LUNAR BASED OBSERVATIONS OF THE EARTH AS A PLANET

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ABSTRACT

The Camera for Lunar Observations of the Variable Earth (CLOVE) is a concept for a moon-based instrument to characterize the remotely detectable physical and biological signatures of Earth over time. The study is being undertaken as part of the NASA Lunar Science Institute's program "Scientific and Exploration Potential of the Lunar Poles". The lunar polar surface deployment enables these data to be obtained continuously over long timescales and this unique vantage point makes it possible to track Earth's ever-changing photometric, spectral and polarimetric signatures in a manner analogous to future observations of extrasolar terrestrial planets. Empirical data from observations of the Earth from space, from Earthshine and from the field and laboratory will be integrated with state-of-the-art models to help us understand our ability to characterize Earth-like exoplanets, their habitability and evidence for extant life. In the NLSI study we include investigation of circular polarization as a biosignature, try to detect ocean glint from polarization of the Earthshine, and enhance our ability to model the Earth using observations from recent space missions.

Introduction

The Moon may serve as an excellent platform from which to observe the Earth as a planet. Continuously in view and continuously rotating, we have the potential to acquire extensive time series of astronomical data using a compact camera with spectral and polarimetric capabilities in addition to imaging. We are investigating this concept as part of the NLSI funded team "Scientific and Exploration Potential of the Lunar Poles" (P.I. Ben Bussey, APL). Our efforts are concentrated in three areas. These are: I. spectral modeling of the diurnal and seasonal variations of the Earth; II. linear polarization monitoring of the Earth; and III. estimation of the likelihood of a global biosignature of life's chirality in the form of circular polarization. Each topic involves modeling, and each topic also contains empirical data in the form of actual Earth or field observations. Our goal is to advance our ability to infer the observable nature of the Earth and its biosphere and to assess our ability to apply these methods to extrasolar planets that may be like the Earth.

II. Observations of the Earth's Ocean Glint: Polarization of the Earthshine

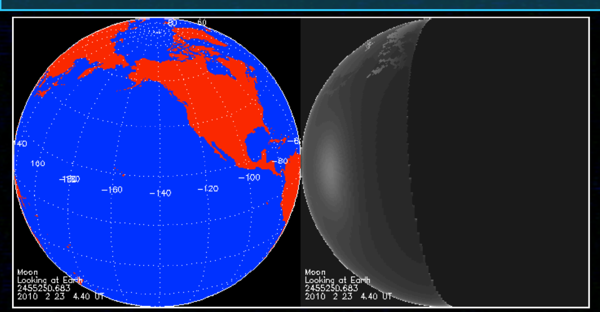
Two important mechanisms act to cause polarization in the light reflected from a planet like the Earth:

- Rayleigh scattering from the atmosphere
- specular reflection, or glint, from the oceans

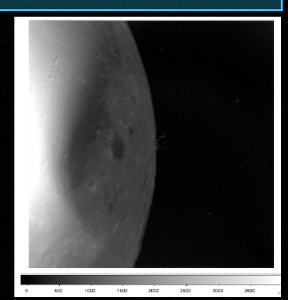
The glint from the Earth depends strongly on the phase presented, and on the nature of the surface at the position of the reflection. By continuously monitoring the intensity and polarization of the Earth (or in the future, planets like the Earth around other stars), there is the potential to infer the extent of lakes and oceans, and the location of continental boundaries. The highly polarized glint abruptly changes as the reflection crosses from the reflective liquid surface to the solid continental surface.

To validate this concept, Peter McCullough is obtaining polarimetric observations of the Earthshine (a.k.a ashen light) configured to optimize and test a range of intensity of the ocean glint. The Perkins 1.8-m telescope at Lowell Observatory was used with a rotating polariod filter to measure the Earthshine's polarization.

Preliminary inspection of the (limited) data available so far yield polarization in the range 6 to 12% (R band to B band) consistent with expectations from earlier work (Dollfus, 1957, Supplements aux Annales d'Astrophysique, 4, 3) and models (McCullough 2007astro-ph/0703328). More observations are required to empirically validate the drop in polarization expected as the glint spot moves from ocean to land.



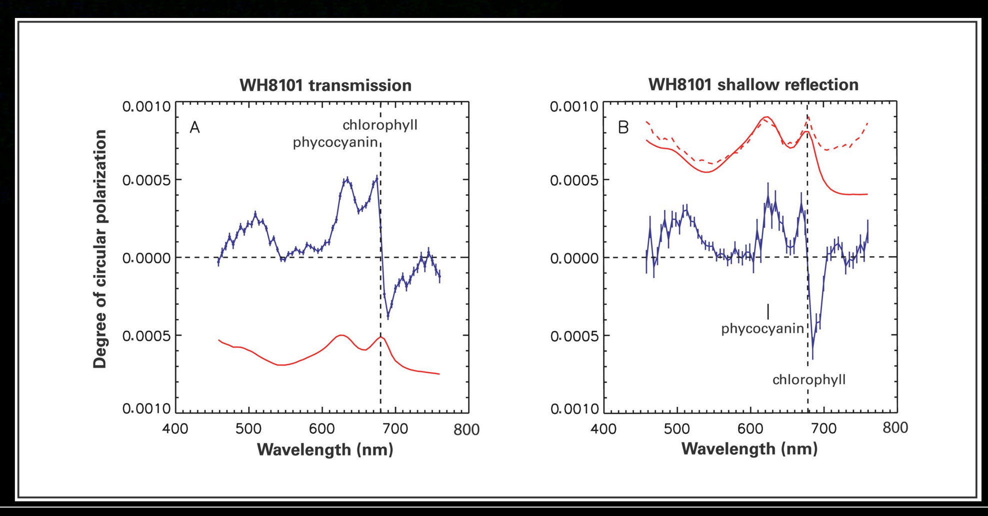
Left: Configuration of the Earth as seen by the Moon during the initial observations. Right: snapshot of the lunar Earthshine at the telescope.



