EPSC Abstracts
Vol. 13, EPSC-DPS2019-965-1, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Exoplanet reflected light retrieval: what can we learn?

Mario Damiano (1), Renyu Hu (1,2)
(1) Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, USA,
(2) Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125, USA,
(mario.damiano@jpl.nasa.gov)

Abstract

The discovery of thousands of exoplanets with a huge range of masses, sizes, and orbits has extended the horizon of the planetary exploration. The atmospheres of short-period gaseous planets, Jupiter- and Neptune-size, are being observed and characterized. The emission and transmission spectra have revealed molecular absorption of H_2O, CO, CH_4, CO_2, TiO and VO and in some cases the presence of clouds and hazes in the atmosphere. The transit technique has provided most of the current results as it benefits more if the target planets is close to their parent stars. However, these planets show a different environment compared to the planets in the Solar System planets due to higher irradiation received. The high-contrast imaging technique is meant to provide insights into those planets orbiting far away from their host star (distance 1 AU) so that their atmospheric temperature is low enough to show different chemical and dynamical behaviour (e.g. condensation mechanism, cold trap, etc.). In this work, we present a novel model to synthesize the wavelength's dependence of the albedo of a gaseous planetary atmosphere. This algorithm is used as forwarding model for inverse retrieval processes on reflected light spectra. These contain rich information on the molecular composition, and cloud formation processes of exoplanet atmospheres.

1. Introduction

The high-contrast imaging technique is meant to provide insights into those planets orbiting far away from their host star (distance 1 AU) so that their atmospheric temperature is low enough to show different chemical and dynamical behaviour (e.g. condensation mechanism, cold trap, etc.). This technique has proven to be successful in studying forming young Jupiter-size planet [1, 2, 3]. Possible future direct-imaging exoplanet space mission, e.g. Wide-Field InfraRed Survey Telescope (WFIRST, [4, 5]), Habitable Exoplanet Imaging Mission (HabEx, [6]) and Large Ultra-Violet/Optical/InfraRed Surveyor (LUVOIR, [7]) will observe through high-contrast imaging the starlight reflected by exoplanets unveiling their atmospheric structure. Rayleigh scattering, molecular absorption, and scattering and absorption by atmospheric condensates determine the reflection spectra of gaseous exoplanets [8, 9]. Whether there exist clouds is the primary factor that controls the appearance of an exoplanet. Depending on the atmospheric temperature, an exoplanet may or may not have clouds [10, 11]. Assuming an atmospheric elemental abundance the same as the Sun, giant exoplanets may have ammonia, water or silicate clouds in their atmospheres depending on the orbital distance from their parent stars [12, 13, 14]. The radiative properties of the clouds are sensitive to the vertical extent and density of the cloudy layer and the sizes of cloud particles [15]. The elemental abundance of the atmosphere also affects the formation of the clouds [16]. As such, reflected light spectra of exoplanets contain rich information on the composition, and dynamic processes of exoplanetary atmosphere.

2. Model

The focus of the presented work is on cold gaseous planets. We have developed a simplified calculation of the cloud top pressure on gaseous exoplanets H_2-dominated atmospheres and have equilibrium temperatures between 100 and 300 K. The model is an extension of the classical equilibrium cloud model that has successfully predicted the bulk cloud structure of Jupiter [17, 18]. The model considers water and ammonia as potential condensible species, it calculates the particle size to determine the radiative properties of clouds, it includes the cloud feedback on the adiabatic lapse rate and the albedo of the planet. We assume water, methane, and ammonia are always the dominant carrier for oxygen, carbon, and nitrogen. This assumption is valid for the planets of consideration (i.e. cold Jupiter and Neptune-sized planets having atmospheres mainly composed of hydrogen and helium). The hydrogen dominance and low temperatures of the atmosphere ensure these elements on their most hydrogenated forms [19, 20]. The model takes the position and basic physical information of water and ammonia clouds to compute the density, and the particle size of these clouds as well as a T-P profile consistent with the lapse rate equation. This algorithm is used as forward model for the Bayesian sampler nested sampling [21, 22] and its implementation MultiNest [23] to perform inverse retrieval processes on reflected light spectra.

3. The parameters space

As aforementioned (see Sec. 2) we consider water and ammonia to be the species that condensate in the atmosphere. For each of the two molecules, we chose four parameters that fully characterize the position and chemical properties of the respective cloud form. The P_{top} indicates the top position of the cloud and D_{bot} accounts for the vertical extension of the cloud. Then the $Volume\ Mixing\ Ratio$ (VMR) is the molecule per volume unit that can be found below the cloud layer, and finally the $Condensation\ Ratio$ (CR) indicates the ratio between the VMR of the considered molecule on top of the cloud layer and the VMR below the cloud, this will allow the calculation of the density of the cloud and its optical properties (see e.g. Fig. 1).

Aside from these four parameters, we also included the VMR of methane and the planetary gravity g. When all the parameters are fitted we have a model with 10 free parameters, otherwise, when only one of the species between H_2O or NH_3 is considered to condensate we use a model with 7 free parameters (the VMR of the two molecules is always a free parameter).

