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Reflectance spectra of earth-like exoplanets

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Abstract. Numerical simulations on irradiated exoplanets provide spectra that contain informations about the temperature- and density structure and chemical composition of the exoplanetary atmosphere. The calculation of cool objects is challenging, because of the much more complex chemistry, i.e. the strong molecular abundances as well as the occurrence of dust formation. In order to create an object with planetary features, such as size, temperature and abundances, the stellar atmosphere code PHOENIX had to be adapted in an appropriate way. Starting with an object of Venus-like parameters in 1D (spherical setup), temperature and optical depth will be reduced to Earth-like values. But in an optically thin atmosphere, what influence might the surface texture have on the combined spectrum? An albedo module has already been embedded to serve the cases of non-angular dependence (e.g. soils, vegetation) and angular dependence, i.e. water surface. The aim is to expand the work to 3D.

Key words. Extrasolar planets – Radiation transport – Exoplanetary atmospheres – Reflectance spectra – Numerical simulations

1. Introduction

How might the surface texture of an extra-solar Earth-like planet influence its spectrum, if the planets atmosphere is optically thin ($\tau << 1$)? An irradiated exoplanet will produce a reflectance spectrum that resembles mainly the spectrum of its host star (input spectrum) with modifications due to interactions in the planetary atmosphere. But how does the spectrum change if the planets surface is a perfect absorber or a perfect mirror (Fig. 1)? How would an ocean influence the measured spectrum? The numerical tool for this simulation is provided by the PHOENIX code (Hauschildt & Baron 1999). A module has been added that allows to simulate the cases of different constant ground albedos (e.g. different soils) and water-like surfaces with an angular-dependent albedo.

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2. Surface textures and radiation transport

A beam of light is gaining and losing energy throughout its passage through an exoplanetary atmosphere as predictable by radiation transfer calculations. But an optically thin atmosphere like in this model setup for Earth-like exoplanets requires a special treatment of the lower atmospheric boundary, the planets surface. Basically the resulting reflectance spectrum resembles the input spectrum of the planets host star with modifications (e.g. absorption bands) due to atmospheric composition. But

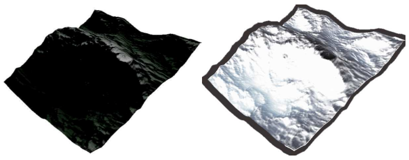

Fig. 1. Two extreme cases of non-angular dependent ground albedos. The surface to the left represents a perfect absorber with an albedo of 0, whereas the surface on the right hand side reflects perfectly with an albedo of 1 (perfect mirror).

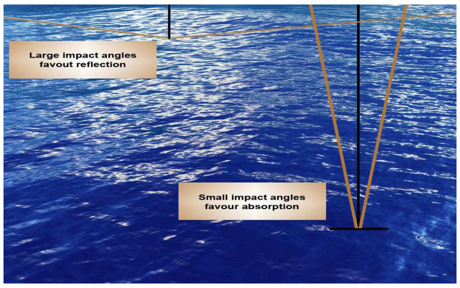

Fig. 2. The albedo of a liquid surface is different for different impact angles of the beams (angular dependence). This case was implemented by the use of the Fresnel equations. Impact angles close to perpendicular favor absorption, whereas large angles favor reflection.

the planets surface being a perfect absorber or a perfect mirror (Fig. 1) should make a difference in the reflected spectrum. In case of a perfect liquid water surface (Fig. 2), the degree of reflection of an incoming beam of light can be calculated using the Fresnel equations. But if non-angular dependent albedo, as it should be applied for soils, vegetation and basically most of other surfaces, or angular-dependent albedo in the case of liquids, the albedo sta ys in the range of $0 \geq$ surface albedo ≥ 1.

