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Modelling the transmission spectrum of the Earth as an exoplanet

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Abstract. Modelling the transmission spectra of exoplanets can provide us some crucial information on the relative abundances of the most prominent elements in their atmospheres. We use a simple one-slab model to generate synthetic spectra to fit the observations of the Earth's atmosphere transmission spectrum obtained during the lunar eclipse of 2008. As input molecular line lists we use the HITRAN database with the last updates from 2012. The observational data reflect a picture of the whole atmosphere that is similar to the situation of an exoplanetary transit. In the present work we conclude that this technique can be used in investigations of exoplanetary atmospheres.

Key words. Earth: abundances – Earth: atmosphere – Exoplanets: atmospheres – Exoplanets: synthetic spectra

1. Introduction

The field of exoplanet research is very promising and exciting, especially with the capabilities of existing and future instruments. It is now possible to discover exoplanets of a few masses of the Earth (Martín 2012). Also, ground-based observations can provide high-resolution spectra of exoplanets to search for chemical elements and biomarkers in their atmospheres (Snellen et al. 2013; Snellen 2013).

Even though there are no high-quality observations of exoplanets yet, a lot of papers are devoted to investigate their atmospheres. Some molecular species have been found recently. For example, it was announced the presence of water, methane and carbon dioxide in the atmosphere of HD 209458b (Beaulieu et al. 2010; Swain et al. 2009). Methane was also found in the atmosphere of the transiting hot Neptune GJ436B (Beaulieu et al. 2011). Future observations are expected to reach into lower mass planets, approaching the mass of Earth.

As a reference for future exoplanet observations, we model the transmission spectrum of the Earth. We have obtained relative abundances in the Earth's atmosphere using the updated molecular database HIRAN 2012 (Rothman et al. 2009) and find them realistic. We argue that this technique can be applied to exoplanetary atmospheres.

2. Observations and method

In this work we use the transmission spectrum of the Earth obtained on August 16, 2008, by

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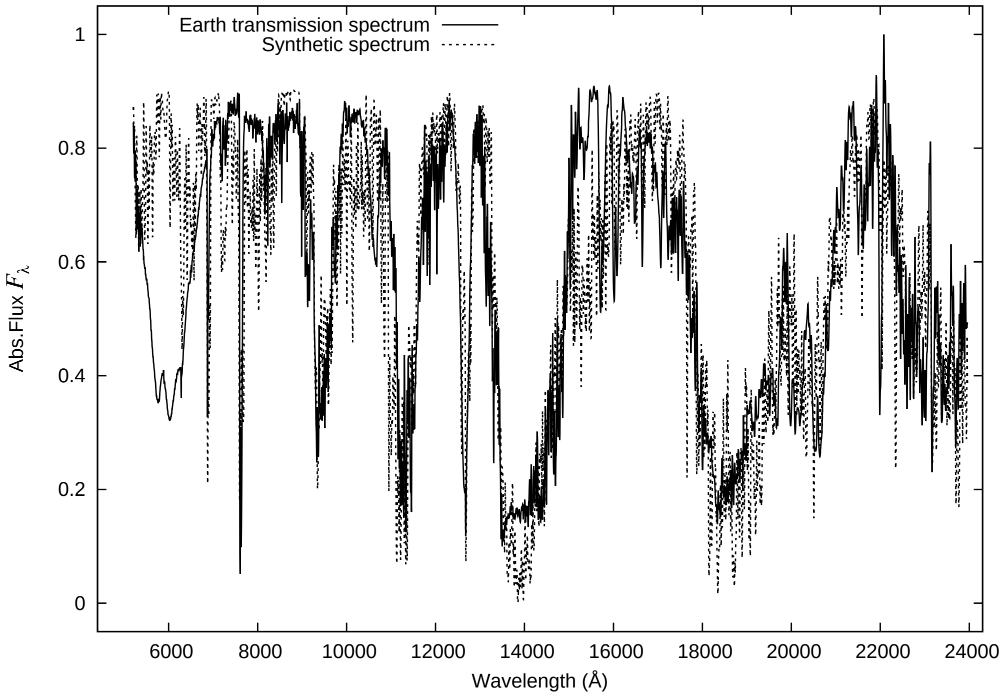

Fig. 1. The observed transmission spectrum of the Earth (solid line) compared with the best fitting spectrum from our grid of synthetic spectra (dotted line), which includes 14 molecular species (see text).

