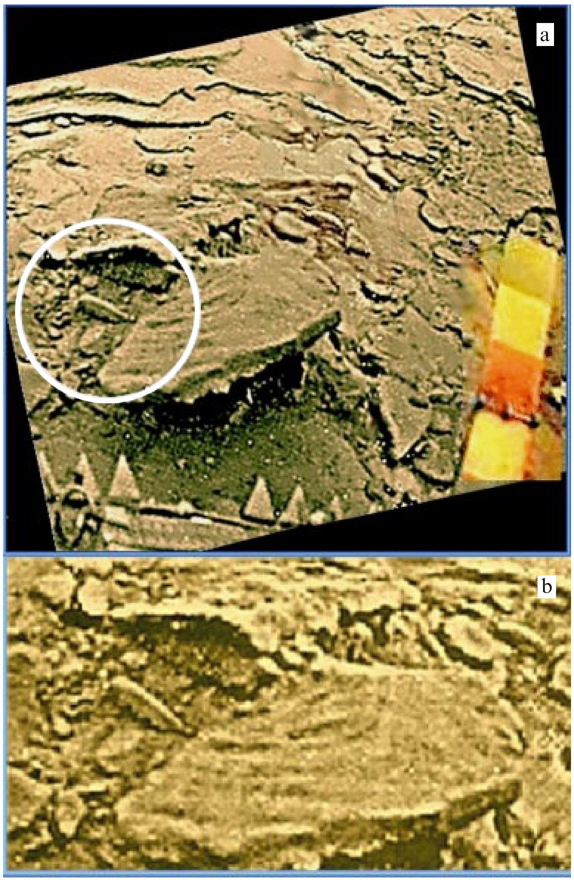

Figure 25. (Color online.) A 'fat man' resembling an amisada was located in a small alcove (a). Its magnified image (b) is an elongated volume body resembling sea inhabitants if seen from above. The body length (without the protruding front part) is about 12 cm. The front (left) part ends by a regular structure, a 'crown' in the form of a semicircle consisting of separate elements.

9.2.2 'Bear cub'.

Of interest is an object conditionally called a 'bear cub' and shown in Fig. 26 (it was found in the additionally processed Venera 9 panorama obtained in 1975). The 'bear cub' is located fairly close to the objective. It was found alone [86] near the Venera 9 landing buffer. Unlike the sharp contours of surrounding stones, the 'bear cub' surface is 'soft', as if 'fluffy'.

The 'bear cub' is seen from above at an angle of 60° to the horizon. It rests on 'limbs' with clearance between them, the 'limbs' resembling animal paws. It looks like a small animal. If we assume that the bear cub's body is oriented vertically, which is indicated by the same position of shadows of stones, then its height should be about 30 cm and length (or width) about 15 cm. To the left of the 'bear cub' in Fig. 26, one can see four or five long grooves running behind it and ending directly near its 'limbs' [94]. One can assume that the 'bear cub' has left such tracks during its motion, which allows us to estimate its motion velocity, possibly even the maximum velocity of its motion. We can assume that the 'bear cub' began to move at a time close to when the spacecraft landed, during the shock or trying to escape the danger: the figure bottom is directly adjacent to the spacecraft's landing buffer. The scan time of the full panorama is 30 min, while the time from the beginning to the scanner passing through the 'bear cub' position is about 16 min. Thus, the maximum velocity that the object could reach under these extremal conditions by leaving 64-cm-long tracks was $64/16 = 4$ cm min^{-1}, or less than 1 mm s^{-1}. As mentioned above, the motion velocity inherent in Venus's fauna can be very low by terrestrial measures.

Is it possible to find other reasons for the appearance of grooves, for example, the 'bear cub's' motion caused by the wind? The wind velocity at the Venera 13 landing site was estimated in [52] as $V \approx 0.45$ m s^{-1} (the equivalent of the terrestrial wind with a velocity up to 8 m s^{-1}). Other Venera measurements gave the same values. The possibility of the

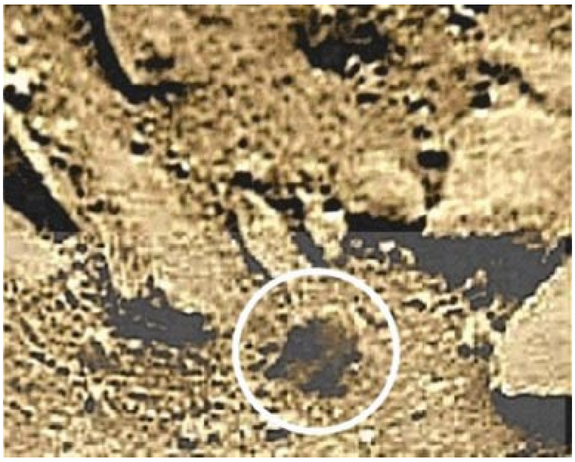

Figure 26. (Color online.) Part of a processed Venera 9 panorama. A small object, a 'bear cub', observed in the front differs in its 'soft' shape from the sharp stone edges. It rests on 'limbs' with clearance between them. On the left, long grooves extend to the 'bear cub'. They look like the tracks of its motion.

