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Model Spectra of the First Potentially Habitable Super-Earth - Gl581d

L. Kaltenegger (1,2), A. Segura (3) and S. Mohanty (3)
(1) MPIA,Germany (2) CfA, USA, (3)UNAM, Mexico, (4)Imperial College, UK (kaltenegger@mpia.de)

1. Abstract

Gl581d has a minimum mass of 7 MEarth and is the first detected potentially habitable rocky Super-Earth. Our models confirm that a habitable atmosphere can exist on Gl581d. We derive spectroscopic features for atmospheres, assuming an Earth-like composition for this planet, from high oxygen atmosphere analogous to Earth's to high CO_2 atmospheres with and without biotic oxygen concentrations. We find that a minimum CO_2 partial pressure of about 7 bar, in an atmosphere with a total surface pressure of 7.6 bar, are needed to maintain a mean surface temperature above freezing on Gl581d.

We model transmission and emergent synthetic spectra from 0.4μm to 40μm and show where indicators of biological activities in such a planet's atmosphere could be observed by future ground- and space-based telescopes. Future observations of atmospheric features can be used to examine if our concept of habitability and its dependence on the carbonate-silicate cycle is correct, and assess whether Gl581d is indeed a habitable super-Earth.

2. Introduction

Spurred by the recent large number of radial velocity detections (Mayor et al. 2009) and the discovery of the transiting system CoRoT-7b (Leger et al. 2009), the study of planets orbiting nearby stars has now entered an era of characterizing massive terrestrial planets (aka super-Earths). The Gl581 system is a particularly striking example among these new discoveries, consisting of an M3V star orbited by a minimum of 4 planets, 3 of which are in the Earth to super-Earth range (Udry et al. 2007, Mayor et al. 2009). Of key interest are the two super-Earths located on either edge of the Habitable Zone (HZ) in this system. The goals of our paper are to explore the atmospheric conditions under which this planet may be habitable. For these Earth-like assumptions, we investigate: a) the minimal atmospheric conditions for Gl581d to be potentially habitable at its current position, b) if habitability could be remotely detected in its spectra in transmission and through direct imaging and c) compare the resulting spectra to Earth's spectra and discuss differences in the chemistry due to the host star spectrum. Note that the model we present here only represents one possible nature of a planet like Gl581d in a wide parameter space that includes Mini-Neptunes. Without spectroscopic measurements we will not be able to break the degeneracy of mass and radius measurements and characterize a planetary environment.

3. Summary and Conclusions

We show that Gl581d is potentially habitable, assuming the carbonate-silicate cycle controls the atmosphere of the planet [1]. We find that a minimum CO_2 partial pressure of about 7 bar, in an atmosphere with a total surface pressure of 7.6 bar, are needed to maintain a mean surface temperature above freezing on Gl581d. The surface temperature of a simulated 90% CO_2 and low oxygen planetary atmospheres at 0.2 AU changes from 237 K to 278 K when increasing the surface pressure from 2.45 bar to 7.6 bar surface pressure. Such a level of atmospheric pressure increase due to CO_2 is reasonable even with a moderate carbonate-silicate cycle or increased outgassing of CO_2. We model synthetic spectra from 0.4μm to 40μm [1] and show where indicators of biological activities in such a planet's atmosphere could be observed by future ground- and space-based telescopes.

The model transmission spectrum of Gl581d is dominated by CO_2 down to 1μm and Rayleigh scattering below that wavelength, not providing information about the habitability of a rocky planet with a dense CO_2 atmosphere (Fig. 1). For the emergent spectra (Fig.2), the larger surface area of a Super-Earth makes the direct detection and secondary-eclipse detection of its atmospheric features and biosignatures easier than for Earth size planets. In the infrared region of the emergent spectrum, CO_2 also dominates the atmospheric features. In the visible part of the emergent spectrum, biomarkers could be detected even for high CO_2 concentrations. Note that we assumed a clear atmosphere and did not include multiple scattering in the atmosphere. Cloud coverage would further reduce the depth of all spectral features.

Our concept of the habitable zone is based on the carbonate-silicate cycle. Even so the measurements are hard (as shown in Fig. 1 and Fig. 2) this concept can be probed by observing detectable atmospheric features by future ground and space- based telescopes like E-ELT and JWST. Observation of the emergent spectrum could also determine if Gl581d is the first habitable world we have discovered.

3. Figures

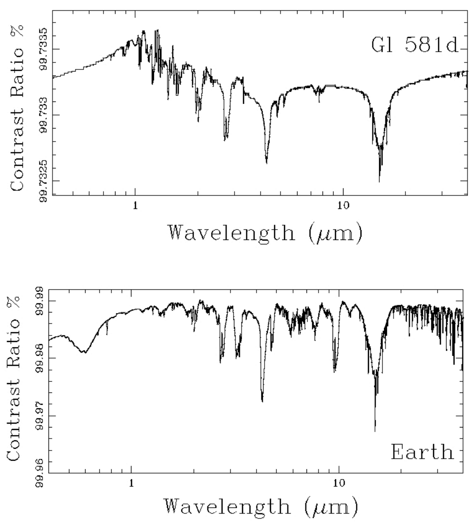

Figure 1: Planet-star contrast ratio for transmission spectra from 0.4 to 40 μm for a clear atmosphere (top) biotic O_2 and high CO_2 model atmosphere (bottom) Earth (adapted from Kaltenegger & Traub 2009).

4.1 Models of Gl 581d

For models by othr groups on Gl518d see also Hu & Ding 2011, Wordsworth et al. 2010, von Paris et al. 2010, von Bloh et al. 2007, Selsis et al. 2007. All groups reach similar results in terms of required CO_2 levels. For remote detectability of such spectral features and biosignatures see e.g. Kaltenegger et al. 2010a, 2010b, DesMaraise et al. 2002.

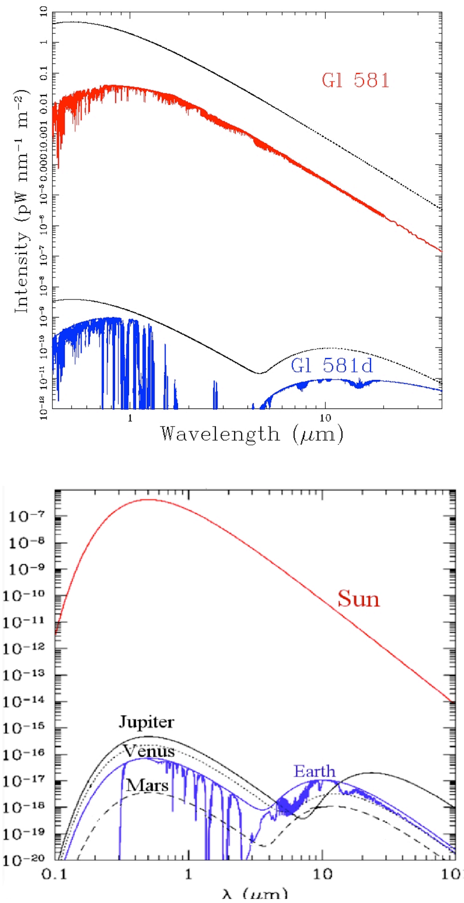

Figure 2: Planet-star contrast ratio for emergent spectra (assuming 1/2 illumination of the planet) from 0.4 to 40 μm for a clear atmosphere (top) biotic O_2 and high CO_2 model atmosphere (black indicated the Earth-Sun system level)), (bottom) Sun and Earth (adapted fromTraub & Jucks 2002).

Acknowledgements

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References

[1] Kaltenegger, L., Segura, A., & Mohanty, S., ApJ. 733,1