Searching for Life on Mars: the Role of Chaos

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Abstract Chaotic/fractal analysis of the Viking LR (Labeled Release) experiment and of Mars rover images provides evidences of present and, respectively, past life on Mars, suggesting the presence of microorganisms on the Red Planet. The possible presence of living beings on Mars is an open question that cannot be disproven at this time.

Chaos: An Historical Introduction

According to the physics that we know from high school,

1) It is possible to build models with deterministic characteristics, which allow us to predict a system in the future and back in time.

2) Time is reversible.

3) The object is simple or reducible in simple systems, but with an increase in entropy, there is a tendency to disorder.

However, according to biology,

1) Complex systems cannot be predicted over time.

2) Time's arrow means that the reversal of time is impossible.

3) Living systems exhibit characteristics of self-organization (teleonomy).

Which is correct: physics or biology?

The triumph of scientific determinism seems evident in the words of Laplace:

> We may regard the present state of the universe as the effect of its past and the cause of its future. An intellect which at any given moment knew all of the forces that animate nature and the mutual positions of the beings that compose it, if this intellect were vast enough to submit the data to analysis, could condense into a single formula the movement of the greatest bodies of the universe and that of the lightest atom; for such an intellect nothing could be uncertain and the future just like the past would be present before its eyes.

Everything appears clear. Everything is understood. Is this true?

Interestingly, we can find analogous descriptions of the world today. According to Giorgio Bellettini, co-discoverer of the last or "top" quark on March 3, 1995, "Knowing what they are and how quarks interact with each other will make it possible to follow mathematically the evolution of the entire universe, especially in the past, but also in the future." In biology recently, "Noise [indeterministic behavior] permeates biology on all levels, from the most basic molecular, sub-cellular processes to the dynamics of tissues, organs, organisms, and populations" (Tsimring). Then, is this a deterministic universe as physics tells us or an indeterministic universe as biology describes? The first warning one century ago presented as the problem of three gravitating bodies.

Oscar II of Sweden proposed a prize to whoever is able to present a general solution that describes three orbiting bodies, whatever the mass and distance. Poincaré demonstrated that a general solution does not exist.

Edward Lorenz was a mathematician and meteorologist at the Massachusetts Institute of Technology. On a particular day in the winter of 1961, Lorenz wanted to re-examine a sequence of data coming from his model. Instead of restarting the entire run, he decided to save time and restart the run from somewhere in the middle. While they matched at first, the runs eventually began to diverge dramatically—the second run losing all resemblance to the first within a few "model" months, a long story that resulted in presenting a way to treat this strange indeterministic world.

Currently, in physics and biology, chaos description clearly appears able to describe our real world. What is chaos? In everyday language "chaos" implies the existence of unpredictable behavior. Chaos embodies important principles: extreme sensitivity to initial conditions due to nonlinearity; complex dynamics where cause and effect are not proportional; long-term prediction becomes impossible; a statistical description of the dynamic system is possible, only.

Chaos owns a geometry; it is the fractal geometry that was revealed by Benoit B. Mandelbrot.

Trees and bronchial trees, tissues under microscope as well as neurons, can be described by the geometry of chaos (fractal geometry), with their statistical laws, like self-similarity. This new geometry permits us to examine, to measure, the biological entities with high deep meaning. Fractal structures are also clearly visible in physics: solar system, galaxies, ...

Our Results: Searching for Signs of Life on the Red Planet by Chaotic Analysis

Chaotic Analysis of Viking LR Experiments

The first (and only) known life detection experiments on Mars were performed by the Viking landers in 1976. One of these was the Labeled Release (LR) experiment by Levin and Straat with the injections of organic com-

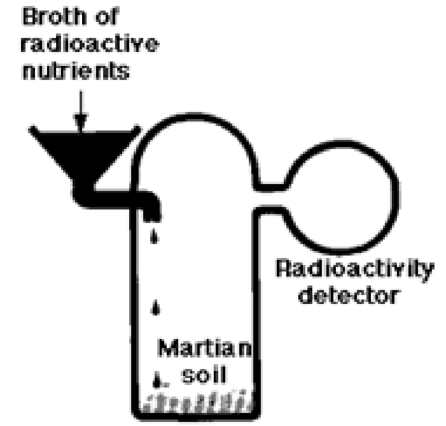

Figure 1. Labeled Release (LR) experiment

pounds in Martian soil samples (Figure 1).