3. Simulation results

Just calculating the radiation transport along the beam that hits the planets surface perpendicular for the case of a perfect absorber and a perfect mirror shows clearly that in the case of albedo=1, the outgoing beam conserves the energy it picked up through its passage inward

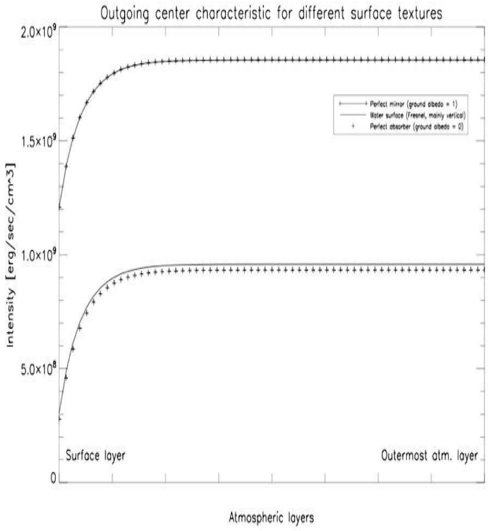

Fig. 3. Test of the radiation transport for the beam of light that hits the surface vertically. In the case of perfect reflection, the outgoing beam continues to pick up energy passing through the atmospheric layers outwards.

to the planetary surface and adds energy on its way outwards. In the case of albedo=0 it has to start to pick up energy anew. Of course this is a highly idealized scenario (figure 3).

Figure 4 shows the reflectance spectrum of an exoplanet of Earth-like dimensions concerning radius, log(g), temperature and optical thickness of the atmosphere. As an input spectrum a Solar blackbody spectrum was used in order to simplify things in the beginning. It is scaled down by a factor of $\approx 10^{-8}$ for a better comparison of the shapes of both envelopes. So far, the code works fine with this new modifications.

Comparison with data from Pallé et al. (2009) shows matching absorption bands in the near infrared (Fig. 5).

4. Conclusions and outlook

A static atmosphere in chemical equilibrium, like it is the case here, is just a first approach to simulate spectra of Earth-like exoplanets, since some important bio-markers like e.g. chlorophyll can just be contributed by vegetation

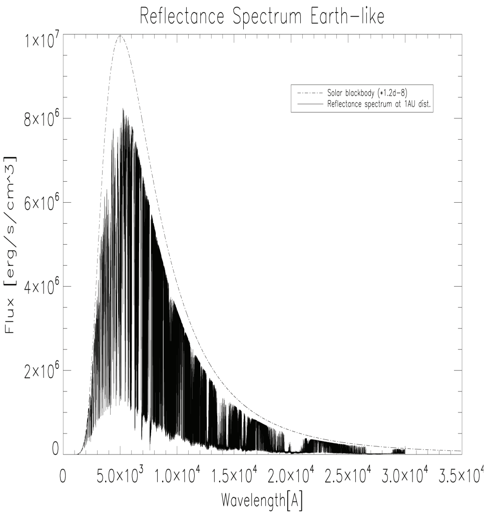

Fig. 4. Reflectance spectrum of an object of Earth-like dimensions, atmospheric composition, temperature, log(g) and distance to the source. The input spectrum is the solar blackbody (scaled down here to fit into the picture).

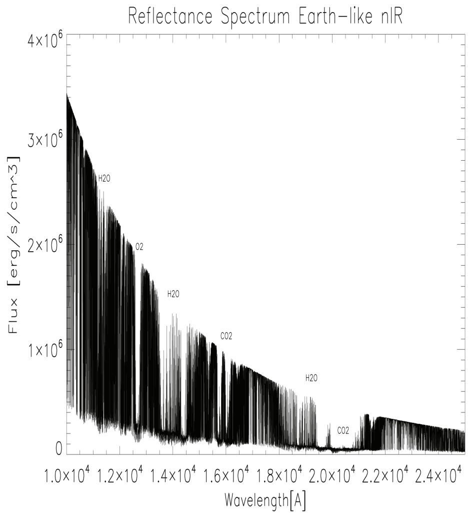

Fig. 5. Molecular absorption bands in the near infrared (nIR).

which is not includable in 1-dimensional models. To compute more realistic and detailed models, an extension into 3 dimensions is recommendable. In both cases (1D and 3D) spectral analysis should answer the question of instrumental precision, required to resolve those delicate spectrum changes that are caused by an exoplanetary surface.

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