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The transit spectra of the Solar System planets

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Abstract

In recent years, an increasing number of observations have been made of the transits of 'Hot Jupiters', such as HD 189733b, from the visible through to mid-infrared wavelengths, which have been modelled to derive the likely atmospheric structure and composition of these planets. As measurement techniques improve, the measured transit spectra of 'Super-Earths' such as GJ 1214b are becoming better constrained, allowing model atmospheric states to be fitted for this class of planet also. While it is not yet possible to constrain the atmospheric states of small planets like the Earth or cold planets like Jupiter, it is hoped that this might become practical in the coming decades and if so, it is of interest to determine what we might infer from such measurements. In this work we have constructed atmospheric models of the Solar System planets from 0.2 - 15 μm that are consistent with ground-based and satellite observations and from these calculate the primary and secondary transit spectra (with respect to the Sun) that would be observed by a 'remote observer', many light years away. From these spectra we test what current retrieval models might infer about their atmospheric states and compare these with the 'ground truths' in order to assess: a) the inherent uncertainties in transit spectra observations; b) the relative merits of primary versus secondary transit spectra; and c) assess the optimal wavelength coverage and sensitivities required to retrieve atmospheric states that reasonably match the Solar System planet atmospheres.

1. Introduction

The field of exoplanetary transit spectroscopy has advanced dramatically in recent years with the observed spectra of 'Hot Jupiter' planets such as HD 189733b and HD 209458b becoming increasingly better constrained. These spectra can be fitted with retrieval models to determine atmospheric states[1, 2] and reveal atmospheres that are very different from anything seen in our Solar System. As the measurement techniques improve, the spectra of smaller, cooler 'Super-Earths' such as GJ 1214b are becoming measurable and ultimately planetary scientists will want to search the local galactic region for planets more similar to what we see in our Solar System and one day, perhaps, identify another Earth-like planet. Should such a situation ever arise, it is of great interest to determine what we might actually deduce from the measured transit spectrum of a Solar System planet. In this work we construct atmospheric models of the Solar System planets deduced from ground-based and satellite observations and from these compute their primary and secondary transit spectra as seen from an observer many light years away from the Sun. We then go on to examine what might be recoverable from these spectra by a 'remote observer' and compare the retrieved results with the actual atmospheric states of these planets.

2. Modelling

The spectra are modelled with the NEMESIS retrieval tool[3], running in correlated-k mode using k-tables generated from the most recently available linedata for the different gases found in the Solar System planets, compiled in the HITRAN and GEISA databases. Clouds are included in the planetary atmospheric models consistent with observations. For secondary transits, the spectra are calculated using a Matrix-Operator multiple-scattering model that can model the reflection of the cloud layers in the visible and near-infrared and also deal with thermal emission at longer wavelengths. Rayleigh scattering of the air molecules is also included. The modelled planet flux is then divided by the solar flux to derive the planet/star flux ratio. For primary transits, NEMESIS computes the limb path transmission at a range of tangent altitudes (again including the Rayleigh scattering optical thickness), calculates the effective disc area of the planet as a function of wavelength and then divides this by the area of the Sun's disc to determine the transit depth. Figure

1 compares the computed flux ratios (i.e. compared with the Sun) for Earth and Jupiter in the secondary transit geometry while Fig.2 compares the planet/sun areas for the primary transit spectra.

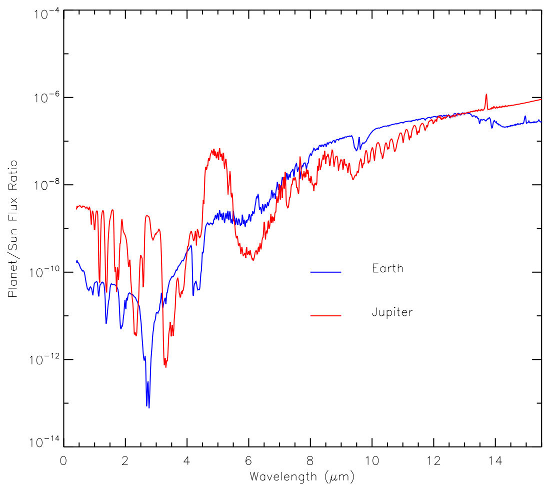

Figure 1: Calculated flux ratios for Earth and Jupiter in secondary transit geometry.

For secondary transits it can be seen that the flux ratio increases steadily with longer wavelengths (although of course the solar flux diminishes) and also that there are many gaseous absorption features that can be used for temperature and abundance retrievals. For Jupiter, the H_2-H_2 CIA absorption spectrum, usually used for tropospheric temperature retrieval for the Solar System's gaseous planets occurs at much longer wavelengths (20 – 50 μm), and so only stratospheric temperatures could be determined from such spectra from the 7.7 μm CH_4 absorption feature. Other mid-IR absorptions of note in Jupiter's secondary transit spectrum are the acetylene (C_2H_2) peak at 13.7 μm, and NH_3 and PH_3 absorption from 8-13 μm. In the near-IR absorption of reflected sunlight is due mainly to CH_4. The 5-μm region is noticeably bright and could provide a good target for future observations. For the Earth the main absorptions are due to H_2O and CO_2 in the near-IR, H_2O near 6.6 μm, O_3 at 9.6 μm and CO_2 at 15 μm, which could be used for temperature sounding.

For the primary transit geometry, the small size of the Earth compared with the Sun makes for very shallow absorptions, but absorptions of H_2O, CO_2 and O_3 are discernible. The Jupiter primary transit spectrum shows clear CH_4 features, together with stratospheric C_2H_2 and C_2H_6.

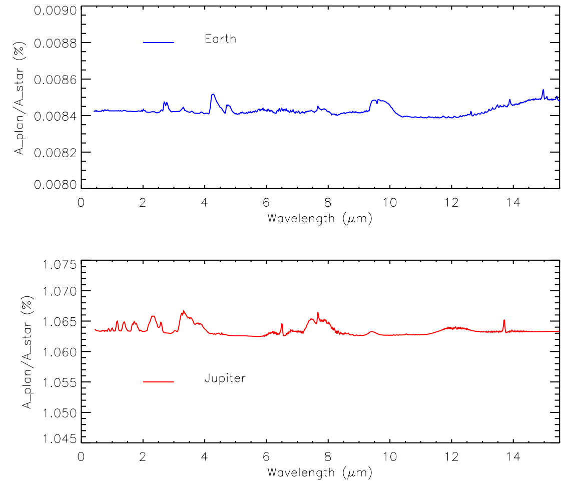

Figure 2: Calculated primary transit spectra for Earth and Jupiter

3. Retrievals

The calculated transit spectra were used as synthetic observations in our retrieval model[3]. Synthetic Gaussian measurement noise was also added [4] at various levels and the atmospheric states determined compared with the true profiles used to generate these spectra. We will show that considerable degeneracy and ambiguity exists and will assess the relative merits of secondary versus primary transits as a function of the wavelength coverage of any future observations.

References

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