LUCAS EXPERIMENT: SEARCHING FOR VEGETATION AND OTHER BIOSIGNATURES ON PLANET EARTH

Danielle Briot
Observatoire de Paris-Meudon, France
danielle.briot@obspm.fr
Luc Arnold
Observatoire de Haute-Provence, France
Stéphane Jacquemoud
University Paris Diderot & Institut de Physique du Globe de Paris, France
Jean Schneider
Observatoire de Paris-Meudon, France
Karim Agabi
Université de Nice, France
Eric Aristidi
Université de Nice, France
Jérome Berthier
Observatoire de Paris-Meudon, France
Erick Bondoux
Concordia Station, Dôme C, Antarctica
Zalpha Challita
Concordia Station, Dôme C, Antarctica
Patrick Rocher
Observatoire de Paris-Meudon, France

ABSTRACT

In order to prepare the future search for biosignatures on exo-Earths or exo-SuperEarths, we investigate the detection of life on the only planet known to shelter life to date, our Earth. We have to see the Earth as a dot, the way future exoEarths will appear to us. This is the case when we observe the Earthshine, using the Moon as a huge reflector to measure the whole Earth's albedo. Observations of the Earthshine made at the Haute-Provence Observatory and the European Southern Observatory showed biosignatures on Earth, including the Vegetation Red Edge (VRE) in the near infrared, which is due to chlorophyll absorption spectral properties. The VRE is only a few percents, and higher when continents instead of oceans are facing the Moon. At very high latitudes and some times of year, it is possible to observe the Earthshine during most of the day, which is not possible at lower latitudes. Throughout these long observing windows, Earth rotation brings various terrestrial "landscapes" in front of the Moon. So we planned to make observations at the French-Italian scientific Concordia Station located at the Dome C in Antarctica, and for this purpose we set up the LUCAS *(LUmière Cendrée en Antarctique par Spectroscopie)* experiment. A dedicated spectrograph was designed and built at the Haute-Provence and Meudon Observatories. The first observations began during the 2008 winterover campaign and go on.

INTRODUCTION

Today, more than 300 extrasolar planets have been discovered. No telluric planet located in the Habitable Zone has been detected so far, as well as no image of an terrestrial extrasolar planet has been obtained. However, it may be presumed that future high-contrast imaging space missions will acquire images of terrestrial extrasolar planets within one or two decades. These instruments will hopefully provide us with unresolved images of extra-solar planets in the habitability zone, as well as their spectra to give us first insights into planet chemistry. We have to prepare now the analysis of the results to come from future space missions. Life on an extrasolar planet may be completely different from life on Earth. Knowing nothing about life forms in the Universe, we try to detect them using the the only known planet sheltering life as a model, i.e. the Earth. So a way to answer this question is to consider how the spectrum of our Earth would look like when observed from a very large distance, typically several parsecs. This could be done from a space probe traveling through the Solar System and looking back at the Earth as Voyager 1 did in 1990, or Mars Express in 2003. Unfortunately, no spectrum in the interesting wavelengths for life detection was available. An alternative method to obtain the Earth-averaged spectrum, following an idea of Jean Schneider (1998), consists in taking a spectrum of the Moon Earthshine, i.e. the Earth light backscattered by the nonsunlight Moon. During the period close to the New Moon, the Sun light arriving upon the Earth, is reflected in the direction of the Moon where it is reflected again, and finally comes back to the Earth, where it is observed. During this path, light crossed three times the Earth atmosphere. We have to point out that the "phases of the Earth" as seen from the Moon are inverse of the phases of the Moon seen from the Earth. So an enlighted Earth faces the Moon when the Moon phase is near the New Moon. Because of the lunar surface roughness, any place of the Earthshine reflects all of the enlighted part of the Earth facing the Moon. So a spectrum of the Moon Earthshine directly gives the disk-averaged spectrum of the Earth.

SOME HISTORIC POINTS

Various interpretations of the Ashen Light of the Moon have been given for centuries. Greek philosophers already speculated on the origin of the faint light seen in the dark part of the Moon, but it seems that Leonardo Da Vinci was the first to understand the cause of Earthshine [1]. However, the first published explanation was given by Galileo in the « Sidereus Nuncius » about a century later [2]. The potential of the Moon's Earthshine for providing global data on the Earth was identified during the XIX^{e} century (see [3] for example) and may be earlier. In 1912, Arcichovsky [4] suggested to look for chlorophyll absorption features in the Earthshine spectrum to calibrate this pigment in the spectrum of other planets, but the spectral resolution of spectrometers at that time was not good enough to achieve it. This approach was completely forgotten till 1998.

DETECTION OF EARTH LIFE

The search for life in extrasolar planets can be done using two types of biosignatures. The first type consists of biological activity by-products, i.e. atmospheric molecules such as oxygen, ozone, in association with water vapour, methane and carbon dioxide. A second type of biosignature is provided by indications that stellar light is transformed into biochemical energy, i.e.

photosynthetic pigments contained in plant leaves and that are the cause of vegetation color. The reflectance spectrum of vegetation is typically much higher in the near infrared than in the visible by a factor of approximately 5. This produces a sharp edge around 700 nm, the so-called: Vegetation Red Edge (VRE) [5]. For example, in a landscape photography taken at 1.1μm, vegetation appears very bright and water very dark.

