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THE LUCAS EXPERIMENT: SPECTROSCOPY OF EARTHSHINE IN ANTARCTICA FOR DETECTION OF LIFE

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Abstract. So as to prepare future observations of terrestrial extrasolar planets liable to shelter life, we attempt to detect the life on the Earth seen as a dot. We use the Moon Earthshine, in which any place reflects the totality of the enlightened part of Earth facing the Moon. Observing from OHP and from ESO, we detected terrestrial chlorophyll in the near infrared, the so-called Vegetation Red Edge, and this detection is larger when forests are present than when an ocean is mainly visible from the Moon. Only if observations are made from a high latitude location, and at some moments in the year, Earthshine can be observed during a large part of the day. During these long observing windows, different "landscapes" are facing the Moon. So the Earthshine corresponding to various parts of our Earth could be studied. Preliminary testing observations have been made at Concordia since the first winterover campaign and the LUCAS experiment has been set up.

1 Introduction

Today, several hundred of extrasolar planets have been discovered. Among them, at least some ones are Earths or SuperEarths located in the Habitable Zone, *e.g.* Gliese 581 d. 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

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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 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.

2 Some Historic Points

Since Greek philosophers, several interpretations have been suggested about the origin of the faint light seen in the dark part of the Moon: translucent or luminous Moon, Moon enlighted by stars or by Venus. The earliest correct interpretation of the "Ashen Ligth", or "secondary light" is probably the one which can be found in some manuscripts of Leonardo Da Vinci, written between 1506 and 1509, but never published. The first publication that we know today about this subject is some part in the *Sidereus Nuncius* by Galileo 1610. However, it is possible that Sarpi and Maestlin, contemporaries of Galileo, spread the good hypothesis before the publication by Galileo. The potential of the Moons Earthshine for providing global data on the Earth was identified during the XIXe century (Flammarion 1877), and maybe earlier. In 1912, Archikowski 1912 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.

3 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) (Clark 1999). For example, in a landscape photography taken at 1.1 μm, vegetation appears very bright and water very dark.

4 Results Already Obtained

Several visible and near infrared Earthshine spectra have been published to date. Results obtained are reviewed by Arnold (2008). Even the values of VRE are only a few percents, we found larger values when continents are facing the Moon and smaller values in case of an ocean. Our first results were obtained from the Observatoire de Haute-Provence (Arnold *et al.* 2002). More accurate observations were made with the New Technology Telescope of the European Southern Observatory (Hamdani *et al.* 2006). Results are 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.

5 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 at 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). 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. 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 Concordia Station actually offers us a unique opportunity to make such observations.

6 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.

7 LUCAS Instrumentation and Improvements for the 2009 Campaign

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. The position of the slit on the lunar surface was precisely defined: the observing slit is to be positionned first on both the lighted crescent and the sky, and then on both the earthshine and the sky. The places to be observed on the Moon are precisely determined to avoid different physical characters corresponding to different places: on East side, the slit is centered on Mare Spumans, and on West side, on crater Hevelius; both places are located near the lunar Equator.

The feedback we got from the first observing campaign in 2008 was very important to detect, analyze and correct instrumental problems due to extreme temperature and extreme physical conditions. Some important instrumental improvements were carried out for the 2009 winterover campaign.

1) Improvement of heat insulation:

A significant thermal leak was induced by an aluminium beam in the instrument. Therefore a new insulation has been carried out. A heating resistance of 300 W was installed. Moreover the instrument benefits from the ASTEP dome. Internal temperature is +20°C.

2) Problems with the shutter:

During the 2008 campaign, the shutter broke after one month of operation. The heat dissipated to warm it was probably not sufficient. We think that the friction in the shutter (the moving metal blades probably warped by the cold) becomes too high and killed the shutter motor. Actually, problems with shutters happened also in some other instruments. Moving parts are always weak points in an instrument in harsh environment and require special care during the instrument design!

3) The flip-mirror was very unconvenient for the observer and we replaced it by a static beam-splitter. Here again, moving elements are to be restricted as possible.

4) An eyepiece initially installed to verify the pointing reveals also highly unconvenient and almost unsuable. It as been replaced by a videocamera and the observer controls the accuracy of the pointing from the "igloo".

8 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.

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