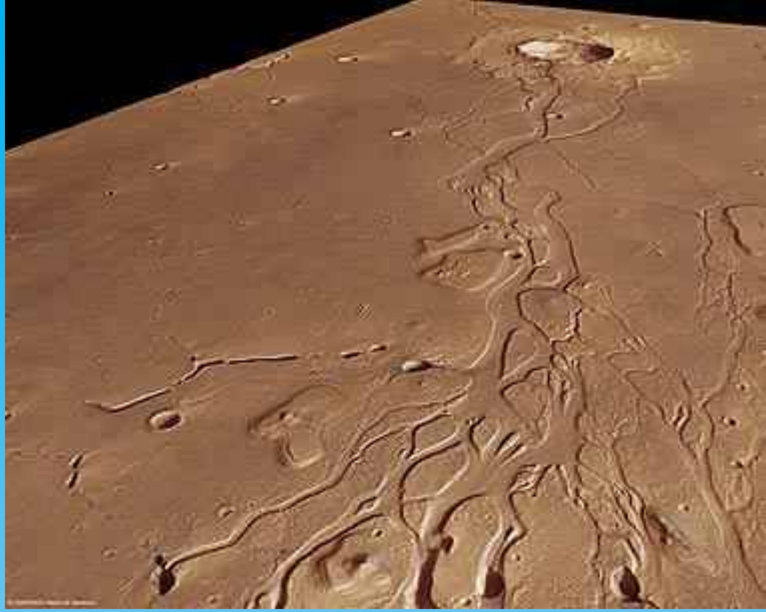
Advances in the study of life on Mars. A biological point of view



ADVANCES IN THE STUDY OF LIFE ON MARS

a Biological Point of View

Giorgio Bianciardi, MS, MD, PhD

University of Siena (retired)

Italy

Is/was there life on Mars?

Photo by Mars Express, ESA

Mars, Mojave crater

Mars: the abode of life?

"©"NASA, 2017

Mars 4 billions years ago Mars today

On the ancient Mars, liquid water was widespread, volcanic activity and heat flow were present, a global magnetic field that have protected against hostile radiation, a thicker atmosphere and temperature possibly approximating the same of Earth.

The four ages of Mars

1) Pre-Noachian (4.5 - 4.1 billion years ago)

A serious hypothesis describes Mars at that time with a very dense atmosphere, a global ocean, a mean temperature > 0° C: a first window for the possible emergence of life on Mars around 4.4 to 4.3 billion years ago (hundreds of millions of years before life arose on Earth).

The four ages of Mars

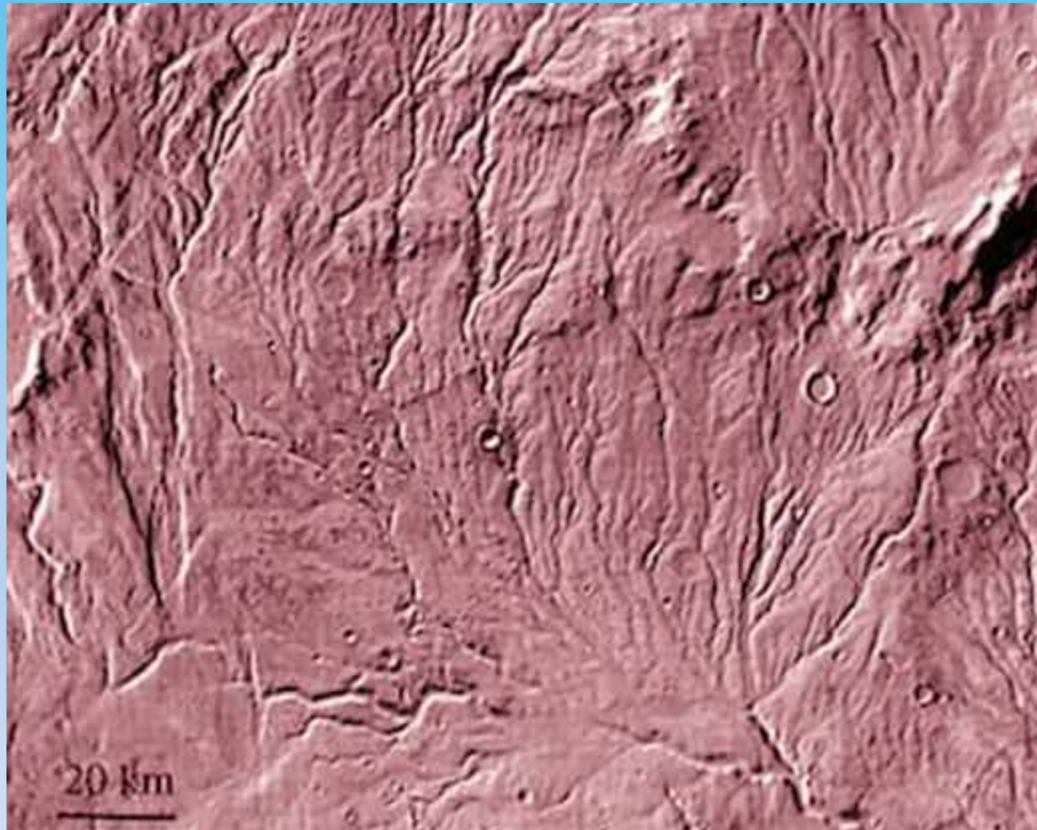
2) Noachian (4.1 – 3.7 billion years ago)

A period of heavy bombardment, with numerous asteroid and comet impacts (as on Earth in the same time). Large-scale volcanic activity was taking place, pouring ash and gases into the atmosphere: the planet warmed. Precipitation rained down: without a doubt, the conditions remained favorable for life.

The four ages of Mars

3) Hesperian (3.7 - 2.9 billion years ago)

Global geological activity was slowing down, although there was still considerable volcanism. Huge amounts of water and sulphur dioxide were emitted by erupting volcanoes, which then rained onto the surface. The climate became colder, much of the water became locked up as permafrost or subsurface ice, but ready to erupted onto the surface when heated by impacts, causing catastrophic floods: short-lived flash floods unleashed torrents equivalent to thousands of Mississippi Rivers.



The four ages of Mars

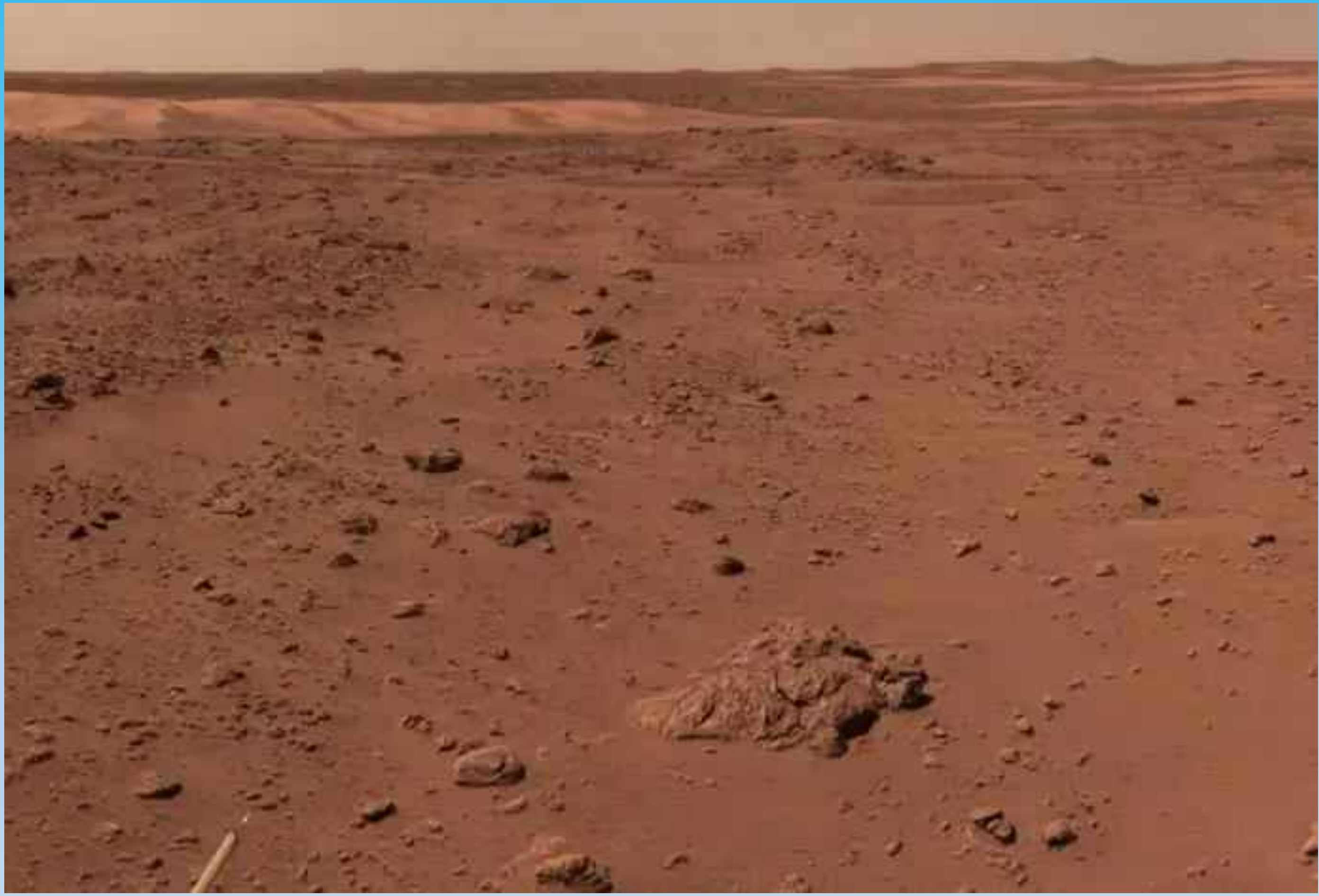
4) Amazonian (2.9 billion years ago-present)

The planet's surface turns dry and arid. The rocks slowly altered by weathering, punctuated only by occasional, short-lived, returns to warmer, wetter conditions.

The atmosphere became so thin that water instantly vaporizes on the surface.

The current appearance of Mars began.

Mars: a cold, dry desert – today



Mars, *Utopia Planitia*: China's Zhurong Rover

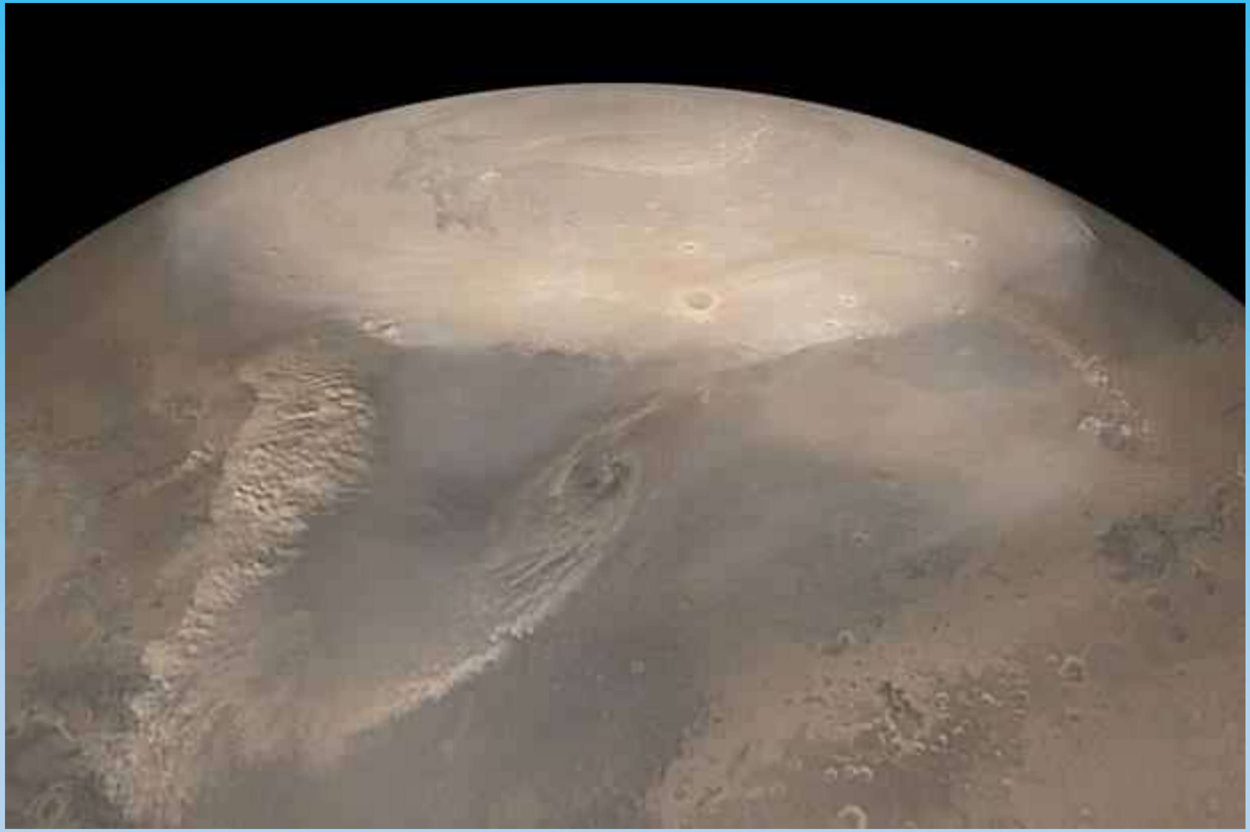
The four ages of Mars

4) Amazonian (2.9 billion years ago-present)

However, the climate and the stability of water at the surface vary over thousands to millions of years as the axial tilt of the planet undergo cyclical changes.

At present, Mars is experiencing an Ice Age, but **every 50 000 years the atmosphere becomes denser, the temperature increases, snow (water!) falls all over the planet.**

An environment that becomes once again favorable to life

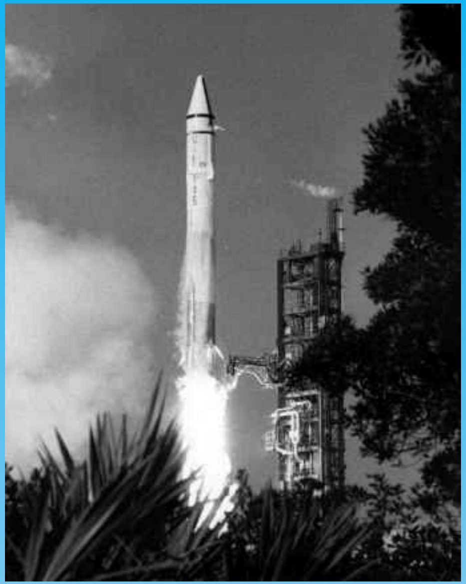


Mars: the abode of life?

