The Brownian motion fractal nature as a joint property in relation to scale sizes within space and submicroelectronics hybrid integrations

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Abstract

- One of the most important fractals' characteristics is that they are scale-independent which provides the possibility to apply fractal analysis on any scale existing in nature, including space, like macro, micro, or nano. It means that we can apply fractal nature characterization on large or small space bodies, as well as on microelectronic ceramic materials and also on biophysical systems, considering fractal nature as a general phenomenon within the whole Universe, comprising alive and nonalive matter.
- Submicroelectronics hybrid integrations imply the integration of biophysical and condensed matter systems structures, which is possible due to fractal nature self-similarities of Brownian motion, represented by living and nonliving systems particles motion.
- Electrons and other submicroparticles Brownian motion is the joint property of biophysical and condensed matter systems because these particles "don't recognize" which system they are a part of, thus their properties and motion are identical in both systems.
- If we presume the existence of some kind of alien life forms in space, we can consider the living and nonliving space systems integration too, also in the frame of Brownian motion fractal nature.
- The goal of our research is to open new frontiers for complex integrations regardless of scale size, from submicroelectronics hybrid systems, up to the space level in the sense of exploring existence of life and intelligence on other space bodies.

Introduction

- Advanced research frontiers are very extended from biophysics relations on the Earth up to the discovering anytype of alive matter within the whole space.
- Nowadays, modern science and technological development demonstrate very important advancement in biosystems and condensed matter particles, including even quantum level in computers and high level integrations for joint information, telecommunications applications, and space exploring.
- From this point of view the fundamental research which include the different phenomena related to paricles in bio and condensed matter systems is of great importance.

- Our research and reports come up to the level of investigations to the particles motion as a joint characteristic in bio and condensed matter subsystems.
- The idea of joint examination and linking of living and nonliving systems, as a biomimetic approach, is of great importance for further microelectronics miniaturization and integration, and also for developing new advanced technologies for complex biodevices.
- The whole idea of our research work is to open new perspectives for interconnecting biophysical and physical systems, as they are biunivocaly correspondents, which is very significant from the aspect of alive and nonalive matter structures integrations towards designing new materials and technologies.
- Regarding the advanced research in the field of new solutions for high-level microelectronics integrations, which include sub-micro biosystems like part of even organic microelectronics considerations, together with some physical systems of particles in solid states solutions as a nonorganic part.

- The substantial integrative characteristic of these systems is Brownian motion with its fractal nature, which is the basis of the biomimetic motion similarities.
- Brownian motion is important as a bridge between biomatter and condensed matter, especially solid-state solutions in microelectronic applications.
- Our research is based on Brownian motion minimal joint properties within the integrated biophysical systems in the whollyness of nature.
- In this way, there are no limitations in biophysical systems in advanced submicroelectronics solutions and designs.
- We use the fractals self-similarities as a bridge from biomimetic structures and shapes to our higher level and even submicroelectronics hybrid integrations.

Short intro to fractals

- The inspiration for the world of mathematical fractal structures came from nature, as well as the Euclidean geometric shapes, and, now, it returns to nature to serve it [1].
- The fractal nature exists independently everywhere within the structures and contact surfaces, from microstructures, even down to the nano-scale level, up to the global bulk and massive shapes.
- This exciting story about the fractals, must begin from some substantial point as a part of Nature and Matter. There is the biunivocal correspondence between the Fractal Nature and the Nature, recognized by Fractals existing, and at the end, from these two aspects, the source and meeting point are the same. The Fractals' world is everywhere around us and we are substantial part of such Fractals Space Nature.
- From that aspect the relation large-small in the light of fractal analysis is very important [2]. Our microstructures do not differ regarding fractality from macrostructures.

- The Euclidean geometry classical objects only idealize real world abstractions and their use in modeling real phenomena and objects, which have a much more complex structure, are not always adequate and do not yield good results.
- There are many examples like clouds formation, polarized light, the arrangement of stars in galaxies, vegetation, the relief irregular forms, the coastline contours, alveolar configuration of the lung tissues, etc. In addition to the morphological sphere, noise in telecommunications, variation in different plants biomass and animal species, or a statistical performance of a spoken language are the examples from the functional sphere.
- These objects, i.e. phenomena, have one property in common and that is their structure being replicated and we call such objects fractals. Thus, it is about objects that possess the characteristic of selfsimilarity, where each part of an object is similar to the whole.

- The problem is how to describe objects with such complex structure in a finite way. As the Euclidean geometry axioms states: "The whole is greater than the part.", thus, it fails to describe fractals as they are objects whose proper part is equal (in some way) to the whole.
- Regarding its complexity, fractal objects cannot be successfully described in a simple way, without involving infinity. In the early 20th century, it became clear that the Euclidean geometry is not sufficient to describe some common phenomena such as chaotic motion, turbulence, crystal growth *etc*, because of their fractal nature as geometrical objects having broken, fragmented, wrinkled or amorphous forms or being highly irregular in some other way.
- So, these objects are subjects of fractal geometry. The term fractal is a neologism derived from the Latin adjective *fractus* meaning fragmented, irregular.
- Over the years, there have appeared some partial solutions and these attempts were systematized by Benoit Mandelbrot in the 1980s in his epochal book [3], which cast a new light on the order of things in nature.

- The topological dimension TD describes common, intuitive dimension of Euclidean geometry objects, with TD = 1 for curves, 2 for surfaces, 3 for solids, etc. Natural extension of topological dimension that recognize fractals is fractal (Hausdorff) dimension FD.
- Unlike the topological dimension TD, fractal dimension FD is typically a non-integer for a fractal object. For example, a calm liquid surface has TD = FD = 2, i.e. the superficial layer of liquid molecules can be approximated as a mathematical plane. Any disturbance, for example by heating, will make the surface geometry more complicated, with $2 < FD \leq 3$. The upper limit, FD = 3 can occur through evaporation of all liquid particles, transforming the planar layer into a 3-dimensional space.
- It may be noted that, fractal dimension is not a unique descriptor. It is likely that, fractal structures or patterns can have same fractal dimension FD, but be dramatically different. There are many other fractal descriptors.

Scale sizes within space

- The fractal analytic method of structural reconstruction of materials, grains and pores, in order to make possible an advanced microstructural property prognosis, is a new procedure in materials microstructural characterization [4].
- Electronic microscopy methods [5], regardless of resolution and magnification, enables one getting micrographs. This was applied on barium-titanate [6], silicate, refractory and other ceramics, but can be applied also to any material.
- Based on the grains and perimeters fractal analysis, their reconstruction is made by using the Richardson method of variable yardstick [7]. It gives a more realistic picture as obtained with an Euclidean geometry frame, which replaces the role of modeling, because it gives the real micrographs shapes. The obtained micrographs, through shape reconstruction, lead to prognosis possibility of the designed microstructural properties [4, 8].

- From this point of view, all modern and maximal optimized microstructure methods are faced with open questions, how to provide more flexibility in the field of the structural units (grains and pores).
- Their reconstruction and interrelations have the final goal to be in function of future high level integrations and better packaging of microelectronic components, devices, and integrated circuits.
- This is on the way to understand that the fractal nature exists everywhere independently of distances. This opens a new view, namely that the shapes of the objects on Earth, under the telescope from space, are like the microstructures seen with the aid of a microscope.

- We analyzed these questions with experimental results obtained from a comet, here 67P, and also from ceramic grain and pore morphologies on the microstructure level.
- Our experimental data are based on the results collected by some instruments of the ESA spacecraft Rosetta and Philae of the Rosetta mission [9,10, 11] obtained on comet 67P/Churyumov–Gerasimenko, and on our results on the characterization of grains and pores of ceramics microstructure morphologies.
- In both cases we applied fractal analysis which demonstrates common characteristics on space bodies and down to the level nano and sub-nano structures.

- Figure demonstrate the variety of different space bodies structures down to the level of sub-micro structures, which are part of the general scale of features of the universe.

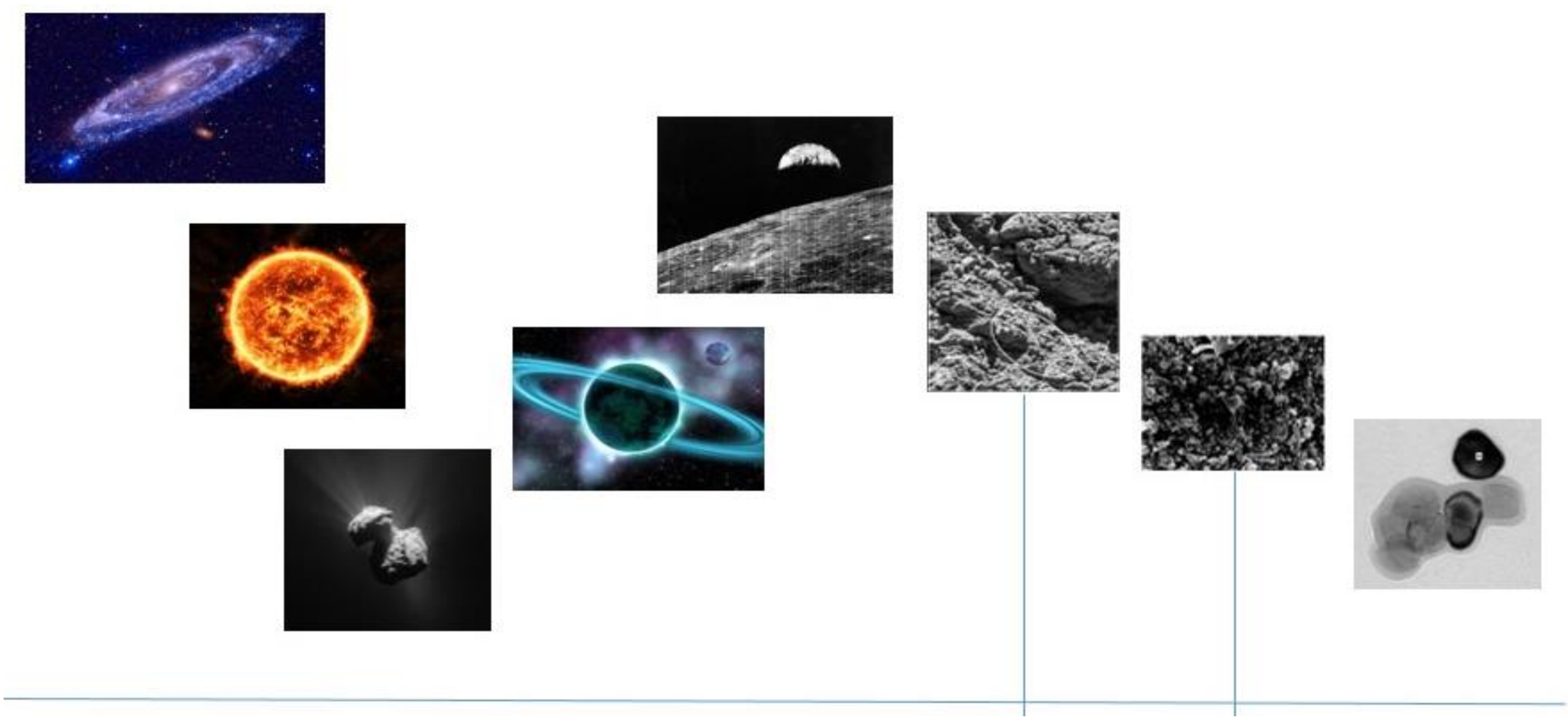


Figure. Universe scales (public databases, comet, Industrial Technology Research Institute (ITRI), Taiwan).