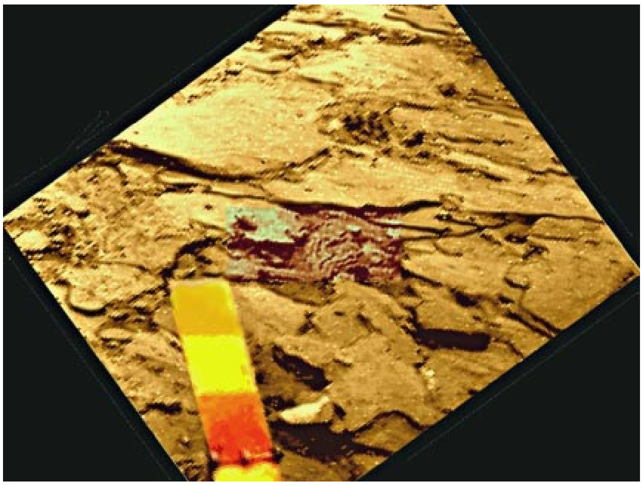

Figure 27. (Color online.) The 'snake' object looking like a coiled snake is located in a pit at the figure center (part of the processed Venera 14 panorama).

'bear cub's' motion due to the wind is determined by wind velocity head $F = 1/2\rho S V^2$. For the gas density $\rho = 64$ kg m^{-3} and the side surface of the object $S = 0.05$ m^2, we obtain the wind pressure $F = 0.26$ N, insufficient for moving the object.

9.2.3 'Snake'. The analysis of Venera 14 panoramas revealed a 'snake' object with an unfolded length of 40–50 cm (Fig. 27, at the center). The cellular, spotted surface of the 'snake's' body drastically differs from the background of the surrounding stone plates, The 'snake' is among the most interesting findings among hypothetical objects of Venus's fauna, resembling in shape some terrestrial living organisms. At the same time, some strange, incomprehensible objects were found.

A 'snake', as an unusual object, was first noticed in the Venera-14 panorama back in 1983 directly after the mission was completed. The geological analysis of the region performed by K P Florenskii et al. was published in the topical issue of *Space Research* [95]. The authors of [95] focused on the unusual part of the surface located quite close to the TV camera objective (Fig. 27). They pointed out that "in the B14-1 panorama, to the right of the color test end, in a shallow lowering of the microrelief, a relatively dark spotty (cellular?) surface with a peculiar striped orientation of spots was observed.... This formation can either put a layered pack down or produce some 'foreign' body inside the layered pack." This was all the authors of [95] said, although "a spotty, cellular, foreign body in the B14-1 panorama" could be their most surprising finding (shown by the arrow in Fig. 28).

Regularly arranged spotty cells cover the surface of the 'foreign body'. The object is located in a small pit (5–10 cm) and indeed looks like a coiled snake (Fig. 28b). It seems that this object has certain terramorphic features inherent terrestrial reptiles: flexibility, a cellular structure, and the corresponding color. The figure was obtained by group processing of the most distinct initial parts of the panoramic images.

The extreme right part of the 'snake' (Fig. 28b), hereafter called the 'head', has a pointed right part resembling a beak. The 'head' is turned to the camera by a round 'eye' (a round light spot). It is reasonable to assume that this is really the vision organ. An arc located over the 'eye' passes on the right to a pointed 'beak'. The 'head', 6–8 cm in size, resembles the head of many terrestrial birds or reptiles observed from the side. To the left of the 'eye' is located a slightly elongated small dark spot which changes its shape from elongated to round in successive frames. We can assume that, similarly to terrestrial creatures, this is an acoustic organ (acoustic phenomena on Venus were pointed out in [93, 96]). The lower part of the stretched out 'neck' borders on the left regularly arranged cells (mentioned in [88]). Cells cover the entire front part of the 'snake'. A dark fold where the coiled body bends changes its shape from an arc to a straight line in successive images. The cellular surface extends from the bend to the widening, passing to the tail of the 'snake'. The position of the 'snake' changes somewhat in successive panoramas. Over the cellular body, a 'comb' is seen, consisting of separate elements restricted from above by an arc about 4 cm in length. The comb position noticeably changes in successive panoramas: it is displaced with respect to a small dark part of the surface adjacent to it on the left. The motion of the comb is revealed during the superposition of images. The head and protruding parts of the 'snake's' body also move somewhat in the animation produced by a sequence of frames. It seems that the 'snake' ends in a long and wide 'tail'. On the right, the tail is leaning against a light triangular plate fragment. Spotty cells on the tail are not seen. A light ledge is observed on the tail. Cells and the ledge move together with the tail by no less than 10 cm. Details are presented in [93, 97].

Successive images of the snake obtained for 1.5 h of operation of the lander on Venus's surface were presented in the form of animation. Although the snake is not displaced as

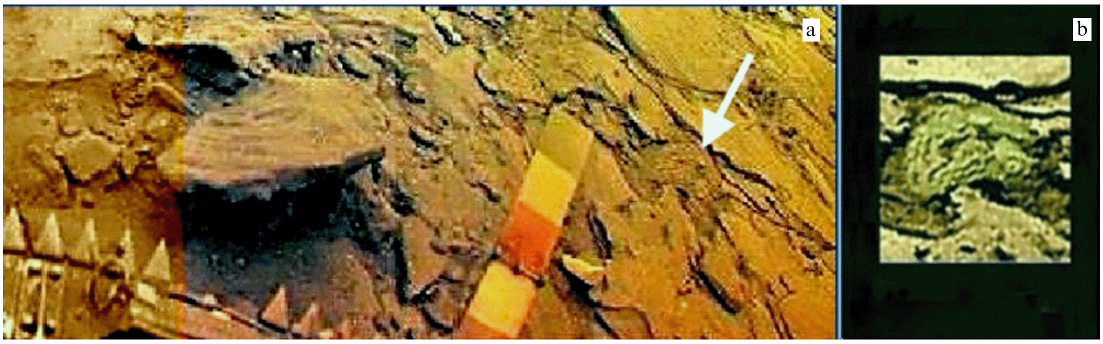

Figure 28. (Color online.) (a) Portion of the Venera 14 panorama. The arrow shows a 'spotty, cellular, foreign body' [95]. (b) The same object after processing (the image is turned by 40°), The object resembles a coiled snake about 0.5 m in length. The 'head' is at the right, the 'eye' of the object facing the reader. The body has a greenish tint enhanced in the figure.