Mars 4 billions years ago

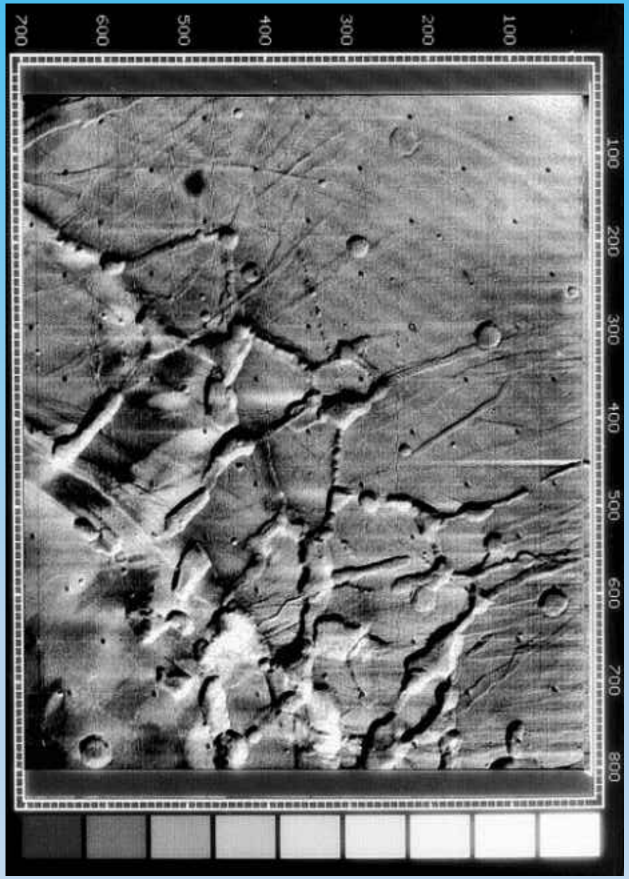
Mars today

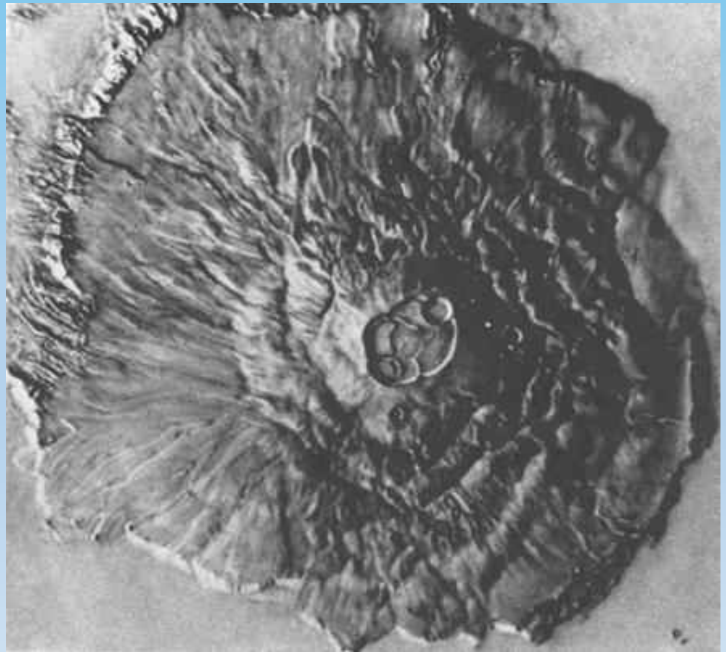
Mariner 9, 1971

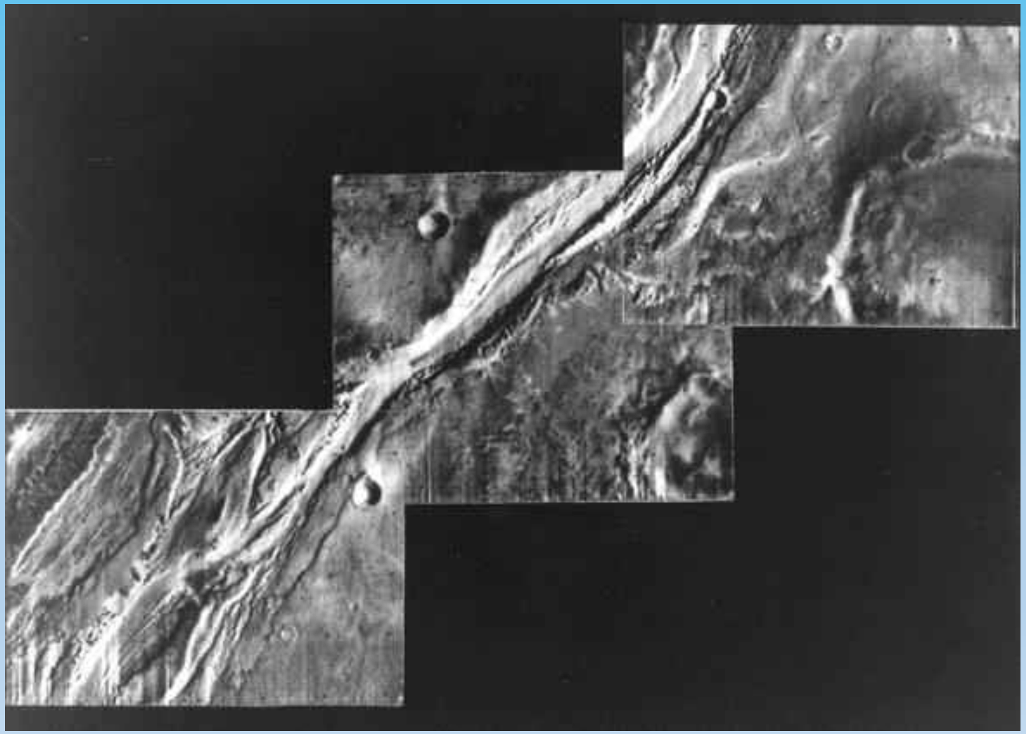


Mariner 9 (NASA) reaches Mars and for the first time enters low orbit and take high resolution photos.

Mars: huge volcanoes, active until recently, rivers, now dry, but which once flowed for thousands of kilometers.







At the beginning of this century new probes flew to Mars providing new data on the planet's potential habitability

2001 Mars Odyssey (orbiter) (USA)

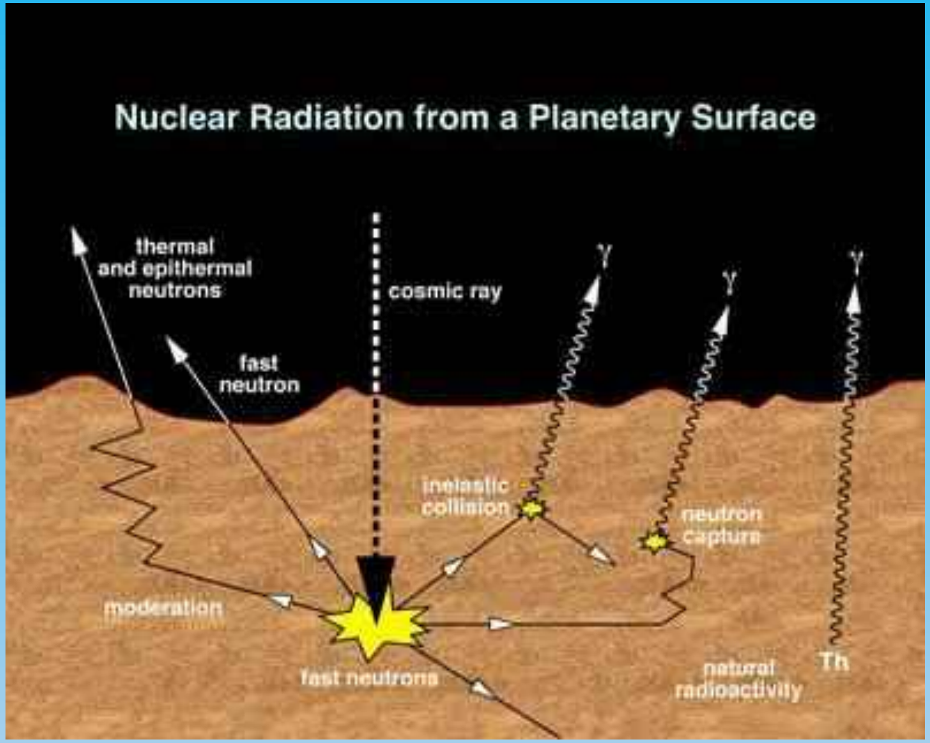
Mars Exploration, 2003
Spirit & Opportunity
(rovers) (USA)

Mars Express, 2003 (EU) (orbiter)

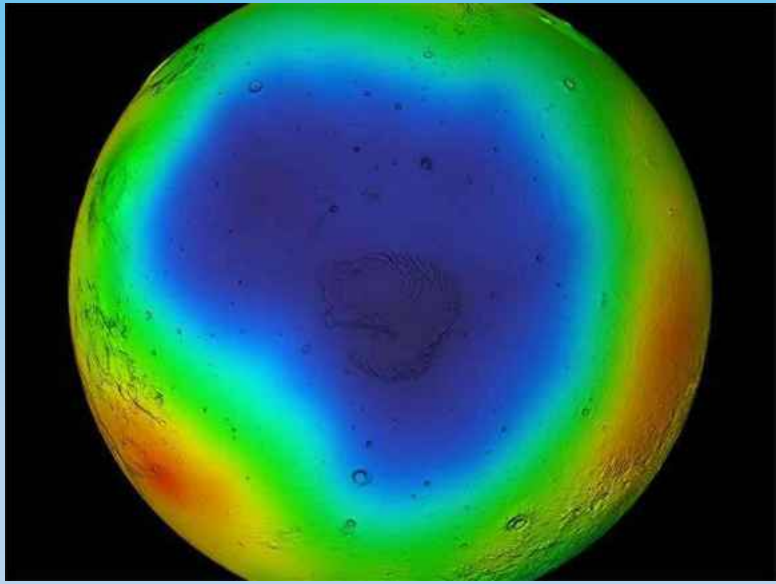
Early 2000s

Mars: Water!

Mars Odyssey



Mars Odyssey (orbiter) (NASA)



Martian equator : 1 meter below the surface: large amount of water ice

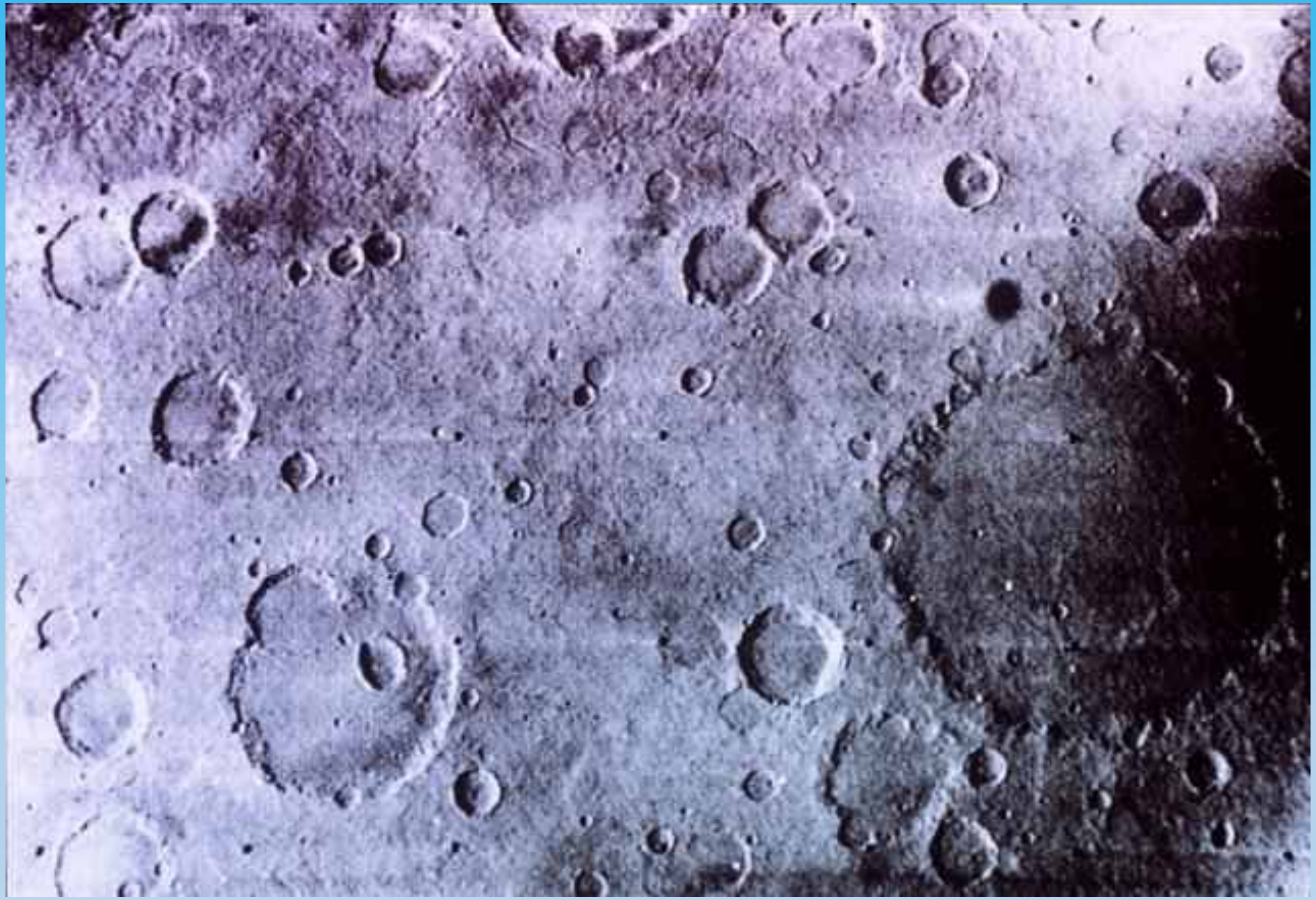
South Pole of Mars: a huge amount of frozen water it' s a frozen hoof, 3 km deep, 600 km large

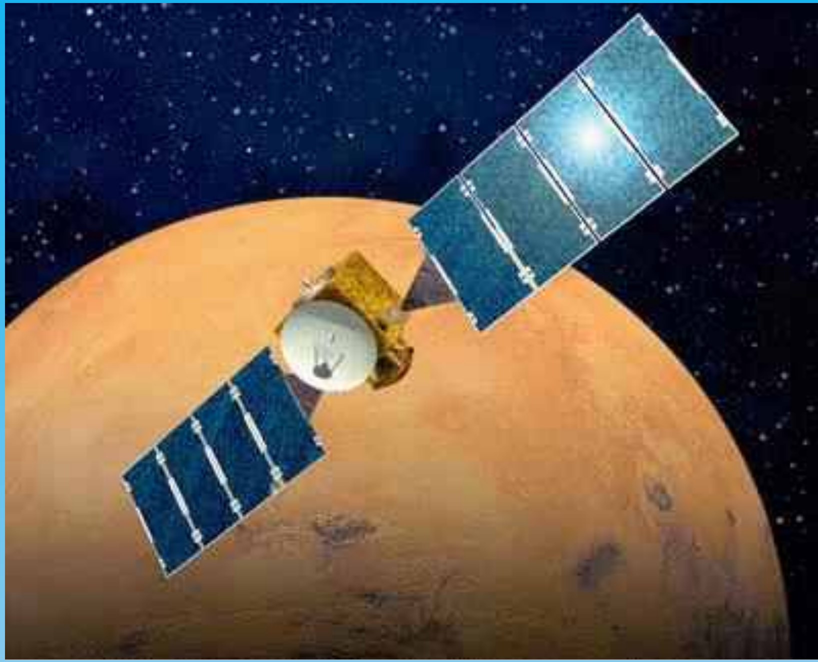
Korolev crater, Mars, today. Frozen water with fresh snow in a crater: Long ago there was an 80 km water lake

Mars Express, ESA

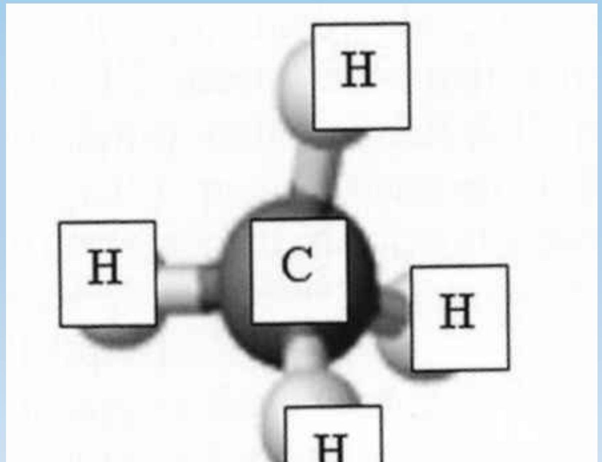
Methane, a possible biomarker, on Mars!