- A comet may represent the results of morphology structures as typical for our solar system. We analyzed the microstructural shapes at the final landing site Abydos of the Rosetta Mission lander Philae. Also we reconstructed and characterized the „grain“ perimeters as shown in Figure.

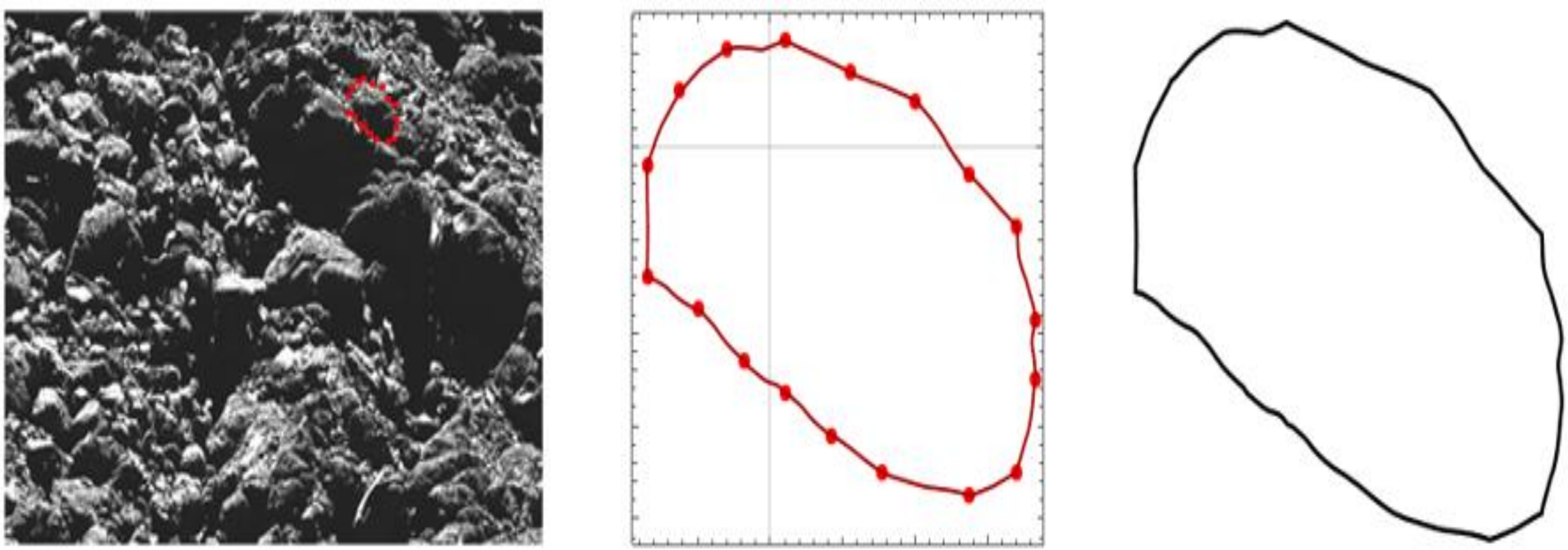


Figure. Left: Comets surface microstructure at final landing place Abydos; Center and right: Fractal analysis related parameters of some structure morphologies

- From materials science we selected, as a base for a beginning, ceramics materials. Regarding the analysis of this extreme on the Solar system scale, grains from ceramics morphologies are studied. The ceramics samples are made of $BaTiO_3$ with different additives like Ho which are consolidated by standard procedure.
- We carried out the microstructure analysis with five different magnifications and based on that the perimeter of the grains is shown in Figure.
- On this way we have the same fractal analysis on the scale of mega bodies sizes and micro and sub micro structures on the other extreme scale sizes.

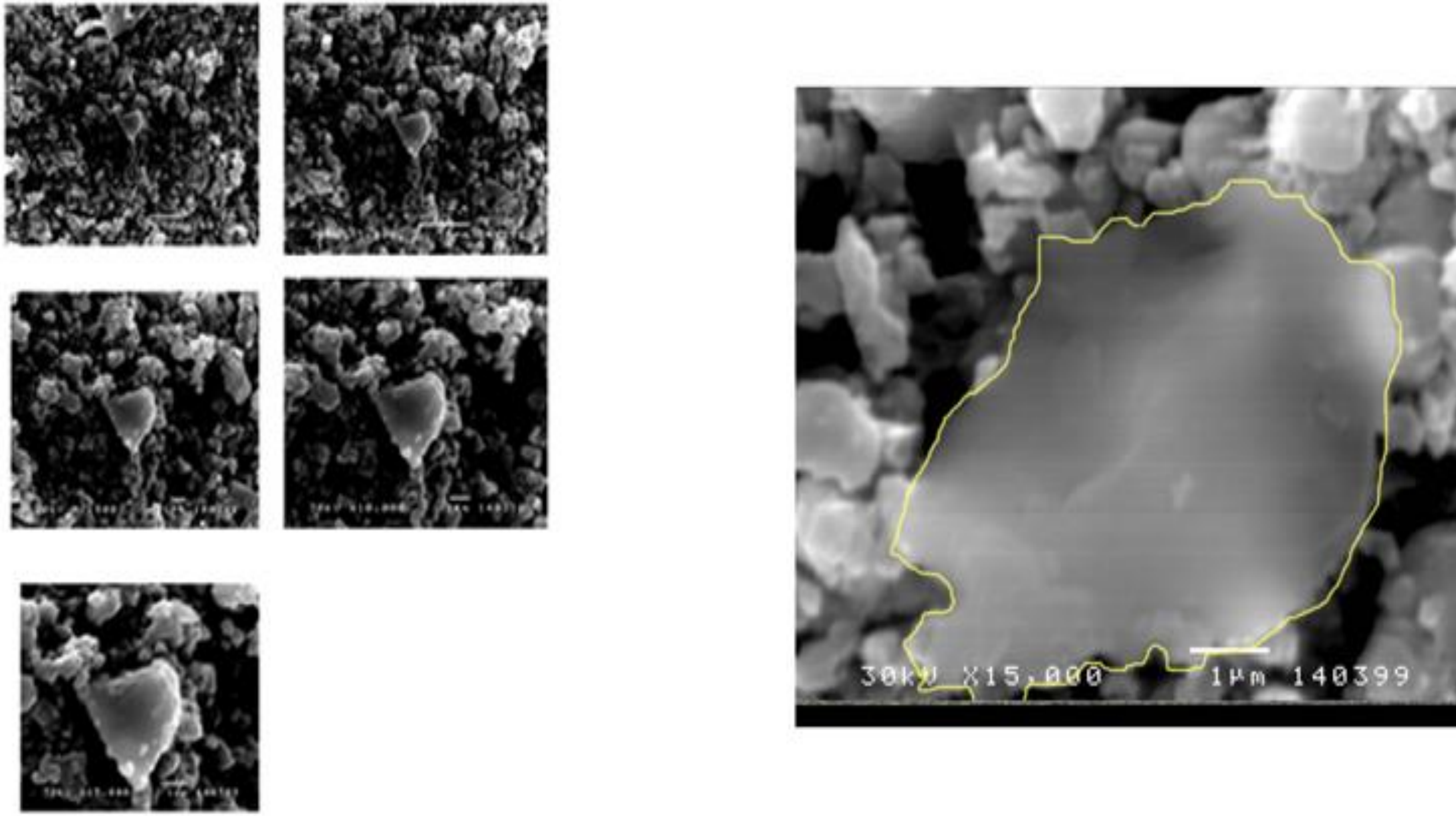
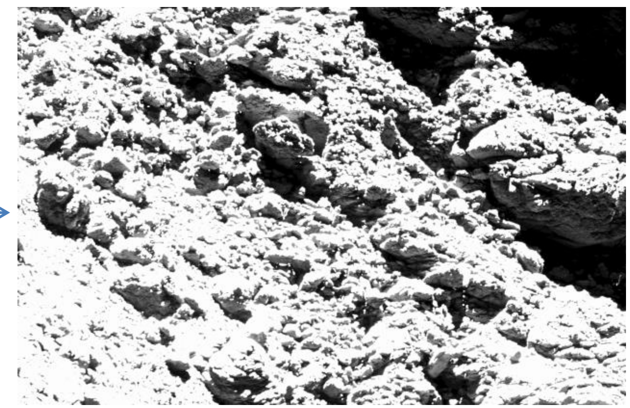
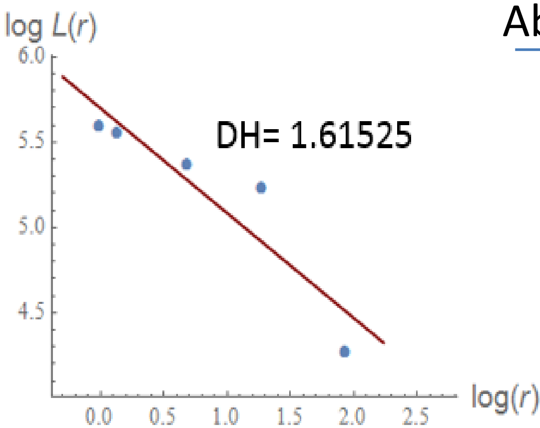


Figure. Microstructures of $BaTiO_3$-ceramics and fractals reconstructing the perimeter of the grain.

- Based on microstructure and fractal analysis from experiments, we completed the calculations of Hausdorff dimensions and disposed the related graphs. Fractal analysis of the comet's surface structure are shown in Figures.

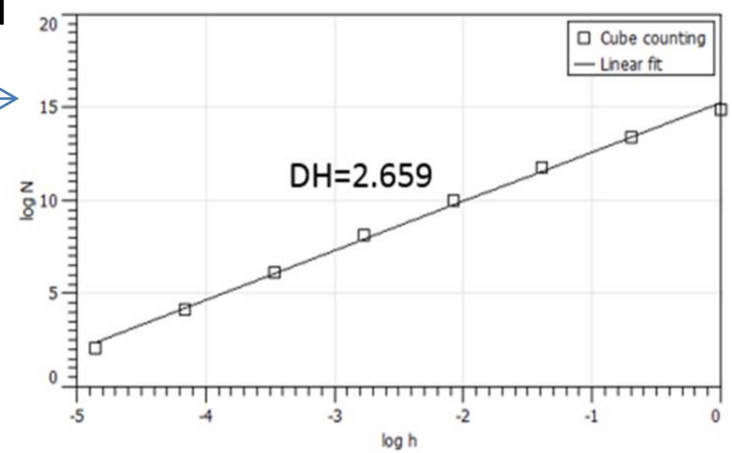
Comet 67P surface structure near the touch-down site Abydos





The diagram of contour fractal dimension from the structures at the comet touch-down site Abydos.

