A TEST FOR THE DETECTABILITY OF VEGETATION ON EXTRASOLAR PLANETS: OBSERVING THE TERRESTRIAL VEGETATION IN THE EARTHSHINE SPECTRUM

D. Briot [(1)], J. Schneider [(2)], P. François [(1)], L. Arnold [(3)]

[(1)] GEPI, Observatoire de Paris-Meudon, 61 avenue de l'Observatoire,F75014 Paris (France), danielle.briot@obspm.fr, patrick.francois@obspm.fr

[(2)] LUTH, Observatoire de Paris-Meudon, 5 Place Jules Janssen,F92195 Meudon Cedex (France), jean.schneider@obspm.fr

[(3)] Observatoire de Haute-Provence, F04870 Saint Michel l'Observatoire (France), arnold@obs-hp.fr

ABSTRACT

The search for life on extrasolar planets can be made either indirectly by the detection of by-products of biological activity, such as oxygen and methane, or directly by "vegetation-like" spectral features. They should both be associated with detection of water, assumed to be a prerequisit for the development of life. After a review of the compared advantages and disadvantages of both approaches (artefacts, universality, etc), we focus on a test of the detectability of vegetation on Earth seen as a single dot: the detection of vegetation in the spectrum of the global Earth on the lunar surface, or Earthshine. We review the first results obtained by different groups, new ongoing observations and future plans.

1. INTRODUCTION AND MOTIVATIONS

The search for Life on extrasolar planets can be done by using two kinds of "biosignatures" (e.g. [1]). The first type of signature consists of detection of biological activity mineral by-products such as oxygen and methane [2]. This approach raises some problems detailed in [3], such as a possible confusion with abiotic production of oxygen and a lack of universality, as shown by the existence of anoxygenic photosynthetic bacteria [4]. The second kind of biosignature is the direct detection of the living system themselves such as an extrasolar "vegetation" [3]. For instance, on Earth, the vegetation has a common spectral feature: a shoulder at ~ 725 nm as it can be seen in [5]. Whereas the presence of oxygen is easily detected in the Earth's spectrum, it is necessary to check that the vegetation would be detectable in the spectrum of an extrasolar Earth-like planet. Vegetation could also be searched for by the circularly polarized reflectance properties of leaves [6].

2. HOW TO DETECT VEGETATION ON THE EARTH SEEN AS A SINGLE DOT ?

The detection of vegetation on Earth is already made with satellites in low orbit [7]. They always resolve the Earth spatially, whereas an extrasolar planet will be seen as a single dot.

To test this approach, a prerequisit is to determine if the vegetation spectral features would appear in the spectrum of the Earth seen as a single dot. This question can be solved by two possible approaches. One possibility is the use of the Earth's observation satellite data to build synthetic Earth's spectra. However in this case, observational data are far from those obtained from Earth seen as a whole: the vegetation is generally detected vertically so that obliquity and limb effects would be missing. In addition, the data of many satellites are very difficult to calibrate to achieve a homogeneous flux calibration and the cloud coverage is difficult to take into account. Another possibility is to observe the Earth from a spacecraft sufficiently remote to see it as a single dot. However, no existing remote Solar System space mission (such as Voyager or Cassini-Huygens) has the capability (pointing and/or instrumentation) to take a global spectrum of the Earth with a spectral resolution > ~50 in the 500 - 800 nm spectral region.

3. A NEW SUGGESTION: EARTHSHINE SPECTRUM - PRINCIPLES

The earthshine, or ashen light, is the glow of the dark part of the lunar disk visible to a nighttime observer. It is sunlight reflected from the Earth and retroreflected by the lunar surface. Thanks to the quasi-isotropic diffusion of light rays when reflected on the Moon's surface, the light rays coming from different parts of the Earth are mixed together in the ashen light and mimic the Earth as a single dot. So the earthshine spectrum is the spectrum of sunshine, multiplied by the Earth surface albedo, multiplied by the moon albedo and transmitted 3 times through the Earth atmosphere, whereas the moonlight spectrum is the spectrum of sunshine, multiplied by the moon albedo and transmitted once through the Earth atmosphere.