PFS, Mars Express, ESA. Formisano V.- et al.Science
3 Dec 2004 Vol 306, Issue 5702 pp. 1758-1761



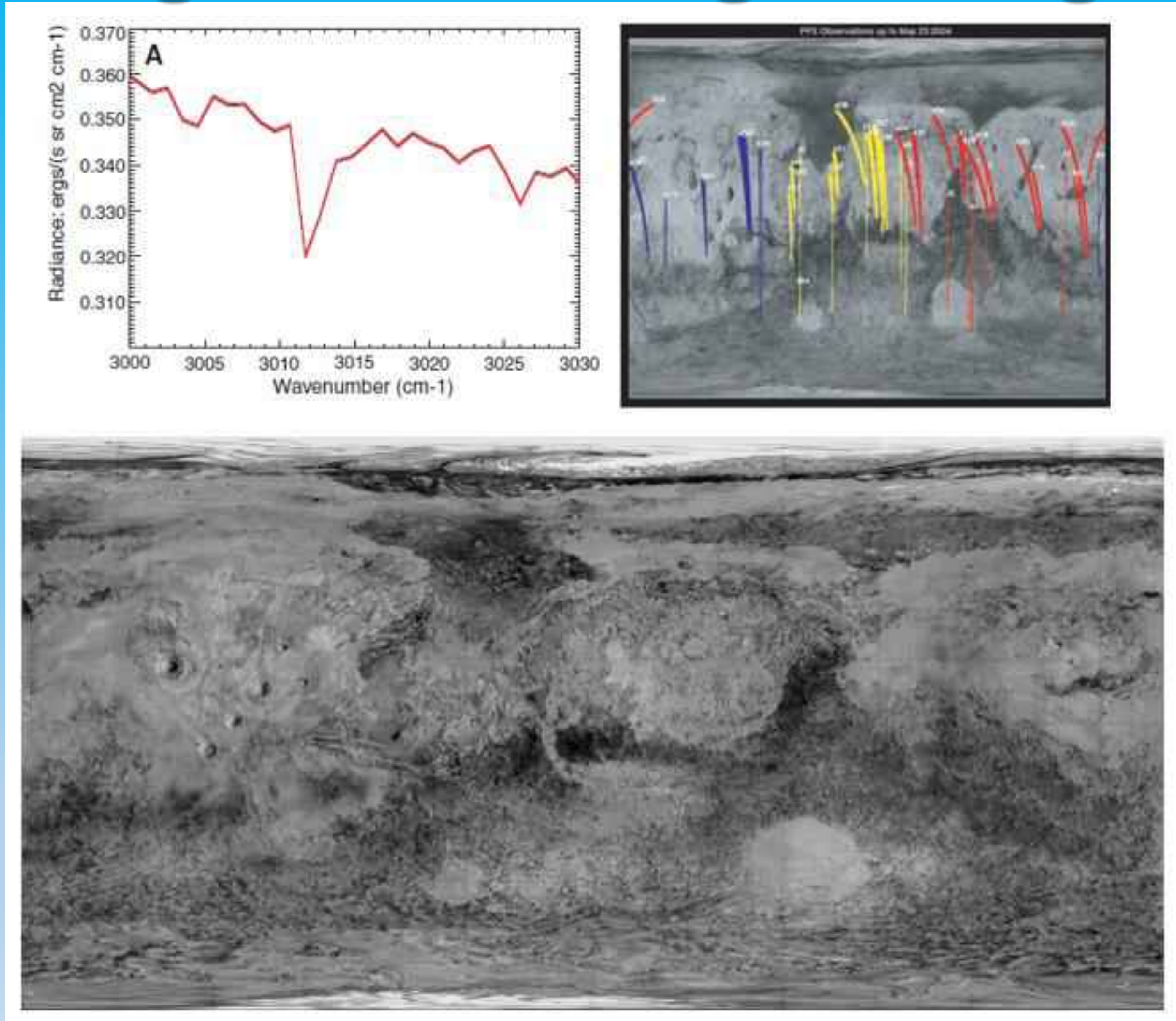


Mars Express, ESA



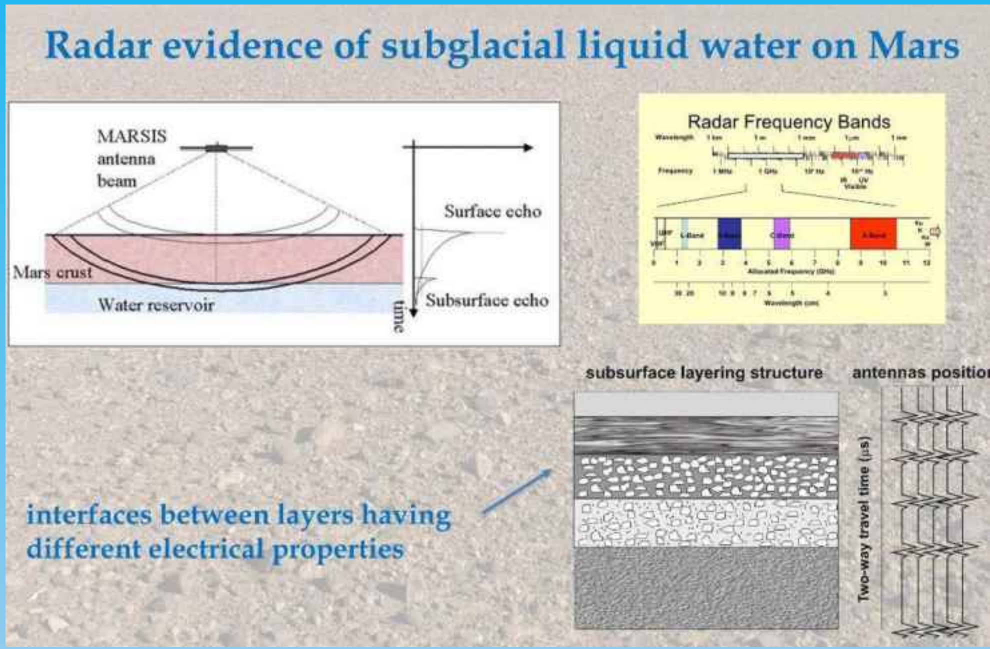
Martian methane: geological or biological origin?

…and perhaps formaldehyde!? (another possible powerful biological signature)



PFS, Mars Express, ESA. Formisano et al., 2004.

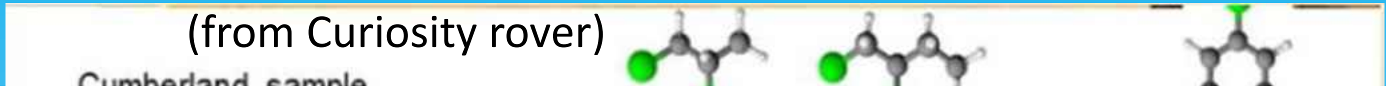
THE DEEP LAKES (liquid water!) OF MARS (today!)



MARS EXPRESS:
ESA / ASI, EU, 2018 – 2020

Lauro SE, Pettinelli E, Caprarelli G et al. (2020)
Multiple subglacial water bodies below the south pole of Mars unveiled by new MARSIS data.
Nature Astronomy 5: 63-70

In the meantime, a number of organic molecules were discovered on Mars, by NASA Curiosity and Perseverance Rovers



.. till 10C..

Modern water at low latitudes on Mars: Potential evidence from dune surfaces

(from Perseverance rover)

XIAOGUANG QIN, XIN REN, XU WANG, JIANJUN LIU, HAIBIN WU, XINGGUO ZENG, YONG SUN, ZHAOPENG CHEN, SHIHAO ZHANG AND ZHENGTANG GUO +11 authors Authors Info & Affiliations

SCIENCE ADVANCES • 28 Apr 2023 • Vol 9, Issue 17 • DOI: 10.1126/sciadv.add8868

and

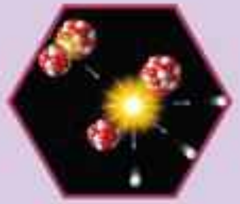
rov

Has life ever arisen on Mars?
If so, did anything survive?

Signs of Life on Mars

hen we talk about searching for signs of ancient life on Mars, what we are actually looking for is a biosignature: an object, substance, pattern that could only have been made by life. There are 6 specific kinds of biosignatures that we might encounter on Mars:

ORGANICS
Organic compounds contain carbon and hydrogen and other light elements. All life on Earth is made of organic compounds, but organic compounds also form in the absence of life. Systematic patterns in the types of organic matter could be a biosignature.



ISOTOPES
Atoms of one chemical element always contain the same number of protons but can have differing numbers of neutrons. On Earth, biological processes sometimes prefer one isotope over another, and that preference can be preserved in rocks.

MINERALS
On Earth, some minerals are uniquely associated with life. Discovery of a mineral that requires life to form would be a biosignature.

CHEMICALS
Earth-life metabolic activity often has a chemical signature. Signs of varying pH or oxidation state over very small scales might be the signature of microbial metabolism in an ancient environment.

SMALL-SCALE STRUCTURES
At the microscopic level, it's possible to spot signs of individual microscopic life forms: fossilized cells, or molds of cells, or casts of cells.

LARGE-SCALE STRUCTURES
At the macroscopic level, microbes on Earth build mats, stromatolites, reefs, and other structures.

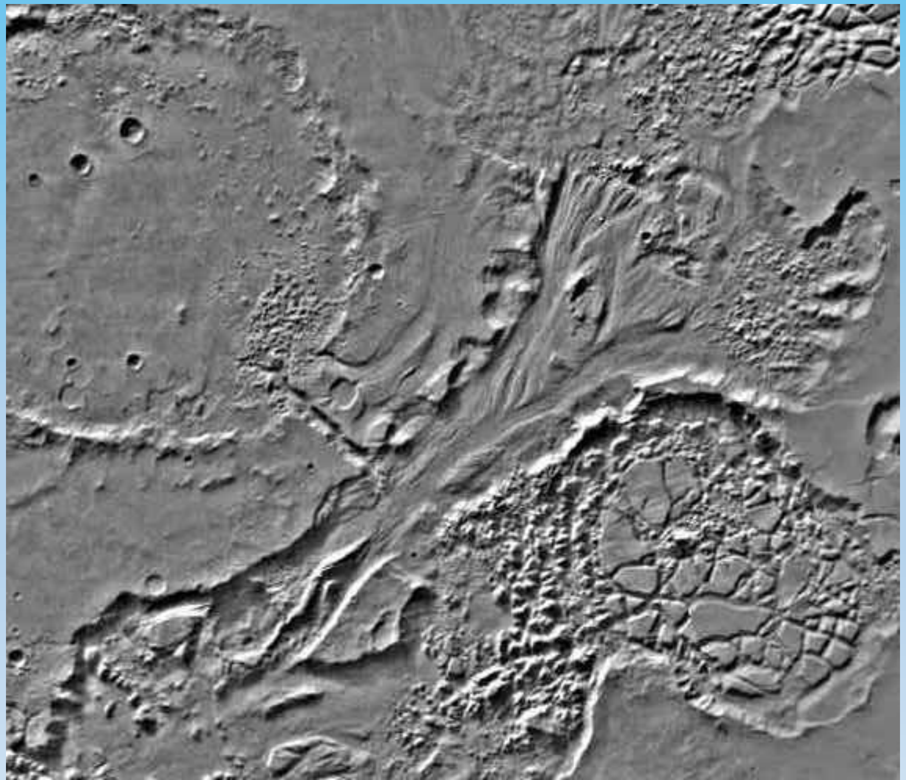
On Earth, geologists look for biosignatures in ancient rocks to learn when life originated. The record for oldest evidence for Earth life is from stromatolites in the Pilbara region of Australia. They show mineral, chemical, and structural evidence for the presence of life on Earth 3.5 billion years ago. The more different kinds of biosignatures observed, the more confident we can be in the conclusion that life was present.

ABOVE *A 3.7-billion-year-old fossil stromatolite from western Australia preserves some of the oldest evidence for life on Earth.*

THE PLANETARY SOCIETY

1976
Viking missions (NASA): the search of life on Mars starts!

Viking 1 & Viking 2, the orbiters confirm what was previously discovered by Mariner 9: undoubtedly in a distant time, albeit billions of years ago, water flowed and enormous floods of water shaped the surface of Mars



BIOSIGNATURES

Vikings on Mars : searching for metabolism and organics

ORGANICS
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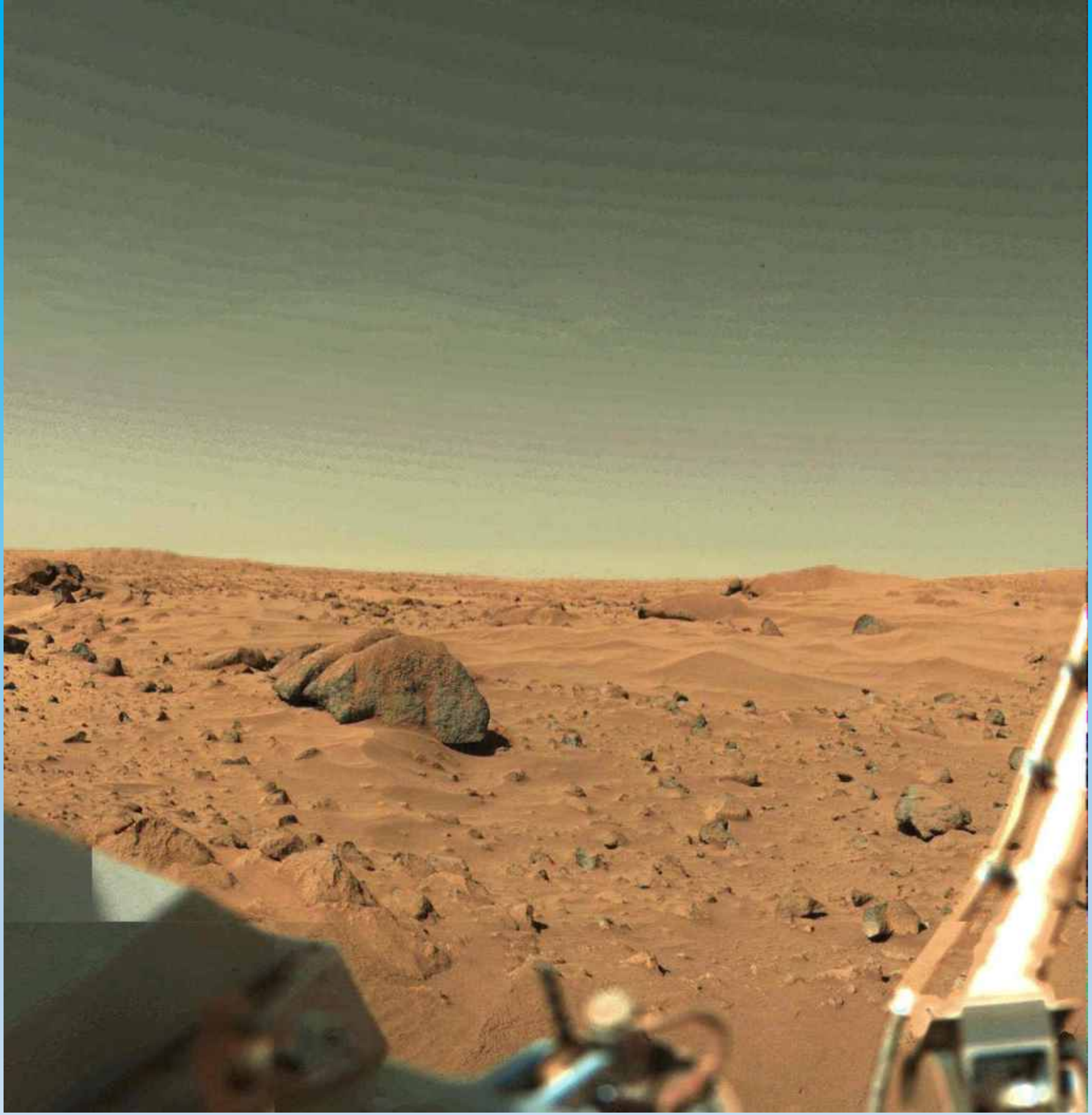
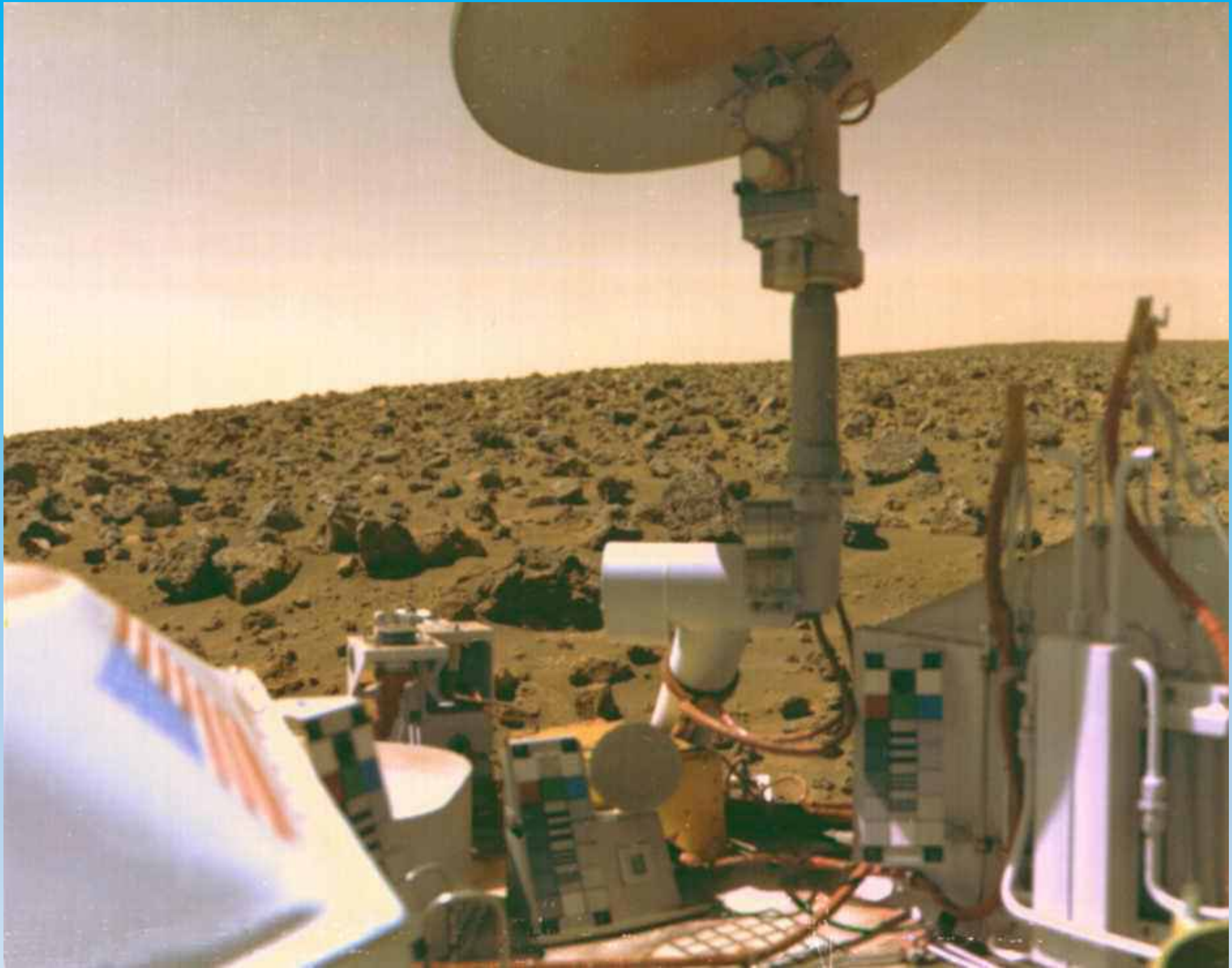
Vikings: Biological analysis of the Martian regolith.