Related surface fractal dimension.



- The results analysis from the BaTiO3-ceramics structures, taken as other extreme on the Solar system scale, is completed by contour fractal dimension and is shown in Figures.

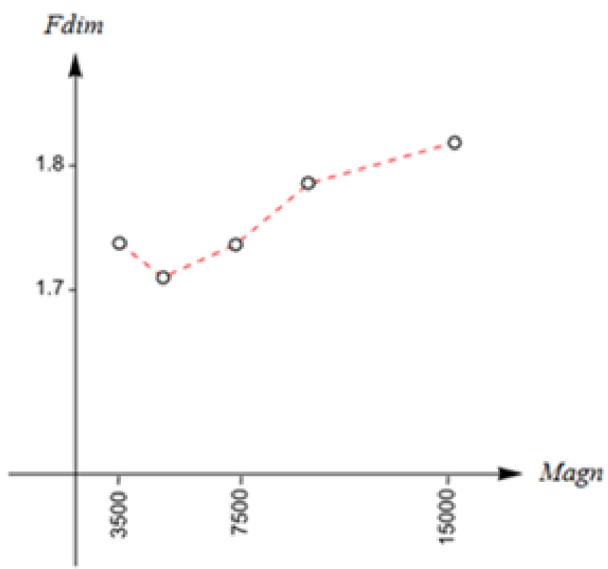


Figure. The contour fractal dimension based on $BaTiO_3$-ceramics structures.

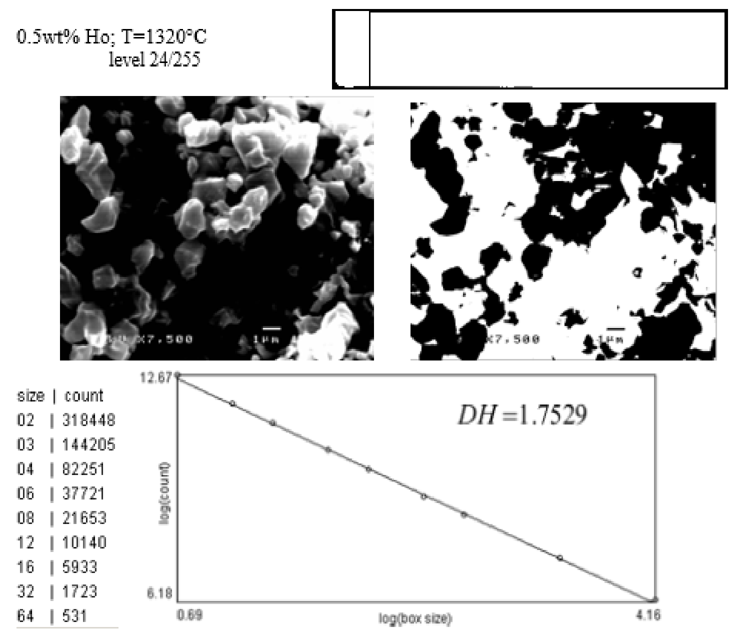
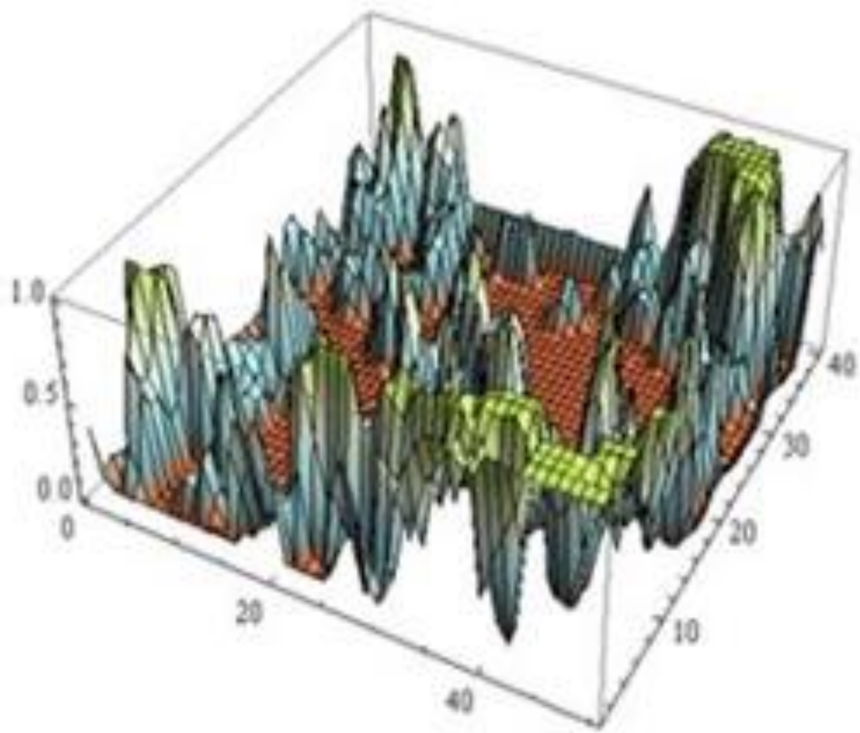
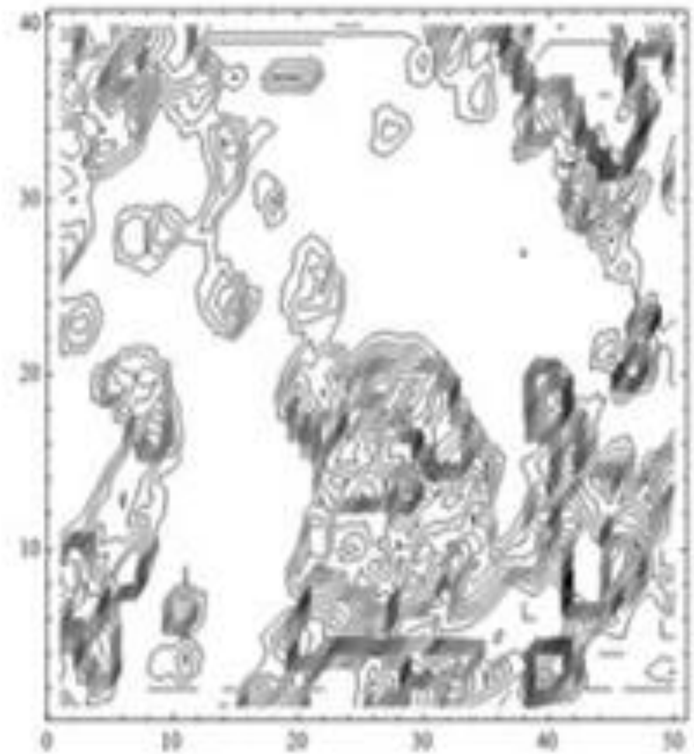


Figure. $BaTiO_3$-ceramics sample and its fractal dimenssion.



3D-surface representation of the sample



Level lines

- Regarding the data from Figures, we used the different images of the Barium-titanate samples consolidated with different additives quantities, sintering temperatures and pressures. So, this is principally one of all of these microstructure results which are very similar.
- Based on the sub-micro analysis of the ceramic grain surfaces, we applied Fourier analysis of the spectra roughness’s which definitely confirms the similarity of the surface nature on the micro level with surfaces morphology at the large space bodies like on the comet.

- Based on all of these results, it is evident that fractal characteristics are a common property both for the surface structure of small bodies of our solar system like comets, and for the microstructure of ceramics taken from SEM micrographs analysis.
- These results are quite usable in comparing two different samples and is not an obstacle in having insight in complicated relationship between space consolidation processes as well as on ceramics micro-level.

Bio and physical systems electron motion

- At the basis of all microorganisms' life functions, including bacterial motility as well, lie various molecular biology processes, which on the molecular and submolecular level determine occurrences on the microorganism level.
- These processes are based on particles motion, which is identical in both living and nonliving systems. Molecular and submolecular particles motion, affects the entire bacterial organism motion and therefore, it is very important to establish the relation between molecular, submolecular and microorganisms levels.

- Alive and nonalive matter structures integration is one of the major issues in nowadays advanced complex materials and technologies scientific research, because it provides the possibility for higher level integrations.
- If we take into consideration the fact that the electrons, atoms and molecules are constituents of both alive and nonalive matter systems, we can approach this subject from the biomimetic aspect. It implies joint examination of biosystems’ and condensed matter systems’ micro and submicroparticles, based on the fractal nature of their Brownian motion [12,13].
- Electron motion is based on the same principles in alive organisms and in condensed matter, so it should be observed as a joint property to get the complete insight into this fundamental process.
- Based on our current knowledge and possibilities, we are not able to determine electron motion. However, we can determine motion of the molecules that contain those electrons.

- Every molecule which is moving, carries an electron “cluster“ making it move as well.
- In this case we treat the molecules like „clusters“ of electrons in different matter organizations from atomic to molecular level.
- This way we avoid the lack of worldwide research recorded electron motions. Hence, we now observe the molecules as “packages“ of electrons or other particles.
- Within molecules as parts of biosystems, existing atoms and electrons “are not aware of“ whether they are a part of an alive organism or condensed matter.
- From the other hand, we also analyze all of these molecules as a part of alive bacterial matter.
- That is very important because it distinguishes the molecule as the significant integrative factor between living and nonliving systems.

- Nowadays fundamental research and science do not have high-tech and also resolution possibilities to recognize, separately, the electron motion. We can consider only the indirect effects.
- We can observe the effect of electron motion at the molecular and microorganisms level.
- Here, we must stress the complexity in the matter based on quantum mechanical principles and Heisenberg uncertainty principle.
- The particles motion based on Brownian motion fractals effects, is the base for deeply understanding all of these processes within the submicro scale sizes with the joint characteristic which we can nominate as “actio in distans“ in motion.

- The intrinsic property of every molecule in both living and nonliving matter systems is its energy state layout, as a self inherent spectrum, which in itself provides all the important information about the molecule.
- Due to the fact of constant and overall exposure to internal and external electromagnetic fields influence, the molecule energy state and the molecular spectrum, as well, are being changed.
- Thus, electrons are crossing over energy levels end from one molecule to another, as well, being influenced by Brownian motion all the time, resulting in electromagnetic induction, as well.

- Regarding ceramic grains or grain clusters, collision effects of electrons on grain boundaries affect the grains' shape, size, orientation, and micro-capacitive structure and distribution [14]. , and because of that, it is very important to control consolidation of ceramics materials microstructure and properties [15].
- If we apply Brownian motion characterization and fractalization on electron trajectories on grain boundaries,as shown in Figure, we can predict and design appropriate dielectric, ferroelectric, and rest other microelectronic properties, which opens new frontiers for further microelectronic circuits miniaturization and integrations.

