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Investigating cloud cover variability on Earth-like exoplanets using polarimetry

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Abstract

Because clouds scatter and absorb incident radiation, they play crucial roles in the radiative balance, the atmospheric chemistry, climate, and thus the habitability of a planet. Clouds usually affect the planet's observables. We investigate here the effect of partial and variable cloud coverage on the light that is reflected by an Earth-like exoplanet, exploring not only the total flux but also the linearly and circularly polarized fluxes.

1. Introduction

Clouds can have a strong effect on the thermal balance of an exoplanetary atmosphere and thus on the presence of liquid water on the surface, and therefore on the habitability [3, 9]. They also affect the appearance of absorption bands [8, 1] and transit spectra [4]. Finally, they could hide surface biomarkers, such as chlorophyll and/or the so-called red edge [7].

Polarimetry has proven to be an effective way to characterize the properties of a planetary atmosphere. In particular, the degree and direction of polarization will change with phase angle, depending on the micro- and macro-physical properties of the atmosphere and the clouds, and an underlying surface. A famous example is the derivation that the clouds of Venus [2] consist of 1μm, sulfuric acid solution droplets from disk–integrated linear polarization observations.

In this study, we discuss the effect of horizontally inhomogeneous cloud covers on the flux and polarization of light reflected by an Earth-like exoplanet.

2. Modeling Earth-like exoplanets

Our radiative transfer computations are performed using PyMieDAP, a Python–Fortran doubling–adding code that we created and made available online[1] [5]

[1] http://gitlab.com/loic.cg.rossi/pymiedap under a GNU GPL license

The model planetary atmosphere is locally plane–parallel, and vertically divided in homogeneous layers filled with gas, and one of them, optionally, also containing cloud particles. The planetary disk as seen by the observer is divided into a grid of square pixels. For each pixel we compute with the reflected total and polarized fluxes, allowing us to study both disk-resolved and disk-integrated signals. Each pixel can be assigned a different model atmosphere such that we can study the effects of different cloud coverage maps on the reflected signals.

Here, we use three types of coverage: sub-solar clouds, polar clouds, and patchy clouds. For each type we vary the fraction of cloud cover F_c for the whole planet. We use Earth- or Venus-like clouds consisting of water or sulfuric acid solution particles [5, 6].

3. Results

3.1. Linear polarization

As can be seen in Fig. 1, sub-solar clouds show a distinct phase curve pattern in the disk–integrated polarization signal, with a clear transition when the cloud rotated out of the observer's view. The polar cusps and patchy cloud coverages show similar patterns, but the variability in the position of the patches yields a more variable polarization signal than with polar clouds. The variability shown by the patchy clouds is related to the amount of clouds, and could be used for a rough estimate of F_c. Note that the variability will influence the derivation of mixing ratios of gaseous absorbers [1] and is thus a parameter of interest when trying to identify biomarkers such as the amount of oxygen.

At phase angles where the rainbow is visible, its strength is not affected by the type and amount of coverage, potentially allowing to use it to derive cloud particle sizes (the composition and particle shape are known). Finally, at short wavelengths (UV-blue) the polarization phase curves for planets with different cloud coverages are similar, as they are dominated by

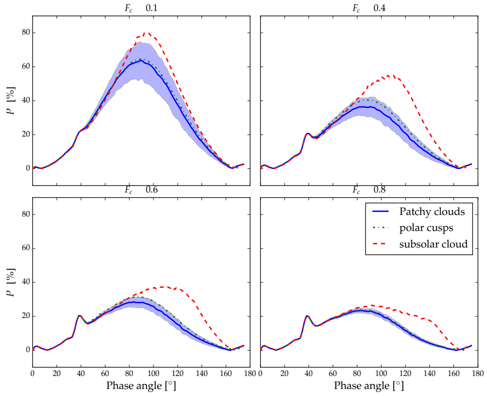

Figure 1: Comparison of the degree of linear polarization at $\lambda = 500$ nm for different cloud coverage types for $F_\mathrm{c} = 0.1$, 0.4, 0.6, and 0.8. The cloud-top pressure p_c is 800 mb. Solid lines and shaded areas show the average and the variability over 300 patchy cloud patterns, respectively.

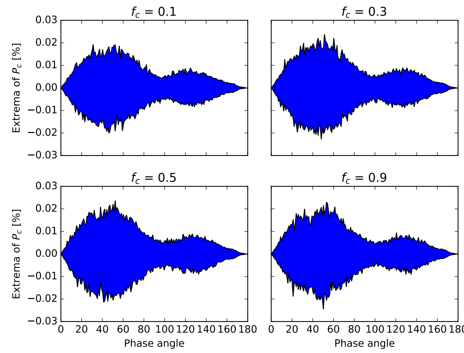

Figure 2: Maximum values of the degree of circular polarization P_c computed for 300 cloud patterns as a function of the phase angle, for different cloud coverage fractions F_c for Earth–like cloud particles.

the contribution of Rayleigh scattering by gas above the clouds. This suggests that at these wavelengths, assuming purely gaseous atmospheres is a reasonable approximation, which would allow to derive orbital parameters from a planetary system using polarimetry.

3.2. Circular polarization

The disk–integrated circular polarization of a planet with a horizontally homogeneous atmosphere is zero, since both hemispheres would produce polarization of the same value but with opposite signs. We therefore investigate the effect of patchy cloud covers on the disk–integrated degree of circular polarization P_c of Earth- and Venus-like planets.

Our simulations (Fig. 2) show that while an increase of the amount of cloud cover, F_c, increases P_c (since Rayleigh scattering doesn't generate circular polarization), it also increases the global symmetry of the cloud cover and therefore leads to a decrease of P_c. The highest values for P_c occur when F_c is about 40% to 50%. Note that the absolute values of P_c are very small anyway (smaller than 0.02%) and therefore likely below the current and (near) future exoplanet detection capabilities.

3.3. A realistic model Earth

To go beyond the ideal cases discussed above, we used MODIS observations to simulate the flux and polarization signals of a model Earth with realistic cloud coverage. The preliminary results show the importance of including the spatial and temporal variability of both the surface and cloud cover on the observed signals. It also appears to be possible to retrieve information about the diurnal rotation or seasonal effects, in line with previous studies based on total flux signals only.

4. Summary and Conclusions

We investigated the effect of cloud variability on the polarization of light reflected by Earth-like and Venus-like planets. Polarimetry should allow to distinguish different sorts of cloud coverage and could help to determine the amount of clouds. A multi-wavelength approach should help to reduce degeneracies when deriving orbital parameters from polarization signals.

References

[1] Fauchez, T., Rossi, L. and Stam, D. M. 2017, ApJ, 842, 41

[2] Hansen, J. E. and Hovenier, J. W., 1974, J. Atmos. Sci., 31, 1137

[3] Kitzmann, D., Patzer, A. B. C, von Paris, P., et al. 2010, A&A, 511, A66

[4] Line, M. R. and Parmentier, V. 2016, ApJ, 820, 78

[5] Rossi, L., Bersoza-Molina, J., Stam, D. M., A&A, in press

[6] Rossi, L. and Stam, D. M., A&A, in press

[7] Tinetti, G., Meadows, V. S., Crisp, D., et al. 2006, Astrobiol., 6, 881

[8] Vasquez, M., Schreier, F., Gimeno Garcia, S. et al. 2013, A&A, 577, A46

[9] Yang, J., Cowan, N. B., & Abbot, D. S., 2013, ApJ, 771, L45