Spectroscopy markers of habitability variables on Earth, Mars, Venus and planetary atmospheres

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1. Introduction

Even before any exoplanet had been detected, the problem of bio-signatures was addressed by visionary scientists. Here what is called a bio-signature is a spectroscopic feature that could be related to the presence of life in the spectrum of an observed exo-planet. In 1991, the first Earth fly-by of Galileo spacecraft was an opportunity to examine the planet Earth from outside, and a number of measurements were conducted (figure 1). They were interpreted in Sagan et al., (1993). We quote: "…the Galileo spacecraft found abundant gaseous O_2, a widely distributed surface pigment with a sharp absorption edge in the red [chlorophyll], and atmospheric methane in extreme thermodynamic disequilibrium; together, they are strongly suggestive of life on Earth."

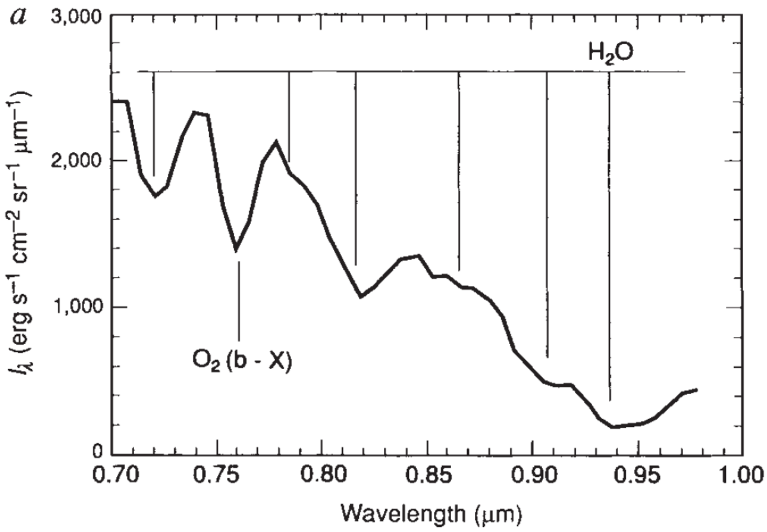

Figure 1. Spectrum of Earth reflected solar radiation collected by Galileo during its Earth fly-by over ocean. Within this small spectrum range, H_2O has several bands, and O_2 shows the conspicuous A band (also noted (b-X). From Sagan et al., 1993 [4].

Today, with a new knowledge of Earth, Venus, and Mars atmospheres and outgoing spectra, we will examine the spectra of these three terrestrial planets to understand what they can tell us about their potential habitability, and the possible presence of life on these planets.

2. The case of water, gas, liquid or solid.

Liquid water is a pre-requisite for life as we know it. This is because it is a fantastic solvent in which many chemical reactions may take place easily. Given the phase diagram of water, liquid water requires that the surface temperature T_s must be >273 K. Then, the relative humidity must be measured, by comparing the observed column of H_2O (vapour) to the one of saturation at temperature T_s. A relative humidity of 20% or less is considered as very dry on Earth. Liquid water has no specific spectral signature (except its very low albedo), while water ice may be recognized from its reflectance spectrum.

3. The case of other gases.

Molecular oxygen O_2 is produced by photosynthesis on Earth and was suggested by Owen [2] as a main life indicator target to be searched for. The main O2 absorptions are at 0.76 µm and 1.27 µm. A by-product of O_2 is O_3, which UV absorption protects life on ground from DNA damaging solar UV. Ozone was abundant enough only 500 million years ago, and before life was only in water. It means that the fact that there is life on Earth is known in the whole Galaxy, and many other galaxies too. The case of other gases like Methane, N_2O, and chloromethane (CH_3Cl) potentially biogenic, and other freons, potentially produced by high technology, will be discussed also.

4. Mars.

The day side spectum of Mars is a combination of atmospheric absorption features and surface reflectances (H_2O ice, CO_2 ice, hydrated minerals…) which can be disentangled with sufficient spectral resolution. The thermal IR spectrum of Mars reveals a mean surface temperature well below 0°C (-63° C). Therefore, there is no liquid water, a very dry atmosphere, no measurable O_2, and the ozone columns, though detectable (in the UV), is not enough to protect life on the ground. The CH_4 observations are sporadic and reveals very small quantities. Mars would fail our criteria for habitablity.

5. Venus

The day side spectrum of Venus is fully dominated by the solar spectrum scattered by cloud droplets, a moderate temperature (below 0° C), with a small column of CO_2 and very small H_2O. It could be interpreted as a solid surface and a cool and dry atmosphere. Ozone is present but in a very small amount, insufficient to protect life as we know it. If it is possible to observe the night side emission (difficult), then the observed spectrum (figure 2) reveals an extremely hot surface, an enormous quantity of atmospheric CO_2 (which greenhouse effect may be calculated for consistency), and only a small amount of water vapour. With the absence of liquid water, Venus fails the criteria for habitability as we know it.

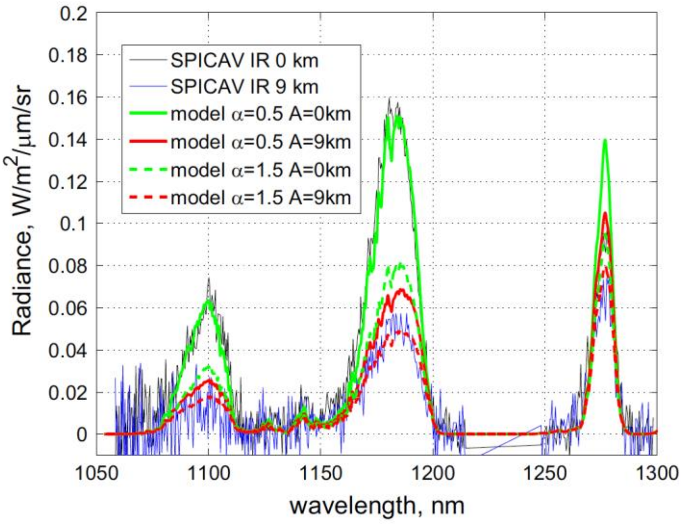

Figure 2: Spectrum of the night side emission recorded by SPICAM-IR instrument on board Venus-Express, in three spectral windows (not fully absorbed by CO_2 or H_2O), compared to various models. The black and blue curves are the measurements obtained respectively over a terrain at 0 and 9 km altitude (from Fedorova et al., 2015).

6. Changes with time: a sign of extra-terrestrial stupidity and poor overall political management

When monitoring Earth from outside, an extra-terrestrial astronomer would notice a very rapid increase of the quantity of CO_2 in the atmosphere: + 50% in 80 years, correlated with a decrease of O_2, one major constituent. With a little thinking (facilitated perhaps by the presence of radio-electric "noisy" signals), he could conclude that there is a massive burning of fossils hydrocarbons, uncontrolled. He would interpret this CO_2 rapid change as a sign of stupidity and poor overall political management by the inhabitants of this planet (Bertaux, 2017).

References

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Short Summary

We review a number of bio-signatures which have been proposed in the past, like molecular oxygen, methane, water vapour, temperature, chlorophyll, N2O and Chloromethane. We examine he case of Earth, Mars and Venus. Only the Earth is showing positive signs of life, but CO2 changes indicates poor managment from inhabitants.