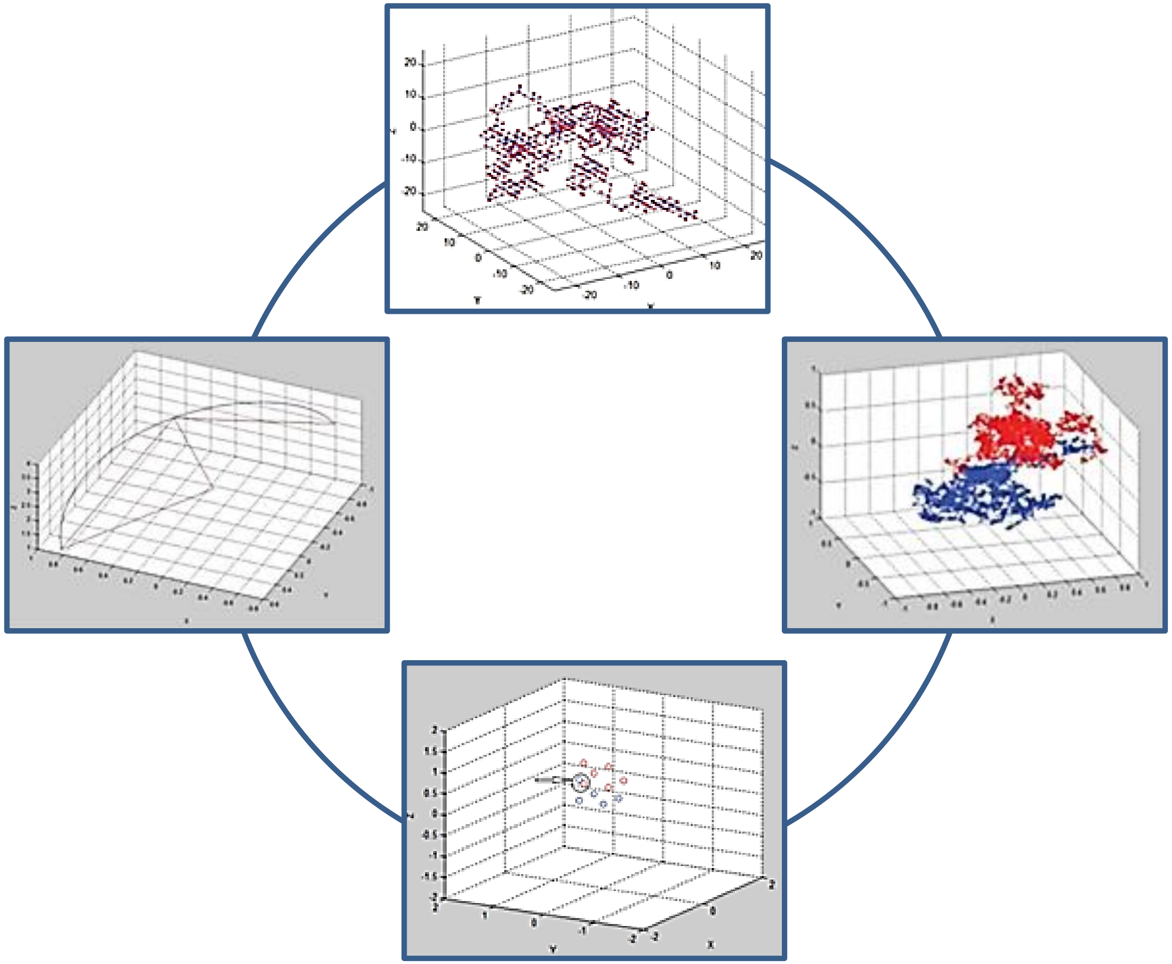


Figure. Electrons Brownian motion trajectories on grain boundary [16].

- Dimensions and motion patterns of bacteria and viruses, as well, allow us to consider condensed matter particles motion and these organisms motion as biomimetic similarities. Microorganisms are small enough, as their motion could be jointly considered with condensed matter particles.
- We used Brownian motion fractal nature, as a general characteristic of alive and nonalive systems, to establish the relation between these two different systems, but consisting of identical particles.
- One of the objectives of our research is to explain the Brownian motion as the joint characteristic of biomolecule and physical system particles.
- At the end, we can jointly understand the biophysical integrated systems with one important characteristic and that is just the Brownian motion.

- Bacteria motility behavior, which implies velocity, direction and trajectory, is also influenced by environmental changes like temperature, pH, or different energetic impulses.
- In our experimental research we examined the influence of various energetic impulses on bacterial motion [17], in order to obtain significant data regarding bacterial Brownian motion, which we used for further mathematical processing.
- We introduced two bacterial species (*Staphylococcus aureus* and *Pseudomonas aeruginosa*) into a liquid phase, and observed their motion patterns.

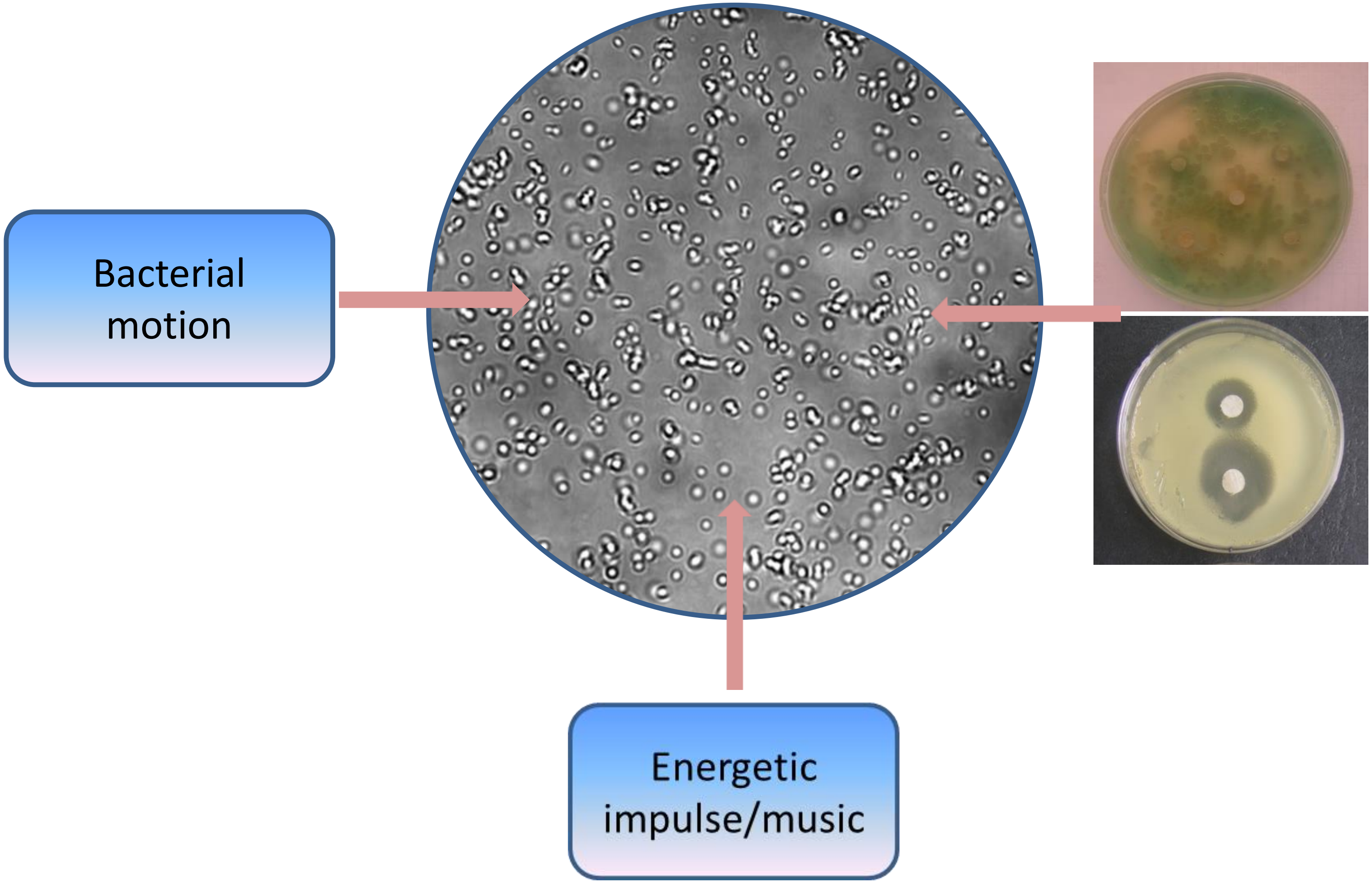


Diagram of the experiment with bacteria influenced by different energetic impulses.

- Based on this experiment we obtained significant data regarding bacterial motion and accordingly established mathematical analytical forms and 3D diagrams.
- In our theoretical experiment regarding molecular motion, we obtained the results and established mathematical equations and 3D diagrams, as well, based on some available research results [18].
- We obtained some interesting results regarding both, the bacterial and molecular motion, and we used them for creating mathematical analytical forms.

- Based on the experiment we obtained important bacterial positions data which are presented in the Tables [19].

i	x_i	y_i	z_i
1	0	0	0
2	0.1043	-0.3698	-0.2869
3	0.0521	-0.4622	-0.3641
4	0.0521	-0.2773	-0.4809
5	0.0521	-0.2773	-0.7842
6	0.0521	-0.1849	-0.7605
7	0.1564	-0.5547	-0.7709
8	0.2607	-0.7396	-0.7757
9	0.5213	-0.7396	-1.0163
10	0.4170	-0.8320	-0.9330
11	0.3649	-0.8320	-0.9349

Coordinates of the first bacterium positions without music on.

i	x_i	y_i	z_i
1	0	0	0
2	0.1043	0.1849	-0.1822
3	-0.2607	0	-0.1127
4	-0.3649	0.3698	-0.0791
5	-0.3128	0.4623	-0.1107
6	-0.2607	0.2774	-0.0054
7	-0.3128	0.1849	-0.1336
8	-0.2607	0.1849	-0.1031
9	-0.2607	0.1849	-0.0806
10	-0.2607	0.0092	-0.0581
11	-0.3649	0.3698	-0.1685

Coordinates of the first bacterium positions with music on.

i	x_i	y_i	z_i
1	0	0	0
2	-0.3127	0.4622	-0.8545
3	-0.6776	-0.4622	-1.7845
4	-1.1989	-0.5547	-2.1152
5	-0.9383	-0.2773	-2.6437
6	-0.9904	0.1849	-2.9061
7	-1.0425	-0.0092	-3.662
8	-0.8862	-0.2773	-3.4277
9	-1.1989	0.4622	-3.8249
10	-1.0947	-0.2773	-3.8952
11	-0.8862	0.3698	-4.4158

Coordinates of the second bacterium positions without music on.

i	x_i	y_i	z_i
1	0	0	0
2	-0.0521	0.1849	0.5398
3	0.2607	0.7396	0.811
4	0.2085	0.5547	0.9604
5	0.2085	0.9245	1.012
6	-0.1564	0.6471	1.7786
7	0.1043	0.4623	1.9442
8	0.4171	0.4623	2.3245
9	0.5213	0.4623	2.3744
10	0.5213	1.0169	2.7151
11	0.5213	1.5716	2.1193

Coordinates of the second bacterium positions with music on.

