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Searching for signs of habitability with LOUPE, the Lunar Observatory of Unresolved Polarimetry of Earth

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Abstract

We present LOUPE, a novel type of spectropolarimeter to measure the flux and state of polarization of sunlight that is reflected by the Earth from 0.4 to 0.8 μm. LOUPE has been designed as payload of a lunar lander. From the moon, the Earth can be observed as a whole, during its daily rotation and at all phase angles, just as if it were an exoplanet. LOUPE will provide benchmark data for the development of instruments for Earth-like exoplanet characterization, and for the testing of numerical retrieval algorithms.

1. Introduction

As of today, more than 700 exoplanets have been detected. Even though most of these exoplanets are gas giants, the number of smaller mass planets is increasing [9]. A near-future detection of an Earth-sized exoplanet in its star's habitable zone seems unevitable.

To confirm that a planet in a habitable zone is actually habitable, we need information about the properties of its atmosphere and surface. For Earth-sized planets orbiting solar-type stars, the direct detection of starlight that is reflected by the planet or of thermal radiation that is emitted by the planet, appears to be the best tool to get such information. Since the starlight that is reflected by a planet is usually polarized, the characterization of planets can be done with polarimetry. Additionally, as known from Solar System planets [1, 4], polarimetry could provide unique information on the composition, sizes and shapes of aerosol and cloud particles, that cannot be obtained from flux measurements alone [1, 7, 2, 3]. It could also help detecting the glint of starlight reflected on liquid surfaces, such as oceans, of exoplanets [8]. Such a detection would be major step forward in the search for life.

If we observe an exoplanet directly, the planet itself will be unresolved. Thus, a major challenge for the interpretation of future exoplanet observations, will be disentangling the contributions from different surface types and clouds. A number of numerical codes have been developed to calculate spectral signatures of atmospheric and surface features, and the further development and validation of these codes and that of retrieval algorithms will benefit enormously from benchmark data such as disk-integrated observations of the Earth itself. An excellent location for performing such observations is the lunar surface facing the Earth. Thanks to the monthly orbit of the Moon around the Earth and the tidal locking of the Moon with respect to the Earth, a spectropolarimeter on the lunar surface could in principle observe the whole Earth, during each day, at all phase angles, and throughout the seasons.

2. Signals of Earth-like exoplanets

In [3] we describe our algorithm to calculate the reflected flux and polarisation signals of horizontally and vertically inhomogeneous planets. Figure 1 shows calculated polarisation signals of a model Earth–as–an–exoplanet as could be observed from the Moon at phase angles from 0° to 180° and including diurnal rotation. Our model Earth has ocean, ice, sand and forest surface types and has clouds made of model A particles of [2]. The rainbow, visible mostly in the polarization around a phase angle of 40°, uniquely indicates the presence of liquid water clouds.

3. The LOUPE instrument

LOUPE, the Lunar Observatory for Unresolved Polarimetry of Earth, fulfills the following requirements: 1) It performs flux and polarization measurements of the sunlight that is reflected by the Earth from 0.4 to 0.8 μm. 2) The spectral resolution for the flux measurements is such that the O_2 A-absorption band (around 0.76 μm) is resolved. 3) The spectral resolution for the polarimetric measurements is such that limited spectropolarimetry across the O_2A- and other bands can be done. 4) Measurements will be done that

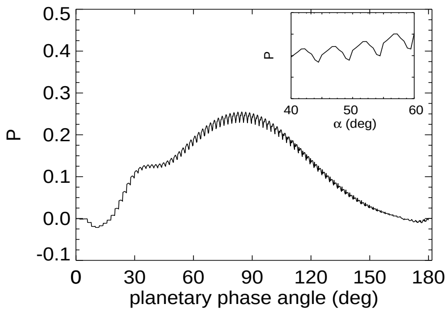

Figure 1: Numerically calculated signals of a model Earth as could be observed from the Moon at 0.55 μm.

resolve the Earth's rotation, and that span a period long enough to capture phase angle changes. 5) The instrument is small and robust.

The basic version of LOUPE performs spatially unresolved flux and linear polarization measurements. Depending on the available space on the carrier (e.g. a lander), this version can be upgraded to measure also circular polarization and/or to spatially resolve the Earth. Spatial information about the actual coverage of the Earth's disk will help testing of retrieval algorithms, but also allow to distinguish flux and polarization signals of specific types of surfaces and/or clouds. It will especially help to search for circular polarization signals that are expected to be very small when integrated across the disk of the Earth [6], but that might be relatively strong over e.g. the Amazonian rainforest. Figure 2 shows the optical components of LOUPE, with the spectropolarimetric technique based on spectral modulation [5].

4. Summary and Conclusions

We present LOUPE, the Lunar Observatory for Unresolved Polarimetry of Earth. LOUPE is a small and robust spectropolarimeter that can observe the Earth as if it were an exoplanet from a vantage point on the lunar surface. From the Moon, LOUPE will be able to observe the whole disk of the Earth, in principle all days, at all phase angles and throughout the seasons. LOUPE data will provide valuable benchmark data for exoplanet characterization retrieval algorithms.

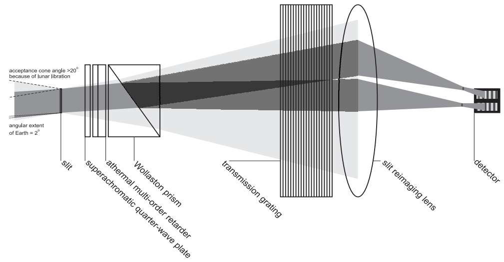

Figure 2: Schematic design of LOUPE with linear spectropolarimetry and no spatial resolution. This instrument only needs to be roughly pointed towards the Earth as it accepts light from all angles within the range determined by the lunar libration.

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