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Inverse problems in space remote sensing:
A sensitivity study on the atmospheres of Earth-like exoplanets

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Abstract

More than one thousand exoplanets have been discovered in the past two decades, with some dozen of them in the host stars' habitable zone and with size and mass similar to Earth. Furthermore, spectra of exoplanets become available with reasonable quality (resolution and noise) that trigger the question of remote sensing of the planet's atmosphere. The objective of this sensitivity study is to identify the optimal state vector representing the atmosphere in the inverse problem. Solving the inverse problem will ultimately allow to characterize the planet and determine its habitability. Using a high resolution infrared radiative transfer code with a line-by-line molecular absorption model, we calculate synthetic spectra of exoplanets orbiting dwarf stars. Key parameters describing the atmosphere (i.e., molecular abundances, temperature, pressure) are identified and the Jacobians (i.e. partial derivatives of the spectra) are evaluated to investigate the feasibility to retrieve the state of the planetary atmosphere.

1. Introduction

This work addresses the main question regarding how much can we learn from spectroscopic observations of Earth-like exoplanets along with what can we identify in terms of atmospheric conditions and biosignatures that may be present on the planet and serve as evidence of life. Since, in reality, there is limited information in the measured spectra of distant planets and scarce a priori knowledge, it is essential to determine which atmospheric parameters can be retrieved in preparation to characterize the atmospheres of small size planets. Using a high resolution infrared radiative transfer model, we calculate the emission spectra of Earth-like exoplanets and their partial derivatives with respect to the unknowns of the inverse problem (i.e. the so-called Jacobians). The analysis of the Jacobians, the (ill-) conditioning of the problem, and the correlation of the parameters allows to identify an optimal set of parameters that can be retrieved despite the limited quality of measured spectra.

2. Figures

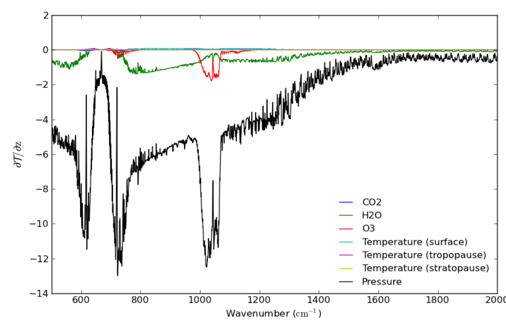

Figure 1: Computed Jacobians for a planet orbiting an M-type of star.

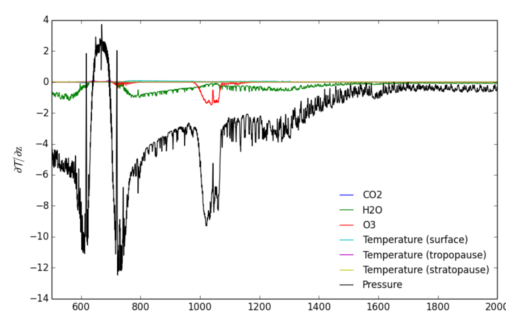

Figure 2: Computed Jacobians for a planet orbiting a G-type of star.

3. Summary and Conclusions

Sensitivity analyses based on Jacobian matrices (Figs. 1 and 2) revealed which parameters can be retrieved independently and which parameters have to be set a priori, depending on the type of observation and spectral domain. A set of few optimized state vectors were used for extensive retrieval simulations investigating impact of the initial guess and a priori data information content. The calculations provided information on data quality depending on the spectral range, resolution, and number of molecular species considered in the atmosphere. Larger correlations were found between certain parameters, what provided information about the difficulty of retrieving a certain parameter independently.