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A Test for the Detection of Vegetation on Extrasolar Planets : Detection of Vegetation in Earthshine Spectrum and its Diurnal Variation

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Abstract. The search for life in extraterrestrial planets is to be tested first with the only planet known to shelter life. If the planet Earth is used as an example to search for a signature of life, the vegetation is one of its possible detectable signature, using the Vegetation Red Edge due to chlorophyll in the near infrared (0.725 μm). We focus on the test of the detectability of vegetation in the spectrum of Earth seen as a simple dot, using the reflection of the global Earth on the lunar surface i.e. Earthshine. On the Antartic, the Earthshine can be seen during several hours in a day (not possible at our latitudes) and so variations due to different parts of Earth, that is to say oceans and continents facing the Moon could be detected.

Keywords. Earth, Moon, Astrobiology, Techniques : spectroscopy, Vegetation red edge, Biomarker, Earthshine, Exolife

1. Introduction

It could be hoped that in few years (>2015) we will search for detection of life in terrestrial extrasolar planets. Life on extrasolar planets will probably present unusual and unknown forms. However, as we know nothing about these forms of life, we look for indices of presence of life similar to the one we know on Earth. Firstly, we explore classical biosignatures like H_2O, CO_2, O_3 and O_2 but it is also interesting in visible wavelengths to search how vegetation can be distinguished on a planet seen from space.

2. Detection of vegetation

Vegetation spectrum presents an increase at 0.5 μm in the green range, which implies that plants are seen as green, but mostly a very sharp rise at 0.725 μm, known as the "Vegetation Red Edge" (VRE) (Arnold et al. 2002). That is the signature of photosynthetic plants. If our eyes would be sensitive in the near infrared, plants would be seen as red. The Vegetation Red Edge can be much more easely detected than the bump at 0.5 μm, and this signature corresponds hardly to other element than chlorophyll. The search for vegetation in extraterrestrial planets is to be tested first with the only planet known to shelter life. Vegetation can be detected on the planet Earth from a spacecraft as made by Sagan et al. (1993) using the Galileo spacecraft, but in this case, vegetation is detected vertically and obliquity and limb effects are not considered. Moreover, satellite data are complicated to be calibrated and the cloud cover can hardly be taken into account. Earth has to be observed as a whole as it would be done for an extrasolar planet, that is to say Earth seen as a dot. Theoretically a distant satellite could make this kind of observation but actually, no distant satellite have abilities to take a spectrum of the whole Earth.

3. Earthshine

Another possibility is to use the Moon as a giant reflector and to observe ashen light or Earthshine. Earthshine can be seen on the dark part of the Moon during the first or the last days of

the lunar cycle. This corresponds to a Earth light on the Moon. The light of the Sun arrives on Earth, is reflected by Earth, arrives on the Moon, is reflected by the Moon and comes back on Earth. The light coming from the different parts on Earth is blended, as in the case of an extra-solar planet seen as a whole. Then :
$[EarthshineSpectrum] = [SolarSpectrum] \times [EarthAlbedo] \times [MoonAlbedo]$
and transmitted 3 times through Earth atmosphere
$[Moonlightspectrum] = [SolarSpectrum] \times [MoonAlbedo]$
and transmitted once through Earth atmosphere
Arcichovsky suggested as soon as 1912 to look for chlorophyll absorption in the Earthshine spectrum, with the aim to calibrate chlorophyll in the spectrum of other planets (Arcichovsky 1912), but at these times, Earthshine observations did not have sufficient spectral resolution for that purpose (Tikhoff 1914; Danjon 1928). And this idea was quite forgotten up to 1999. Earthshine shows Rayleigh scattering in the Earth atmosphere and allowed, since the beginning of the twentieth century (Tikhoff 1914) to predict that Earth from space would be seen as blue. The red side of the Earth reflectance spectra shows the presence of O_2 and H_2O absorption bands, while the blue side clearly shows the Huggins and Chappuis ozone (O_3) absorption bands.

4. Results obtained

The first detections of vegetation from the Earthshine spectrum were obtained by Arnold et al. (2002) at the Haute-Provence Observatory, and Woolf et al. (2002) at the Tucson observatory. New observations made at the NTT of ESO (Hamdani et al. 2006) obtain a Vegetation Red Edge lower than previous estimations and previous studies which were near 8-10% when Africa and Europe light the Moon (Arnold et al. 2002). The present results are from 3 to 4% when Africa faces the Moon and 1.3% when the Pacific faces the Moon. So even with these lower values, VRE over Pacific Ocean versus Africa remains different thus allowing the detection of Vegetation on Earth. These observations show also significant variations in Rayleigh scattering depending of the cloud cover, implying that Earth "pale blue dot" can be almost white.

5. Interest of observations from Antarctic, Dome C

Observations of Earthshine can be done during the first days or during the last days of the lunar cycle. From intermediate Earth's latitudes, observations of the waxing Moon are possible in the evening and observations of the waning Moon in the morning. In both cases, observations are twilight observations which cannot be carried on during a long time. The part of Earth facing the Moon depends on the localisation of the telescope and of the lighted part of the Earth, that is to say to the West of the telescope in the evening and to the East in the morning. Only in high latitudes it is possible to observe the Moon in the first or the last days of the cycle during several hours, and even sometimes during all the day long. This opportunity happens at the Concordia station in Dome C (75°06′S and 123°21′E) approximatively six times in a year. So, during one observing time, continents and oceans successively face the Moon and the variations of the Vegetation Red Edge according the successive "landscapes" of the planet Earth could be detected. A rather small telescope and low resolution spectra can be used to detect VRE in Earthshine spectra. After some unsuccessfull attempts due to bad weather conditions during the 2005 Winter Campaign, preliminary observations, since March 2006, are presentely carried out by one of us (E.A.).

6. Conclusion

Antarctic offers a unique opportunity to observe reflectance of terrestrial vegetation on Earthshine during several hours whereas various "landscapes" face the Moon, so preparing future detections of vegetation on extra-terrestrial planets.

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