a whole and does not creep, the mutual displacement of its parts is well seen. A comparison of all the frames of the sequence gives approximately the same velocity of the relative motion of the snake's parts as for other objects, about 1 mm s^{-1}. For example, the displacement of the comb between successive frames was 3–4 cm for 30 min.

9.2.4 'Owl'. The 'owl' object (Fig. 29) has a complex structure, which at once attracted the attention of researchers. In paper [95], the Florenskii geological group considered, along with "a spotty cellular body with a peculiar striped orientation of spots" ('snake'), an object called a "strange stone with a rod-like ledge and lumpy surface." The authors of [95] wrote: "It was difficult to determine the shape of a 'strange' stone.... We see it in a strong perspective. A specific feature of this stone is the general roundness of its convex side facing the TV camera combined with a spotty (probably, small-lumpy) surface which is darker than plate stones.... At the left of this stone, a light elongated rod-like ledge 15 cm in length and a base thickness of 5 cm protruded from the stone...."

Figure 29 presents a view of a 'strange stone' in the Venera 9 panorama in the modern processing (object *1*). The stone is inside a thin white oval. The complex shape, the white 'tail', and other features of the object distinguish it against the background of the stony surface of the planet in the Venera 9 landing place. The size of the object was about 0.5 m.

Traditional concepts about the impossibility of life at high temperatures proved to be an insurmountable barrier to any alternative discussions of the origin of the 'strange stone'. Nevertheless, a year before the publication of paper [95], the image of a 'strange stone with an unusual shape' was presented in the book *Planets discovered anew* [36] with the comments: "Details of the object are symmetric with respect to the longitudinal axis. The insufficient sharpness conceals its contours, but... Is it possible that Venera 9 has landed near a living habitant of the planet?"

The 'owl' is distinguished by a pronounced longitudinal symmetry. This object resembles a sitting bird. The position of details of the 'lumpy' (or maybe feathery?) surface reveals a certain radial character, 'lumpy rows' going from a 'head' in the right part and moving to a straight tail. The 'head' itself has a lighter tint and a more complicated symmetric structure with large figures, also symmetric dark spots and, possibly, some ledges at the top. It cannot be rulled out that small stones accidentally coinciding in their light tints are situated in such a way so as to appear to be part of the 'head'. However, the shapes of the main part of the 'owl' are so regular that it is difficult to believe that it is a large 'strange' stone. The straight uplifted light 'tail' mentioned above is indeed 13–16 cm in length, while the length of the entire 'owl' reaches 35 cm or 48–51 cm with the white tail. The shadow under its body completely repeats the contours of all parts of the object, which is uplifted over the surface by several centimeters. Its height is no smaller than 25 cm. Thus, the size of the 'owl' is large enough to obtain quite detailed images of the object closely located to the camera, even for the restricted resolution of the scanning Venera 9 camera. Noise in the processed Venera 9 panorama barely affects the image.

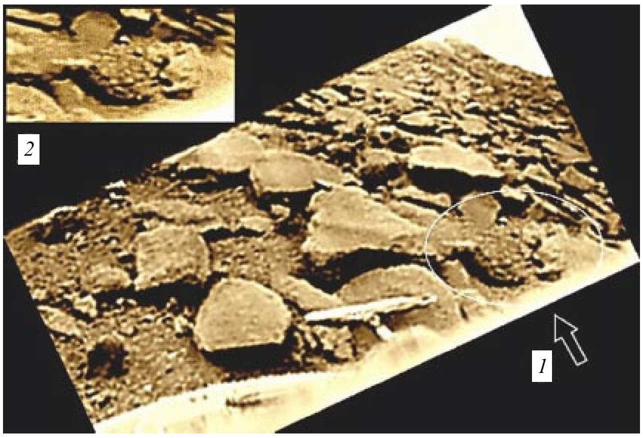

Figure 29. (Color online.) The object conditionally called the 'owl' (*1*) in the processed Venera 9 panorama. The 'owl' has a distinct longitudinal symmetry and a white straight tail 15 cm in length. Its view with a partially corrected geometry (*2*) is difficult to interpret as a 'strange stone' or 'volcanic bomb with a tail'.

Image *2* in Fig. 29 with a partially corrected geometry completely corresponds to the object located in front of the camera during shooting. It seems that the obviously intricate and rather ordered morphology of the 'owl' complicates the search for other assumptions about its origin, like a 'strange stone' or 'volcanic bomb with a tail'. Any other objects with a similar structure are absent in Fig. 29.