The first (and only) time biological tests were conducted to search for life outside of planet Earth.



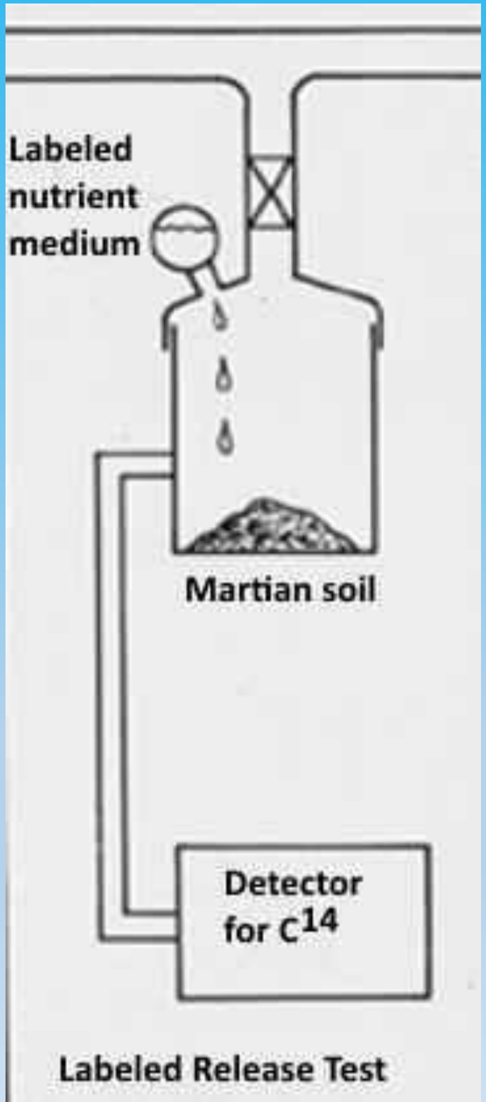
July 20 1976 Viking 1, lander (Chryse Planitia)



September 3 1976
Viking 2, lander
(Utopia Planitia)

Life on Mars?

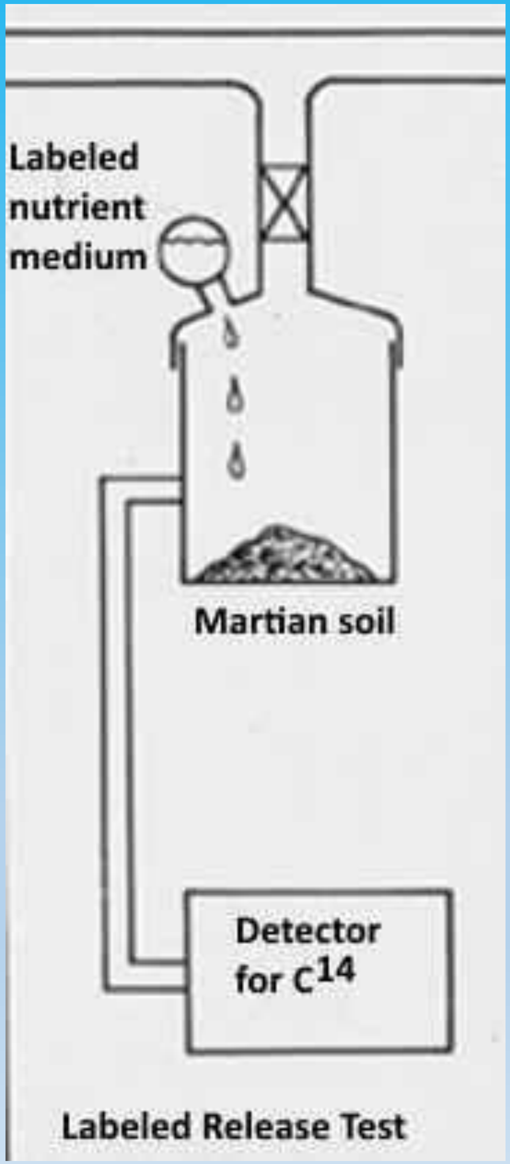
1976
Viking 1
Viking 2



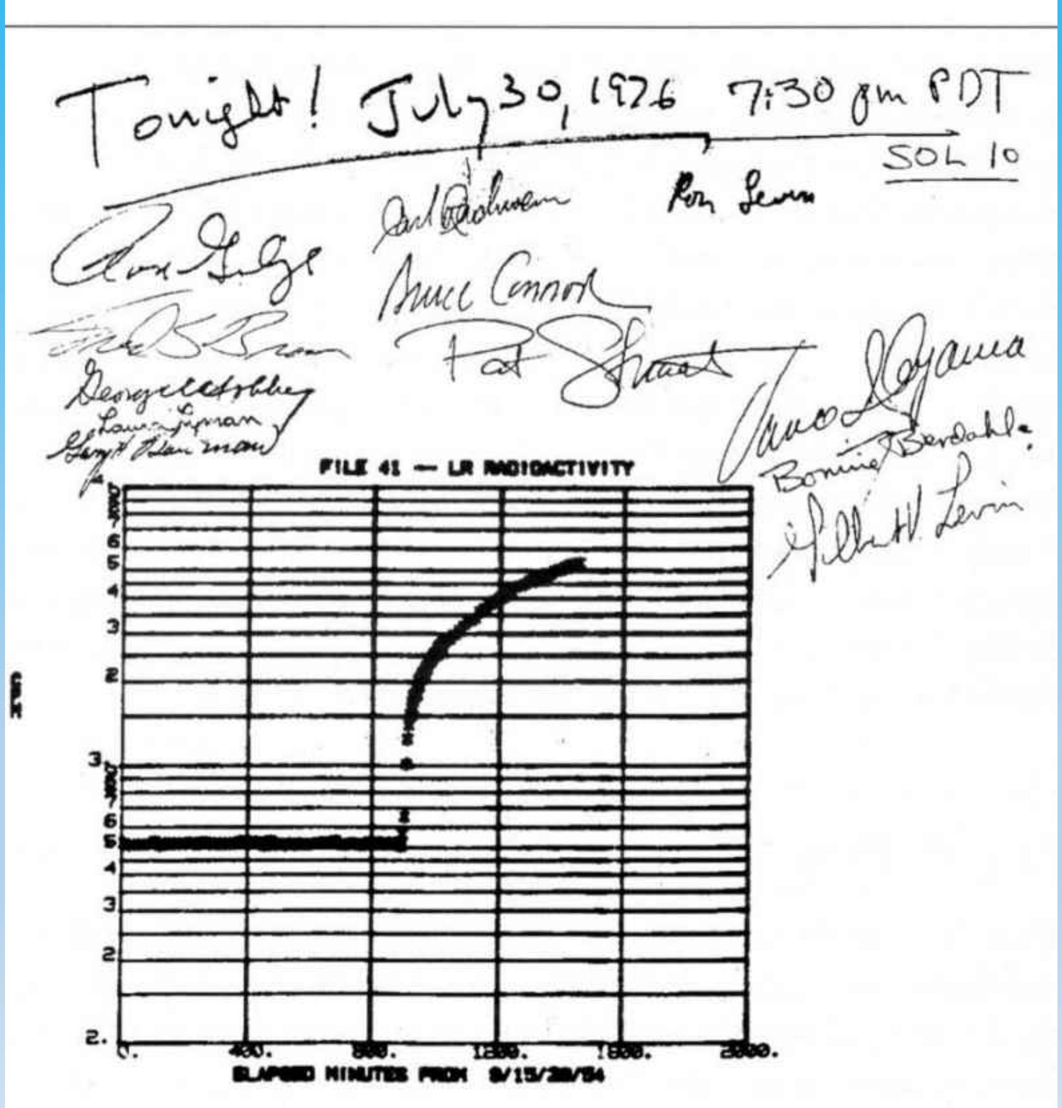
Labeled release test: simple organic compounds (sugars and amino acids) were added to the Martian regolith.
In the presence of living beings (bacteria, algae ..), the organics would have been decomposed and CO_2 would be released. Preliminary sterilization at 160 ° C would have eliminated the response confirming the biological response.

Viking1
July 30, 1976

Life on Mars?



Labeled Release test: the answer is YES

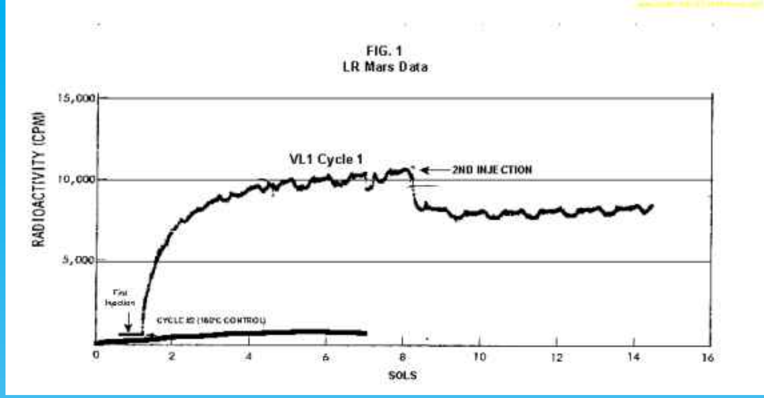


G.V. Levin, LR Principal Investigator (and inventor of the device)

August-September 1976
Viking1/Viking 2

Chryse Planitia: 10 000 cpm

Utopia Planitia: 13 000 cpm



Labeled release: CO2 released after sugars and aminoacids were added.

Preliminary sterilization at 160 ° C reduced the response to almost zero.

The experiment was repeated several times:

Around 50 ° C the response was around zero.

A sample under a rock of Martian soil (to prevent the possible "activation" by the solar UV of oxidizing substances) was positive.

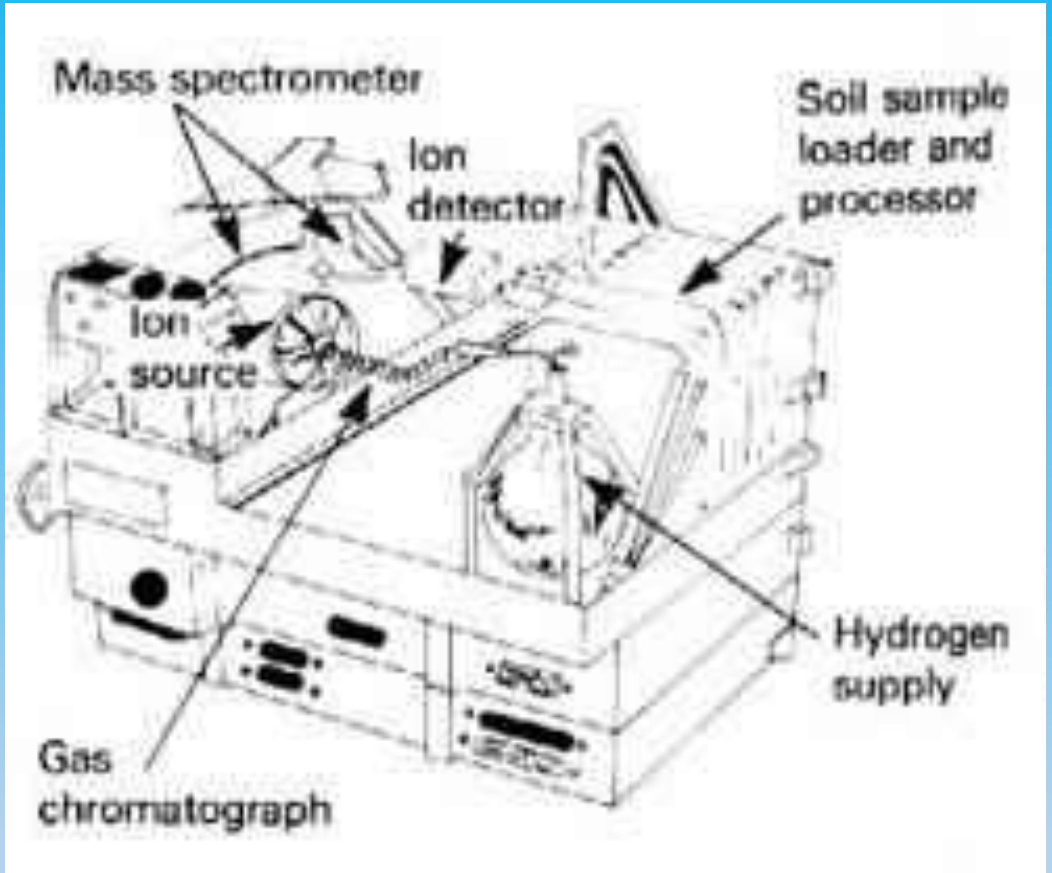
A regolith sample left for more than 100 days inside the probe did not react (" starvation ").

The same happened in the samples taken 3000 km away (Viking 1 vs Viking 2) .

Everything happened by confirming the biological response.

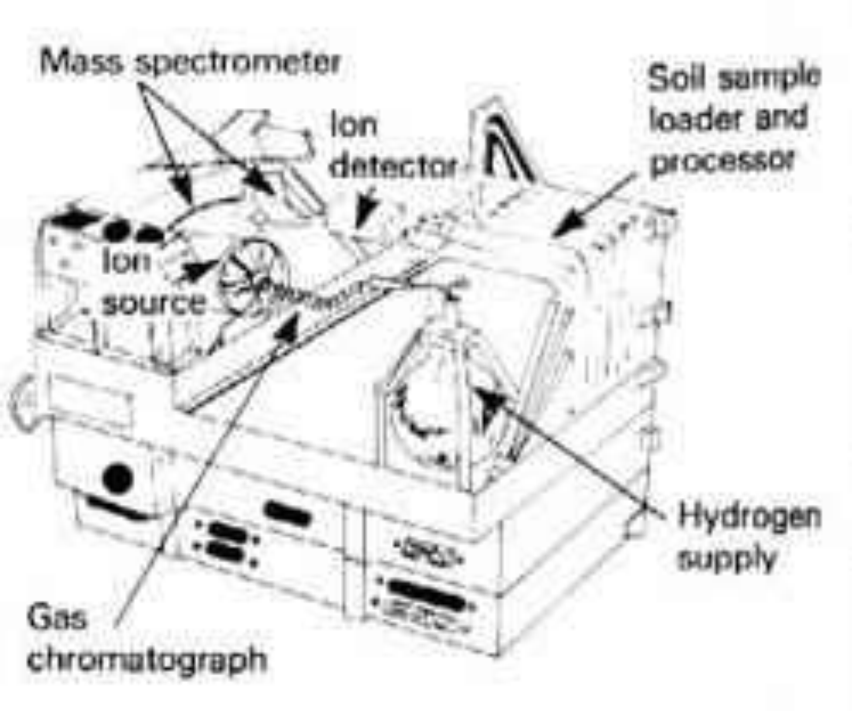
No organic compounds? No life!