Immediately after the injections of organic compounds in Martian samples, radioactive gas evolved approaching a plateau. These "active" experiments were run many times with similar results. Interestingly, the LR response in 160°C was very low, so satisfying the premission criteria for life. (Figure 2)

However, a controversy toward a biologic interpretation of the LR data suddenly arose and continues today: the Gas Chromatograph/Mass spectrometer (GCMS) did not find any organic compounds on Mars. Do no organic compounds = no life, or was the GCMS lacking sensitivity? In an attempt to resolve this issue, we have employed chaotic analysis of the Viking LR data and of terrestrial LR pilot studies using bacteria-laden active or inactive sterilized tests as well other biological and abiological controls. In particular, we performed a reanalysis of Viking LR experiments on 16,000 test points from #9 LR experiments carried out on Mars (active, sterilized, starved, Sun protected tests), as well as from biological samples (positive controls, presence of life: a terrestrial bacteria-laden active test and a 23-day series of core temperature readings taken every minute from a rat in constant darkness) and abiological samples (negative controls, absence of life: pre-nutrient administration, background radioactivity, series of internal Viking Lander 1 temperature measurements, series of external Mars atmosphere temperature, terrestrial heat-sterilized sample test). Seven nonlinear chaotic indexes were used: Lempel-Ziv complexity, Hurst and Lyapunov exponents, Entropy (Kolmogorov), Time Correlation, BDS (Brock-Dechert-Scheinkman statistics), Correlation Dimension. The set of all the chaotic parameters distinguished the active LR experiments on Mars and the biological ones on Earth from the abiotic control tests ($p<0.001$), giving evidence to us that LR experiments detected extant life on Mars (Table 1. Bianciardi et al. 2012).

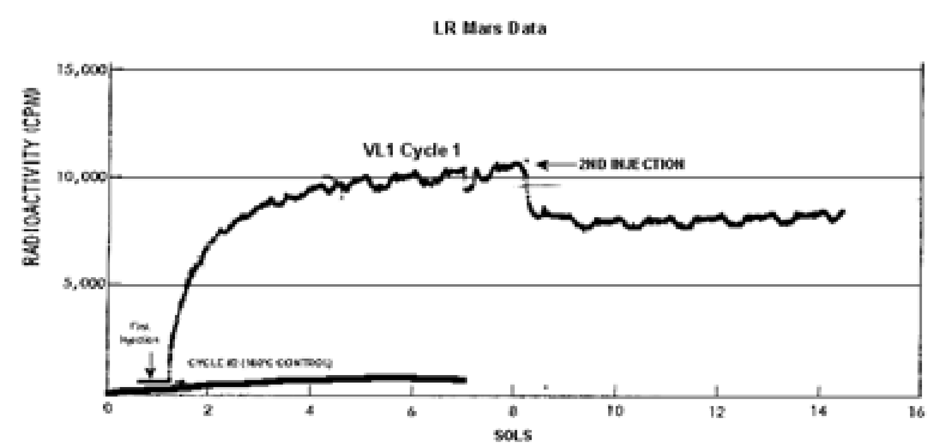

Figure 2. Release of CO_2 after injections of organic compounds and (below) its inhibition after pre-treatment at 160°C. LR experiment, Mars

Cluster 1 (controls/physical) of 2 Contains 8 Cases

Members			Statistics		
Case	Distance	Variable	Minimum	Mean	Maximum
VL2C4	0.464	LZ	0.294	0.790	1.379
Vl1C2	0.593	H	-0.984	-0.706	0.111
VL1C4	0.479	λ	0.000	0.724	2.404
VL2C5	0.966	K	-1.434	0.534	1.449
BIOL 6	0.311	BDS	-2.010	-0.721	0.190
DT VL2C3	0.790	τ	-0.645	-0.508	-0.156
VL1 Atmo. temp	0.413				
Pre-inj radioactivity	0.494				