9.2.5 'Toothed object'. In some cases, unlike the examples presented above, it is difficult to assign the details of images to hypothetical living forms, and a comparison is required, for example, to a photographic map. This applies to a 'toothed object' [98]. In the left part of the processed Venera 9 panorama, a large elongated bright object about 1.3 m in size with strange toothed edges is seen (Fig. 30) which resembles in shape the toothed leaves of terrestrial trees. It was assumed that the toothed edges of the object are observed as the linear structure of a TV image. However, such a structure is absent in other surrounding details of the image. The object, provisionally called the 'toothed object', is considerably lighter than the surrounding stones (Fig. 30). The 'toothed object' is uplifted over the surface, and a deep shadow is observed under it. It is quite large. However, because it is located at a large distance (about 4 m) from the camera, it is difficult to determine its structure, but some information can be obtained from comparisons with the photographic map. Unfortunately, only the working version of the phtoplan exists based on the primary processing of Venera 9 data. Nevertheless, we can see that the structure of the toothed object is more complicated than that of the surrounding large stones. It looks like a radially organized

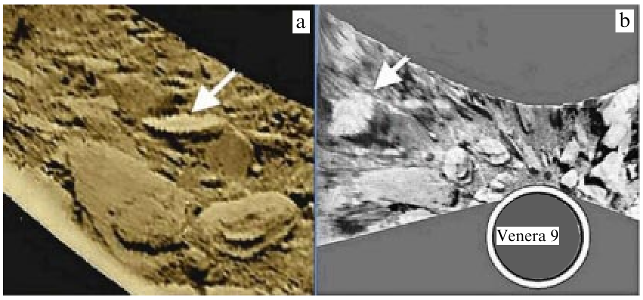

Figure 30. 'Toothed object' (a) in the processed Venera 9 panorama (shown by the arrow) and its horizontal projection (b) (photographic map). The circle shows the position and diameter (2 m) of the Venera 9 landing buffer.

object with a ray-like periphery (Fig. 30b). The photographic map can be considered the horizontal projection of the toothed object, resembling somewhat in its symmetry a stingray. Because the photographic map resolution is low, we cannot make more certain conclusions about the toothed object's nature and cannot assign it to Venusian flora or fauna.

The toothed object is located on a large stone. The elongated shape of its parts, observed at the edge of the object (Fig. 30b), is similar to a bird's feathers. Recall that the resolution of the Venera 9 TV camera (21′) is half that of the Venera 13 and Venera 14 cameras. Therefore, our attempts to identify the details of the toothed object should be considered with care. The symmetric shape of the toothed object in the photographic map resembles a bird with a wingspan of almost 1.5 m and a protruding 10–15-cm tail. As mentioned already, the dense Venusian atmosphere could be a convenient medium for flying hypothetical living creatures.

9.2.6 'Victim'. From a place on the torus of the landing Venera 9 buffer indicated by an asterisk in Fig. 31, a dark continuous mark on the stone surface goes to the left, then leaves the stone, expands, and ends near a light round object with a pointed dark left part, possibly a specimen of Venus's fauna. Neither of the other Venera panoramas exhibit such dark marks, and its density suggests that the trace is produced by some liquid substance of an unknown nature which cannot be water. The critical temperature and pressure for water are 647 K and 22 MPa, and therefore a temperature of 735 K and a pressure of 9.2 MPa near Venus's surface do not allow the presence of liquid water there. The substance should be either an unknown high-temperature water solution or some other, also unknown, liquid medium. The origin of the mark, which begins directly near the spacecraft landing buffer, can be tentatively explained as follows. If the object really belongs to Venus's fauna, it could have been damaged by the buffer during landing and, crawling away, left a dark track of its damaged tissue. For terrestrial animals, such a mark would be called 'bloody'. (Thus, the first victim of Earth's studies of Venus might be related to this object observed on 22 October 1975). The position of the object in the panorama approximately corresponds to the 6th scan minute, and the distance which the object could crawl away by the 6th min was 26–30 cm. A scanning camera was switched on 1 min after the landing. Therefore, we can find from the scan time (6 min) and the object's position that the velocity of its motion leaving traces was about 6 cm min^{-1} or 1 mm s^{-1}, i.e., similar to that indicated in previous sections.

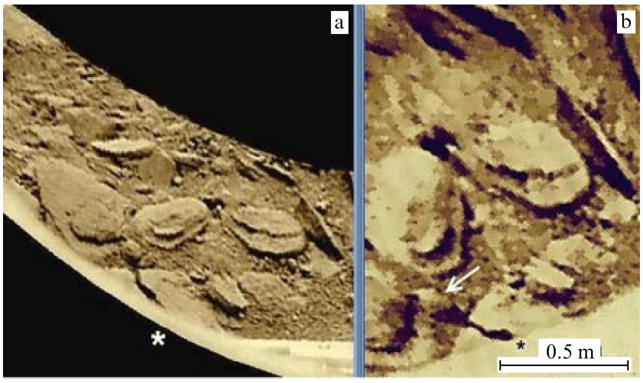

Figure 31. (a) A dark mark extending to the left from the landing buffer shown by the asterisk was possibly left by an object wounded by the lander. (b) Part of the photographic map allowing us to estimate the size of the object (indicated by the arrow) and to compare the positions of image details. The mark is produced by a liquid substance of unknown origin (liquid water cannot exist on Venus). The object (about 18 cm in size) was able to crawl away 26–30 cm in a time of no more than 6 min.

The shape of the object with the corrected geometry and the spatial scale are shown in the photographic map, where the damaged object is seen between large stones (Fig. 31b). We have failed to find out whether it moved or not because the second Venera 9 panorama does not contain its image. The dark mark shows that objects observed on Venus's surface are capable of moving in case of serious danger at a velocity of no less than 6 cm min^{-1} (1 mm s^{-1}), even in a damaged state. Recall that a 'scorpion' disappeared from the panorama field in the interval between the 93th and 119th minutes of the lander's operation, which means that it should be displaced by a distance of no less than 1 m, i.e., it moved with a velocity of no less than 4 cm min^{-1}. The same estimates are also obtained for other objects of the hypothetical fauna of the planet.