BUT, successively



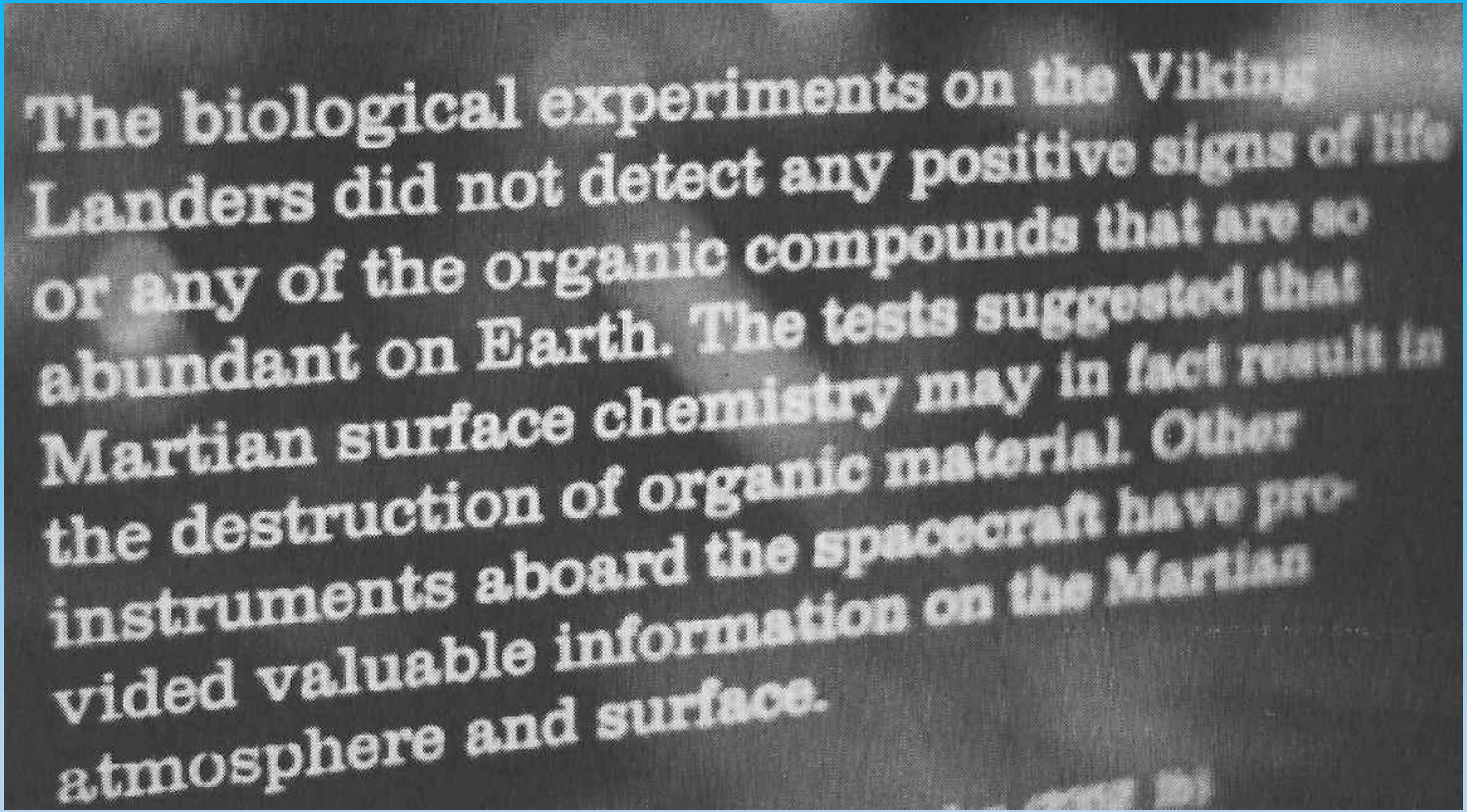
Viking's GCMS (gas chromatograph – mass spectrometer) found no traces of organic compounds in Martian soil (regolith)

No organic compounds? No life!



Many scientists, after the data from GCMS, hypothesized **that the release of carbon dioxide in the LR experiments would be the** result of the action of strongly oxidized compounds **(superoxides and peroxides)** that could be present in the Martian regolith: **Chemistry not Biology!**

Today, an epitaph for the presence of life on Mars

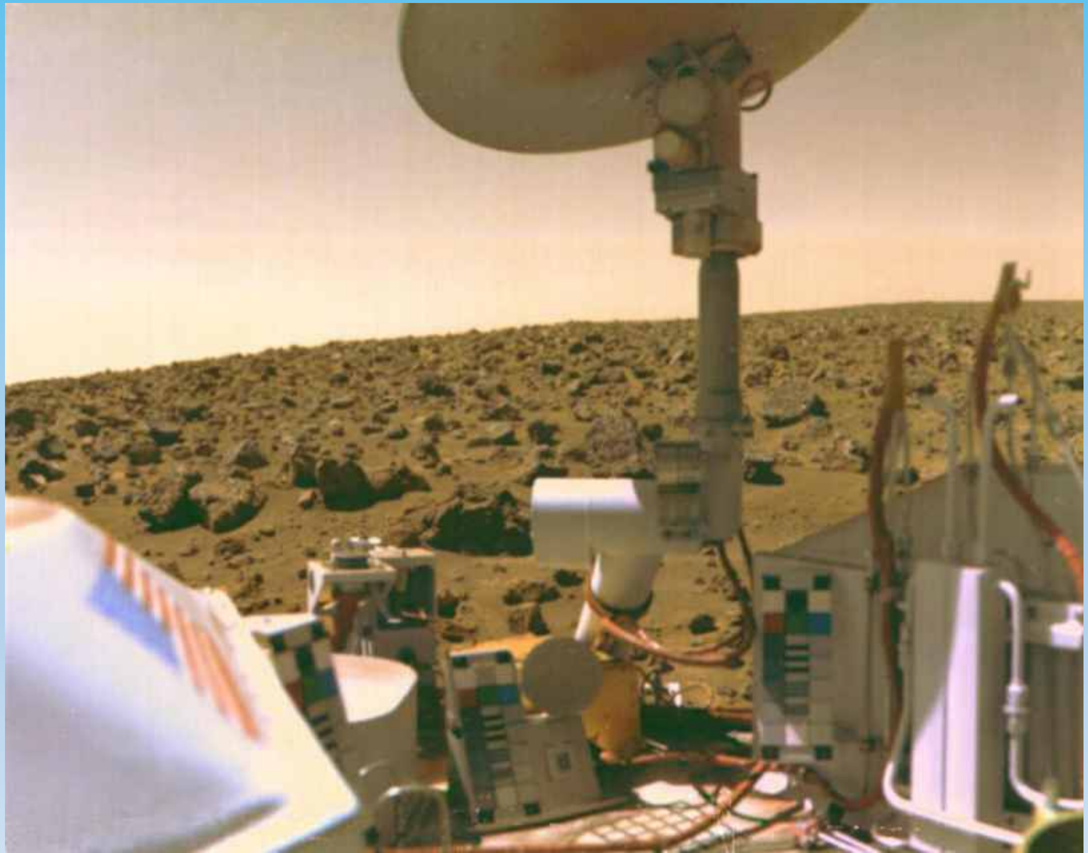


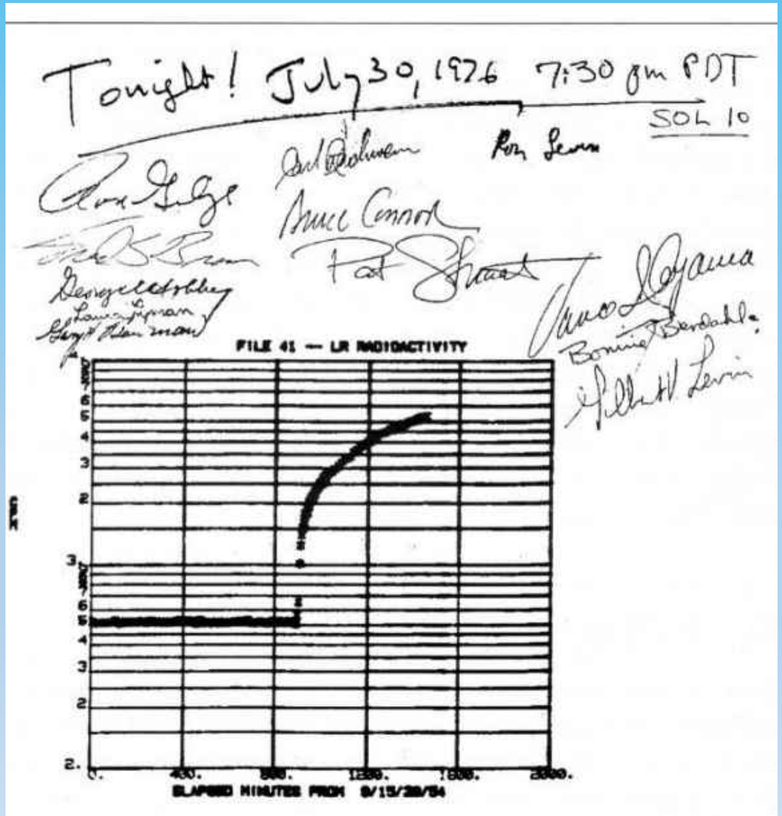
The plaque placed in front of the Viking Lander Exhibit, Smithsonian National Air & Space Museum, Washington D.C. , USA.

DE PROFUNDIS FOR «LIFE ON Mars»?

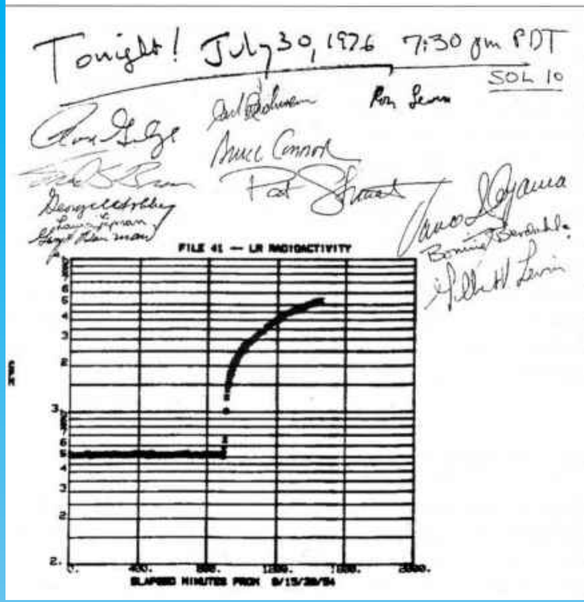
Andrew C. Schuerger & Benton C. Clark
Viking Biology Experiments: Lessons Learned and the Role of Ecology in Future Mars Life-Detection Experiments
Space Sci Rev (2008) 135:

RETURN TO THE
LEVIN'S LABELED RELEASE TEST!





Many cocluded that there are not any trace of life in the present Mars,
but others take LR evidences of life in the distant past of Mars very seriously, and **return to the results of Levin's Labeled Release**



Glavin D.P. et al., 2001

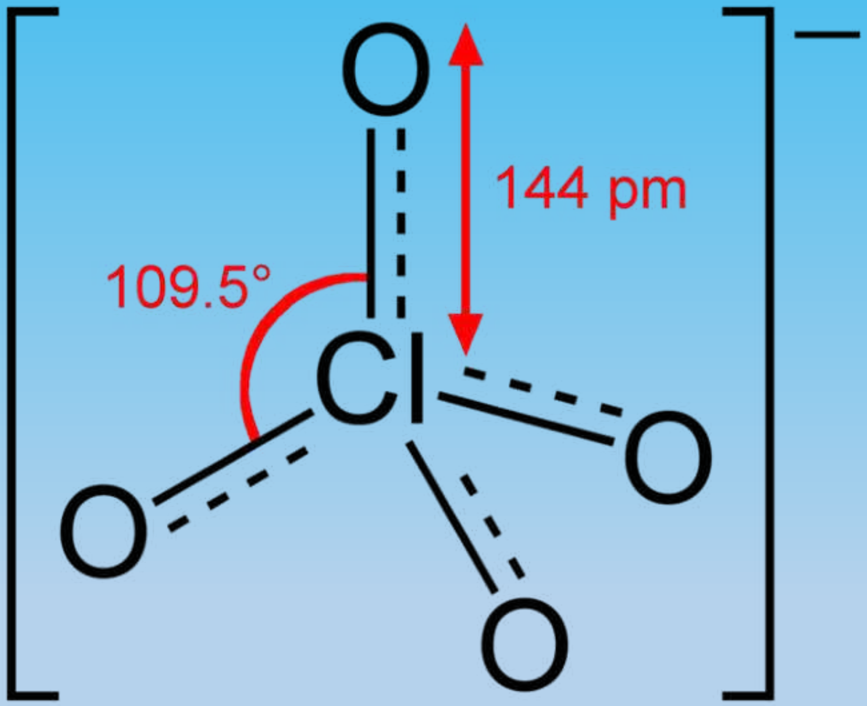
Detecting pyrolysis products from bacteria on Mars Daniel P. Glavin, Michael Schubert, Oliver Botta, Gerhard Kminek, Jeffrey L. Bada, Earth and Planetary Science Letters Volume 185, Issues 1–2, 15 February 2001, 1–5

Viking GCMS cannot recognize pyrolysis products of <1 million Escherichia coli, bacteria / g (while LR is able to recognize 10 bacteria / g) > **GCMS had a huge sensitivity problem**

Phoenix, 2008

The *Phoenix* lander (NASA) descended on Mars on May 25, 2008

discovering **Perchlorate on Mars**



Rafael Navarro Gonzalez et al. Reanalysis of the Viking results suggests perchlorate and organics at mid-latitudes on Mars, Journal of Geophys. Res.-Atmosph.), 115 /(E12010) 1-11, 2010

Repeating the GCMS test in the Atacama Desert, Earth (it contains organic compounds: bacteria and fungi!) by adding perchlorates (as now we know they are on Mars)
 the GCMS DENIES THE PRESENCE OF ORGANICS, except some chlorinated derivatives of methane, EVEN IF AT ATACAMA LIFE BEINGS WERE PRESENT!

Rafael Navarro Gonzalez et al., 2010: Reanalysis of the Viking results suggests perchlorate and organics at mid-latitudes on Mars

Perchlorates destroy organic compounds when heated to 500 ° C (as in GCMS) and produce chloromethane and dichloromethane, ATTENTION: the same compounds was detected by the GCMS on Mars (and attributed to solvents left over during the preparation of the probe): the GCMS actually recognized the presence of organic compounds on Mars!

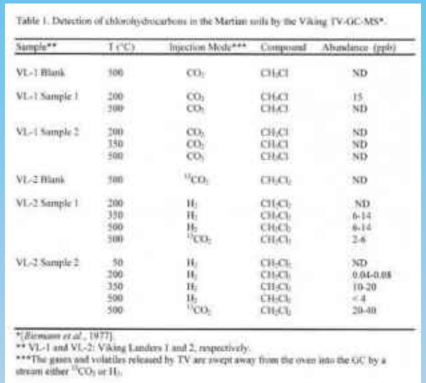


Table 1. Detection of chlorohydrocarbons in the Martian soils by the Viking TV-GC-MS*.

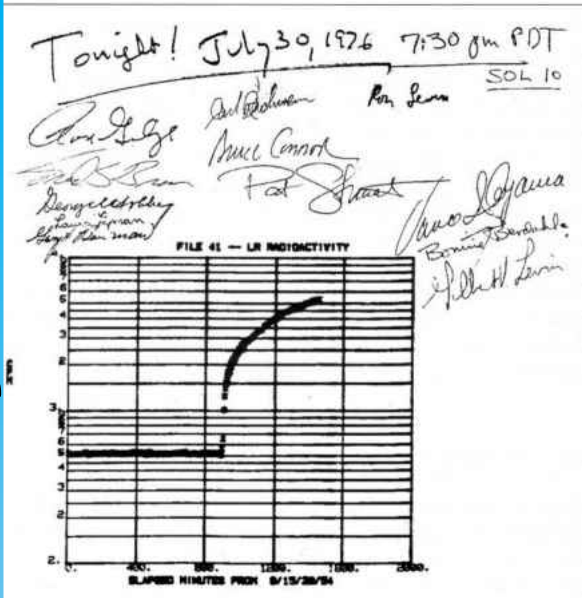
Sample**	T (°C)	Injection Mode***	Compound	Abundance (ppb)
VL-1 Blank	500	CO_2	CH_3Cl	ND
VL-1 Sample 1	200	CO_2	CH_3Cl	15
	500	CO_2	CH_3Cl	ND
VL-1 Sample 2	200	CO_2	CH_3Cl	ND
	350	CO_2	CH_3Cl	ND
	500	CO_2	CH_3Cl	ND
VL-2 Blank	500	$^{13}CO_2$	CH_2Cl_2	ND
VL-2 Sample 1	200	H_2	CH_2Cl_2	ND
	350	H_2	CH_2Cl_2	6-14
	500	H_2	CH_2Cl_2	6-14
	500	$^{13}CO_2$	CH_2Cl_2	2-6
VL-2 Sample 2	50	H_2	CH_2Cl_2	ND
	200	H_2	CH_2Cl_2	0.04-0.08
	350	H_2	CH_2Cl_2	10-20
	500	H_2	CH_2Cl_2	< 4
	500	$^{13}CO_2$	CH_2Cl_2	20-40

*[*Biemann et al.*, 1977].
** VL-1 and VL-2: Viking Landers 1 and 2, respectively.
***The gases and volatiles released by TV are swept away from the oven into the GC by a stream either $^{13}CO_2$ or H_2.

