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Ground and space based spectroscopy of exoplanetay atmospheres

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Abstract

The characterisation of ever smaller and fainter extrasolar planets requires a intricate under- standing of the data and the analysis techniques used and correcting the raw data at the 10^{-4} level of accuracy is one of the central challenges. So far several observational strategies have been employed for ground-based spectroscopy. Whenever we have multiple observations of the same eclipse event, we can statistically filter the desired lightcurve from the systematic noise components. This filtering can be done in several ways. Using new IRTF data, in the K and L-bands, we will illustrate the intricacies of two spectral retrieval approaches: 1) the self-filtering and signal amplification achieved by consecutive convolutions in the frequency domain, 2) the blind de-convolution of signal from noise using non-parametric machine learning algorithms.

1. Introduction

The field of extrasolar planets is rapidly evolving, both in terms of number of planets discovered and techniques employed in the characterisation of these distant worlds. With the removal of spectroscopic capabilities for Spitzer, increased efforts need to be undertaken to ensure spectroscopic capabilities using ground-based observatories. As inarguably difficult as this is, various groups have succeeded in the detection of metal lines and complex molecules from the ground in the recent past [1, 2, 3, 4].

So far several observational strategies have been employed for ground-based spectroscopy and are distinct in their advantages and dis-advantages. Using time-resolved spectroscopy, we obtain an individual lightcurve per spectral channel of the instrument. The benefits of such an approach are multifold since it allows us to utilise a broad spectrum of statistical methods.

2. Unsupervised machine learning

In Waldmann (submitted, [6]), we worked towards the deconvolution of the desired astrophysical signal from non-Gaussian systematic noise components using unsupervised machine learning. Such a process is often referred to as 'blind source deconvolution' or the 'Cocktail Party Problem'. Here several statistical independent signals are convolved with one another and the challenge becomes to disentangle these signals without any a priori knowledge of the system or the data. Such non-parametric approaches are an important new development since they guarantee the highest amount of objectivity in spectral retrieval and are not limited by so called 'optical state vectors' in the case of Hubble and Spitzer observations. Waldmann (in prep.) will demonstrate the applicability to HST data-sets.

3. Convolution in Fourier Space

A complementary technique, as it employs very different statistics to the above, we have successfully used lightcurve convolution in the Fourier domain to extract atmospheric signatures [4, 5]. By multiplying individiual lightcurves in the Fourier domain, we can show that one lightcuve becomes the filtering function of the other and by consecutively repeating this procedure, this self-filtering amplifies common lightcurve signal whilst suppressing variable systematics noise components.

4. Application to HD 189733b

We applied the Fourier technique to three gound-based data sets of the secondary eclipse of HD 189733b, obtained with the SpeX instrument on the NASA Infrared Telescope Facility (IRTF). The night of the August 11th 2007 has previously been presented by S10 and the instrumental setup described therein has been equally applied to the other two nights obtained [5].

We have computed the K and L-band emission spectra of HD 189733b for the three individual nights obtained and found these to be consistent with each other within the error bars. The individual nights were combined to form an average spectrum shown in figures 2 & 3. In the L-band, figure 3, we detect very strong emission features at $\sim$3.3μm. These emissions peak at a brightness temperature of $T_{bright} \sim$ 3000 K. With the average planetary temperature being significantly lower at $T_{eff} \sim$ 1200 K, these emissions cannot be associated to LTE processes. It becomes clear that LTE models derived and tested on solar-system planets reach their limits of applicability. The association with non-LTE emissions of the methane ν3 branch is at hand. Similar fluorescence effects have been observed in our own solar system, mainly CO_2 in telluric and CH_4 in giant solar system planets.

In the K-band (figure 2) a comparison with two LTE simulations, one including CH_4 plus CO_2 in absorption and another model with CH_4 in LTE emission were computed. However, neither of the two simulations perfectly capture the spectrum observed. Given the stronger non-LTE emission features detected at $\sim$3.3 μm, one should expect to find non-LTE effects in the K-band as well. However, further observations are required in order to decisively constrain the excitation mechanisms at work.

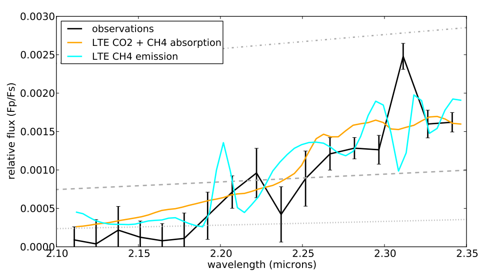

Figure 1: Three night combined K band spectrum compared with three black body curves at 1000, 1500, 2000 K. Furthermore two LTE models of CH_4 in emission (turquoise) and CH_4 plus CO_2 in absorption (orange).

5. Summary and Conclusions

Here we introduce two complementary methods for exoplanetary spectral retrieval, namely: 1) unsupervised machine learning and 2) self-filtering of the data using multiple convolutions. Both techniques are non-parametric and do not depend on a priori information

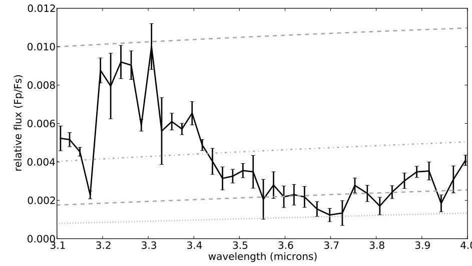

Figure 2: Three nights combined L-band spectrum. Overlaid are black body curves at 100, 1500, 2000, 3000 K.

in order to correct instrumental and telluric systematics. We demonstrate the feasibility of such techniques by analysing three secondary eclipse nights of the hot-Jupiter HD 189733b using the SpeX instrument on the IRTF. We confirm the existence of a strong feature at $\sim$ 3.3μm which is inconsistent with LTE models presented in this paper. This suggest a non-LTE process to be the most likely origin of the emission and we associate this emission to a non-LTE feature of the methane ν3 branch.

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