RESULTS ALREADY OBTAINED

Several visible and near infrared Earthshine spectra have been published to date, e.g., [6] to [11]. The latter found a VRE of about 4.0 % when forests are present (Africa and Europe) and a smaller one, 1.3% when clouds and oceans are mainly visible (Pacific Ocean). In addition to the Vegetation Red Edge, the red side (600-1000 nm) of the Earth reflectance spectrum shows the presence of O_2 and H_2O absorption bands, while the blue side (320-620 nm) clearly shows the Huggins and Chappuis ozone (O_3) absorption bands [11].

INTEREST OF HIGH LATITUDE OBSERVATIONS

At mean or low latitudes, it is well known that Earthshine observations are possible during twilight, i.e. just after sunset or just before sunrise. So observations last a short time, and roughly speaking, for one telescope, only two enlighted parts of the Earth face the Moon: either the part located at the West of the observing telescope for evening observations (beginning of the lunar cycle), or the part of the Earth located at the East of the observing telescope for morning observations (last days of the lunar cycle). However, there are other possibilities. If observations are made from a site located in high latitudes, conditions of Earthshine observations are different. From six to eight times in a year, around equinoxes, Earthshine can be observed during several hours, and even, in very high latitudes, during a full Earth rotation (total nycthemere). During these long observing windows, different « landscapes » alternately face the Moon, while the Earth rotates. In consequence, the Earthshine corresponding to various parts of our Earth could be studied: continents with vegetation or oceans. The scientific Concordia Station in Antarctica actually offers us a unique opportunity to make such observations.

THE CONCORDIA STATION

The Concordia Station is a French-Italian scientific permanent base located at the Dome C on the Antarctic Plateau and dedicated to polar research programs including astrophysics. Its construction was decided in 1993, and works began in 2002. Whereas many stations were settled along the Antarctic coast, only two were then located in the continent. A strong scientific argument to choose the Dome C was the quality of its atmosphere that is specially stable, pure and dry, i.e. an ideal atmosphere for astronomical observations. The distance is about 1100 km from the Dumont d'Urville French Station (Terre Adélie) and about 1200 km from Terra Nova Bay (Italian station).

Concordia is situated at latitude -75°06' South and at longitude 123°23' East. The altitude is 3220 m, on a plateau. The average air temperature is - 50.8°C and the minimum - 84.4°C. The station is put on a sub-horizontal ice ground with no crevasses. There is no presence of local fauna or flora. The sun completely disappears from the beginning of May and reappears around the 15th of August. The two main permanent building were made during three summer campaigns since 2002 and the first winterover campaign of a French-Italian team took place in 2005. Isolation is complete during nine months, from February to October.

PRELIMINARY ANTARCTIC OBSERVATIONS

Checking the feasibility of Earthshine observations considering the darkness of the sky was the first point. Is the sky dark enough for Earthshine observations? Whereas bad weather conditions during test times prevent us from obtaining results during the first winterover campaign, the second one in 2006 clearly showed that such measurements could be possible from this site. The LUCAS *(LUmière Cendrée en Antarctique par Spectroscopie)* experiment was then imagined in 2006 and installed in 2007. Considering the time it takes to design and build the special special intrumentation, the first observations of the Vegetation Red Edge and biomarkers have been planned during the southern winter of 2008.

LUCAS INSTRUMENTATION AND OBSERVING TIMES

A dedicated instrumentation for Earthshine spectroscopic observations was designed and built at Haute Provence and Paris-Meudon observatories. Due to the extreme weather conditions in Antarctica, it was prepared with very special care: all parts of the instrument (telescope, spectrograph and receptor) are adapted to withstand the very low temperatures that prevail in the Concordia Station, like for space missions. Acquisition and storage of the observational data are provided by a computer located in a « igloo-hut » situated at about twenty meters from the telescope. Several tests carried out at the Haute-Provence observatory validated the instrumentation.

As said above, Earthshine observations are possible during 6 to 8 periods a year, around the equinoxes. Observations around the equinox of March correspond to the last days of the Lunar Cycle, and observations around the equinox of September correspond to the first days of the Lunar cycle.

CONCLUSION

LUCAS is one of the first « pure » astrophysical experiments at the Dome C site, and the first program involving spectroscopic observations. As such, it is also a test for the design of small instruments, the qualifying statement of data collecting and the management of observations in a extremely cold environment. The extreme weather conditions withstood during the first winterover observational campaign mean that Concordia is a very hard observation environment. LUCAS suffered because of them in 2008… An improved instrumentation has been prepared and sent to Concordia for the next winterover campaign.

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Funds have been obtained from the University of Paris Diderot, IPGP (Institut de Physique du Globe de Paris), and CNRS (Centre National de la Recherche Scientifique).