9.2.7 Sounds recorded by Venera spacecraft detectors. In conclusion, we will mention sounds recorded by acoustic detectors on Venera 13 and Venera 14 [93]. The field of acoustic signals in the high-density Venusian atmosphere can give information about the activity of natural processes and activity of hypothetical fauna on Venus. Acoustic experiments were performed on the Venera missions in 1982 along with other experiments. The Groza instrument aboard the Venera 13 and Venera 14 spacecraft had acoustic detectors (electromagnetic microphones with a metal membrane). The microphones were located outside the spacecraft at a height of about 240 mm over the surface. The frequency characteristic of the microphone together with an amplifier at the level of 0.5 of sensitivity maximum covered the frequency range from 0.2 to 4 kHz (in the cold state) and shifted to lower frequencies at operating temperatures. The microphone could operate at temperatures up to 500 °C.

The limited possibilities of telemetry allowed the transmission of only information on the signal level first during descent through the atmosphere, then for 240 s after landing, and then during 8-second intervals repeating in turn after 200 and 392 s. The telemetric sampling rate frequency was 2.5 Hz. The acoustic experiment was pioneering. The data obtained are presented in Fig. 32. The first result of the acoustic experiment was the above-mentioned measurement of the wind velocity at the Venera 13 and Venera 14 landing sites. For this purpose, a sister instrument of the same type was placed into an aerodynamic tunnel at Lomonosov Moscow State University and calibrated by the approach stream velocity and angles, and then the results were recalculated for Venusian conditions [52]. Other than the acoustic noise of the wind, the microphones also detected other noises. First, the spacecraft itself produced strong noises (the left part of Fig. 32): pyrotechnic cartridges fired and a drilling rig operated. The noise level reached approximately 93 dB.

The results of the acoustic experiment presented here were obtained during the Venera 13 mission. The main technical operations were completed in 20 min. The peak above 75 dB at 31.5 min is probably also related to the lander. The later counts to 66–70 dB are related to Venus's atmosphere. The origin of peaks at 33 min is unknown, but they are probably

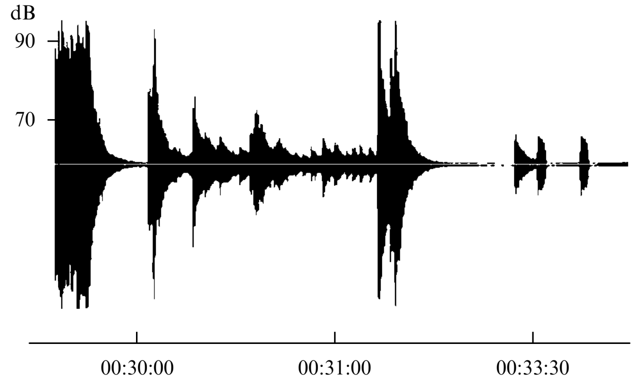

Figure 32. Venera 13 acoustic experiment (1982) in the interval of 30–33 min (the landing time was 00:29:36). The exponential decrease in the rear edge of the input signal of the acoustic channel is related to the output of the electronic device and is not related to the properties of the sound source.

not related to the lander. They can be partially due to the wind noise. No drastic changes in the signal were observed that could be related to the assumed activity of fauna. However, these results cannot be representative due to very short sampling periods and long 'deaf' intervals. Acoustic measurements can be important experiments for searching for Venusian fauna, if this fauna really exists and its acoustic effects can be detected with instruments used in spacecraft.