- Molecule positions in 3D were determined based on the theoretical experiment and are presented in Table.

i	x_i	y_i	z_i
1	2	5.8	4
2	2.2	2	4.2
3	2.5	4.4	4.5
4	2.8	3.2	5.2

Molecule positions coordinates.

- We applied fractal interval approach in Brownian motion phenomenon analysis, and therefore, we provide the elementary methodological data for this method application.
- Approximation theory deals with the problem of replacing one function with another. One of the most commonly used forms of the approximation function is the polynomial form

$$\boldsymbol{f}(t) = \boldsymbol{a_1} t^n + \boldsymbol{a_2} t^{n-1} + \cdots + \boldsymbol{a_{n+1}}.$$

- The parameters $\boldsymbol{a_i},\ i = 1, \ldots, n+1$ are determined so that some conditions are fulfilled.
- In our paper, we use the condition that the function passes through predefined points.
- This type of approximation is called interpolation, and the function itself is called an interpolation function.

- Suppose that the given points $\boldsymbol{x}_i$, $i = 1, \ldots, n+1$ are through which we want the interpolation function to pass. We get the interpolation function in parametric form

$$\boldsymbol{x}(t) = \sum_{k=0}^{n} \boldsymbol{x}_k \frac{\boldsymbol{g}(t)}{(t - \boldsymbol{x}_k)\boldsymbol{g}'(t)},$$

where

$$\boldsymbol{g}(t) = \prod_{k=0}^{n} (t - \boldsymbol{x}_k).$$

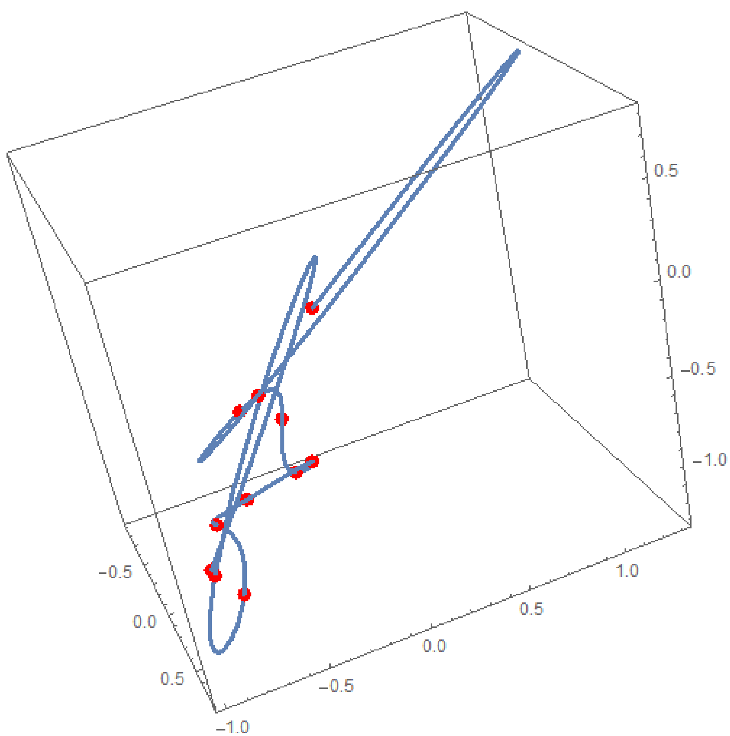
- The bacterial motion experiment and the theoretical experiment with molecule motion are the basis for our further research, which implied the creating of mathematical analytical equations, generating adequate 3D interpolating diagrams, and applying the fractal interpolation method for designing 3D fractal interpolating diagrams of bacterial and biomolecule motion.
- We use the fractal interpolation mathematical method in our research in order to find and establish the relation between biophysical and condensed matter particles systems and to connect them in the asymptotic way.
- The substantial integrative characteristic of these systems is Brownian motion with its fractal nature, which is the basis of the biomimetic motion similarities.

- Based on the data from Table for the first bacterium without music on, we obtained the following analytical equations:

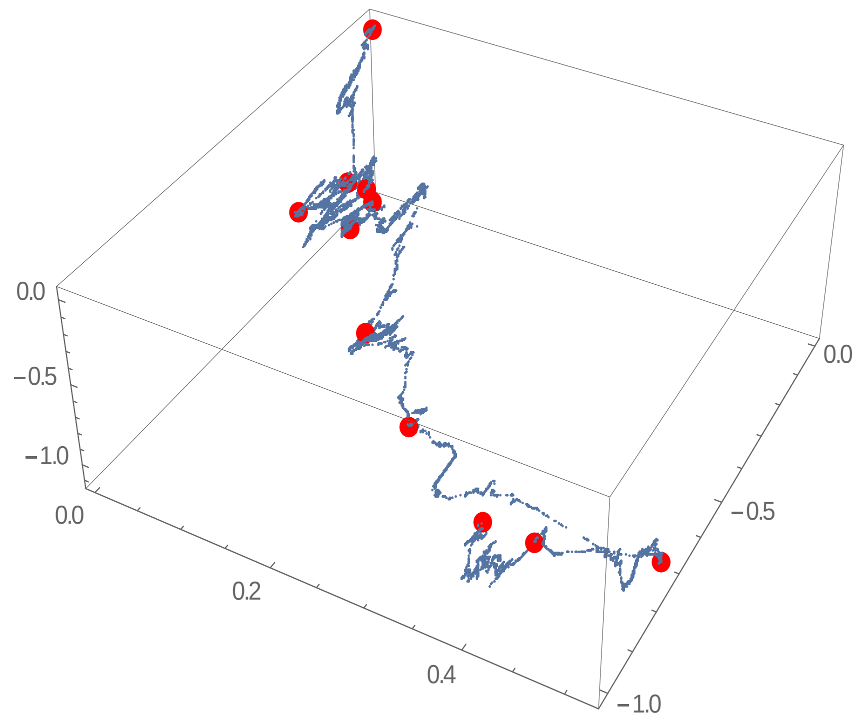
- $x(t) = 18.7129\ - 55.2529\,\mathrm{t} + 66.3847t^2 - 43.3618t^3 + 17.2814t^4 - 4.4358t^5 + 0.748566t^6 - 0.0825332t^7 + 0.00571969t^8 - 0.000225966t^9 + 3.87861 * 10^{-6}t^{10}$
(18)

- $y(t) = -100.479 + 285.098\,t - 327.188t^2 + 203.865t^3 - 77.5513t^4 + 19.0238t^5 - 3.07207t^6 + 0.324507t^7 - 0.0215696t^8 + 0.000818207t^9 - 0.0000135009\,t^{10}$
(19)

- $z(t) = -69.5243 + 197.979t - 228.023t^2 + 142.468t^3 - 54.2881t^4 + 13.3306t^5 - 2.15519t^6 + 0.228139t^7 - 0.0152186t^8 + 0.000580324t^9 - 9.64145 * 10^{-6}t^{10}$
(20)



3D interpolating diagram of the first bacterial motion without music on.



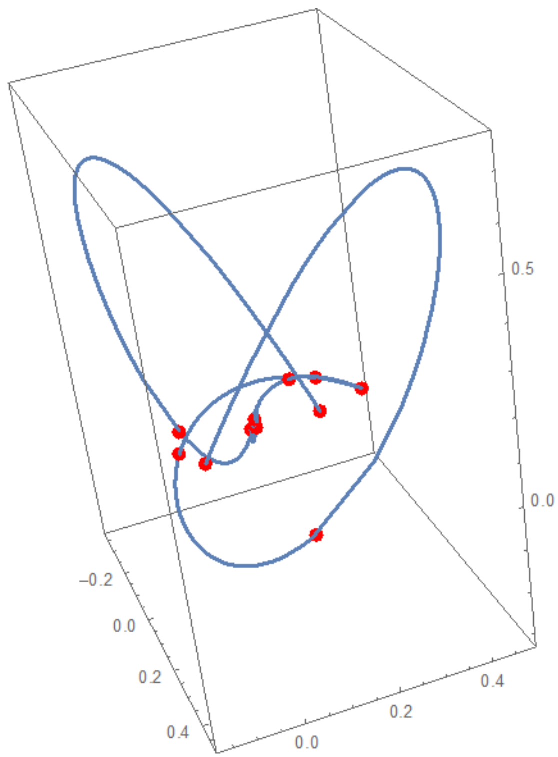
Bacterial motion (the first bacterium trajectory without music on) 3D fractal interpolating diagram.

- Based on the data from Table for the first bacterium with music on), we obtained the following analytical equations:

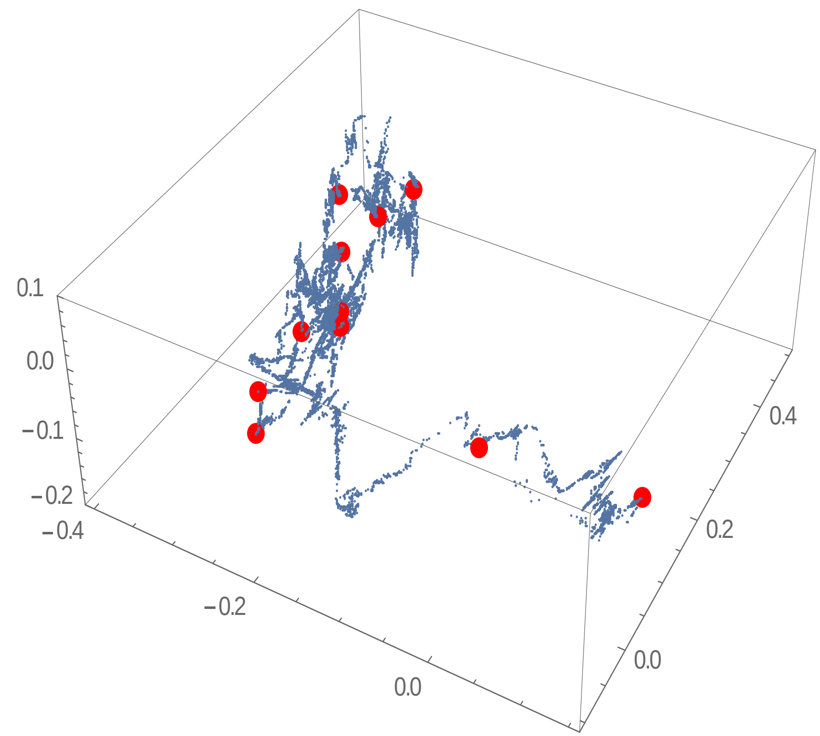
- $x(t) = -24.4494 + 67.194\,\mathrm{t} - 75.0942\,t^2 + 46.2836\,t^3 - 17.6857\,t^4 + 4.40531\,t^5 - 0.727088\,t^6 + 0.0787646\,t^7 - 0.00537635t^8 + 0.000209451t^9 - 3.54704 * 10^{-6}t^{10}$ (21)

- $y(t) = -5.8331 + 9.43531\,t - 1.64148\,t^2 - 4.52017\,t^3 + 3.60785\,t^4 - 1.27716\,t^5 + 0.258226\,t^6 - 0.0317402\,t^7 + 0.00235233\,t^8 - 0.0000968886\,t^9 + 1.70649 * 10^{-6}t^{10}$ (22)

- $z(t) = -62.159 + 178.622\,t - 208.148\,t^2 + 131.792\,t^3 - 50.9074\,t^4 + 12.6652\,t^5 - 2.07194\,t^6 + 0.221514\,t^7 - 0.0148915\,t^8 + 0.00057099\,t^9 - 9.5189 * 10^{-6}t^{10}$ (23)



Bacterial motion 3D interpolating diagram (the first bacterium with music on).



