Search for Chiral Signatures in the Earthshine

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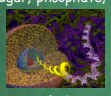
We search for circular polarization in the spectrum of the earthshine as induced by chiral molecules of living material on the surface of th e Earth. Biotic material with its helical molecular structure is known to produce circular polarization of reflec ted light up to levels of a few percent, thus in the range of detectability of FORS1 mounted at the Very Large Telescope in Paranal/Chile.
Organic material on Ear th is abundant, but its detectability using astronomical remote sensing techniques, e.g. through the Vegetation Red Edge, is usually difficult, and not undisputed. Our experiment is a benchmark required for future attempts to detect biotic material on other astronomical objects.
Preliminary results of the experiment show that circular polarization in the Earthshine can be detected, and correlates with the fractional vegetation cover observed.

The Building Blocks of Life ...

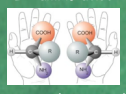
C O H N

D - sugar, phosphate, base

L - amino acids



RNA, DNA (information)



proteins (structure)

... are chiral (on Earth)

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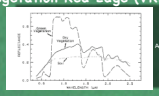
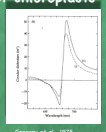
Signatures of Life

Vegetation Red Edge (VRE)



Arnold et al., 2002, Proc. 36. ESLAB Symp., p.259

circular dichroism of chloroplasts



diffuse reflectance of plant leaves

Hebe – Evergreen

Hypocalles Sanguinenta – Poka-Dot Plant

Gregory et al., 1975, BioChem.J., 148, p.487

Wolstencroft, 2004, Bioastronomy 2002, IAU Symp. 213, p.349

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Remote Sensing

Atmospheric Biosignatures

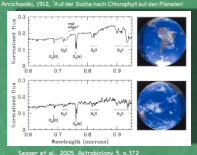
Galileo: O_2 and CH_4 not in chemical equilibrium

Sagan et al., 1993, Nature 365, p.715

Surface Biosignatures

VRE sensing of the Earthshine: integrated diffused reflectance spectra

Arcichowski, 1912, "Auf der Suche nach Chlorophyll auf den Planeten"



Arnold et al., 2002, A&A 392, p.231

maybe?

Woolf et al., 2002, ApJ 574, p.430

maybe?

Montanes-Rodriguez et al., 2005, ApJ 629, p.1175

no!

Montanes-Rodriguez et al., 2006, ApJ 651, p.544

yes, time/phase variability !

Hamdani et al., 2006, A&A 460, p.617

yes, but careful modeling is needed

Seager et al., 2005, Astrobiology 5, p.372

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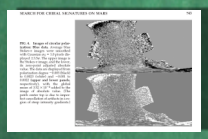
Search for Chiral Signatures on Mars

NB imaging-polarimetry w/ FORS1 during 2003 Mars opposition



43% coverage
210km resolution

V/I < 0.1%

Sparks, Hough, Bergeron, 2005, Astrobiology 5, p.737

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Chiral Signatures on Earth?

- compare two phases w/ different vegetation cover
- search for a differential signal in Stokes V/I with a presicion of < 10^{-4} @ 750nm (VRE)

Earth as seen by the Moon

26-Nov-2006UT01:00

15-Dec-2006UT08:00

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Sources of Circular Dichroism

C.D. Expectation in the Earthshine

- assume 1% C.D. from diffuse reflectance of leaves @ VRE: 10^{-2}
- assume a dilution factor of 10 (from VRE experiments): 10^{-3}
- depolarization by lunar diffuse backscattering: 10^{-4}

DeBoo, et al., 2005, App. Opt., Vol. 44, No. 26, p.5434

C.D. other sources ("dirt effects")

- scattering from lunar surface (V/I < 3-4·10^{-5} at the poles)

Meierhenrich et al., 2002, ESA SP-518, p.243

- zodiacal dust scattering, aerosols: negligible < 10^{-6}

Wolstencroft, 1985, IAU Symp. 112, p.171

- instrument! crosstalk from linear polarization: spatial + chromatical

< 1% requires careful calibration, characterization, MM modeling

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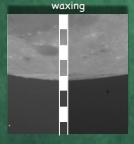
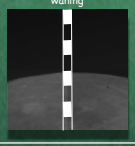
Spectropolarimetry w/ FORS1

- wavelength coverage 600 - 1000nm
- spectral resolution R ~ 660
- dark limb (earthshine) and bright limb (moonshine)

26-Nov-2006UT01:00 phase = 131deg FLI=17% waxing



15-Dec-2006UT08:00 phase = 120deg FLI=25% waning



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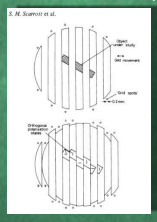
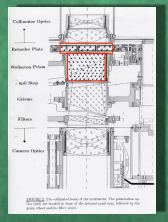
Polarimetry w/ FORS1





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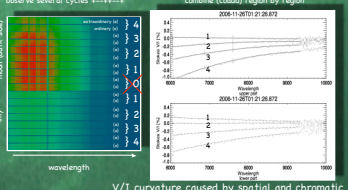
Data Signatures

two retarder positions: +45° and -45°
observe several cycles +–+–+–+–
combine (coadd) region by region

V/I = 0.5*[(f₁-f₂/f₁+f₂) -(f₃-f₄/f₃+f₄)₋]



V/I curvature caused by spatial and chromatic dependent crosstalk from linear polarization

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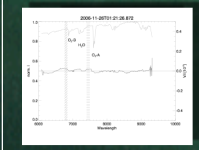
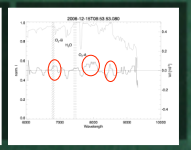
C.D. Spectra: Earthshine

26-Nov-2006UT01:00



15-Dec-2006UT08:00



VRE ~ 2.9%
V/I < 2 × 10^{-5}

VRE ~ 4.2%
V/I ~ 5-10 × 10^{-5}

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Caveats

- linear to circular crosstalk model and/or calibr.
- V/I noise and error budget analysis
- quantitative analysis of cloud coverage
- rigorous VRE analysis
- "Moonshine" should be parallel to "Earthshine"
- data from Dec. are of lower quality (CCD 4x4)
- reproducibility?

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Conclusions

- Precision measurements of circular polarization of the Earthshine are possible
- V/I < 10^{-5} can be achieved in low-res. spectra
- Significant levels and variation of circular polarization appear related to the VRE (800nm)
- Circular polarization levels measured depend on the phase of Earthshine observations
- Relatively higher levels of C.D. are correlated with a higher fraction of vegetation coverage as seen in the Earthshine
- First things first:
  Find Life on Earth, then elsewhere ...

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