References

1. Hackerman N et al. (Eds) *The Search for Life's Origins* (Washington, DC: National Academy Press, 1990)
2. Dobretsov N et al. (Eds) *Biosphere Origin and Evolution* (New York: Springer, 2008)
3. Galimov E M (Ed.) *Problemy Zarozhdeniya i Evolyutsii Biosfery* (Problems of Biosphere Origin and Evolution) (Moscow: Librokom, 2008)
4. Rozanov A Yu, Lopatin A V, Snytnikov V N (Eds) *Problemy Proiskhozhdeniya Zhizni* (Problems of Life Origin) (Moscow: PIN RAN, 2009)
5. Rozanov A Yu *Paleontolog. J.* **37** 600 (2003); *Paleontol. Zh.* (6) 41 (2003)
6. Sklyarov E V "Geologicheskaya evolyutsiya Zemli" ("Geological evolution of Earth"), in *Razvitie Zhizni v Protsesse Abioticheskikh Izmenenii na Zemle. 2-ya Vseross. Nauchnaya Konf., Irkutskaya obl., pos. Listvyanka, 23–27 Avgusta 2011 g.* (Life Development in the Process of Abiotic Changes on Earth. 2nd All-Russia Scientific Conf., Irkutsk Region, Listvyanka, August 23–27, 2011) (Irkutsk: Listvyanka, 2008)
7. Martin D, McKenna H, Livina V *J. Physiolog. Sci.* **67** (1) 97 (2017)
8. Snytnikov V N "Azotnaya zhizn' na Venere" (Nitrogen life on Venus), Report at the Space Research Institute, RAS (2016)
9. Jones B W *Life in the Solar System and Beyond* (London: Springer, 2004); Translated into Russian: *Zhizn' v Solnechnoi Sisteme i za ee Predelami* (Moscow: Mir, 2007)
10. Parmon V N *Herald Russ. Acad. Sci.* **72** 592 (2002); *Vestn. Ross. Akad. Nauk* **72** 976 (2002)
11. Parmon V N, in *Biosphere Origin and Evolution* (Eds N Dobretsov et al.) (Boston, MA: Springer, 2008) p. 89
12. Ebeling W, Engel A, Feistel R *Physik der Evolutionsprozesse* (Berlin: Akademie-Verlag, 1990); Translated into Russian: *Fizika Protsessov Evolyutsii* (Moscow: URSS, 2001)
13. Sorokina K N et al. *ChemSusChem.* **10** 562 (2017)
14. Snytnikov VN *Vestn. Ross. Akad. Nauk* **77** (3) 218 (2007)
15. Snytnikov V N, in *Biosphere Origin and Evolution* (Eds N Dobretsov et al.) (Boston, MA: Springer, 2008) p. 45
16. Spirin A S *Solar Syst. Res.* **46** 381 (2012); *Asron. Vestn.* **46** 411 (2012)
17. Ksanfomaliti L V *Kinemat. Phys. Celest. Bodies* **26** 200 (2010); *Kinemat. Fiz. Nebesn. Tel* **26** (4) 84 (2010)
18. Ksanfomaliti L V, Shematovich V I *Solar Syst. Res.* **44** 354 (2010); *Asron. Vestn.* **44** 381 (2010)
19. Ksanfomaliti L V *Dokl. Phys.* **57** 367 (2012); *Dokl. Ross. Akad. Nauk* **446** 42 (2012)
20. Wainwright M et al. *Int. J. Astrobiol.* **3** (1) 13 (2004)
21. Wainwright M et al. *J. Astrobiol. Outreach.* **3** (2) 130 (2015)
22. Grotzinger J P et al. *Science* **350** aac7575 (2015)
23. Goetz W et al. *Int. J. Astrobiol.* **15** 239 (2016)
24. Smith D J *Astrobiology* **13** 981 (2013)
25. Guaita C *Eur. Phys. J. Plus* **132** 346 (2017)
26. Voosen P *Science* **357** 535 (2017)
27. Voosen P *Science* **355** 444 (2017)
28. Vago J L et al. *Astrobiology* **17** 471 (2017)
29. Glein C R, Baross J A, Waite H (Jr.) *J. Geochim. Cosmochim. Acta* **162** 202 (2015)
30. Vance S D, Hand K P, Pappalardo R T *Geophys. Res. Lett.* **43** 4871 (2016)
31. Norman L H *Astron. Geophys.* **52** (1) 1.39 (2011)
32. Morowitz H *Astrobiology* **11** 931 (2011)
33. Cockell C S *Planet. Space Sci.* **47** 1487 (1999)
34. Dartnell L R et al. *Icarus* **257** 396 (2015)
35. Morowitz H, Sagan C *Nature* **215** 1259 (1967)
36. Ksanfomaliti L V *Planety, Otkrytye Zanovo* (Planets Opened Anew) (Moscow: Nauka, 1978)
37. Daniel I, Oger P, Winter R *Chem. Soc. Rev.* **35** 858 (2006)
38. Clarke A et al. *PLoS ONE* **8** e66207 (2013)
39. Kashefi K, Lovley D R *Science* **301** 934 (2003)
40. Takai K et al. *Proc. Natl. Acad. Sci. USA* **105** 10949 (2008)
41. Hoff M *PLoS Biol.* **7** e1000258 (2009)
42. Macalady J L, Jones D S, Lyon E H *Environment. Microbiol.* **9** 1402 (2007)
43. Peet K C et al. *Appl. Environ. Microbiol.* **81** 2881 (2015)
44. Cox M M, Battista J R *Nature Rev. Microbiol.* **3** 882 (2005)
45. Musilova M et al. *Astrobiology* **15** 1076 (2015)
46. Parnell J et al. *Origins Life Evol. Biospher.* **46** 107 (2016)
47. Slobodkin A I, Slobodkina G B *Microbiology* **83** (3) 169 (2014)
48. Horneck G, Klaus D M, Mancinelli R L *Microbiol. Mol. Biol. Rev.* **74** (1) 121 (2010)
49. Siddiqi A A *Deep Space Chronicle*: *A Chronology of Deep Space and Planetary Probes 1958 – 2000. Monographs in Aerospace History.* (Monographs in Aerospace History, No. 24) (Washington, DC: National Aeronautics and Space Administration Office of External Relations NASA History Office, 2002)
50. Zasova L V *Mekh. Upravl. Inform.* **7** (3) 102 (2015)
51. Bonnet R-M, Grinspoon D, Pio Rossi A *Intern. Space Science Institute Scientific Report Series Book* **11** 7 (2012)
52. Ksanfomaliti L V, Gorshkova N V, Khondrev V K *Kosm. Issled.* **21** (2) 218 (1983)
53. Ksanfomality L V, Scarf F L, Taylor W W L, in *Venus* (Eds D M Hunten et al.) (Tucson, AZ: Univ. of Arizona Press, 1983) p. 565
54. Ksanfomaliti L V *Asrtronom. Vestn.* **24** (1) 59 (1990)
55. Schulze-Makuch D, Irwin L N *Astrobiology* **2** 197 (2002)
56. Schulze-Makuch D et al. *Astrobiology* **4** 11 (2004)
57. Yates J S et al. *Astrophys. J.* **836** 184 (2017)
58. Atri D *J. R. Soc. Interface* **13** 0459 (2016)
59. Landis G A *J. Brit. Interplanet. Soc.* **56** (7–8) 250 (2003)
60. Grinspoon D H, Bullock M A, in *Exploring Venus as a Terrestrial Planet* (Geophysical Monograph Series, Vol. 176, Eds L W Esposito, E R Stofan, T E Cravens) (New York: Wiley, 2007) p. 191
61. Way M J et al. *Geophys. Res. Lett.* **43** 8376 (2016)
62. Wickramasinghe N C, Wickramasinghe J T *Astrophys. Space Sci.* **317** 133 (2008)
63. Goordial J et al. *ISME J.* **10** 1613 (2016)
64. Montmessin F et al. *Icarus* **216** 82 (2011)
65. Limaye S S et al. *Astrobiology* **18** 1783 (2018)
66. Polishchuk G M, Pitchkhadze K M (Eds) *Avtomaticheskie Kosmicheskie Apparaty dlya Fundamental'nykh i Prikladnykh Nauchnykh Issledovanii* (Automatic Spacecrafts for Fundamental and Applied Scientific Studies) (Moscow: Izd. MAI-Print, 2010) Sect. 10