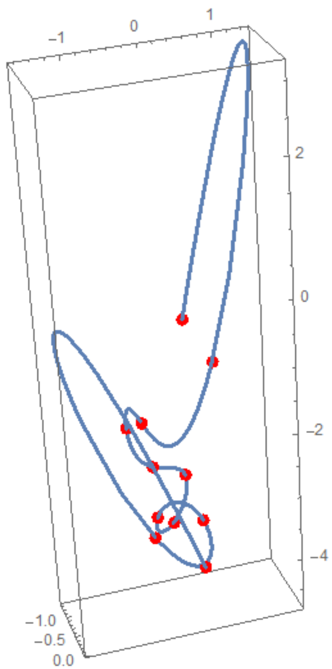
3D fractal interpolating diagram of the first bacterium trajectory with music on.

- Based on the data from Table 3, regarding the second bacterial motion without music on, we established the following analytical equations:

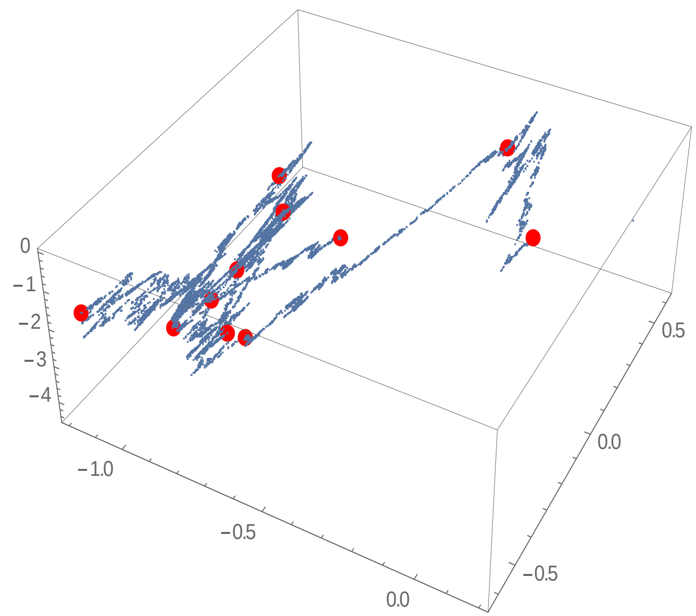
- $x(t) = 72.5157 - 196.258\,\mathrm{t} + 212.062\,t^2 - 122.976\,t^3 + 42.9447\,t^4 - 9.54724\,t^5 + 1.38096\,t^6 - 0.129201\,t^7 + 0.00751896\,t^8 - 0.000246545\,t^9 + 3.46398 * 10^{-6} t^{10}$ (24)

- $y(t) = -60.6098 + 159.254\,t - 167.228\,t^2 + 95.3259\,t^3 - 33.1614\,t^4 + 7.39731\,t^5 - 1.07329\,t^6 + 0.0999718\,t^7 - 0.00570623\,t^8 + 0.000179092\,t^9 - 2.31454 * 10^{-6} t^{10}$ (25)

- $z(t) = -243.028 + 691.829\,t - 798.683\,t^2 + 502.32\,t^3 - 193.506\,t^4 + 48.1848\,t^5 - 7.91272\,t^6 + 0.851038\,t^7 - 0.0576426\,t^8 + 0.00222896\,t^9 - 0.0000374927\,t^{10}$ (26)



Bacterial motion 3D interpolating diagram (the second bacterium without music on).



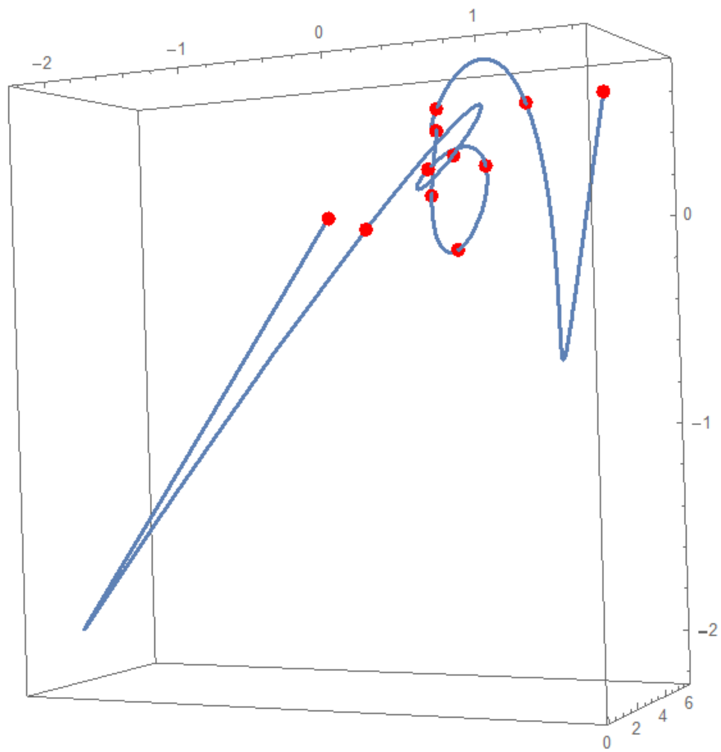
3D fractal interpolating diagram of the second bacterium trajectory without music on.

- Regarding the second bacterial motion, with music on, based on Table 4, we obtained the analytical equations:

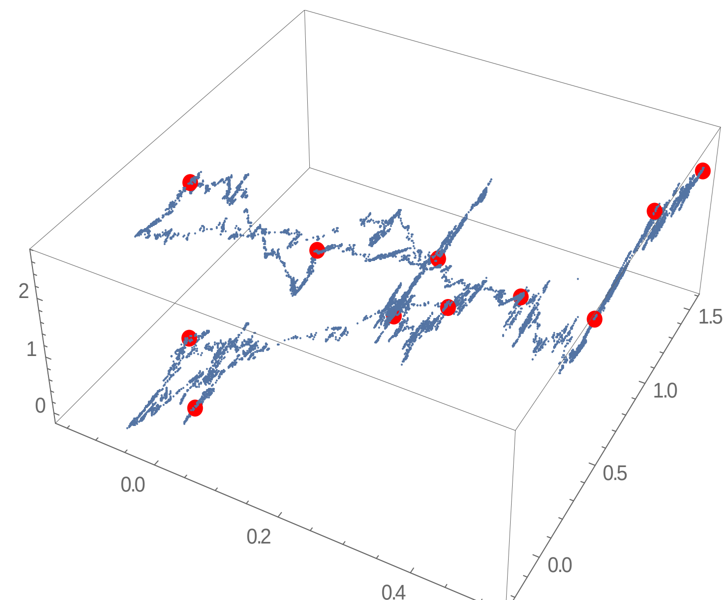
- $x(t) = 134.716\ - 377.973\,\mathrm{t} + 429.189\,t^2 - 265.261\,t^3 + 100.224\,t^4 - 24.4295\,t^5 + 3.92017\,t^6 - 0.411493\,t^7 + 0.0271835\,t^8 - 0.00102513\,t^9 + 0.0000168232\,t^{10}$ (27)

- $y(t) = 149.064\ - 410.619\,t + 454.682\,t^2 - 272.539\,t^3 + 99.5592\,t^4 - 23.432\,t^5 + 3.63071\,t^6 - 0.368318\,t^7 + 0.0235467\,t^8 - 0.000860675\,t^9 + 0.0000137119\,t^{10}$ (28)

- $z(t) = -206.087 + 584.869\,t - 674.022\,t^2 + 423.528\,t^3 - 162.661\,t^4 + 40.2841\,t^5 - 6.56588\,t^6 + 0.699926\,t^7 - 0.0469524\,t^8 + 0.00179779\,t^9 - 0.0000299493\,t^{10}$ (29)



3D interpolating diagram of the second bacterium motion with music on.



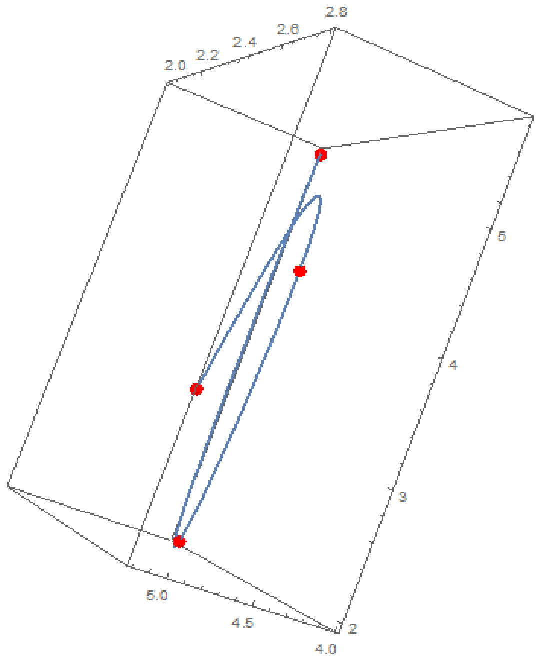
Bacterial motion 3D fractal interpolating diagram (the second bacterium trajectory with music on).

- Regarding the molecular motion with the positions coordinates given in Table, there are also associated mathematical equations:

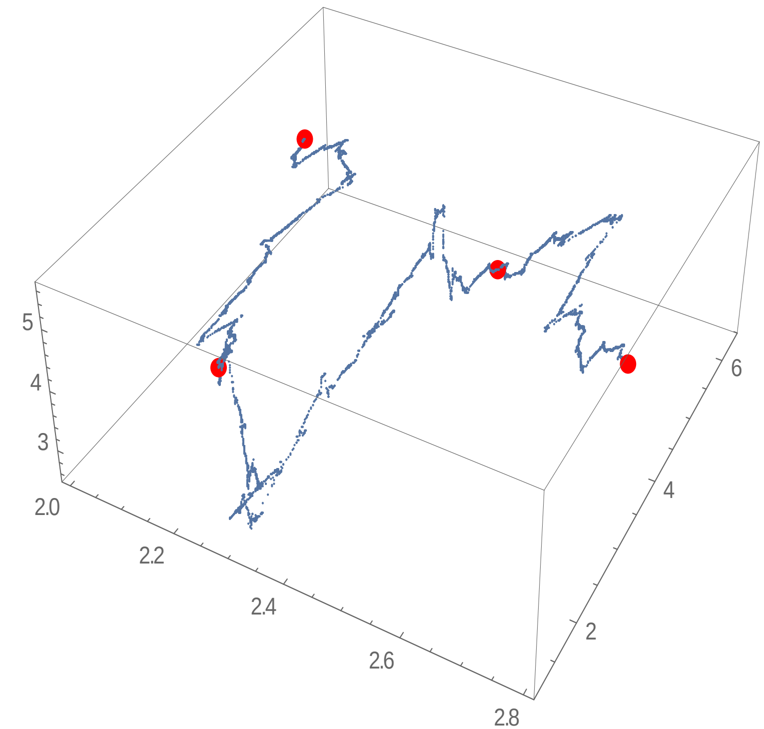
- $x(t) = 2 - 0.133333\, t + 0.15t^2 - 0.0166667t^3$ (30)

- $y(t) = 25.6 - 31.0667\, t + 12.9t^2 - 1.63333t^3$ (31)

- $z(t) = 3.6 + 0.6\, t - 0.25\, t^2 + 0.05\, t^3$ (32)



Molecular motion 3D interpolating diagram.



