EPSC Abstracts
Vol. 9, EPSC2014-574, 2014
European Planetary Science Congress 2014

LOUPE: Spectropolarimetry of the Earth from the surface of the Moon

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Abstract

We present our prototype for the LOUPE instrument: A small and robust imaging spectropolarimeter that can observe the Earth from the surface of the moon, with as primary objective to characterize the Earth's linear polarization spectrum throughout the Earth's daily rotation and monthly phase angle changes. The purpose of LOUPE is to provide benchmark data for future polarization observations of possibly habitable exoplanets. Our instrument concept has been proven to work in a laboratory setting, and efforts are being made to design and produce a flight model.

1. Introduction

To date, almost 2000 exoplanets have been discovered, and the rate of discovery is increasing rapidly. Exoplanet characterization however, is not advancing at the same pace. As of 2014, the interpretation of high-quality photometric and spectral observations of even the largest exoplanets is critically confusion-limited. And the currently used methods for exoplanet characterization are not expected to be of any help for the characterization of small, Earth-like exoplanets. With polarimetric capabilities, the next generation of telescopes will be able to lift some of the degeneracies currently encountered in exoplanet characterization. A measurement of the polarization spectrum of starlight that is reflected by a planet imposes stringent constraints on the properties of the atmosphere and/or surface of a planet. Specifically, biologically relevant phenomena such as water droplets and vegetation are known to display distinctive polarization features [3, 2] and are expected to be detectable with future (space) telescopes.

One persistent issue is the lack of understanding of the appearance of habitable planets across interstellar distances. Many searches focus on finding habitable (or otherwise 'Earth-like') exoplanets, but a detailed description of the appearance of Earth and the variations therein from across interstellar distances is missing. Therefore, the Lunar Observatory for Unresolved Polarimetry of Earth, LOUPE, has been proposed [1]. LOUPE aims to characterize the Earth's disk-integrated linear polarization spectrum, at limited spatial and spectral resolution from the surface of the Moon, to capture all variations in the signal due to weather systems, daily rotation, monthly phase angle changes, and seasons.

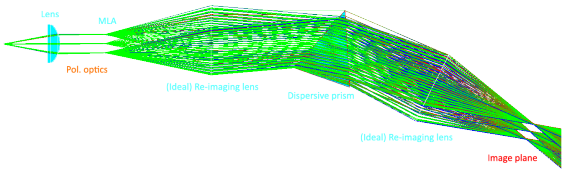

Figure 1: A rudimentary ray-trace of LOUPE. Light enters through a 1 mm pupil on the left, then passes through a lens which images the Earth onto the micro-lens array. The beam is split into 50x50 micro-beams, which are separately dispersed and re-imaged onto the detector, producing a grid of micro-spectra (see Fig. 2).

2. The LOUPE prototype

LOUPE uses the SPEX-principle to encode the degree and direction of linear polarization into the spectral dimension using solely solid-state (i.e. motionless) components, as described by [4]. The light is split into 50x50 beams by a micro-lens array (MLA), which are passed through a dispersive optic and re-imaged onto a 1 MP detector (see Fig. 1 for a rudimentary ray-trace). This allows for the simultaneous measurement of spectral and polarization information, while maintaining limited spatial resolution. The entire field measures 400 square degrees, so that the monthly apparent motion of the Earth due to libration is fully encompassed. In the current set-up, the instrument is sensitive to wavelengths between 550 and 750 nm, and sen-

sitive to polarization fractions of a few percent, at intervals of roughly 20 nm. It has been constructed using only off-the-shelf optics and components, measures about 1 meter in length, and weighs roughly 5 kg. Figures 2 and 3 show polarization measurements of a styrophome test target, representative of a weakly polarizing target such as the Moon itself. The instrument is able to measure the polarization present in the light reflected by this target, thus providing the LOUPE project with a proof of concept.

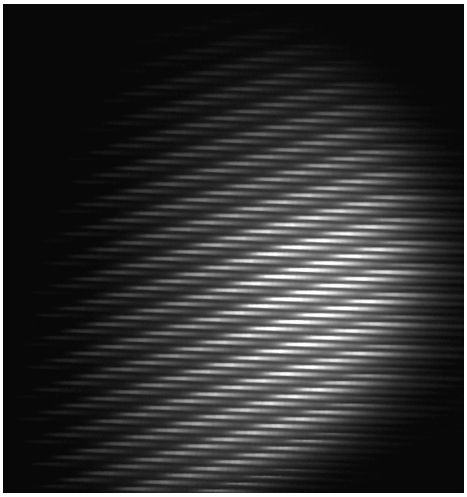

Figure 2: A single-channel observation of a styrophome test sphere, representative of a weakly polarizing target planet. Each smudge is a micro-spectrum belonging to a single field-point generated by the MLA.

3. Summary and Conclusions

LOUPE is a small and robust imaging spectropolarimeter which can measure the Earth's flux and polarization spectrum and provide real-world benchmark data of the only habitable planet known to exist. A prototype of the instrument is now operational, and deployment of the instrument outside the lab environment with the purpose of measuring the polarization spectrum of the Moon itself, is underway. In addition, the design is being re-evaluated with the aim of miniaturizing the instrument to achieve a total mass below about 1 kg, and morphing it into a flight-capable addition to a future lunar landing mission. If successful, LOUPE will be ready to catch a ride to the moon within the timespan of one to two years.

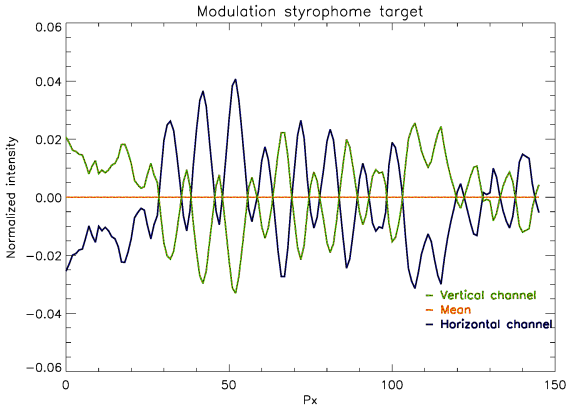

Figure 3: Spectral modulation within both polarization channels of a single micro-spectrum after subtraction of the mean intensity spectrum. The amplitude of the modulation pattern is representative of a few percent of linear polarization of the light scattered by the styrophome target.

Acknowledgements

H. J. Hoeijmakers acknowledges funding through the Leiden/Huygens Fellowship Programme.

References

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