Previous works on the topic (e.g. [24, 25]) were designed to retrieve optical properties (optical depth, scattering, albedo, and asymmetry factor) and cloud depth as model parameters, but not linking them to a physical model of cloud composition (such as particle size, cloud density and cloud spectral information). The clouds composition and their structure are instead the core of our model.

4. Result

By using this model to perform a Bayesian inverse retrieval process on a cold gaseous reflection light spectrum, we have been able to determine cloud structure and main chemical composition (Fig. 2). In particular, the methane abundance is retrieved without showing any significant correlations with other parameters. From the retrieved gravity we are able to infer also the radius of the planet. Moreover, we are able to characterize water and ammonia clouds in the atmosphere; in particular, the density, the optical depth and the particle size are parameters derived from the retrieved VMR vertical profile of H_2O or NH_3 (see e.g. Fig. 1).

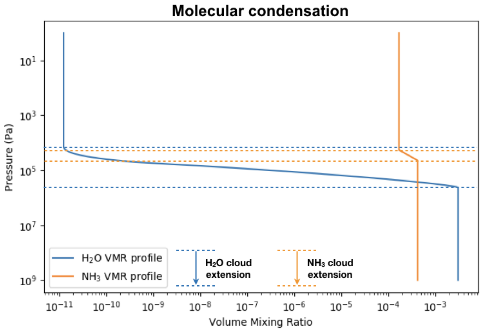

Figure 1: VMR H_2O and NH_3 vertical profile. The VMR of the two molecules decreases when they pass into the condensate form. This is highlighted with dashed lines.

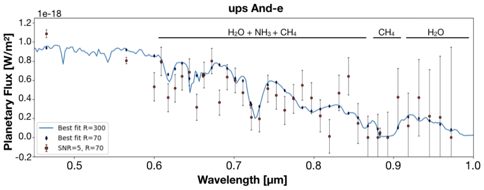

Figure 2: Simulated reflection spectrum in the optical wavelength. The data is a simulation for the planet *ups And-e*. The best fit model has been calculated by using the Bayesian sampler *MultiNest*.

Acknowledgements

This work has been supported by the California Institute of Technology Jet Propulsion Laboratory Exoplanet Science Initiative. This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

References

[1] Barman, T. S., Macintosh, B., Konopacky, Q. M., & Marois, C. 2011, ApJ, 733, 65.

[2] Skemer, A. J., Marley, M. S., Hinz, P. M., et al. 2014, ApJ, 792, 17.

[3] Macintosh, B., Graham, J. R., Barman, T., et al. 2015, Science, 350, 64.

[4] Spergel, D., Gehrels, N., Breckinridge, J., et al. 2013, arXiv e-prints, arXiv:1305.5422.

[5] Spergel, D., Gehrels, N., Baltay, C., et al. 2015, arXiv e-prints, arXiv:1503.03757.

[6] Mennesson, B., Gaudi, S., Seager, S., et al. 2016, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 9904, Space Telescopes and Instrumentation 2016: Optical, Infrared, and Millimeter Wave, 99040L

[7] Peterson, B. M., Fischer, D., & LUVOIR Science and Technology De

nition Team. 2017, in American Astronomical Society Meeting Abstracts, Vol. 229, American Astronomical Society Meeting Abstracts 229, 405.04

[8] Marley, M. S., Gelino, C., Stephens, D., Lunine, J. I., & Freedman, R. 1999, ApJ, 513, 879

[9] Seager, S., Whitney, B. A., & Sasselov, D. D. 2000, ApJ, 540, 504

[10] Sing, D. K., Fortney, J. J., Nikolov, N., et al. 2016, Nature, 529, 59

[11] Barstow, J. K., Aigrain, S., Irwin, P. G. J., & Sing, D. K. 2017, ApJ, 834, 50

[12] Sudarsky, D., Burrows, A., & Pinto, P. 2000, ApJ, 538, 885

[13] Sudarsky, D., Burrows, A., & Hubeny, I. 2003, ApJ, 588, 1121

[14] Burrows, A., Sudarsky, D., & Hubeny, I. 2004, ApJ, 609, 407

[15] Ackerman, A. S., & Marley, M. S. 2001, ApJ, 556, 872

[16] Cahoy, K. L., Marley, M. S., & Fortney, J. J. 2010, ApJ, 724, 189

[17] Weidenschilling, S. J., & Lewis, J. S. 1973, Icarus, 20, 465

[18] Atreya, S. K., Wong, M. H., Owen, T. C., et al. 1999, Planetary and Space Science, 47, 1243

[19] Madhusudhan, N. 2012, ApJ, 758, 36

[20] Hu, R., & Seager, S. 2014, ApJ, 784, 63

[21] Skilling, J. 2004, in American Institute of Physics Conference Series, ed. R. Fischer, R. Preuss, & U. V. Toussaint, Vol. 735, 395-405

[22] Skilling, J. 2006, Bayesian Analysis, 1, 833

[23] Feroz, F.,& Hobson, M. P. 2007

[24] Lupu, R. E., Marley, M. S., Lewis, N., et al. 2016, AJ, 152, 217

[25] Feng, Y. K., Robinson, T. D., Fortney, J. J., et al. 2018, AJ, 155, 200,