67. Selivanov A S et al. *Cosmic Res.* **14** 593 (1977); *Kosm. Issled.* **14** 674 (1976)
68. Selivanov A S et al. *Kosm. Issled.* **21** (2) 176 (1983)
69. Keldysh M V (Exec. Ed.) *Pervye Panoramy Poverkhnosti Venery* (First Venus's Surface Panoramas) (Moscow: Nauka, 1979)
70. Baklunov A M et al. *Kosm. Issled.* **21** (2) 151 (1983)
71. Selivanov A S, Gektin Yu M *Kosm. Issled.* **21** (2) 200 (1983)
72. Gektin Yu M, Panfilov A S *Cosmic Res.* **16** 455 (1979); *Kosm. Issled.* **16** 557 (1978)
73. Volkov V P *Khimiya Atmosfery i Poverkhnosti Venery* (Chemistry of Venus: Atmosphere and Surface) (Moscow: Nauka, 1983)
74. Krasnopol'skii V A, Parshev V A *Kosm. Issled.* **18** (3) 429 (1980)
75. Khodakovsky I L *Planet. Space Sci.* **30** 803 (1982)
76. McGill G E, Warner J L, Malin M C, in *Venus* (Eds D M Hunten et al.) (Tucson, AZ: Univ. of Arizona Press, 1983) p. 69
77. Saundes R S et al. *J. Geophys. Res.* **97** 92JE01397 (1992)
78. Pettengill G H, Ford P G, Nozette S S*cience* **217** 640 (1982)
79. Ksanfomaliti L V *Planeta Venera* (Planet Venus) (Moscow: Nauka, 1985)
80. Brackett R A, Fegley B, Arvidson R E *J. Geophys. Res.* **100** 1553 (1995)
81. Schaefer L, Fegley B (Jr.) *Icarus* **168** 215 (2004)
82. Häusler B et al. *Planet. Space Sci.* **54** 1315 (2006)
83. Surkov Yu A, Moskaleva L P, Shcheglov O P *Kosm. Issled.* **21** (2) 308 (1983)
84. Titov D V *Kosm. Issled.* **19** (5) 794 (1980)
85. Ksanfomality L *Icarus* **200** 367 (2009)
86. Florenskii K P et al., in *Pervye Panoramy Poverkhnosti Venery* (First Venus's Surface Panoramas) (Exec. Ed. Keldysh M V) (Moscow: Nauka, 1979)
87. Nepoklonov B V et al., in *Pervye Panoramy Poverkhnosti Venery* (First Venus's Surface Panoramas) (Ed. Keldysh M V) (Moscow: Nauka, 1979)
88. Ksanfomality L V *Acta Astronautica* **105** 521 (2014)
89. Ksanfomality L V *Dokl. Phys.* **59** 555 (2014); *Dokl. Akad. Nauk* **459** 173 (2014)
90. Ksanfomality L V et al. *Cosmic Res.* **54** 217 (2016); *Kosm. Issled.* **54** 229 (2016)
91. Ksanfomality L V *Dokl. Phys.* **58** 514 (2013); *Dokl. Akad. Nauk* **453** 272 (2013)
92. Ksanfomality L V *Dokl. Phys.* **59** 498 (2014); *Dokl. Akad. Nauk* **458** 647 (2014)
93. Ksanfomality L V *Dokl. Phys.* **57** 497 (2012); *Dokl. Akad. Nauk* **447** 391 (2012)
94. Ksanfomality L V *Astrobiol. Outreach* **2** 112 (2014)
95. Florenskii K P et al. *Kosm. Issled.* **21** (3) 340 (1983)
96. Ksanfomality L V *Int. J. Astron. Astrophys.* **3** 57 (2013)
97. Ksanfomality L V, Selivanov A S, Gektin Yu *Am. J. Mod. Phys.* **7** (1) 34 (2018)
98. Ksanfomality L V, Selivanov A S, Gektin Yu M *Int. J. Biotech. Bioeng.* **4** (4) 81 (2018)
99. Karyagin V P et al. *Kosm. Issled.* **21** (3) 392 (1983)
100. Moshkin B E et al. *Kosm. Issled.* **21** (2) 236 (1983)
101. Blankenship R E *Molecular Mechanisms of Photosynthesis* (New York: Wiley, 2008)
102. Zavarzin G A *Priroda* (8) 3 (2008)
103. McMillan P F *Chem. Soc. Rev.* **35** 855 (2006)
104. Zhang W et al. *Science* **342** 1502 (2013)
105. Goncharov A F et al. *J. Chem. Phys.* **142** 214308 (2015)
106. Crowhurst J C et al. *J. Phys. Chem. A* **118** 8695 (2014)
107. Hu C-H et al. *Phys. Rev. Lett.* **110** 165504 (2014)
108. Qian G-R et al. *Sci. Rep.* **4** 5606 (2014)
109. Komatsu T *Phys. Chem. Chem. Phys.* **6** 878 (2004)
110. Stavrou E et al. *Chem. Mater.* **28** 6925 (2016)