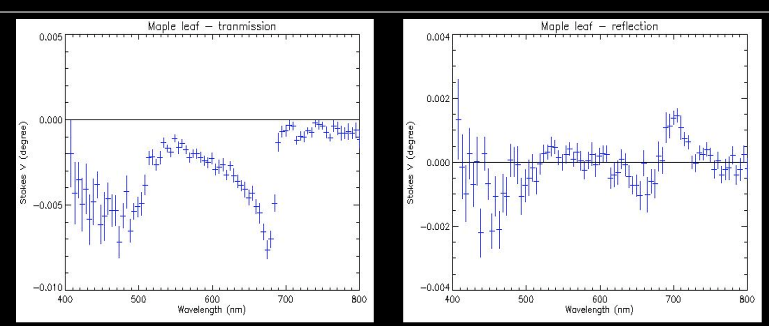
Left: Ocean glint on another World – a lake of hydrocarbons on Titan

III. Remotely Sensing Life's Signature

A candidate universal biosignature is homochirality, which is likely to be a generic property of all biochemical life. Due to the optical activity of chiral molecules this unique characteristic may provide a suitable remote sensing probe using circular polarization spectroscopy. Photosynthetic microbial organisms are of major importance to astrobiology through the evolutionary advantages accrued by photosynthesis and the easy "observability" of photosynthesis. We have shown that the chiral molecules of photosynthesis produce measureable circular polarization signatures (Sparks et al 2009 PNAS 106, 7816; 2009 JQSRT 110, 1771). Circular polarization spectroscopy could provide a powerful remote sensing technique for generic life searches. Our goal in the current study is to assess the magnitude of any global circular polarization signature that may result from photosynthetic activity and hence its possible utility as a biosignature in the future.



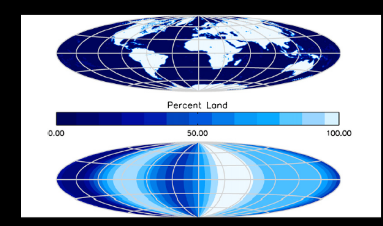
Above: Photosynthetic cyanobacteria, which can dominate the optics of the ocean, yield a distinctive circular polarization signature (blue lines) due to the chirality of the photosynthetic molecules. The polarization features correspond to electronic absoption bands of photosynthesis (red lines). Below: A green leaf also revealing its biological nature through circular polarization. Is there sufficient biological material to yield a global chiral signature for the Earth?



I. Validation with Spacecraft Observations of the Earth

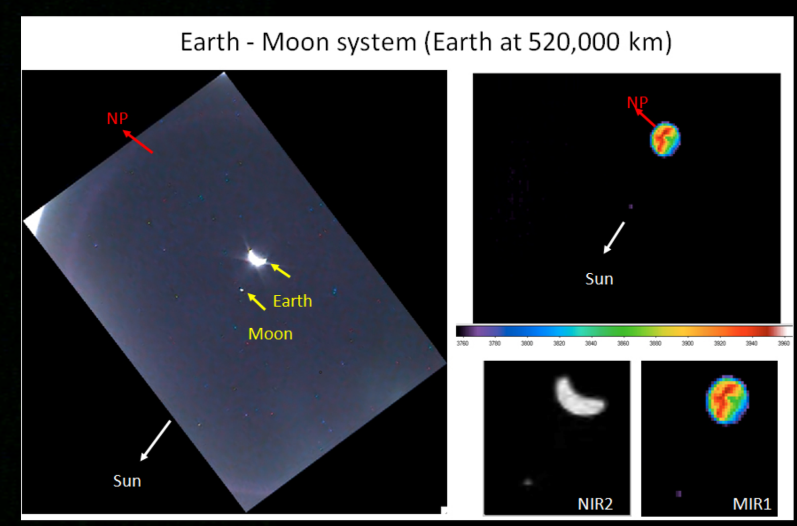
With data from the EPOXI mission (née Deep Impact), Cowan et al (2009) ApJ, 700, 915 used disk averaged time-resolved photometry of the Earth to understand the extent to which terrestrial features could be extracted. Even with typical cloud cover, both continents and oceans could be identified by proper analysis of the lightcurve. Using long timeseries, wider spectral coverage and simultaneously acquiring ground truth images, CLOVE has the potential to optimize and advance this important technique.

The Lunar CRater Observation and Sensing Satellite (LCROSS) made three sets of observations of the Earth en route to the Moon. The data comprise optical/NUV spectroscopy, NIR spectroscopy and both Near IR and Mid IR imaging. Our goal is to utilize these data in conjunction with the tools available through the NASA Astrobiology Institute's Virtual Planetary laboratory (P.I. Vikki Meadows; see http://vpl.astro.washington.edu) to validate the terrestrial planet models all the way into the thermal IR and to seek identifiable features visible in the optical and NUV spectra.



Above: Fig 10 of Cowan et al 2009 showing the actual land distribution of Earth, above , and the reconstruction from disk-integrated light curves obtained by EPOXI, below. The success in recovering the longitudinal dependence is remarkable.

Below: Example observations of the Earth and Moon from LCROSS en route to its impact on the Moon's surface.



Summary

We are investigating an instrument concept for Earth observing using the Moon as a platform. Long, continuous time series of spectral and polarimetric measurements using the "Camera for Lunar Observation of the Variable Earth" (CLOVE) have the potential to inform and improve our ability to discern important characteristics of the Earth and its biosignatures and apply that knowledge to future observations of extrasolar terrestrial planets.

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Background image: JAXA/NHK