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Polarized signals of Venus-like exoplanets

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Abstract

Polarized signals of extra-solar planets atmospheres are thought to be of crucial importance for the characterization of their atmospheres and surfaces and for the detection of signs of life. We report the modelling results of polarized signals of different Venus-like atmospheres and analyze their polarimetric features for different wavelengths.

1. Introduction

The atmosphere of Venus is much denser and hotter than that of Earth. The surface temperature of Venus is 735 K and its atmosphere is composed by opaque clouds made of sulphuric acid and nitrogen [1], making it impossible to observe its surface. Feeble amounts of water vapour may also be found in the atmosphere, but liquid water is non-existent on the surface of Venus. However, Venus in the past may have had water clouds [2]. The present climate of Venus is driven by a CO_2 greenhouse effect that sustains its current surface temperature [2], making it a hostile place for life. The composition of the clouds in an atmosphere could give hints about the properties of the difficult to observe surface.

Polarimetry is a technique that allows to access crucial information about the nature and distribution of the scattering particles in the atmospheres of planets. The goal of this work is to show typical polarimetric features of extra-solar planets that may have a Venus-like atmosphere, providing clues about a planet's habitability. Our model calculations follow the cases described by [2].

2. Flux and polarization of light

The intensity and state of polarization of a light beam can be described by an intensity vector $\boldsymbol{I} = [I \quad Q \quad U \quad V]$, where I is the total intensity, Q and U are the linearly polarized fluxes and V the circularly polarized flux, all with dimensions of W m^{-2} sr^{-1} Hz^{-1}. We will also consider a flux vector defined as $\pi F = \pi[F, Q, U, V]$, where all the parameters have dimensions of W m^{-2} Hz^{-1}. Usually light that comes from a star is unpolarized, meaning that $\pi F_0 = \pi\ F_0[1,0,0,0]$. The degree of polarization of a light beam is defined as $P = \sqrt{Q^2 + U^2 + V^2}/F$. The degree of linear polarization can be obtained by setting $V = 0$.

3. Our atmosphere model

We modelled polarized signals for a six layer atmosphere of a horizontally homogeneous planet, considering the three different cases discussed by [2], for two different wavelengths: 0.55 and 1.00 μm. Each layer of an atmosphere contains gas molecules and/or cloud particles that scatter the starlight. For the scattering by gas molecules, we use the anisotropic Rayleigh scattering theory as described by [3]. We used the double adding code described by [4]. We used the size distribution of the clouds defined by [1], adopting $b = \nu_{\text{eff}} = 0.07$ and different values for $a = r_{\text{eff}}$: 1.00, 1.05, 2.00 and 5.00 μm. For the three models, we used a cloud thickness of 10 kms and the following altitudes: 50-60 kms for model 1 (with clouds composed of H_2O) and 3 (with clouds composed of H_2SO_4); 40-50 kms for model 2 (with clouds composed by a mixture of H_2O and H_2SO_4). In model 2, we assumed that $n_r = 1.8$. The optical thickness of the clouds is 10 and the total gaseous optical thickness of the atmosphere is 20, for the three models. We assumed that the Venusian-like atmosphere is mainly composed of CO_2. The CO_2 depolarization ratio is 0.0096, which is wavelength dependent, but this effect can be neglected.

4. Preliminary results and Outlines

Figure 1 shows the model simulations for a Venus-like atmosphere at $\lambda = 1.00$ μm: the normalized flux and P as functions of the phase angle. The flux is normalized such that at a phase angle of 0° degrees, the total flux is equal to the geometric albedo. One can observe that there are not many distinct typical features. We used the circular polarization, V, in the modelling process. But this effect is so small (the values are of the order of 10^{-4}) that P for the different models is very similar to the degree of linear polarization. At $\boldsymbol{\lambda} = 1.00$ µm there are not many differences between the different curves.

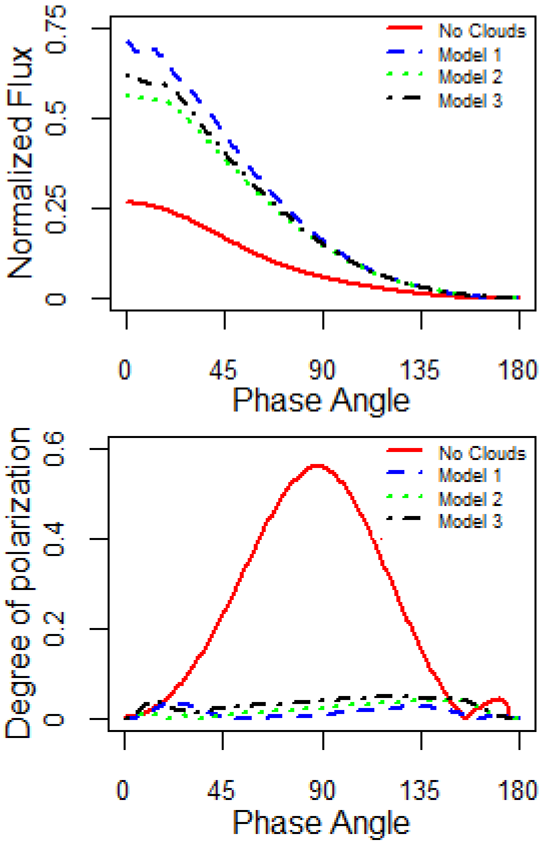

Figure 1: πF and P versus the phase angle for $\lambda = 1.00\ \mu m$, $a = 1.05\ \mu m$ and $b = 0.07$.

Figure 2 shows simulations of model 1 for the Venus-type atmosphere at $\lambda = 0.55$ µm: the variation of the reflected flux and P as function of the phase angle for different values of a. One can observe typical rainbow signatures of water clouds for the largest particles ($a = 5.00$ µm).

It is foreseen to extend this work and study these models and effects for different wavelengths and compare the results with observational studies [1].

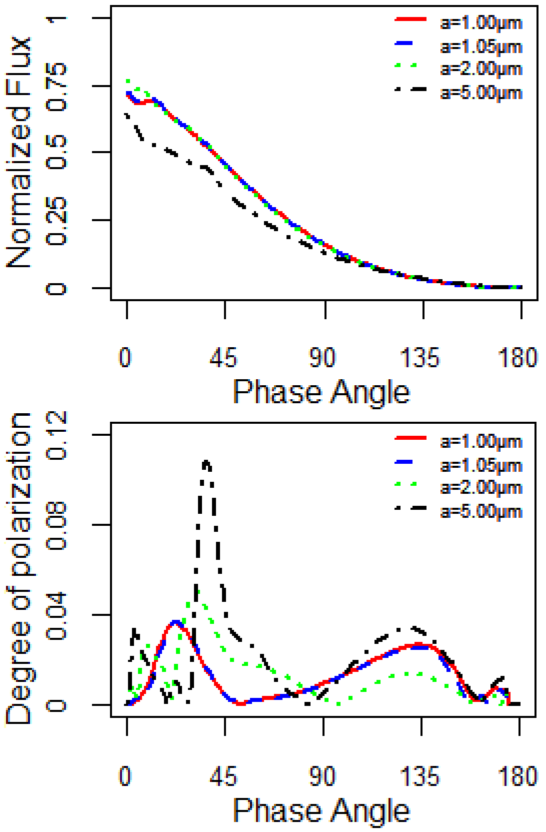

Figure 2: Similar to Fig.1, except for $\lambda = 0.55\ \mu m$, $b = 0.07$ and different values of a.

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