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Feasibility study for a retrieval from transit spectra of Earth-like planets in the habitable zone

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Abstract

Exoplanetary atmosphere retrievals gain more and more importance with every new discovered planet. Due to the lack of prior information, the feasibility of such retrievals is widely unknown and primary limited by the number of transits (noise). With nonlinear least squares fitting and some model atmospheres, we quantitatively investigate the influence of noise, wavelength range, initial guess and resolution to assess the range of possible outcomes.

1. Introduction

The demand for atmospheric retrievals of habitable exoplanets is a rising field and will become more important the more possible candidates are discovered. At the moment there are more than 3700 exoplanets discovered and although the data coverage and/or resolution and noise level is not as good as for the Earth, the possibility to develop a retrieval is granted. The methodology of atmospheric retrievals is a classical inverse problem which is typically ill-posed. The solution of such a problem is obtained by a nonlinear least squares fit. In this contribution we want to asses the performance of our retrieval algorithm for Earth-like exoplanets and future approaches despite of their different start-ups how to retrieve the molecular vertical columns.

2. Method

The retrieval of an exoplanetary atmosphere is done by a series of forward calculations with different starting values to find the best fit of the model spectrum to the real spectrum. We only see the additional transit depth or effective height of an exoplanet, i.e. the integral of individual limb spectra traversing the atmosphere with different tangent heights and therefore we focus on estimating the vertical column densities (VCDs) of every molecule in the spectrum. We parameterize the profile by a single scale factor. For that we consider different initial guesses, noise levels and wavelength intervals to determine some limits of the retrieval. The impact of missing/additional molecules has already been studied previously [5].

2.1. Forward Model

The "Generic Atmospheric Radiation Line-by-line Infrared-microwave Code" [1] is a radiative transfer model with the purpose to simulate spectra. The code has been used for exoplanet studies, e.g. [2, 3] and has been verified by intercomparisons to other radiative transfer models, e.g. [4]. Transmission spectra are calculated with atmospheric information, limb geometry and molecule information. These limb spectra are then combined to an effective height spectrum of the atmosphere.

3. Model atmospheres

As input for the retrieval we used a set of climatological atmospheres, where all of these atmospheres have different attributes, e.g. (surface) temperatures, water content and integrated ozone content, and are provided with some important molecule profiles. The range of the temperatures and pressure levels are representative for the Earth and therefore well suited for an exoplanet retrieval of Earth-like planets in the habitable zone.

4. Results

The overall water content in the atmosphere has a huge impact on the goodness, as well as the shape of the profile. Water should be retrieved at 6.7 microns and then this value should be used as prior for other wavelength intervals. The initial guess should not be too far away otherwise the fit might end in a local minimum and not at the optimum.

5. Summary & Conclusions

A lot of retrieval results have been analyzed which lead to the following conclusions. Nonlinear least squares proved to be a good tool for exoplanet retrievals and might be even better if the prior is near the true value. The noise of Earth-like exoplanets is critical for a reliable retrieval. The wavelength window for a retrieval should be chosen according to the apparent molecules. In future, we expect better retrievals, because of the increasing number of transits and better resolutions provided by the JWST.

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