Molecular motion 3D fractal interpolating diagram.

- If we apply multiple linear regression we can determine the mutual dependence of the coordinates and obtain explicit formula for predicting and calculating positions.
- Based on the data from Tables, we applied the procedure of forming an approximation function

$$\boldsymbol{\varphi(x, y) = ax + by + c}, \qquad (3)$$

by using the least squares method.

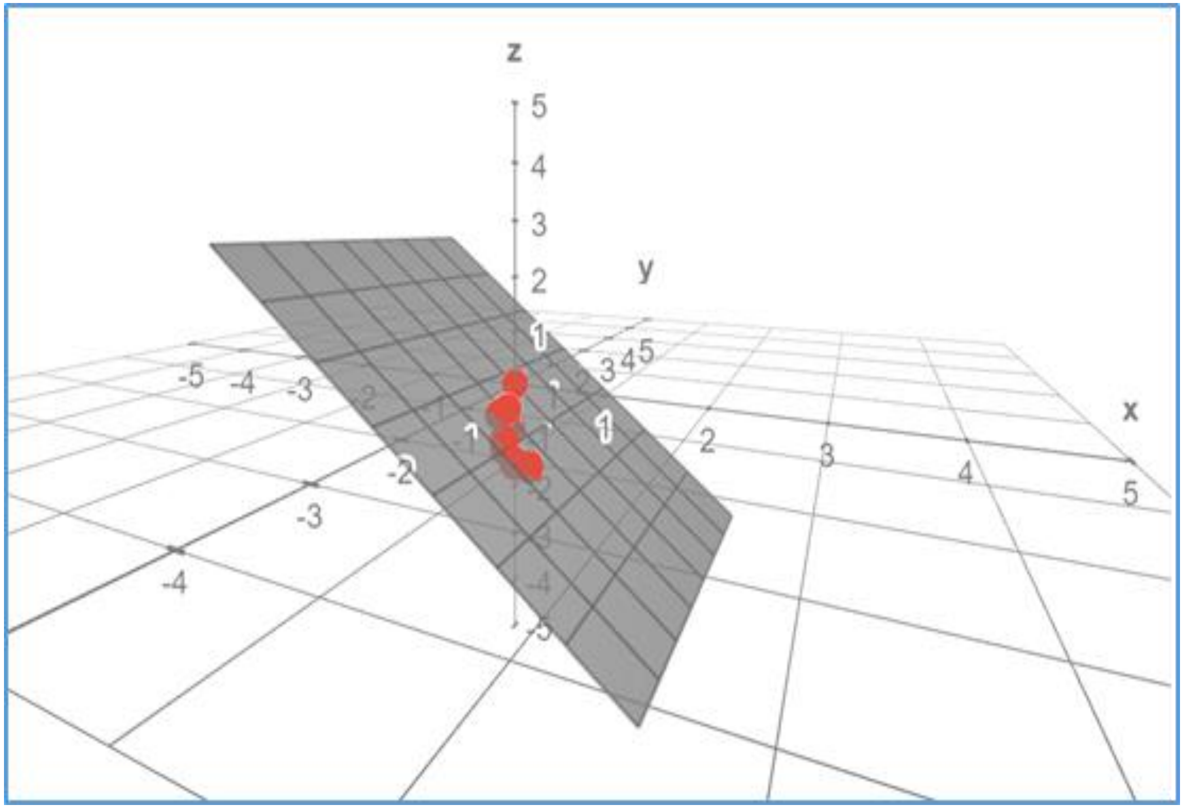
- We obtained next results considering the best linear fit for the presented model: the coefficients of the resulting linear function are respectfully a=–1,47999912, b=–0,02844679 and c=–0,36733904 and the estimated regression function is of the form:

$$\boldsymbol{\varphi(x, y) = -0,746871x - 0,421536y - 0,306160}. \qquad (4)$$

We can compare values and precision of dependent variables z_i in given points and results obtained by formula trough the absolute and relative error.

x_i	y_i	z_i	φ_i	Δ	%
0	0	0	-0.3061600	0.3061600	
0.1043	-0.3698	-0.2869	-0.5399426	0.2530427	-88.20%
0.0521	-0.4622	-0.3641	-0.5399059	0.1758059	-48.29%
0.0521	-0.2773	-0.4809	-0.4619639	0.0189361	-3.94%
0.0521	-0.2773	-0.7842	-0.4619639	0.3222361	-41.09%
0.0521	-0.1849	-0.7605	-0.4230139	0.3374860	-44.38%
0.1564	-0.5547	-0.7709	-0.6567966	0.1141034	-14.80%
0.2607	-0.7396	-0.7757	-0.8126373	0.0369373	-4.76%
0.5213	-0.7396	-1.0163	-1.0072718	0.0090281	-0.89%
0.4170	-0.8320	-0.9330	-0.9683232	0.0353232	-3.79%
0.3649	-0.8320	-0.9349	-0.9294112	0.0054888	-0.59%

Comparison between real and approximate coordinates, absolute and relative error



The plot obtained with the least squares method.

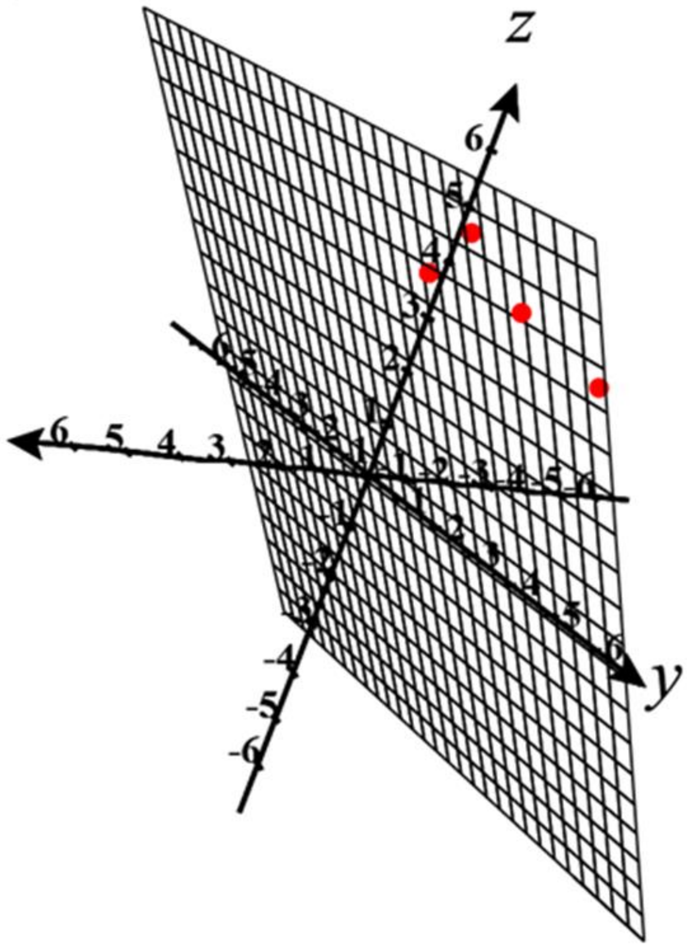
- Similarly, as in previous procedure applied on bacterial motion experimental data, we obtained next results for molecule motion in different time intervals, considering the best linear fit for the presented model: the coefficients of the resulting linear function are respectfully a=1.4685067, b=0.0035386 and c=0.973673 and the estimated regression function is of the form:

$$\boldsymbol{\varphi(x,y) = 1{,}4685067x + 0{,}0035386y + 0{,}973673.}$$

- Next, by using the estimated regression function (5) and by implementing the 2D coordinates we obtained the estimated dependent values of the z-coordinates, presented in the Table, together with the evaluated absolute and relative error of this approximation:

x_i	y_i	z_i	φ_i	Δ	%
0	0	0			
2	5.8	4	3.9312102	0.0687898	1.72%
2.2	2	4.2	4.2114649	0.0114649	0.27%
2.5	4.4	4.5	4.6605095	0.1605096	3.57%
2.8	3.2	5.2	5.0968150	0.1031850	1.98%

Z- coordinates with the absolute and relative error



The plot obtained with the least squares method

Conclusion

- The relativization of different structure sizes on large scales is very important in regard to microstructural and electrophysical relations for matter properties in general. So, the fractal characterization of structures of comets is definitely the most effective bridge to the microstructure of materials on Earth, even on a nano level.
- The key property of fractals is their scale-independence. The practical value is that the fractal objects' interaction and energy is possible at any reasonable scale of magnitude, including the nanoscale and may be even below.
- This is a consequence of fractal scale independence. This brings us to the conclusion that properties of fractals are valid on any scale (macro, micro, or nano).