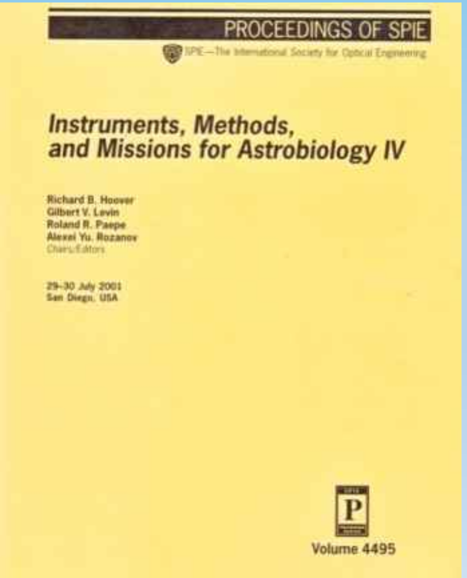
So, **Viking GCMS can't deny the results of the Labeled Release test on Mars: organics were present at the Vikings sites!**

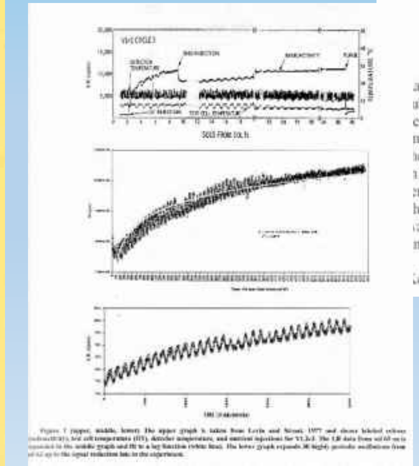
JD Miller & GV Levin, 2002

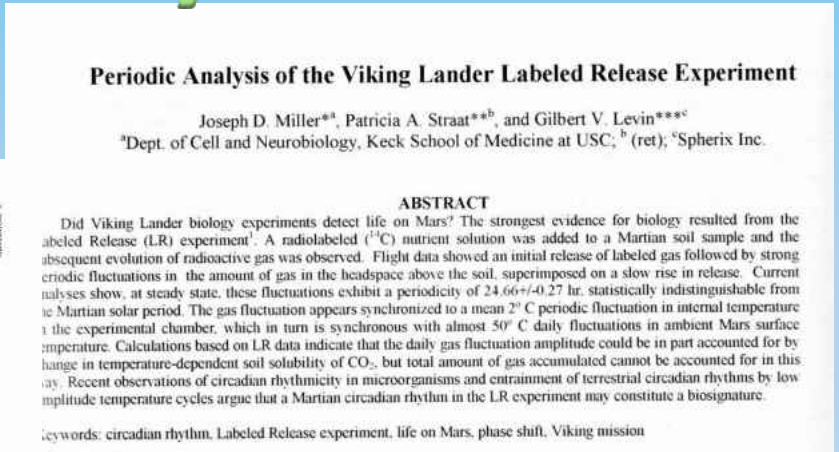
The Viking LR showed a highly periodic gas release: the signal has a rhythm: 24.66 h, the length of a Martian day (Sol): a possible circadian rhytm?



Circadian rhythm is Biology!







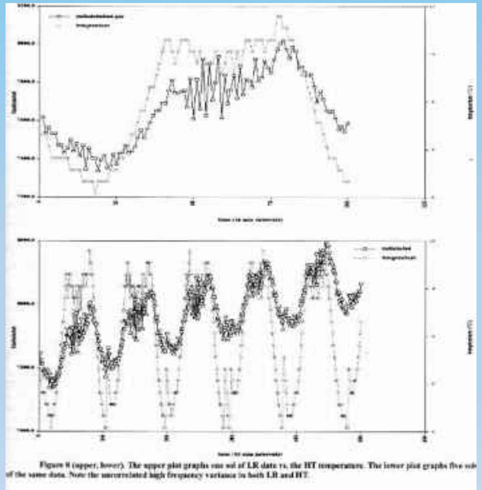
Periodic Analysis of the Viking Lander Labeled Release Experiment

Joseph D. Miller*[a], Patricia A. Straat**[b], and Gilbert V. Levin***[c]
[a]Dept. of Cell and Neurobiology, Keck School of Medicine at USC; [b] (ret); [c]Spherix Inc.

ABSTRACT

Did Viking Lander biology experiments detect life on Mars? The strongest evidence for biology resulted from the abeled Release (LR) experiment[1]. A radiolabeled (^{14}C) nutrient solution was added to a Martian soil sample and the ubsequent evolution of radioactive gas was observed. Flight data showed an initial release of labeled gas followed by strong eriodic fluctuations in the amount of gas in the headspace above the soil, superimposed on a slow rise in release. Current nalyses show, at steady state, these fluctuations exhibit a periodicity of 24.66+/-0.27 hr, statistically indistinguishable from ie Martian solar period. The gas fluctuation appears synchronized to a mean 2° C periodic fluctuation in internal temperature 1 the experimental chamber, which in turn is synchronous with almost 50° C daily fluctuations in ambient Mars surface emperature. Calculations based on LR data indicate that the daily gas fluctuation amplitude could be in part accounted for by hange in temperature-dependent soil solubility of CO_2, but total amount of gas accumulated cannot be accounted for in this /ay. Recent observations of circadian rhythmicity in microorganisms and entrainment of terrestrial circadian rhythms by low mplitude temperature cycles argue that a Martian circadian rhythm in the LR experiment may constitute a biosignature.

Ceywords: circadian rhythm, Labeled Release experiment, life on Mars, phase shift, Viking mission

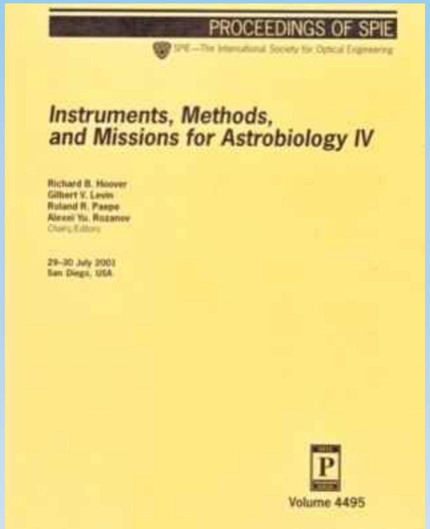


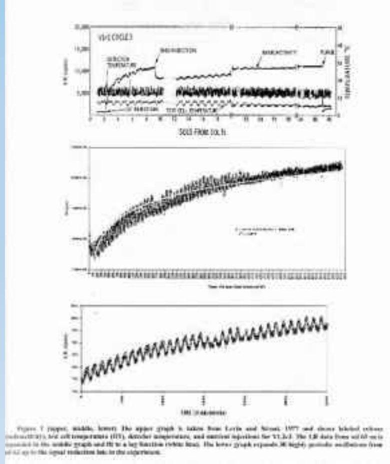
But the temperature inside the Lander also showed a 2 ° C temperature fluctuation (reflection of the temperature variation during the day on Mars).

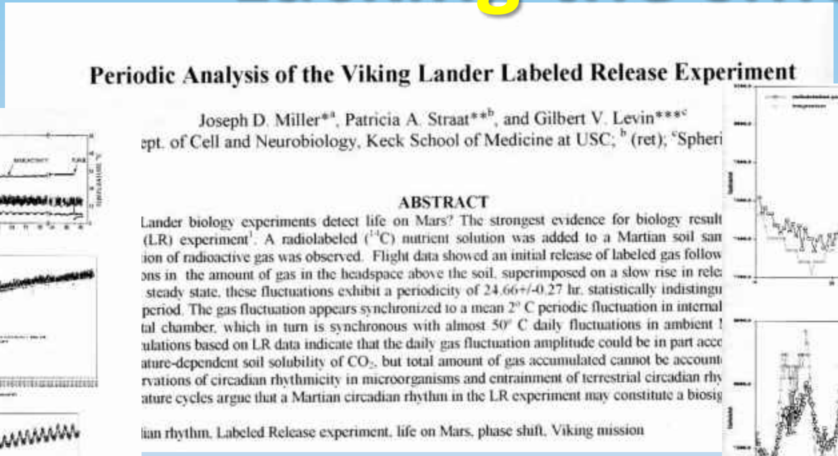
If the circadian rhythm of the released gas was determined by temperature, it would be a chemical phenomenon and not a biological one.

Chemistry or Biology?

Lacking the smoking gun!







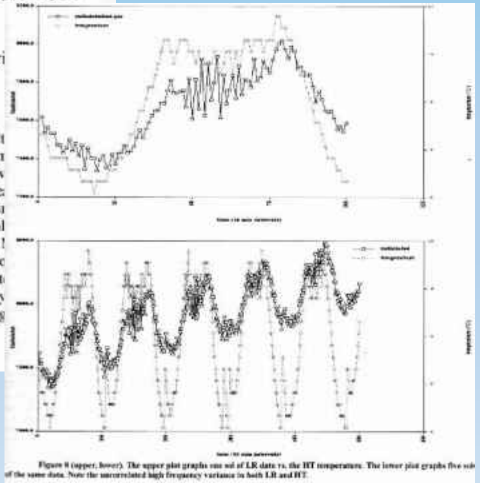
Periodic Analysis of the Viking Lander Labeled Release Experiment

Joseph D. Miller*[a], Patricia A. Straat**[b], and Gilbert V. Levin***[c]
ept. of Cell and Neurobiology, Keck School of Medicine at USC; [b] (ret); [c]Spheri

ABSTRACT

Lander biology experiments detect life on Mars? The strongest evidence for biology result
(LR) experiment[1]. A radiolabeled (^{14}C) nutrient solution was added to a Martian soil san
ion of radioactive gas was observed. Flight data showed an initial release of labeled gas follow
ons in the amount of gas in the headspace above the soil, superimposed on a slow rise in rele
steady state, these fluctuations exhibit a periodicity of 24.66+/-0.27 hr, statistically indistingu
period. The gas fluctuation appears synchronized to a mean 2° C periodic fluctuation in internal
tal chamber, which in turn is synchronous with almost 50° C daily fluctuations in ambient
ulations based on LR data indicate that the daily gas fluctuation amplitude could be in part acco
ature-dependent soil solubility of CO_2, but total amount of gas accumulated cannot be account
rvations of circadian rhythmicity in microorganisms and entrainment of terrestrial circadian rhy
ature cycles argue that a Martian circadian rhythm in the LR experiment may constitute a biosig

lian rhythm, Labeled Release experiment, life on Mars, phase shift, Viking mission

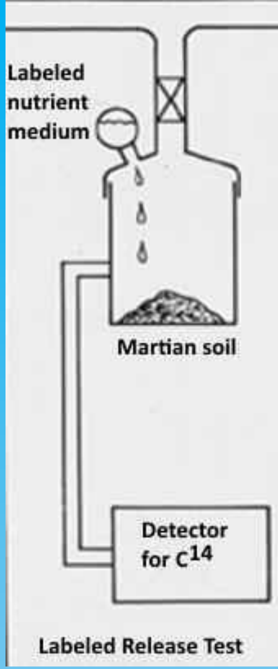


Life on Mars?

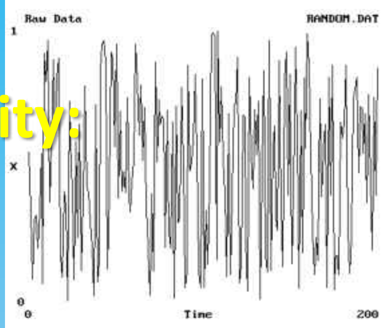
Using Caos analysis on LR Viking results,

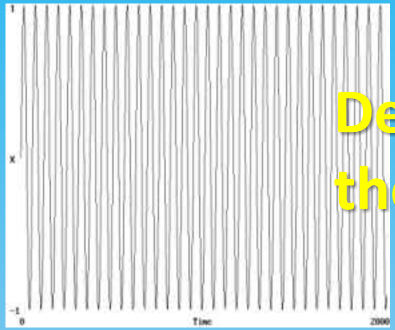
G. Bianciardi with Miller & Levin

Labeled Release Experiment on Mars: a new approach. Complexity analysis: Order and Chaos



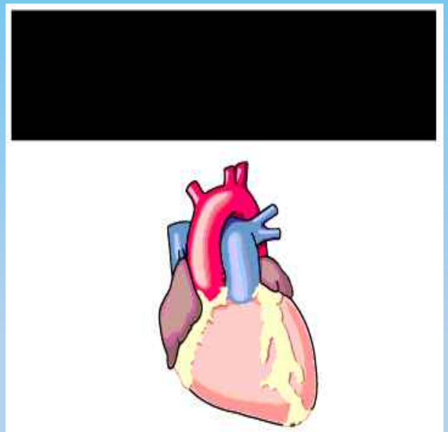
Unstructured causality: White noise





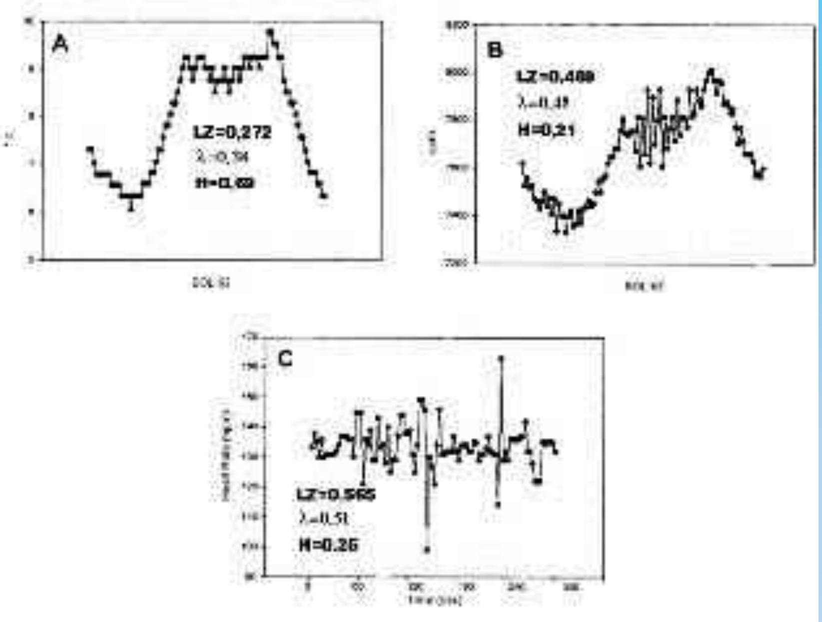
Deterministic dynamics: the sine function

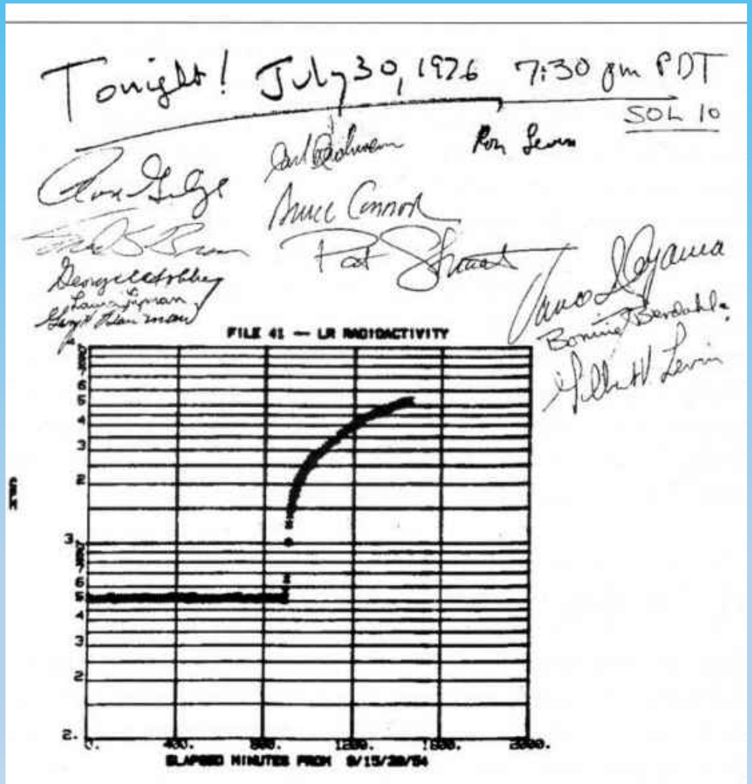
Heartbeat

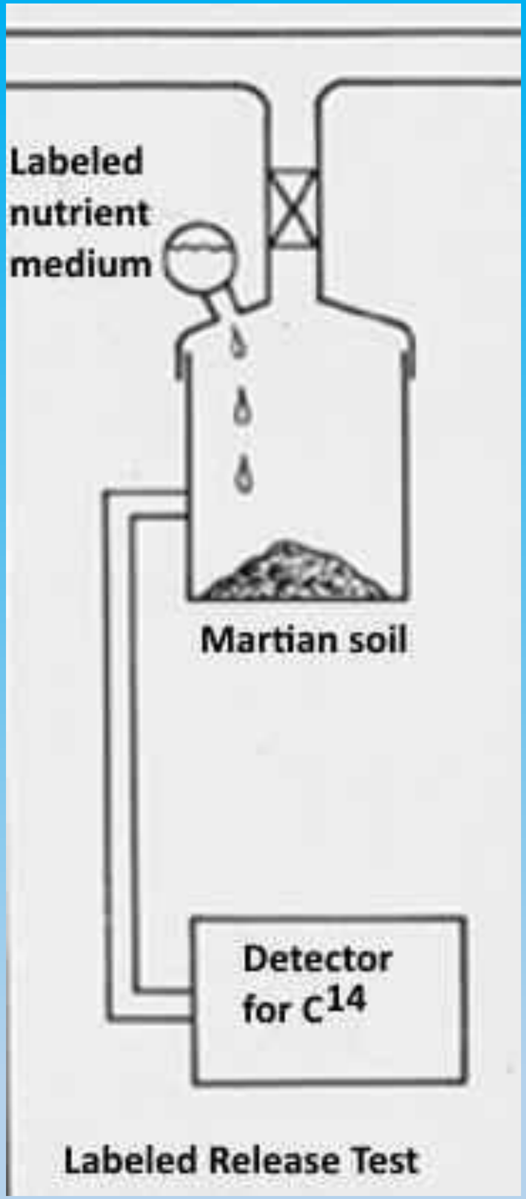


Life: there is no deterministic order of mathematical functions, but a highly chaotic, non-deterministic dynamic.

