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Modelling of the Earth's transmission spectrum in the framework of one-slab model

G. Polinovskyi[1,a], Ya V. Pavlenko[1,2,b] and E.L. Martin[3]

[1] *Main Astronomical Observatory of the National Academy of Sciences of Ukraine*
[2] *University of Hertfordshire*
[3] *INTA-CSIC Centro de Astrobiologia, Madrid, Spain*

Abstract. We discuss the possibility of using the transmission spectrum of the Earth in the measurements of the molecules abundance ratios. We use optical and near infrared transmission spectrum of the Earth obtained during observations of a lunar eclipse in 2008 by Enric Palle and others (E. Pallé et al., 2009). This task is interesting in terms of estimation of the chemical composition of the Earth-like planets around other stars during their transits. We use one-slab model approach for modelling transmission spectra using HITRAN line database. Comparison with observational data gives us clues to our problem.

1. INTRODUCTION

Over the last decades we can see quite significant advances in the detection extrasolar planets (for example see [8], [12], [4]) with different methods involved (for example, [3], [15], [14] and others). With existing technique and instruments it is now possible to discover exoplanets of a few masses of the Earth [8]. As soon as the Earth-like rocky planets are discovered the researches will be concentrated on the characterization of their atmospheres. There are few possible strategies for investigation of the extrasolar planets atmospheres: (i) the direct detection of the light reflected or emitted by the planet and (ii) in case of transits of the planet, in and out of transit comparative spectroscopy.

There are many papers devoted to the exoplanets atmospheres investigations but in general there is no any facts of the exoplanet's spectra precise analyzing because of the lack of qualitative observational data as yet. There are some evidences of the presence of some molecules in the spectra of exoplanets. For example, methane is expected to be found in the atmosphere of Transiting Hot Neptune GJ436B [1]. It was announced about the presence of water, methane and carbon dioxide in the atmosphere of HD 209458b the [2], [13]. All this reviews should be supported by the qualitative observational data in the nearest future.

In the present paper we show that the modelling of the spectra of exoplanets can provide us some crucial information of the relative abundances of the most prominent elements in their transmission spectrum. We use simple one-slab model to generate synthetic spectra to fit the observations. As observational data we use the Earth's atmosphere transmission spectrum obtained during the lunar eclipse in 2008 by E. Palle and others [9]. As input line lists we use HITRAN [11] database. The observation data reflect a picture of the whole atmosphere at the moment (the ring of the atmosphere over the terminator) that is similar for the situation of the exoplanet's transit. The idea is described in [6], also in the paper authors have presented an analysis of the spectrum and show the importance

[a] e-mail: greg@mao.kiev.ua
[b] e-mail: yp@mao.kiev.ua

Table 1. The dependencies of relative abundances on the temperature.

Element	200 K	270 K	400 K
H_2O / CO_2	3.85	1.15	7.22
O_2 / CH_4	2.6E+5	1.6E+6	5.4E+5

Table 2. The relative abundances vs. known data [5].

Element	Mean obtained	Mean known
H_2O / CO_2	4.1	10 – 100
O_2 / CH_4	7.9E+5	1.17E+5

of taking into account refractive effects. If we obtain relative abundances in the Earth's atmosphere and find them realistic we can expect success of investigation of the exoplanets atmospheres by the same technique.

2. DATA AND THE METHOD

In our work we use the transmission spectrum of the Earth obtained in 2008, August 16 by Enric Pallé et al. [9]. There are simultaneous optical and near-infrared observations by two telescopes (William Herschel Telescope (WHT) and the Nordical Optical Telescope (NOT), both at the observatory of El Roque de los Muchachos in La Palma Island) are intercalibrated to provide continuous wavelength coverage from 0.36 to 2.40 μm, the resolution of sthe spectrum is about R $\sim$ 600. The Earth's transmission spectrum was calculated from the brightness ratio of the light reflected by the lunar surface when in the umbra, penumbra and out of the eclipse.

We can only generalize some knowledge and make assumptions concerning exoplanets atmospheres analysis. In this way we do not need complicated models which can be useful for the Earth's atmosphere investigations. Thus, we do not consider radiative transfer modelling, possible volcanic activities, meteor dust, refractive effects (see [6]) and other small facts on which we can say nothing about in case of the atmosphere of exoplanets. We also neglect diffuse sunlight which was found in this spectrum at wavelengths shorter than 600 nm [7]. Authors have attributed it to the effects of the volcanic cloud shed by the Kasatochi volcano in Alaska.

We use one-slab model that can be applied in the study of the exoplanets atmosphere during their transits. Our goal was to calculate a grid of synthetic spectra with different input parameters and find the best fit with observations which would provide us the information of the relative abundance of some molecules. We can expect to evaluate approximate abundance ratio of the elements responsible for the most prominent features in the spectrum.