111. Eremets M I et al. *Nature Mater.* **3** 558 (2004)
112. Raza Z et al. *Phys. Rev. Lett.* **111** 23550 (2013)
113. Saleh G, Oganov A R *Sci. Rep.* **6** 32486 (2016)
114. Inagaki S *Top. Curr. Chem.* **289** 293 (2009)
115. Brinck T *Green Energetic Materials* (New York: Wiley, 2014)
116. Yin K et al. *J. Mater. Chem. A.* **3** 4188 (2015)
117. Nguyen M T *Coord. Chem. Rev.* **244** 93 (2003)
118. Steele B A et al. *Chem. Mater.* **29** 735 (2017)
119. Gao H, Shreeve J M *Chem. Rev.* **111** 7377 (2011)
120. Zhao X et al. *Mater. Des.* **90** 1050 (2016)
121. Critchley J P, Knight G J, Wright W W *Heat-Resistant Polymers. Technologically Useful Materials* (Boston: Springer, 1983)
122. Buhler K-U *Spezialplaste* (Berlin: Akademie-Verlag, 1978)
123. Qian G-R et al. *Sci. Rep.* **6** 25947 (2016)
124. Kaiser R I, Mebel A M *Chem. Soc. Rev.* **41** 5490 (2012)
125. Mikhailin Yu A *Termoustoichivye Polimery i Polimernye Materialy* (Thermostable Polymers and Polymeric Materials) (St. Petersburg: Professiya, 2017)
126. Budisa N, Schulze-Makuch D *Life* **4** 331 (2014)
127. Helen R Hobbs, Neil R *Chem. Rev.* **107** 2786 (2007)
128. Nikitin L N et al. *Ros. Khim. Zh.* **52** (3) 56 (2008)
129. Howdle S M, in *Sverkhkriticheskie Flyuidy* (*SKF*): *Fundamental'nye Osnovy, Tekhnologii, Innovatsii. VI Nauchno-Prakticheskaya Konf. s Mezhdunarodnym Uhastiem, pos. Listvyanka, Irkutskaya obl., Rossiya, 4–7 Iyulya 2011. Tezisy dokladov.* (Supercritical Fluids (SCF): Fundamentals, Technologies, Innovations. VI Scientific and Practical Conf. with International Participation, pos. Listvyanka, Irkutsk region., Russia, July 4–7, 2011. Abstracts) (Novosibirsk: Institut Kataliza imeni G K Boreskova SO RAN, 2011) p. 7; http://www.catalysis.ru/resources/institute/Publishing/Report/2011/037-2011-Abstracts-SUPERCRITICAL-Baikal.pdf
130. Oyama V I et al. *Science* **203** 802 (1979)
131. Krasnopol'skii V A *Fotokhimiya Atmosfer Marsa i Venery* (Photochemistry of Mars's and Venus's Atmospheres) (Moscow: Nauka, 1982)
132. Huber C, Wächtershäuser G *Science* **314** 630 (2006)
133. Bukhtiyarova G A et al. *J. Mol. Catal. A* **158** 251 (2000)
134. Masyuk N, Sherin A, Snytnikov V N, Snytnikov Vl N *J. Analyt. Appl. Pyrolysis* **134** 122 (2018)
135. Sojo V et al. *Astrobiology* **16** 181 (2016)
136. Shapatina EN, Kuchaev V L, Temkin M I *Kinet. Katal.* **29** (3) 603 (1988)
137. Moggi P, Predieri G, Maione A *Catal. Lett.* **79** 7 (2002)
138. Rosowski F et al. *Appl. Catal. A* **151** 443 (1997)
139. Zhang C-J et al. *Nature Commun.* **9** 2137 (2018)
140. Roussel E G et al. *Science* **320** 1046 (2008)
141. Bonch-Osmolovskaya E A *Mikrobiol.* **83** (3) 255 (2014)
142. Inagaki F et al. *Proc. Natl. Acad. Sci. USA* **103** 14164 (2006)
143. Zhang L J et al. *Nature Rev. Mater.* **2** 17005 (2017)
144. Batyrev I G *J. Phys. Chem. A* **121** 638 (2017)
145. Kurzydlowski D, Zaleski-Ejgierd P *Sci. Rep.* **6** 36049 (2016)
146. Titov D V et al. *Solar Syst. Res.* **43** 185 (2009); *Astronom. Vestn.* **43** 195 (2009)
147. Ivanov M A et al. *Solar Syst. Res.* **51** 1 (2017); *Astronom. Vestn.* **51** 3 (2017)
148. Voosen P *Science* **358** 984 (2017)
149. Cooper K, Astrobiology Mag., http://www.astrobio.net/venus/dark-streaks-venus-clouds-microbial-life/ (2017)
150. Ekonomov A P, Ksanfomality L V *Solar Syst. Res.* **52** 37 (2018); *Astronom. Vestn.* **52** 43 (2018)