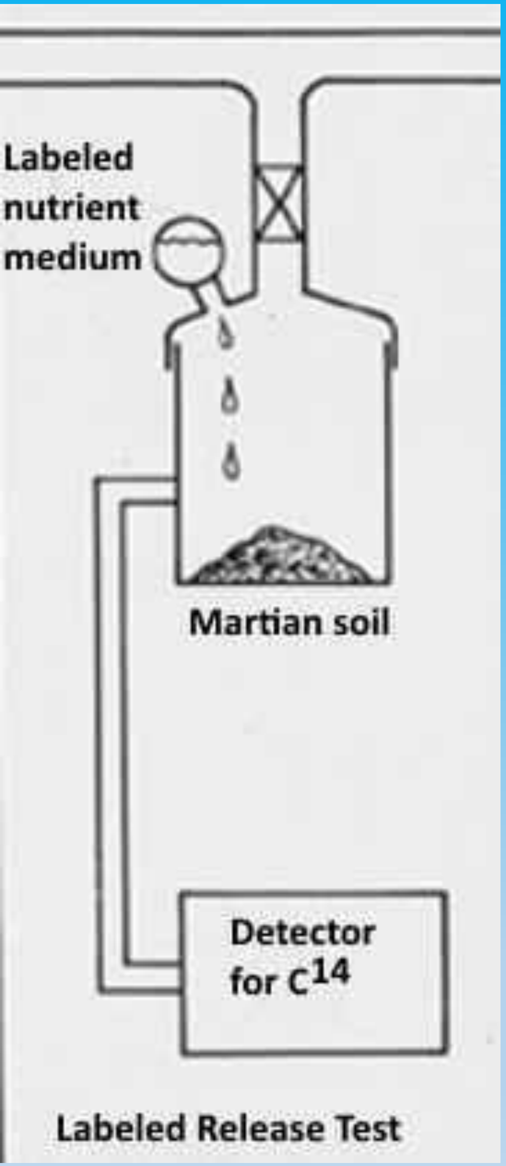
Complexity analysis of the LR data on Mars vs. Biological data, Earth: the same dynamic behavior?







LIFE: chaos, randomness and fractal (statistical) order

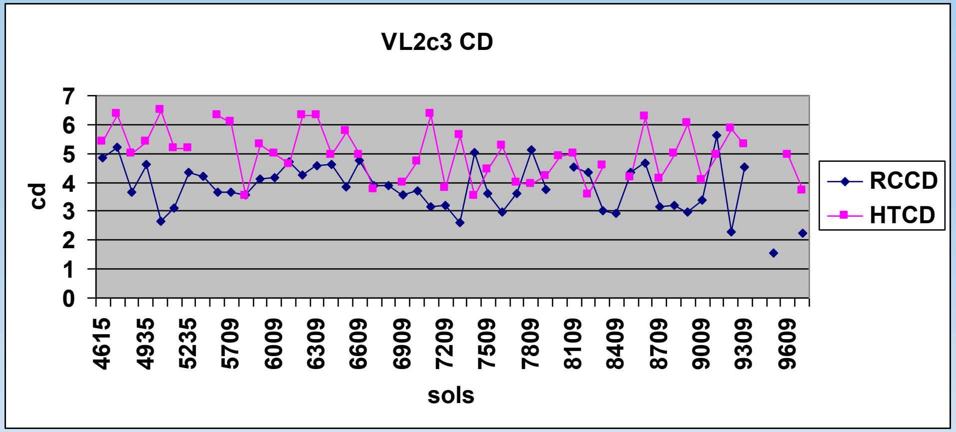


Lempel Ziv Complexity

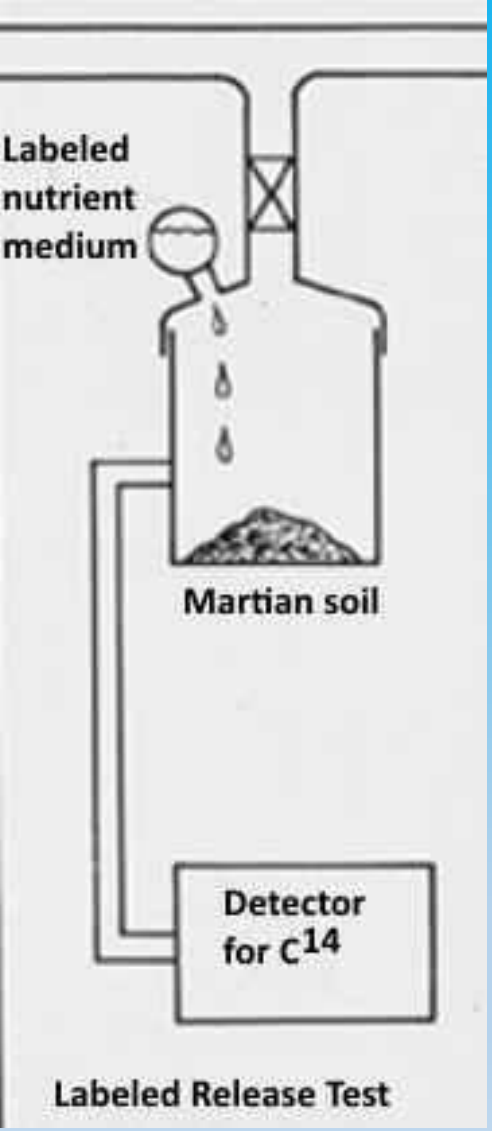
A value of LZ = 0 the time series of data follows a perfectly predictable, regular trend (sorted data)

A value of LZ = 1 the time series of data follows a completely random trend.

Measure the degree of complexity of a time series



Hurst Exponent



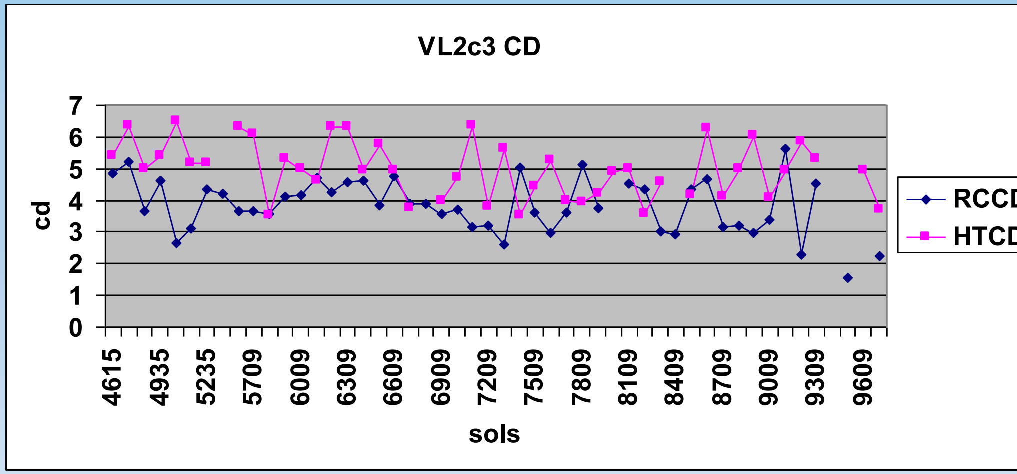
With the Hurst exponent it is possible to distinguish a time series of data whose structure is governed by a random process, from one in which this process cannot be properly defined as such, despite being a non-deterministic type (**process with memory**).

H = ½ the time series under examination follows a random walk process.

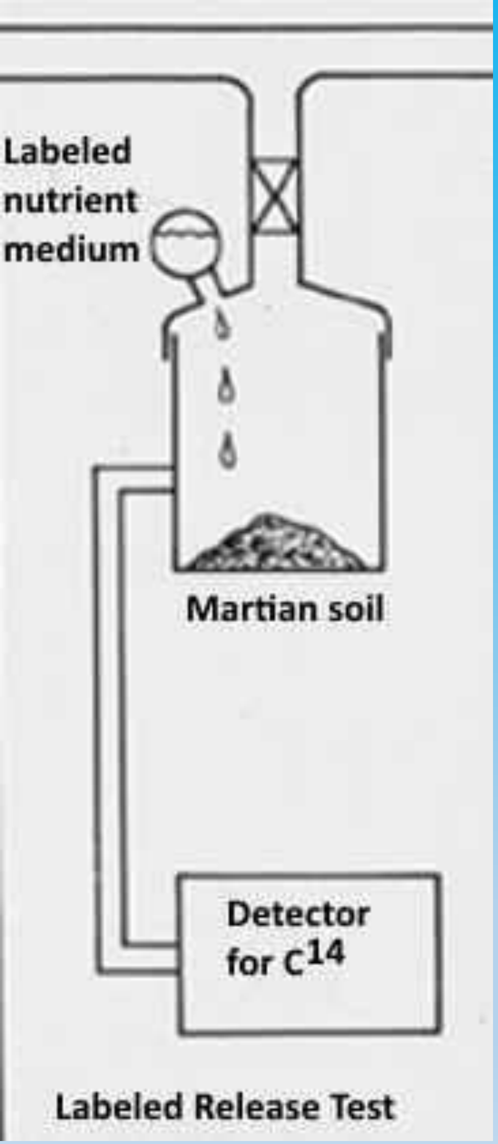
Stochastic processes with memory:

0 <H <½ presence of an anti-persistent effect

½ <H <1 presence of a persistent effect



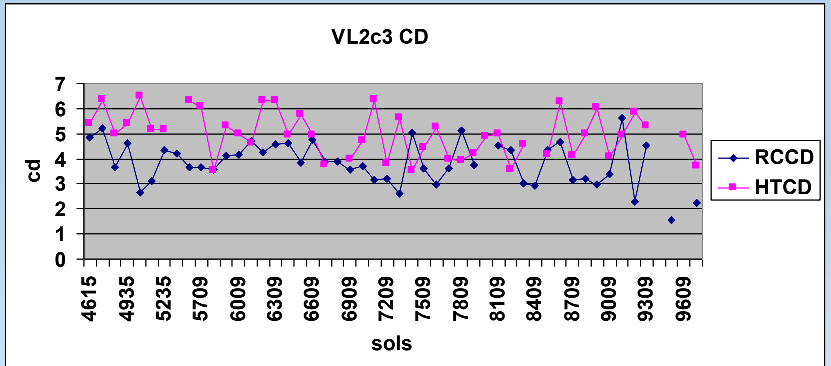
Lyapunov Exponent

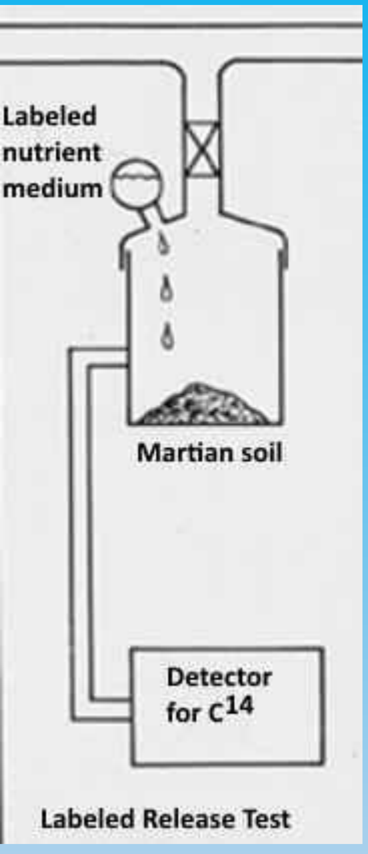


This measure quantifies the degree of sensitivity of a system from the dependence on the initial conditions by measuring the exponential separation of two neighboring trajectories. In regular systems this distance remains constant or decreases (negative λ or zero) while in chaotic systems it diverges exponentially (positive λ).

Since the Lyapunov exponent can also be seen as the divergence tendency of the attractor's orbits, in chaotic systems its value represents the degree of chaoticness of the system.

Lyapunov <0 = ordered and predictable data
Lyapunov> 0 = chaotic system
Lyapunov >> 0 = unstructured data





Entropy (Kolmogorov):

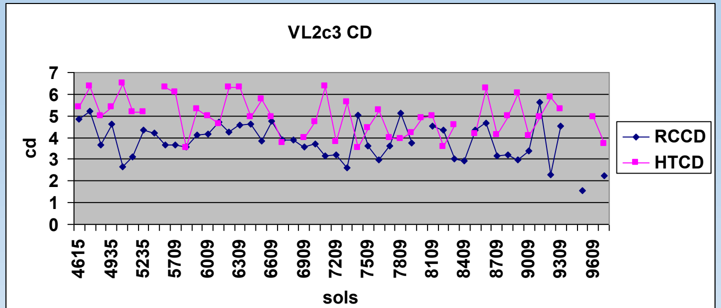
Measure of the disorder of the data,
the greater the more disorder there is.
Sine function, entropy = 0)

BDS (Brock-Dechert-Scheinkman statistic)

Dependence in a time series of the data in succession.
White noise, BDS = - 16.8
Pink noise = - 0.6
heartbeat = - 3.3 - +1.6
sine + noise = + 2.5

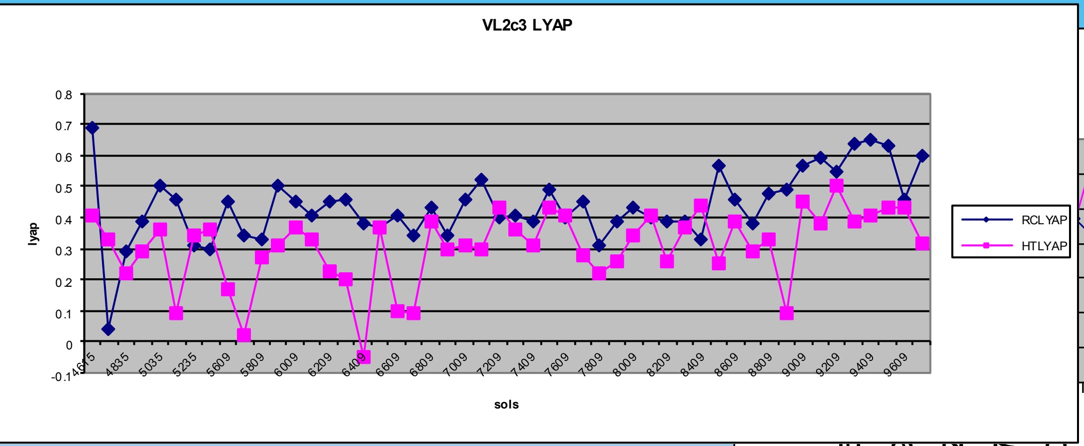
Time correlation, τ:

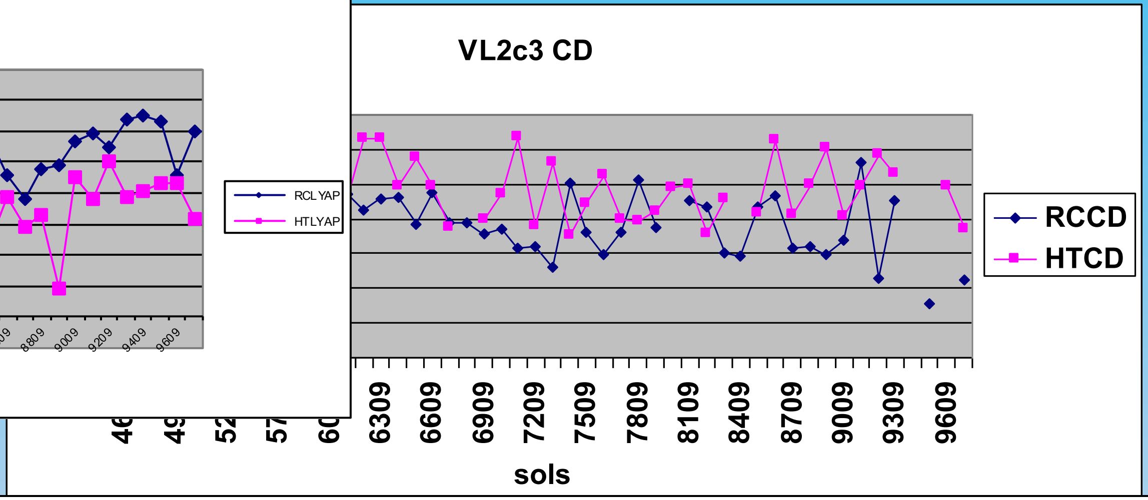
Measurement of the dependence of the data on its neighbors
White noise = 0.64
Pink noise = 21.2
heartbeat = 2.7 - 11.4
sine + noise = 11.9

