Bioastronomy 2007: Molecules, Microbes, and Extraterrestrial Life
ASP Conference Series, Vol. 420, 2009
K. J. Meech, J. V. Keane, M. J. Mumma, J. L. Siefert, and D. J. Werthimer, eds.

Transit Spectroscopy of the Extrasolar Planet HD 209458b

P. Rojo,[1] J. Harrington,[2] D. Deming,[3] and J. Fortney[4]

[1]*Departamento de Astronomía, Universidad de Chile*

[2]*Department of Physics, University of Central Florida*

[3]*Planetary System Laboratory, NASA Goddard Space Flight Center*

[4]*Space Sciences and Astrobiology Division, NASA Ames Research Center*

Abstract. An attempt to detect water in the atmosphere of the extrasolar planet HD 209458b using transit spectroscopy is presented. A radiative transfer model, designed and built specifically for this project, predicts the dependence in wavelength of the stellar spectrum modulation due to a transiting planet, given a planetary temperature/pressure/composition profile. A total of 352 spectra around 1.8 microns were obtained during three transit events using ISAAC at the Very Large Telescope.

Correlating the modeled modulation with the infrared spectra yields a non-detection of water in the atmosphere of HD 209458b due to overwhelming contamination from telluric water lines.

Original data-reduction techniques that were developed during this work are also presented.

At the time of writing this article, around 30 of the almost 270 known extrasolar planets transit in front of their host stars. Despite the small number, those transiting planets have proved invaluable by providing an excellent opportunity to accurately measure planetary properties. The unexpected variety found even in this small sample makes it clear that planets are not just small stars, since not even their bulk properties can be solely determined by their masses.

Strong limits on molecular abundances in exoplanetary atmospheres are eagerly awaited by theorists to validate their models. In addition, conclusions of atmospheric abundances over a statistically-significant sample will undoubtedly help selecting appropriate targets to maximize the science return from ambitious space-based missions in the coming decade. Missions whose ultimate goal will be to detect and characterize Earth-like planets.

Here we present an attempt to use the transit spectroscopy technique on the system HD 209458. This technique uses the fact that the area a transiting planet blocks from its host star varies with wavelength according to the unique spectral features of molecules in the exoatmosphere, allowing identification and abundance measurements from appropriately-timed observations.

1. The Model

We developed an efficient radiative transfer code that predicts the modulation (which is defined as the in-transit spectra divided by the stellar, or out-of-transit,

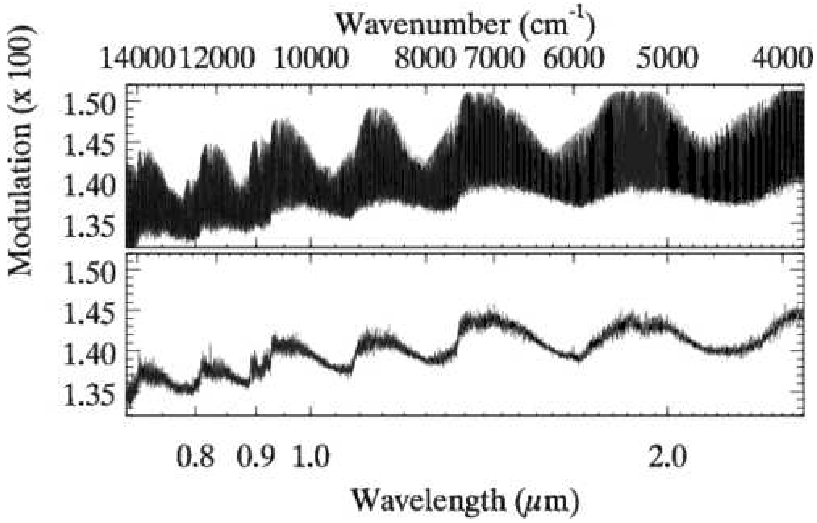

Figure 1. Infrared modulation of HD 209458 due to water, convolved to wavelength resolutions of $R = \lambda/\Delta\lambda = 30000$ and $R = 5000$, for the top and bottom frame, respectively. This modeled modulation includes close to 22 million lines from Partridge & Schwenke (1997) water line database, more than half a million wavenumber points, and over 50 planetary layers. The result was obtained in just a couple of hours with a desktop computer. Planetary profile from Fortney et al. (2005)

spectra) given molecular line data, system geometry, and thermal and abundance profiles for any transiting planet. For each wavelength and projected planetary radius, the code follows a ray through its trajectory into the atmosphere. Besides calculating molecular line opacities from up-to-date molecular line databases, it also calculates continuum opacity for clouds and collision-induced absorption from H2-He and H2-H2 pairs (Borysow et al. 2001; Jørgensen et al. 2000). Fig. 1 shows sample modulation spectra.

2. The Data

Three transit events were observed with ISAAC at the VLT (Moorwood et al. 1998). Chosen wavelength range was believed to be at the right distance from an absorption band in order to obtain an exoplanetary spectrum that is both strong enough for detection and is not overwhelmed by the telluric absorption. The integration time of each spectral frame was limited to 60 seconds and we use the standard ABBA nodding sequence.

Due to the small modulation amplitude (Fig. 1), it was necessary to correct for previously ignored systematic errors. For instance, we developed a new method to remove the appearance of fringes on flat fields that did not appear on data frames (Rojo & Harrington 2006).