We calculated a grid of synthetic spectra with different parameters, such as wavelength range, temperature, number densities of particles, path length, etc. As an input molecular line list and the partition function file we use HITRAN [11] database. Afterwards we use Fito program by Pavlenko ([10]) for instrumental profile convolution and finding best fit of the input grid of calculated synthetic spectra with the observations.

We adopt Gauss profile broadening of the absorption lines and take into account Doppler broadening and turbulent velocity of the gas that absorbs solar radiation.

3. RESULTS

The most abundant element in the Earth's atmosphere is molecular nitrogen N_2 (78.08 %) [5], however it is known to lack electronic transitions from the ultraviolet to the near-infrared wavelengths thus is out of our observational data range. We worked with the most abundant elements in the Earth's atmosphere and that have transitions within the wavelengths of our observational data, they are: H_2O, CO_2, O_2, CH_4,

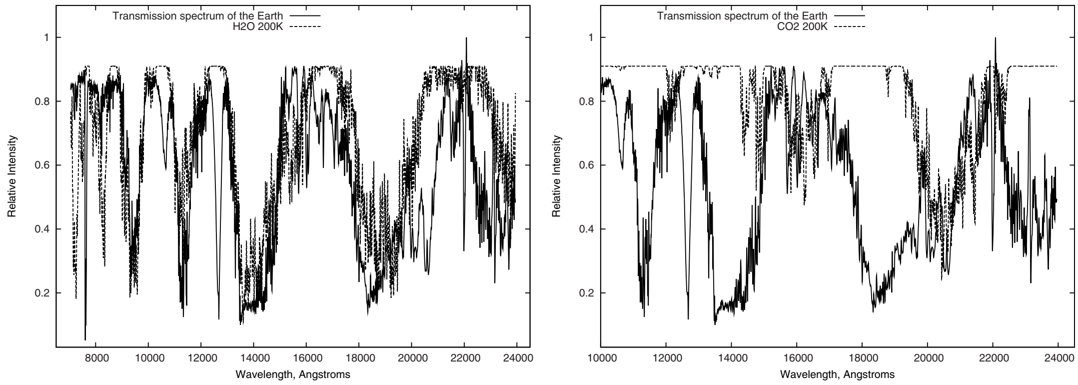

Figure 1. Best fit for the H_2O (left panel) and CO_2 (right panel) molecular bands, T = 200 K.

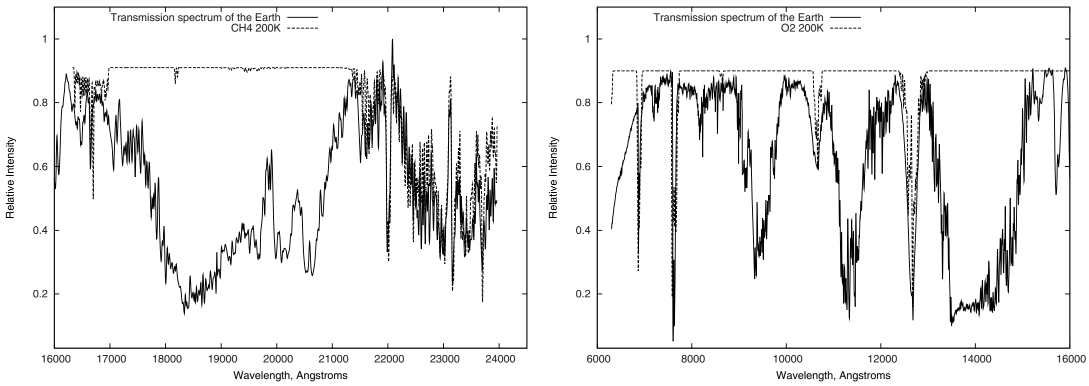

Figure 2. Best fit for the CH_4 (left panel) and O_2 (right panel) molecular bands, T = 200 K.

NH_3, NO, NO_2, N_2O. We found that the most prominent features are caused by water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4) and molecular oxygen (O_2). Thus, we estimated the relative abundances of this species: H_2O / CO_2, O_2 / CH_4. We also found traces of NH_3, N_2O, NO_2 as was previously discussed by authors of the observational data (see [9]).

We calculated relative molecular densities for three temperatures T = 200 K, T = 270 K and T = 400 K that reflect the temperature distribution of the Earth's atmosphere. The results are shown in Table 1. The mean values for these relative abundances by volume are in good agreement with known values ([5]). The water vapor and carbon dioxide have variable amounts in total atmospheric layer and can be estimated roughly. We derive mean values in comparison with known values in Table 2. We received much better agreement that we were expected. The best fits for CH_4, O_2, H_2O and CO_2 molecules at the temperature of environment of $T = 200$ K are shown on figs. 1, 2 (left and right panels) respectively.

We show that this method can be used for estimation of the relative abundance ratios of chemical elements in the atmospheres of exoplanets by using their spectra obtained during transits.

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