EPSC Abstracts
Vol. 12, EPSC2018-467, 2018
European Planetary Science Congress 2018

A comparison of exoplanet retrieval tools

Joanna K. Barstow (1), Ryan Garland (2), Michael R. Line (3), Marco Rocchetto (1), and Ingo P. Waldmann (1)
(1) Department of Physics and Astronomy, University College London, UK (2) Atmospheric, Oceanic and Planetary Physics, University of Oxford, UK (3) School of Earth and Space Exploration, Arizona State University, Arizona, USA
(j.eberhardt@ucl.ac.uk)

Abstract

In recent years, spectroscopic observations of transiting exoplanets have begun to uncover information about their atmospheres including atmospheric structure and composition, and indications of the presence of clouds. Spectral retrieval is the leading technique for interpretation of exoplanet transmission spectra. Whilst several atmospheric models and retrieval algorithms have been successfully employed, as yet the different model suites have mostly been used in isolation and so it is unknown whether results from each are comparable. As we approach the launch of the *James Webb Space Telescope* in 2020, and looking further ahead to the recently-selected *ARIEL* mission, we are entering a new data-rich era in the field of exoplanet atmospheres and so it is important that the tools that will be used to interpret these data are properly verified. We here present a comparative study of three retrieval code suites: *TauREX*; *NEMESIS*; and *CHIMERA*, and demonstrate that they produce comparable results for both forward and retrieval models.

1. Introduction

The launch of the *James Webb Space Telescope* (*JWST*) in 2020 will provide transit and eclipse spectra of exoplanets with unprecedented signal-to-noise and spectral resolution, increasing our capacity for comparative exoplanet science. *ARIEL*, to be launched in 2028, will perform the first atmospheric census of exoplanet atmospheres. For the first time, progress is likely to be be limited by model completeness and robustness rather than data quality, and meaningful comparison between results obtained by different teams will require careful benchmarking of the tools used in interpretation.

Exoplanet retrieval algorithms generate (usually 1-D) forward models of exoplanet atmospheres, then iteratively solve the inverse problem to find the best fitting model solution to the observed data. This technique has been used extensively (e.g. [5, 6, 1, 7]) and is acknowledged to be an efficient and reliable method for constraining exoplanet atmospheres from transmission and eclipse spectra. Whilst all retrieval codes follow the same basic structure, there is substantial variation in both the forward model set up and the method used to solve the inverse problem, leading to the possibility that two different retrieval codes may provide vastly different solutions to the same dataset (e.g. the four analysis of WASP-63b presented by [3]).

To test the robustness of the retrieval approach to this sort of issue we here present a comparison of three different retrieval codes, all of which have been previously used to analyse transmission spectra of exoplanets. *NEMESIS* was originally an optimal estimation retrieval algorithm developed for solar system planets [2], which was expanded to include exoplanets [4] and has recently been upgraded to incorporate a nested sampling algorithm. *TauREX* [8] and *CHIMERA* [5] were both developed for application to exoplanet spectra and also use a nested sampling algorithm.

2. Forward model comparison

The first step of the retrieval comparison was to check that the forward models in each case showed reasonable agreement. We compared output transmission spectra for simple model atmospheres including only a single spectrally active gas, with isothermal temperature profiles. We then moved on to comparing more realistic planet models, including simple clouds and combinations of spectrally active gases. An example is shown in Figure 1; this planet is a super Earth with a cloud-free H_2-dominated atmosphere and an isothermal temperature of 400 K. Trace species in the atmosphere include NH_3, CH_4, and H_2O. An excellent agreement was obtained between the three forward models.

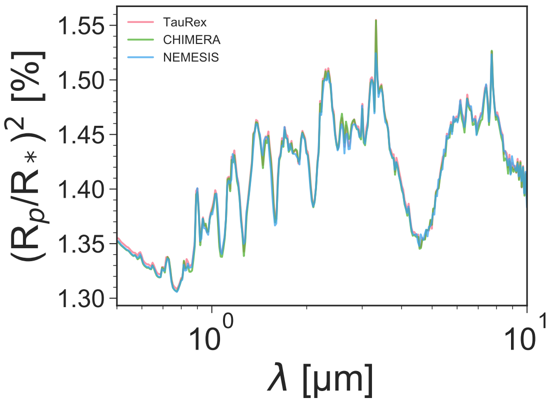

Figure 1: Synthetic transmission spectra for the same model planet generated by each of the three retrieval codes.

3. Retrieval comparison

We take the more realistic model planets such as the case discussed in Section 2 and bin the spectra down to a resolution of R=100 over the wavelength range of 0.5–10 μm. These spectra are cross-retrieved between the three algorithms to assess whether spectra generated with one model can be accurately retrieved using the others. We test error bars at 30, 60 and 100 ppm, with no noise added directly to the spectra to avoid outliers within a noise draw introducing bias into our results. We find that in the majority of cases the cross retrievals produce the correct result, demonstrating that our retrieval codes have been successfully benchmarked against each other.

4. Summary and Conclusions

Benchmarking of forward model and retrieval codes is an important preparatory step for the interpretation of exoplanet spectra obtained with *JWST* and *ARIEL*. We have shown that comparable output can be obtained using retrieval codes with different development histories and parameterizations, and hope this will encourage future efforts in this area.

Acknowledgements

JKB is supported by a Royal Astronomical Society Research Fellowship. IW is supported by European Research Council Starter Grant ExoAI.

References

[1] Barstow, J. K., Aigrain, S., Irwin, P. G. J., & Sing, D. K. 2017, The Astrophysical Journal, 834, 50

[2] Irwin, P. G. J., Teanby, N. A., de Kok, R., et al. 2008, Journal of Quantitative Spectorscopy and Radiative Transfer, 109, 1136

[3] Kilpatrick, B. M., Cubillos, P. E., Stevenson, K. B., et al. 2017, ArXiv e-prints, arXiv:1704.07421

[4] Lee, J.-M., Fletcher, L. N., & Irwin, P. G. J. 2012, Monthly Notices of the Royal Astronomical Society, 420, 170

[5] Line, M. R., Wolf, A. S., Zhang, X., et al. 2013, The Astrophysical Journal, 775, 137

[6] Madhusudhan, N., Crouzet, N., McCullough, P. R., Deming, D., & Hedges, C. 2014, ApJL, 791, L9

[7] Tsiaras, A., Waldmann, I. P., Zingales, T., et al. 2017, ArXiv e-prints, arXiv:1704.05413

[8] Waldmann, I. P., Tinetti, G., Rocchetto, M., et al. 2015, The Astophysical Journal, 802, 107