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Spectral response of Earth-like planets to orbital variations

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Abstract

We present the spectral appearance of Earth-like exoplanets in the habitable zone of different main sequence (F, K and G-type) stars and their spectral response to small orbital distance variations.

Using atmospheric profiles from a 1D atmosphere model, we compute transmission and emission spectra in the infrared using a cloud-free line-by-line radiative transfer model. The orbital distances were chosen such that surface temperatures in the atmospheric model are in the range of 273 K (outer run) to 303 K (inner run).

The spectra are then analyzed in light of current and future space telescopes like the James Webb Telescope (JWST), Spitzer and the ground based European Extremely Large Telescope (E-ELT) in order to discuss the measurability of certain spectral features.

1. Introduction

Since the discovery of the first exoplanet around a pulsar in 1992 [1] and the first exoplanet orbiting a main sequence star in 1995 [2], exoplanets have been found with an ever increasing rate. Satellites dedicated to search for transits of exoplanets in front of their host star, like CoRoT or Kepler supply us today with a comprehensive list of planets and planetary candidates. Increasing instrumental sensitivities as well as long term transit search programmes will help to detect rocky planets as well as planets further away from their host stars, where they more likely retain their atmosphere. The search for these terrestrial planets and their characterization will eventually address the question, whether life on Earth is unique.

Current planetary models mostly rely on knowledge derived from Earth, Venus or Mars. However, Earth is so far the only known example of a habitable and inhabited planet that can be used to investigate the parameter space of habitable conditions. It is straightforward (at least conceptually) to build a spectrum from a given planetary atmosphere, although it is very unlikely that an Earth "twin" will be found. The inverse problem, however i.e. to infer the characteristics of a planet from a spectrum is much more difficult as there may be several degeneracies. It is nevertheless of paramount importance to understand what type of planet lies behind a given observed spectrum.

From the huge number of parameters affecting the atmospheric and spectral appearance of a given planet, we only investigate the spectral response of an Earth-like planet orbiting different main sequence stars to small changes in orbital distance. Thus we consider only small variations away from Earth, where our model assumptions (Earth development, Earth biomass, etc.) are likely to be valid.

2. Models

We use updated atmospheric profiles from [3], who already investigated the chemical response to orbital variations. Their profiles have been computed with a one-dimensional coupled climate and photochemical model, which calculates globally, diurnally averaged atmospheric temperature, pressure, water and concentration profiles for cloud-free conditions.

With the radiative transfer model MIRART-SQuIRRL [4, 5] synthetic emission and transmission spectra are calculated assuming a cloud-free atmosphere. MIRART-SQuIRRL is a line-by-line radiative transfer program, which assumes local thermodynamic equilibrium (LTE). It uses the HITRAN2008 [6] molecular absorption line database for the calculation of absorption cross sections with temperature, pressure and concentration profiles from the atmospheric model as input. High-resolution spectra are calculated and afterwards convolved with a Gaussian function in order to generate the spectral resolution which corresponds to the corresponding instrumental setup considered.

3. Scenarios

In order to study the effect of small variations in orbital distance on the planets' atmospheric temperature and composition, and hence on the spectral appearance, we employ for each stellar type chosen, the same initial Earth-like composition as in [3]. We also used the same orbital distances to the central star: The inner edge in the model is defined where the surface temperature reached $\sim$303 K (30°C) and the outer edge was reached with a surface temperature of $\sim$273 K (0°C). These limits correspond to a definition of the habitable zone given by [7] for complex life.

4. Summary and Conclusions

With the spectral analysis of the scenarios considered, we present ways on how to infer basic atmospheric properties of terrestrial exoplanets, like the temperature structure and presence of atmospheric species even at low spectral resolutions.

We used combined information gathered from transmission and emission spectra in the light of current and near future telescope configurations at high and low spectral resolution. Also photometry channels that are common to most instruments and yield very low-resolution but high SNR values enables the characterization of a given atmosphere.

In general we found that the spectral response of the molecular absorption lines to varying the orbital distance is in agreement with the chemical responses found by [3].

We also computed the signal to noise ratios (SNR) for transmission and emission spectra for different spectral resolutions and found in general higher values for transmission spectra than for emission spectra. Here, the highest values can be found in the near-infrared, whereas emission spectra feature the highest values in the thermal infrared.

In general this study illustrates the need for detailed climate and chemical modeling of terrestrial planets with SNR calculations of the specified instrument band passes used.

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