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Search For Chiral Signatures in the Earthshine

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Abstract. We describe an experiment to search for circular polarization in the spectrum of the Earthshine as induced by biotic material on the surface of the Earth. Organic material on Earth is abundant and its helical molecular structure is known to produce circular polarization of reflected diffuse light up to levels of one percent in the visible wavelength regime. We use the spectropolarimetric capability of FORS1 mounted at the Very Large Telescope in Paranal/Chile to detect such features. Our experiment is a benchmark required for future attempts to detect biotic material on other astronomical objects. We present the idea of our experiment, an estimate of the instrumental sensitivity required, and a short description of the observations. We expect to reach a final accuracy of 10^{-5} to measure Stokes V/I.

1. Motivation

From the ground, the globally integrated terrestrial spectrum can be measured by observing the light reflected by the daytime Earth onto the dark side of the lunar surface (Earthshine). Dependent on the relative phase angle of the Earth surface reflected from the Moon, and the Earths global cloud coverage, the enhanced reflectivity caused by ground vegetation ("Vegetation Red Edge", VRE) can be recovered at a wavelength around 700nm. Observations of this kind have been analysed by various groups, but the detectability of the VRE feature is difficult and not unambiguous (see, e.g., the review of (Arnold 2007)).

An alternative avenue to detect possible biosignatures from remote sensing is to seek for key signatures of life through circular polarimetry (CP). It is well-known that optical activity can be induced by the interaction between light and chiral molecules of which living material is composed (Wolstencroft 2004). Homochirality, i.e. the exclusive use of L-amino acids and D-sugars in biological materials, causes a significant induction of circular polarization in the diffuse reflectance spectra of biotic material (Wolstencroft et al. 2004). Among many other biopolymers, photosynthetic pigments (e.g. chlorophyll) induce between 0.1% and 1% circular dichroism in its absorption bands (Houssier & Sauer 1970).

In a pioneering study (Sparks et al. 2005) searched for chiral signatures on Mars stemming from living material. He obtained high-quality circular imaging polarimetry of the martian surface during opposition in 2003. Although the polarization noise levels were well below 0.1%, i.e. approaching the instrumental capabilities, no regions with significant circular polarization were found. Today, this null result may not seem too surprising, as recent results from the Mars-Express mission indicate no evidence for liquid water anywhere on its surface. This, together with the early loss its atmosphere makes primitive surface-life on Mars highly unlikely (Bibring et al. 2005).

The Earth is the only location where we unambiguously know that organic material is abundant. We therefore searched for optical activity caused by biotic homochirality in the Earthshine. Our experiment is intended as a benchmark for further attempts to characterize potentially living material in a broader, astronomical, context.

2. Observations

Earthshine observations intrinsically yield disk-integrated Earth spectra, i.e. do not contain spatial information, and resemble spatially unresolved observations of the Earth. We obtained data in two observing epochs (end of November 2006, and middle of December 2006), which allow us to compare different phases of the Earthshine contributing surface areas.

FORS1, mounted at the Cassegrain focus of the Very Large Telescope on Cerro Paranal in Chile is an unique instrument at a 8m class telescope that offers both circular and linear spectropolarimetric observing modes through superachromatic $\lambda/4$ and $\lambda/2$ retarder plates mounted in front of a Wollaston prism. We refer to the FORS1 user manual for technical details. The scientific performance and sensitivity of this mode has already been demonstrated, and accuracies of 10^{-4} to measure Stokes V/I in high S/N (≈ 2000) spectra of magnetic stars have been obtained (Bagnulo et al. 2002). Note that the Earthshine has an approximate surface brightness of about $V \approx 12 - 13/''^2$, depending on the actual phase and illumination. High signal levels using the full dynamic range of the detector can therefore easily be obtained within short exposure times, important to repeat the polarimetric cycles and to increase the S/N level. As the lunar surface is spatially extended, and covers a significant fraction of the detector, an accuracy of 10^{-5} in high S/N re-binned and multi-stack spectra of the Earthshine can be obtained. We have chosen to record low-resolution spectra in the red wavelength band, covering approximately 600nm-1000nm, which includes the VRE signature around 700nm. Note that this set-up contrasts to the one used by Sparks et al., who used two discrete narrow-band interference imaging filters (centered at 378nm and 953nm) for their circular polarization detection experiment on Mars.

2.1. Sensitivity Requirement

The degree and spectral shape of the CP signal as expected in diffuse reflectance that arises from living material on Earth (mainly vegetation canopy) is not known. Laboratory measurements of a few species of plant leaves have been reported by (Wolstencroft et al. 2004), and CP of about 1% varies slowly over the visible wavelength range. No better a priori knowledge of the spectral dependency of the CP signal expected from Earth's vegetation is available.