We use an optimal extraction algorithm (Dermody and Harrington, 2006, private communication) to obtain the spectra. Then, we tried 3 different methods to remove the telluric water. This is the most critical step and it is only

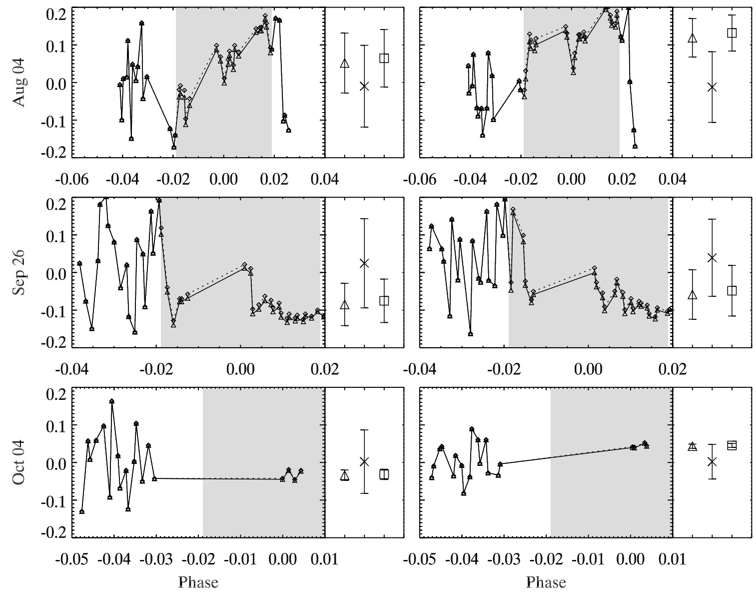

Figure 2. Correlation result for each night and beam (ABBA beams A and B, on the left- and right-side frames, respectively). The left side of each frame shows the correlation value for each spectra. The solid line indicates the results from the real data. The dotted line indicates the result for the synthetic data. The shaded areas indicate the in-transit phases. On the right side of the frame, the symbols triangle, diamond, and square are the average correlation of the out-of-transit, in-transit-real, and in-transit-synthetic spectra, respectively.

possible due to the temperature difference between the telluric and the exoplanetary atmosphere. Wavelength channels that still remained variable were masked out from further analysis. The corrected spectra was divided by an out-of-transit average to obtain the modulation.

3. The Result

The modeled modulation was correlated with each observed modulation. A successful detection would translate in a correlation value of the out-of-transit spectra that is distinctly closer to zero than the correlation values of the in-transit spectra. This is not the case in any of the observing nights. Furthermore, creating a synthetic dataset (by adding the modeled modulation to each in-transit spectra immediately after extraction) does not change the correlation result by a significant amount (Fig. 2) indicating that, even if the signal were there, our analysis would have not detected it.

After performing several tests to check the pipeline (including scaled planetary atmospheres, where detection was indeed attained), the only explanation left is that in the chosen wavelength range the telluric water absorption was too strong and variable, overwhelming any signal there may be from the extrasolar planet.

4. Future Work

Recently, Tinetti et al. (2007) and Barman (2007) identified water in the atmosphere of an exoplanet using broad-band photometry. Their results seem to confirm the existence of water on an extrasolar planet atmosphere with a high degree of confidence, but they were not able to constrain its molecular abundance. A strong result using IR transit spectroscopy will provide more information as it is more sensitive to abundance variations in models.

To overcome the biggest shortcomings on new observations, we developed a new method to choose the best possible observing wavelength from ground-based observations. Observing time has been granted, where improved observations have just recently been obtained.

Acknowledgments. This material is based on work supported by the National Aeronautics and Space Administration under grant NAG5-13154 issued through the Science Mission Directorate. The presentation on this conference was possible by the support from a BioAstronomy 2007 grant, and the Fondap Astrophysics, Chile

References

Barman, T. 2007, ApJ, 661, L191

Borysow, A., Jørgensen, U. G., & Fu, Y. 2001, Journal of Quantitative Spectroscopy and Radiative Transfer, 68, 235

Fortney, J. J., Marley, M. S., Lodders, K., Saumon, D., & Freedman, R. 2005, ApJ, 627, L69

Jørgensen, U. G., Hammer, D., Borysow, A., & Falkesgaard, J. 2000, A&A, 361, 283

Moorwood, A., Cuby, J.-G., Biereichel, P., Brynnel, J., Delabre, B., Devillard, N., van Dijsseldonk, A., Finger, G., Gemperlein, H., Gilmozzi, R., Herlin, T., Huster, G., Knudstrup, J., Lidman, C., Lizon, J.-L., Mehrgan, H., Meyer, M., Nicolini, G., Petr, M., Spyromilio, J., & Stegmeier, J. 1998, The Messenger, 94, 7

Partridge, H. & Schwenke, D. W. 1997, J. Chem. Phys. , 106, 4618, [P&S]

Rojo, P. M. & Harrington, J. 2006, ApJ, 649, 553

Tinetti, G., Vidal-Madjar, A., Liang, M.-C., Beaulieu, J.-P., Yung, Y., Carey, S., Barber, R. J., Tennyson, J., Ribas, I., Allard, N., Ballester, G. E., Sing, D. K., & Selsis, F. 2007, Nat, 448, 169