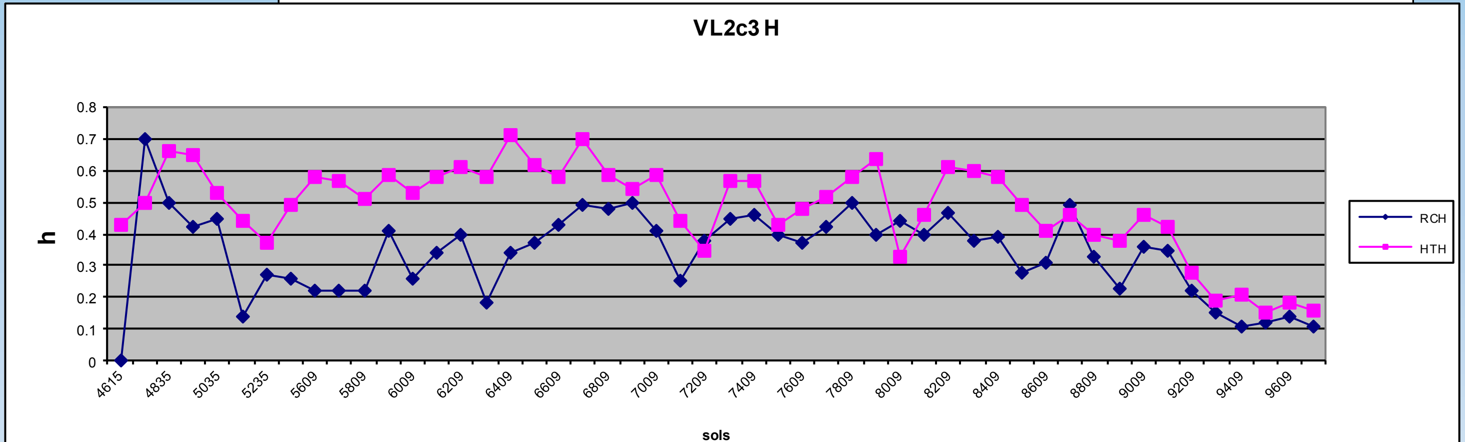


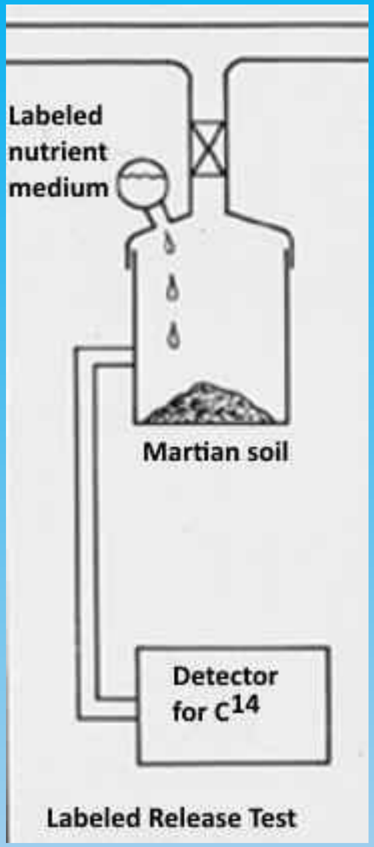
Reanalysis of Viking LR experiment by chaotic analysis

with Miller & Levin: #9 experiments on Mars, 16 000 test points, 2004-2011 years
(sterilized, starved, protected.. martian samples), 7 nonlinear indexes









16,000 Labeled Release data, all sols (+ Bacteria & Rats, Sterilization & Martian LR Active Tests, after Sterilizations, Temperature fluctuations, radioactivity inside the Martian probe), performing chaotic analysis

Technical Paper
Int'l J. of Aeronautical & Space Sci. 13(1), 14–26 (2012)
DOI:10.5139/IJASS.2012.13.1.14
IJASS International Journal of Aeronautical and Space Sciences

Complexity Analysis of the Viking Labeled Release Experiments

Giorgio Bianciardi*
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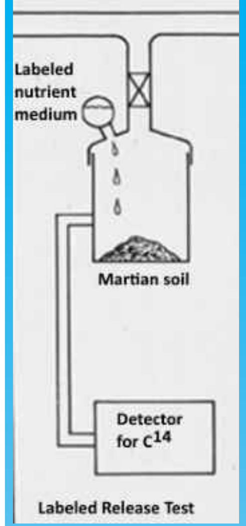
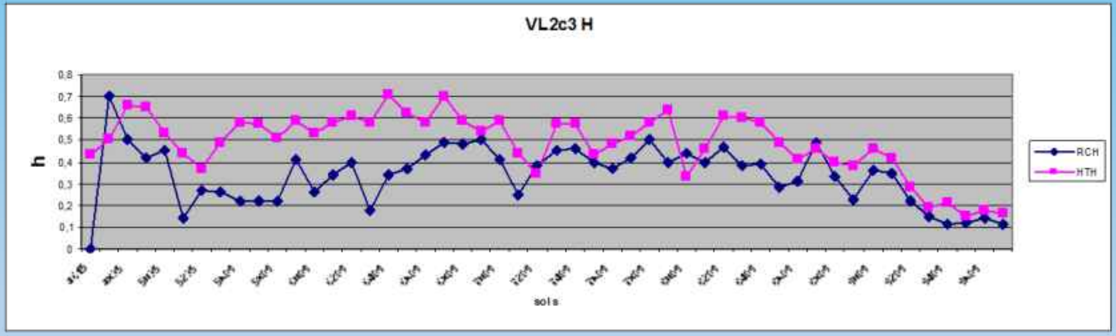
The only extraterrestrial life detection experiments ever conducted were the three which were components of the 1976 Viking Mission to Mars. Of these, only the Labeled Release experiment obtained a clearly positive response. In this experiment ^{14}C radiolabeled nutrient was added to the Mars soil samples. Active soils exhibited rapid, substantial gas release. The gas was probably CO_2 and, possibly, other radiocarbon-containing gases. We have applied complexity analysis to the Viking LR data.





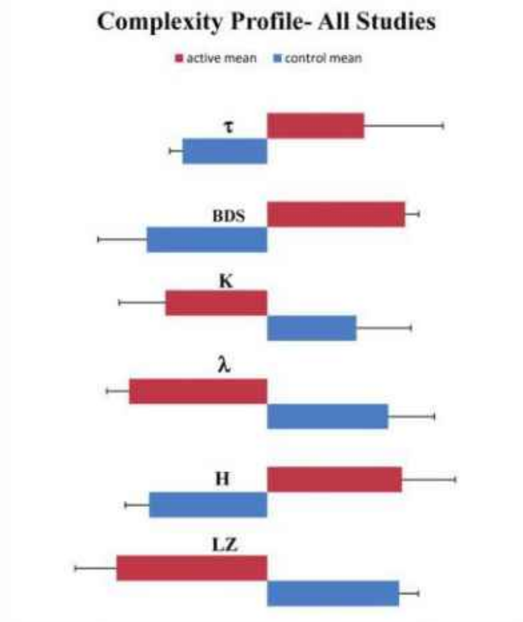


Table 1. K-means Cluster Analysis of Averages across Sols of All Detrended Data Sets Summary Statistics for All Cases

Variable	Between SS	df	Within SS	df	F-ratio	p<
LZ	10.689	1	3.311	13	41.975	.001
H	8.534	1	5.466	13	20.299	.001
λ	8.988	1	5.012	13	23.312	.001
K	4.889	1	9.111	13	6.976	.05
BDS	8.908	1	5.092	13	22.745	.001
τ	4.427	1	9.573	13	6.011	.05
** TOTAL **	46.436	6	37.564	78		

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

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	Standard Error
VL2C4	0.464	LZ	0.294	0.790	1.379	0.115
VI1C2	0.593	H	-0.984	-0.706	0.111	0.144
VL1C4	0.479	λ	0.000	0.724	2.404	0.276
VL2C5	0.966	K	-1.434	0.534	1.449	0.325
BIOL 6	0.311	BDS	-2.010	-0.721	0.190	0.293
DT VL2C3	0.790	τ	-0.645	-0.508	-0.156	0.076
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	Standard Error
BIOL5	0.534	LZ	-2.136	-0.902	-0.080	0.248
VL1C1	0.285	H	-0.218	0.806	2.190	0.320
VL1C3	0.409	λ	-1.202	-0.828	-0.219	0.133
VL2C1	0.544	K	-1.656	-0.610	0.673	0.277
VL2C3	0.622	BDS	0.664	0.824	1.291	0.084
VL2C2	0.587	τ	-0.174	0.581	3.304	0.470
Rat temp	1.354					

LR data on Mars overlaps perfectly with biological data tested on Earth and is clearly separated from all abiological data (p <0.001) after chaotic analysis

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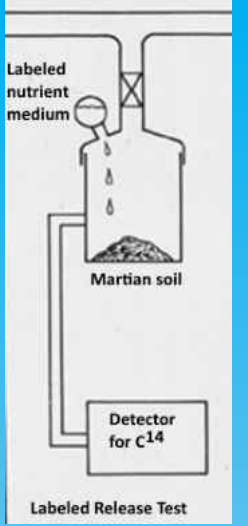

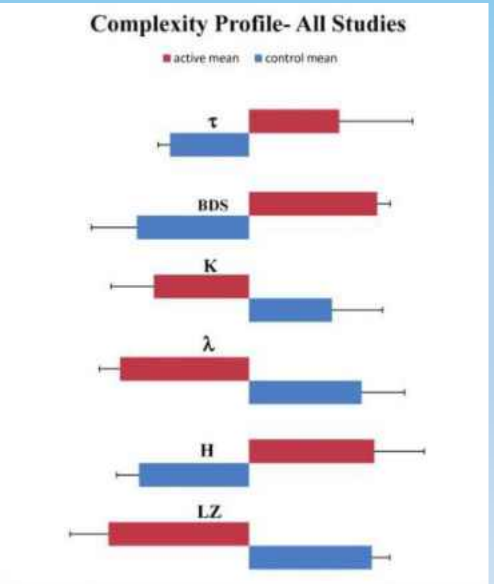

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Focusing on FIRST 6 DAYS (SOLS) ON MARS
Complexity analysis of Labeled Release data

EPSC Abstracts
Vol. 7 EPSC2012-501 2012
European Planetary Science Congress 2012

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When the Viking Missions Discovered Life on the Red Planet

G. Bianciardi (1), J.D. Miller (2) , P.A. Straat (3) , G.V. Levin (4)
(1) Dipartimento di Patologia Umana e Oncologia, University of Siena, Italy, Via delle Scotte 6, 53100 Siena, Italy (gbianciardi@unisi.it)
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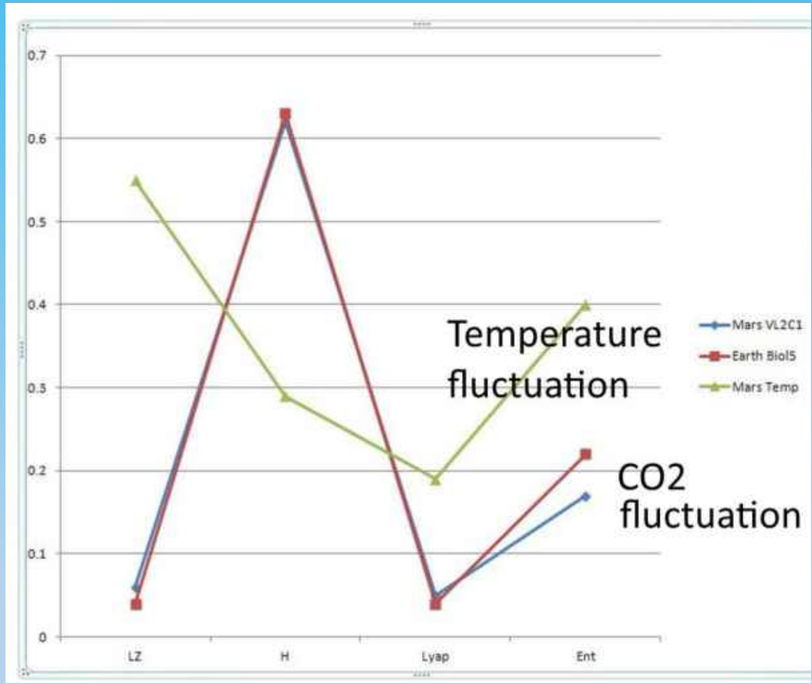
Abstract

The first (and only) dedicated life detection experiments on another planet were performed by the Viking Landers of 1976. In the Viking Labeled Release (LR) experiment of Levin and Straat, injections of organic compounds into Martian soil samples caused radioactive gas to evolve

For almost 36 years a controversy has raged over whether or not the Viking LR experiment detected Although the results of the LR experiment met the pre-launch criteria for detection of life, the dominant explanation of the results was that a superoxide in the soil was responsible for oxidizing the organic molecules in the LR nutrient. None of the strong oxidants proposed over the years exhibits the thermal

LR, active
Earth (biology) vs. Mars



4 LR experiments performed by the Vikings on Mars adding a solution of formate, glycine, glicolate, D- L- Lactate, D- L- Alanine labeled with 14C.and **1 LR experiment performed on Earth, terrestrial soil with a known microbial population,** using the same LR nutrient. The amount of radiolabeled gas released during the first 6 sols (Mars) or 6 days (Earth), read every 16 minutes, was analyzed by **Chaos Data Analyzer Pro**, (Sprott & Rowlands, American Istitute of Physics) to determine : **L-Z , Hurst, Lyapunov, Entropy, BDS, indices**.

Complexity analysis of Labeled Release data, focusing on FIRST 6 DAYS (SOLS) ON MARS

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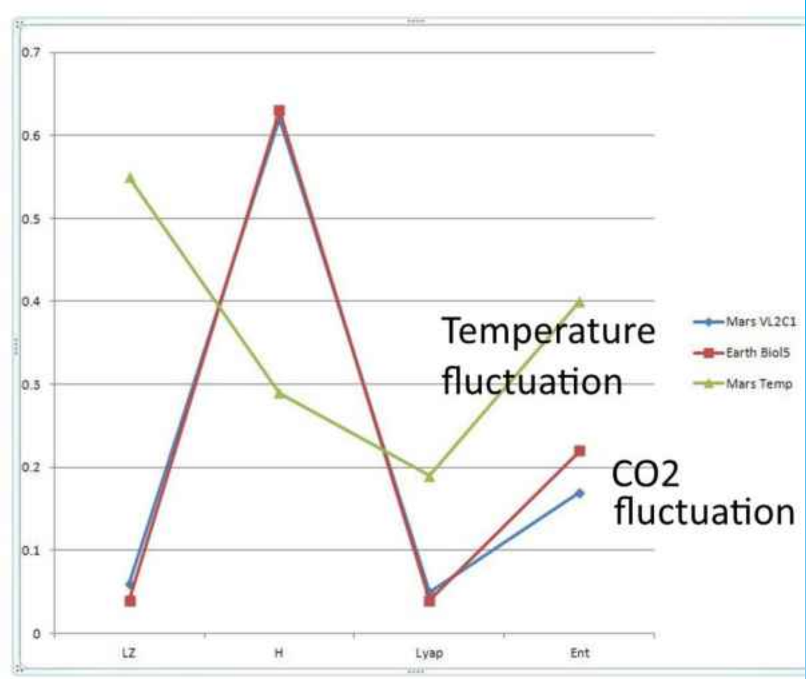
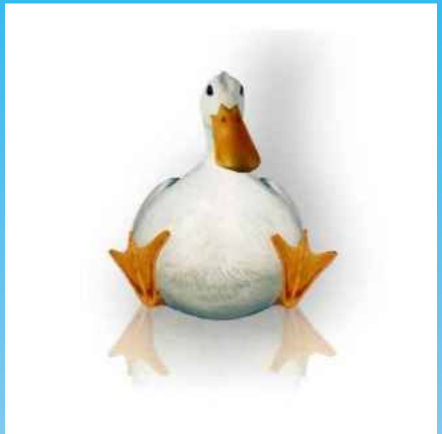


The rhythms observed by Miller in 2001 they were not due to the variation of temperature (we have found the smoking gun!)

A terrestrial biological sample (bacteria) in the LR has a behavior of the chaotic indices perfectly superimposable to what was observed on Mars during the first 6 days (sol) on Mars.

Pluralitas non est ponenda sine necissitate *(William of Ockham)*

Ducks and bacteria:



If it looks like a duck, cackles like a duck and walks like a duck> then IT'S a duck!