Cluster 2 (actives/biological) of 2 Contains 7 Cases

Members			Statistics		
Case	Distance	Variable	Minimum	Mean	Maximum
BIOL5	0.534	LZ	-2.136	-0.902	-0.080
VL1C1	0.285	H	-0.218	0.806	2.190
VL1C3	0.409	λ	-1.202	-0.828	-0.219
VL2C1	0.544	K	-1.656	-0.610	0.673
VL2C3	0.622	BDS	0.664	0.824	1.291
VL2C2	0.587	τ	-0.174	0.581	3.304
Rat temp	1.354				

Table 1. A Cluster analysis separates active LR experiments (Mars and Earth) and biological controls (cluster 2) with sterilized LR tests and abiological controls (cluster 1), p <0.001

Fractal Geometric Analysis of Martian Outcrops

Microbialites, such as stromatolites, are the oldest evidence of life on Earth. Stromatolites/microbialites are an organization of primitive cyanobacteria into large structures, analogous to coral reefs. They grew in vast colonies. Microbialites can be identified through their mineral structures that result from the growth patterns of their constituent bacteria. Stromatolites/-Microbialites are a frequently named target of life-detection missions on Mars (Clarke and Stocker 2013; Jepsen et al. 2007; McKay and Stocker 1989).

Figure 3. Fossil stromatolites

Are there fossil stromatolites/ microbialites on Mars? To solve the problem, we performed a fractal analysis of the microstructures present in the stromatolites and other microbialites on Earth, comparing them with the microstructures present in the outcrops photographed by the Opportunity and Spirit rovers on Mars. The contours present in the terrestrial and Martian images were automatically extracted from the images and converted to single pixel outlines by a canny-edge filter. A fractal analysis was performed evaluating the terrestrial and the Martian images: geometric complexities at low and high scales, information dimensions (entropy) at low and high scales, algorithmic complexity (Lempel-Ziv index or "randomness"), fractal dimension of the minimum path (or "tortuosity"), maximum diameter, minimum diameter. The fractal analysis of the Athena images shot by the Opportunity rover, analyzing 15,000 microstructures, showed fractal parameters that were overlapping the ones of terrestrial biogenic microbialites: the probability of this occurring by chance was less than $1/2^8$, $p<0.004$ (Table 2) (while, abiogenic pseudostromatolites presented morphometric indexes statistically different from the ones of biogenic stromatolites) (Bianciardi et al. 2014). Analogous results were obtained analyzing 20,000 microstructures shot by the Spirit rover (Bianciardi et. al 2015).

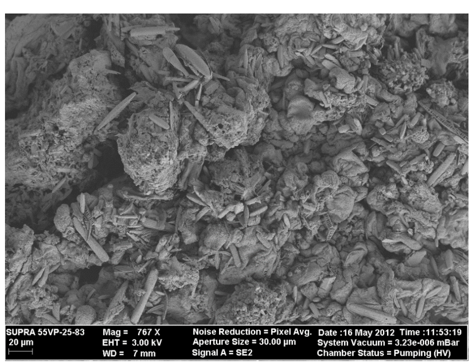

Figure 4. Microspherules and filaments in a living stromatolite at high magnification. Scanning Electron Microscopy, courtesy by M. E. Farias

Summary

Chaotic approaches to the biological LR experiment performed on Mars by the Vikings have shown in our hands evidences of biology. Performed by us, fractal [the Geometry of Chaos] analysis of images shot by Martian rovers

	Earth (mean/SD)	Mars (mean/SD)
Complex, High	1.82(0.02)	1.81(0.02)
Complex, Low	1.48(0.05)	1.52(0.07)
Entropy, High	1.88(0.01)	1.87(0.02)
Entropy, Low	1.41(0.05)	1.44(0.05)
LZ index	0.46(0.04)	0.48(0.04)
Dmin	0.79(0.03)	0.78(0.03)
Max Dia (mm)	0.08(0.001)	0.08(0.001)
Min Dia (mm)	0.21(0.003)	0.21(0.003)

Table 2. Fractal parameters and diameters of the Martian microscopic microstructures overlapped the ones of terrestrial biogenic microbialites. The probability of this occurring by chance is less than p<0.004.

showed evidence of the presence of microbialites on Mars. Other investigators, with different approaches, have reached similar conclusions (Noffke 2015). At present there is not any definitive proof of Martian life, but a great deal of evidence in favor of biology in the present or past on Mars has been collected and is still being collected today. Certainly, the possible presence of life on Mars remains an open question that cannot be disproven at this time.

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