EPSC Abstracts
Vol. 12, EPSC2018-1011, 2018
European Planetary Science Congress 2018

Validation of an exoplanetary atmospheric model for high resolution spectroscopy for remote sensing

Denis Shulyak (1), Miriam Rengel (1), Ansgar Reiners (2)
(1) Max Planck Institute for Solar System Research, Justus-von-Liebig-Weg 3, 37077 Göttingen (denis.shulyak@gmail.com)
(2) Institute for Astrophysics, Friedrich-Hund-Platz 1, 37077 Göttingen

Abstract

The discovery of first planets orbiting other stars opened a new era of (exo)planetary research with a potential to find many planets similar to our own home. Thanks to the great success of the *Kepler* mission, but also other photometric and spectroscopic surveys, we learned that there are many other planets that span a wide range of masses from several Jupiter masses to very small rocky Mercury-size objects. These exoplanets are expected to have very different chemical and physical structures, and studying their atmospheres provides an insight into origin, evolution, composition, temperature stratification, dynamics, and habitability. Present and future observing facilities will make it possible to address these important questions in more detail and will shape the exoplanetary science for decades to come. The aim of our work is to test theoretical models and approach against a model observations in near-infrared wavelengths at very high spectral resolution as provided by, e.g., soon expected CRIRES$^+$ instrument (ESO, Chile). We will apply available and develop a methodology to assess our ability for remote sensing of exoplanetary atmospheres from individual spectral features. We will also present suggestions for the improvements of existing models and analysis techniques in the framework of future observing facilities.

1. Introduction and objectives

Retrieval of atmospheric features from transmission and emission spectroscopy is a powerful method to constrain chemical and physical conditions in atmospheres of exoplanets. Using dedicated inversion techniques and predictions from forward models we can study a variety of physical phenomena originated in planetary atmospheres [1, 2]. Because of obvious limitations of modern instruments for exoplanet research in terms of efficiency, integration time, wavelength coverage, and sources of uncertainties, only a very small group of large planets in close-in orbits (known as hot-Jupiters) were accessible for observations. But already these limited observations were proven to bear an essential information about temperature-pressure atmospheric structure and composition of main absorbing species[3]. It is clear that future instruments and missions will allow us to detect and explore features from even smaller planets.

Until now, some available retrieval methods have been tested against low resolution observations. While providing obvious improvements in terms of, e.g., integration time needed to achieve a required signal-to-noise ratio, there are other physical processes that are difficult or impossible to capture with low resolution (atmospheric winds and circulations, abundances of trace gases, etc.). Therefore, our main goal here is to explore our ability to measure atmospheric properties of extrasolar planets from high-resolution observations. This work is grossly motivated (but not limited to) the soon available CRIRES$^+$ spectrograph mounted at the 8-m VLT telescope of the European South Observatory (ESO, Chile). CRIRES$^+$ will have unique characteristics essential for the exoplanetary research. In particular, it will be able to cover an entire near-infrared range between $0.93-5.3$ μm in only a few exposures and with very high resolving power of R= $50\,000-100\,000$ essential to resolve individual spectral lines and track them simultaneously [4]. Also, it will have a polarimetric module that will open a whole new way to study morphology of planetary atmospheres via the analysis of the linear polarization originated from, e.g., the scattering on particles and condensates presented in, e.g., planetary clouds and hazes.

Thus we want to push the limits of present models and observing facilities to high spectral resolution. Future observation facilities will no doubt provide new, more accurate and robust information about planetary atmospheres, which will also help to better validate and improve our theoretical models.

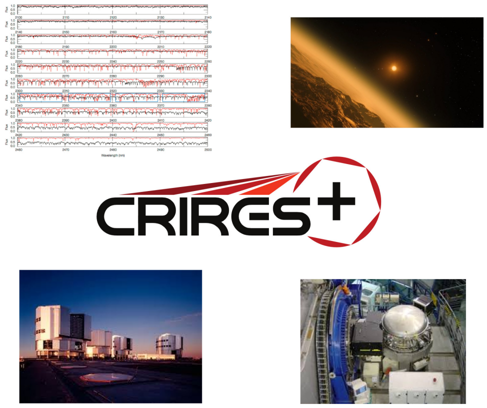

Figure 1: CRIRES^{+} exoplanet research. Image credits: ESO.

2. Analysis methods

In our approach we combine both forward and inverse models. Exoplanet science has benefited tremendously from the decades of work on Solar System planets. We plan to adopt the retrieval technique based on optimal estimator and, e.g., dedicated radiative transfer model [5]. We adapt this model to the observations delivered by modern instruments that are used for exoplanet research. The essential part of our analysis is to predict the amount of information that we can derive by applying our algorithms to different sets of spectral lines. For instance, by studying CO lines at 2.3 μm and their time variability it is possible to constrain the global wind pattern in atmospheres of distant planets [6]. Similar, strong potassium lines in the H-band as well as the lines of molecules like, e.g., H_2O, HCN, NH_3, and CH_4 can be used to probe the atmospheric structure and composition, etc. We plan to investigate the limitations of modern approaches arising from the wavelength range and instrument's resolving power used, and address possible not yet included physics in our forward models. Our final result here is the list of suggestions and improvements that need to be done both in models and retrieval techniques essential for the future research with high resolution instruments.

3. Discussion

In spite of the current very fast progress in exoplanetary science from both theoretical and observation points of view, we still lack instruments capable of catching signatures from atmospheres of planet smaller than Jupiter size giants. Moreover, the spectroscopic observations are too sparse, often suffer from instrument systematics, low SNR, etc. However, future facilities will greatly improve towards better performance and wavelength coverage thus allowing us to address new questions about structure of exoplanetary atmospheres. Increasing the spectral resolution is a promising way to learn more detailed physics and test our models. There are many codes and tools designed for the retrieval and forward modelling of exoplanet atmosphere, but little attention has been paid so far to model individual spectral lines with an efforts in accurate predictions and at near-infrared domain. Because there are a number of new instruments coming to operation exactly at this wavelength range, we find it important to improve the model, make more accurate predictions, and apply our approach to real data.

Acknowledgements

This research is supported by the DFG priority program SPP 1992 "Exploring the Diversity of Extrasolar Planets"

References

[1] Gandhi, S., & Madhusudhan, N.: Retrieval of exoplanet emission spectra with HyDRA, MNRAS, 474, 271, 2018

[2] Waldmann, I. P., Tinetti, G., Rocchetto, M., et al.: Tau-REx I: A Next Generation Retrieval Code for Exoplanetary Atmospheres, ApJ, 802, 107, 2015

[3] Tinetti, G., Encrenaz, T., & Coustenis, A.: Spectroscopy of planetary atmospheres in our Galaxy, A&ARev, 21, 63, 2013

[4] Dorn, R. J., Anglada-Escude, G., Baade, D., et al.: CRIRES+: Exploring the Cold Universe at High Spectral Resolution, The Messenger, 156, 7, 2014

[5] Rengel, M., Hartogh, P., & Jarchow, C.: Mesospheric vertical thermal structure and winds on Venus from HHSMT CO spectral-line observations, P&SS, 56, 1368, 2008

[6] Snellen, I. A. G., de Kok, R. J., de Mooij, E. J. W., & Albrecht, S.: The orbital motion, absolute mass and high-altitude winds of exoplanet HD209458b, Nature, 465, 1049, 2010