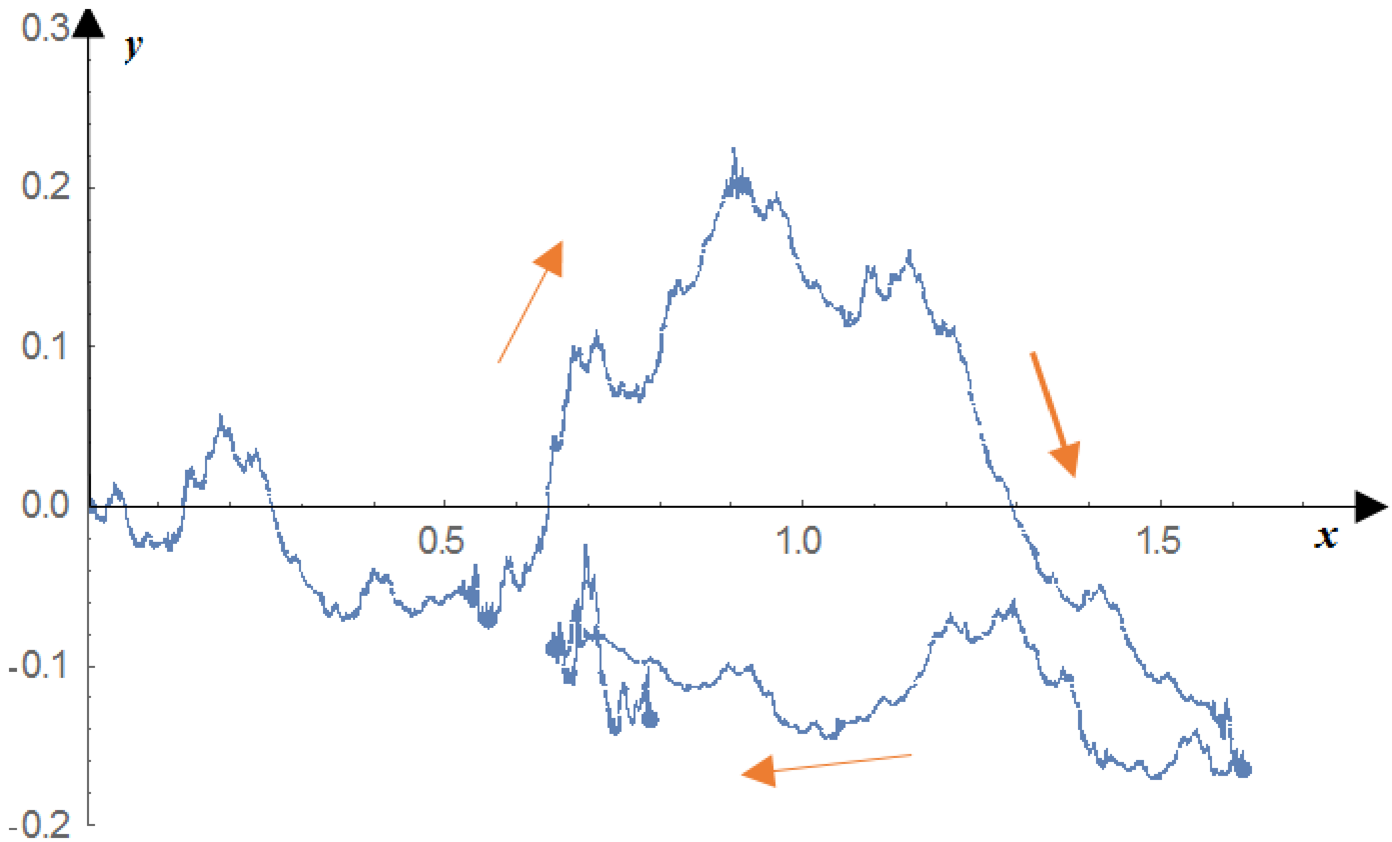
- The fractal nature offers a new approach for the ceramics structure analysis, describing prognosis and modeling the grain shapes and the relations between morphology and electrophysical properties.
- Also, the existence of the fractal nature of ceramic materials is completely confirmed within the electrochemical thermodynamic and fluid dynamics parameters in previous research.

- This research has significance from the ceramic's microstructure consolidation prognosis fractal aspect point of view and possibility of having better insight into some internal properties. There is existing influence of ceramics grains' surface fractality plus particle dynamics in the material on the overall energy distribution, too.
- Through this method and results, we are opening the fractal microstructure scale sizes new frontiers and technological processes, especially specific intergranular relations within grains surfaces in all matter.
- All of these results confirm microstructure constituent's grains and pores shapes.

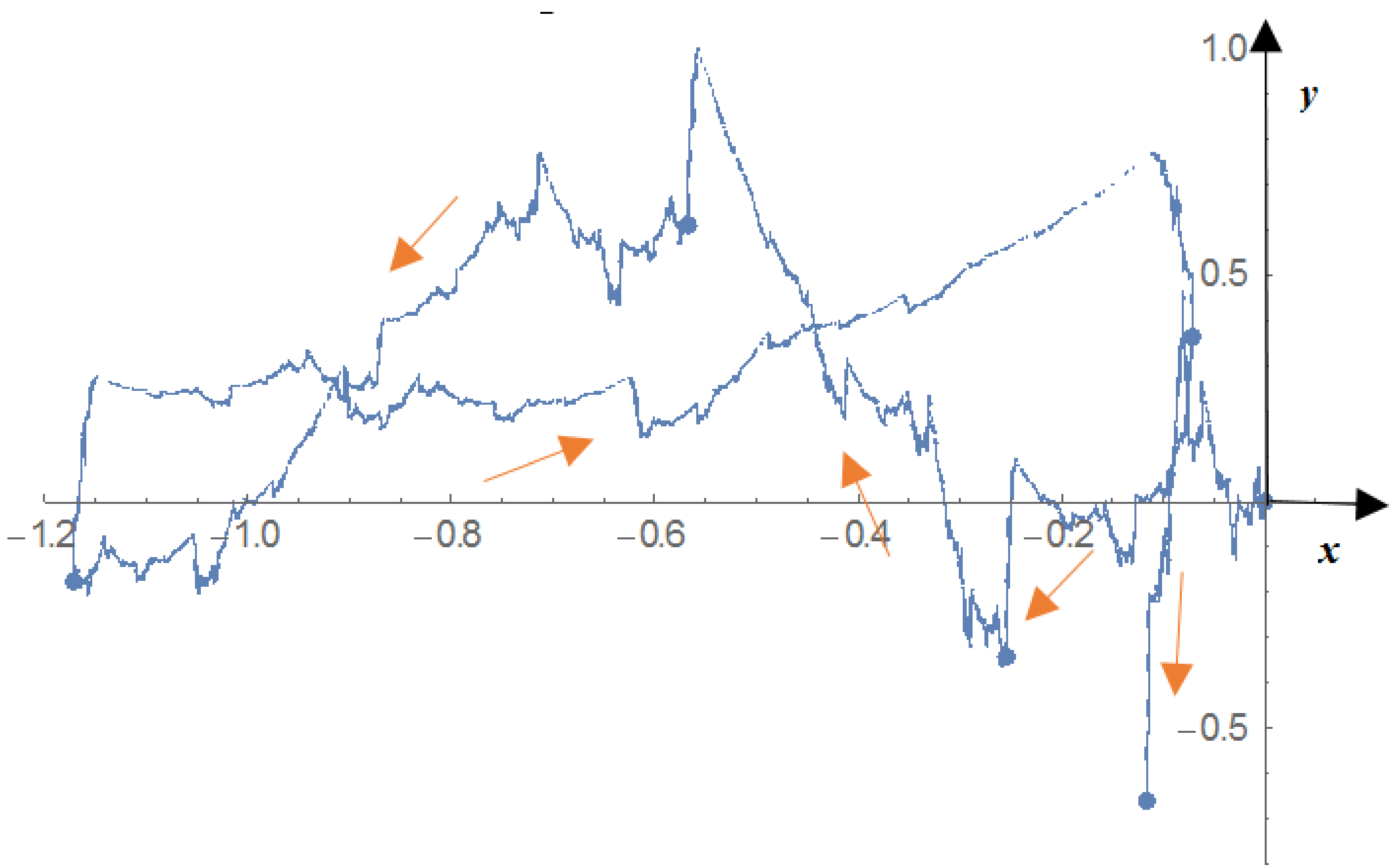
- Also, there are possibilities to analyze the Brownian motion particles phenomena.
- In continuation of our Brownian motion phenomena research, we consistently build molecular-microorganisms structures hierarchy.
- We recognize everywhere biomimetic similarities between the particles in alive and nonalive matter.

- We developed the analysis, inspired by fractal nature Brownian motion, as recognized joint parameter between particles in alive and nonalive biophysical systems. This is also in line with advanced trends in hybrid submicroelectronic intregrations.
- We continue to generate new knowledges in direction to get complex relations between the particles clusters in biophysical systems condensed matter.

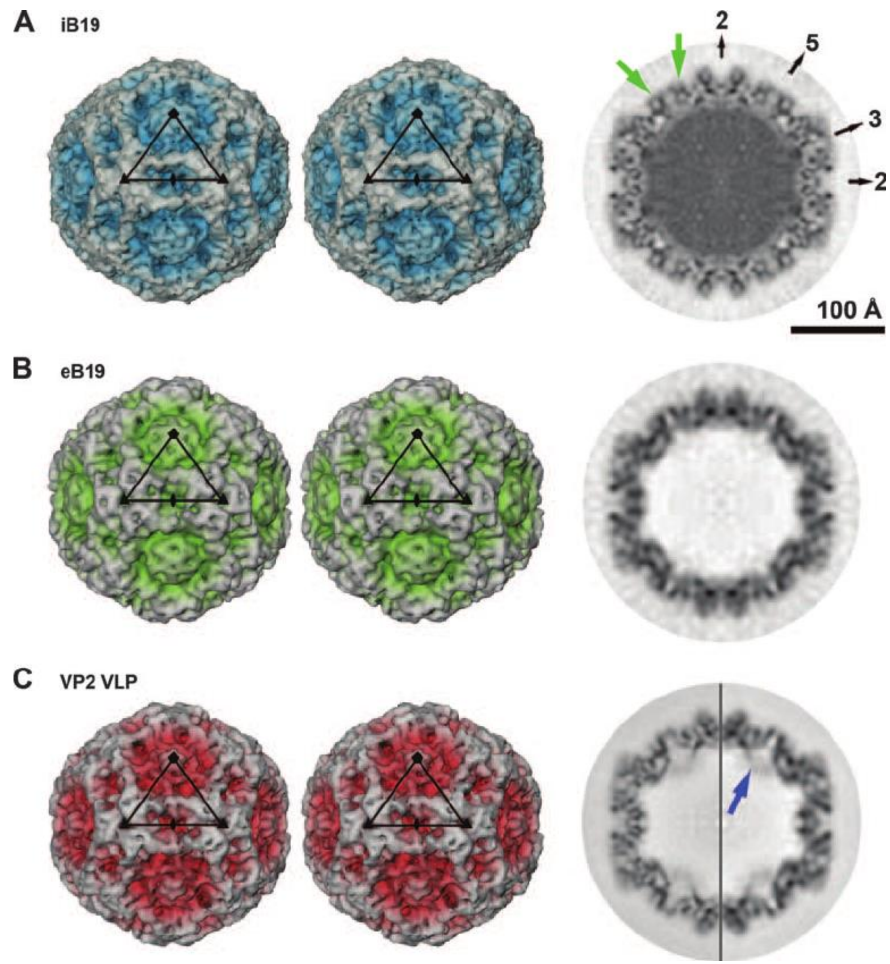
- There is need for long-term scientific research on the relativization of different scale size influences within the whole nature. That is because the fractal nature is the general characteristic everywhere independently of size.
- All of these complex considerations between biophysical subsystems within nature open new perspectives and shed light on advanced microelectronics structures which connect different particle systems within the total nature and matter.



0.3
0.2
0.1
0.0
-0.1
-0.2
y
0.5
1.0
1.5
x



1.0
y
0.5
−0.5
−1.2
−1.0
−0.8
−0.6
−0.4
−0.2
x



A
iB19
2
5
3
2
100 Å
B
eB19
C
VP2 VLP

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