Pallé et al. (2009). Because of refractive effects the observed spectrum is coming mainly from the layers of the atmosphere higher than ~ 20 km (García Muñoz et al. 2012).

The wavelength coverage of the observed spectrum is from 0.36 to 2.40 μm, and the spectral resolution is about R $\sim$ 600. The uniqueness of this spectrum is that it covers the Earth's atmosphere taken in a moment (the ring of the atmosphere over the terminator), with all its temperatures, density gradients, clouds and other atmosphere features corresponding to different climatic zones. In such circumstances, we can try a simple model to describe the observed spectrum. We do not consider radiative transfer modeling, possible volcanic activities, meteor dust, refractive effects, diffuse sunlight (see García Muñoz et al. 2012) and other small effects which are totally unknown in case of the atmosphere of exoplanets.

We use a one-slab model which describes light transmission through a uniform medium. Our goal is to find whether we can obtain synthetic spectra that compares well with the observations. We have calculated a grid of synthetic spectra with different temperatures and concentrations of species. The best fit provides information about the relative abundances of the molecules included in the computations. We have evaluated approximate abundance ratio of the elements responsible for the most prominent features in the spectrum.

Unlike our previous paper (Polinovskyi et al. 2013) where as input line lists and the partition function data we used HITRAN 2008, in the present paper we use the updated HITRAN 2012 (Rothman et al. 2009) database. We use the Fito program by Pavlenko (2004) for the instrumental profile convolution and for finding the best fit of the input grid of calculated synthetic spectra with the observations. We adopt a Gaussian profile broadening of the absorption lines and take into account Doppler broadening and turbulent velocity of the gas that absorbs solar radiation.

3. Results and conclusions

To calculate the synthetic spectra we have used all the available molecular species in the updated HITRAN 2012 database which have transitions within the wavelength range of the observed spectrum. These species are the following: H_2O, CH_4, O_2, CO_2, NH_3, NO_2, NO, OH, HCl, C_2H_2, O_3, CO, H_2S, N_2. The best fit is shown on Fig. 1. 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). We have estimated the relative abundances of these species: H_2O/CO_2, O_2/CH_4. Some of the other species also influence the general view of the spectrum and the total fit, and hence we can say that we have found their traces in the atmosphere. Among them are the following: NH_3, NO, NO_2, CO and O_3. We note that the NH_3 molecule line list from ExoMol database (BYTe; Yurchenko et al. 2011) revealed a bigger influence on the total view of the spectrum than the one from the HITRAN database, as was previously shown in our paper (Polinovskyi et al. 2012). The BYTe line list is much more accomplished than the HITRAN NH_3 line list. We recommend to use BYTe line list rather than HITRAN for any computations involving the NH_3 molecule. We have made our calculations at the mean temperature of the Earth's atmosphere, which is about $T = 270$ K. However, we noticed that the spectra are sensitive to temperature. Thus, one can try to evaluate molecular concentrations depending on temperature profile of the atmosphere. The water vapor and the carbon dioxide have variable amounts in the total atmospheric layer and can be estimated roughly. We estimated the relative abundance ratio of H_2O/CO_2 to be about 67, which lies within the known amounts (from 10 to 100). The O_2/CH_4 ratio is about 3×10^5, which is also similar to known values (about 1.2×10^5; Lutgens & Tarbuck 1992). We have found traces of other species, as their presence in the total spectrum calculations revealed influence on the fit. We argue that this method can be used to estimate the relative abundance ratios of chemical elements in the atmospheres of exoplanets by using the spectra obtained during transits. In the case of exoplanets in the habitable regions around the host stars, this simple model can be useful to quantify how similar their atmospheres are with respect to that of the Earth.

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