4. EARTHSHINE SPECTRUM : FIRST RESULTS

Observations have been made simultaneously by two teams, one in France [8] using a 80 cm telescope, and the other in the USA [9] using a 2.3 m telescope. In both cases, the blue color of the Earth due to Rayleigh scattering in the atmosphere, as known for a long time [10], is visible. Signatures of ozone, molecular oxygen, and water vapour are visible as well. A rise in albedo at around 730 nm is also detected in data of [8] and is interpreted as due to the signature of the terrestrial vegetation chrorophyll: the "red edge", expected to be between 2 and 10 % of the Earth albedo. This feature is more important in the case of a larger observed continents to oceans ratio. This result is very encouraging for the detection of vegetation-like biosignatures on extrasolar planets.
As a by-product, the Rayleigh diffusion (and planet color in general) can be a clue for the planet's mass. Using the relationship between a planet atmospheric density and its color given by Rayleigh diffusion and atmospheric absorption, the planet mass can be estimated within a factor 2 [11].

5. EARTHSHINE SPECTRUM : CURRENT STATUS AND PROJECTS

Several observational campaigns are in progress or planned of which we mention some ones. Observations are currently carried on by a French team using the 3.5 NTT telescope (European Southern Observatory) to obtain more accurate determinations, on the one hand during "morning moons" (last day of the lunar cycle) and during "evening moons" (first days of the lunar cycle) to compare spectra obtained when the Moon faces oceans and faces land, and on the other hand all the year long to detect seasonal variations. An other project is to use the "dome C" site (75° S, 123° E) in Antarctica to monitor the Earthshine continuously along a full Earth rotation, to study more carefully the ocean/land contrast.

6. CONCLUSIONS

The detectability of an amount of vegetation similar to Earth on an extrasolar planet has been demonstrated. The next step will be to extend these observations to a systematic monitoring program. From so planned observations, it will be possible to detect seasonal variations, long term climatic variations, evolution of ozone, changes in vegetation. The part of the Earth facing to the Moon being coordinated with the location of the observing telescope, a network of telescopes has to be used. As observations of earthshine are made near twilight (morning and evening), that is to say outside the time of standard astronomical observations, we suggest to make them systematically at any observatory. This would increase for a very small additional effort, the scientific return of existing observatories.

7. REFERENCES

1. DesMarais D., et al., Remote Sensing of Planetary Properties and Biosignatures. *Astrobiology*, Vol. 2, 153-181, 2002.

2. Owen T., The search for early forms of life in other planetary systems: future possibilities afforded by spectroscopic techniques, *Strategies for the search for life in the Universe*, M. Papagiannis Ed., Reidel, p. 177, 1980.

3. Labeyrie A., et al., Visible and infrared imaging with Darwin: feasibility of a visible precursor, *Darwin and Astronomy*, Fridlund and Liseau Eds. ESA SP-451, p.21-26, 1999.

4. Blankenship R., Madigan T. & Bauer C., *Anoxygenic Photosynthetic Bacteria*, Kluwer, 1995.

5. Clark R., Spectroscopy of Rocks and Minerals, and Principles of Spectroscopy, John Wiley and Sons, 1999.

6. Wolstencroft R. D. & Tranter G., Circularly polarized reflectance properties of leaves and possible application to remote sensing, *Internat. J. of Astrobiology*, Vol. 1, 168, 2002

7. Sagan C., et al., A search for life on Earth from the Galileo spacecraft, *Nature*, Vol. 365, 715-721, 1993.

8. Arnold L., et al., A test for the search of extrasolar planets: Looking for the terrestrial vegetation signature in the Earthshine spectrum. *Astron. & Astrophys*., Vol. 392, 231-237, 2002.

9. Woolf N., et al., The Spectrum of Earthshine: A Pale Blue Dot Observed from the Ground. *ApJ*, Vol. 574, 430-433, 2002.

10. Tikhoff G.A., Etude de la lumière cendrée de la Lune au moyen des filtres sélecteurs, *Mitteilungen der Nikolai-Hauptsternwarte zu Pulkovo*, N° 62, Band VI,2, 15-25, 1914.

11. Brown R., et al., The 4-Meter Space Telescope for Investigating Extrasolar Earth-like Planets, *Nature*, submitted, 2002.