Two effects have to be considered when estimating the final CP signal strength expected in the Earthshine. On Earth, the surface filling factor of vegetation is not only dependent on the geometrical arrangement of oceans, ice, deserts and vegetated land-masses, but also on the global cloud coverage and its distribution at the time of observation. Cloud cover maps are available through the International Satellite Cloud Climatology Project, and can, in principle, be folded with the geometrical distribution of vegetated areas. Previous analysis show that on average about 60% of the Earths surface are affected by clouds. A cloud-free vegetation cover between 0% and up to 50% (in the maximum, typically 20%) can be expected for different observing phases (Montanes-Rodriguez et al. 2006). We have estimated the cloud-free vegetation area during the times of our observations, and estimate the effective contribution of vegetation to about 1% for our November observations, and to about 10% for December. In other words, the CP signal as expected from diffuse reflectance of a homogenous vegetation distribution is diluted by about 0.01 and 0.1 for the November resp. December observations. On the Moon, depolarization caused by scattering on the lunar surface dilutes the CP signal in the Earthshine further. From linear polarization measurements the depolarization strength of the lunar surface has been estimated to be around 10 (Dolfuss 1957), (DeBoo et al. 2005), but no more precise value can be attributed to this effect. We conclude that an accuracy of $\approx 10^{-4\ldots-5}$ is required to determine Stokes V/I in order to positively infer the presence of a CP signal caused by vegetation in Earthshine observations.

2.2. Data Signatures

For both epochs we observed both lunar sides (the bright and the dark side, corresponding to Moonshine and Earthshine). The long slit was positioned perpendicular to the lunar limb in the center of the detector, which allows to record the contributions of the sky background. All spectropolarimetric observations were performed in a standard fashion, i.e. by rotating the quarter-wave plate by 90° in order to remove the instrumental polarization. We have also measured the linear polarization of the Earthshine, which is mainly caused by Rayleigh scattering in the Earths atmopshere. Actually, the dominant contribution to the measured Stokes V/I stems from cross-talk from linear polarization. Its spectral and spacial signatures has to be carefully analysed and removed. In Figure 1 we demonstrate this effect. Stokes V/I has been determined for four different regions across the detector. The effect of increasing cross-talk can be noted in the blue part of the spectrum, and with increasing distance from the detector center. In the same Figure (full lines) we plot the "null polarization" spectrum for each region (Donati et al. 1997). This quantity is particularly useful to estimate the noise level of the data. The r.m.s. of the null polarization is of the order of 10^{-4}, and spectral re-binning, and stacking of more polarization measurements indeed allow to reach the desired accuracy of 10^{-5}.

2.3. Prospect

The careful analysis of the instrumental crosstalk is required to remove the dominant contribution in V/I. Ancillary calibration measurements have therefore been performed. Additional analytic model descriptions will be employed to further characterize the instrumental cross-talk. The data obtained by us have the potential to detect CP signatures down to a level of $V/I \approx 10^{-5}$. Investigations of the strength, and spectral shape of CP in vegetation typical for the

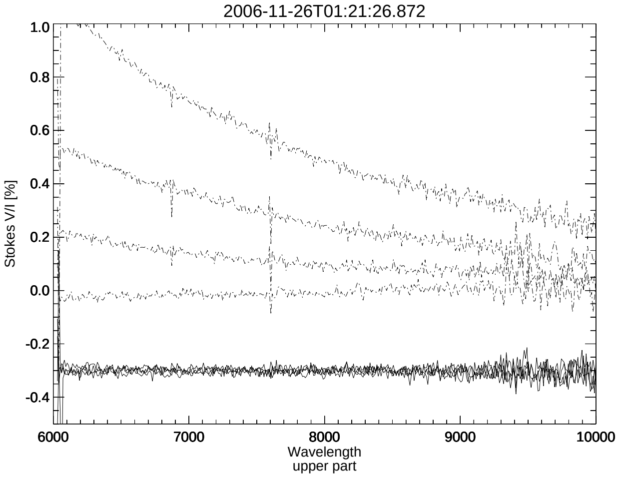

Figure 1. **Spectrum of Stokes V/I as measured in the Earthshine on November 26, 2006. The dashed lines correspond to different regions on the detector. The highest degree of CP is measured in the blue, and at the edges of the field. The socalled "null polarization" spectrum is also given (full lines), shifted by -0.3%. The CP signal is dominated by cross-talk from linear polarization.**

Earths integrated reflectance spectrum are largely absent, and deserve systematic follow-up. Intensive laboratory measurements of the CP of different plant and leaf species are therefore highly desirable.

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