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Line-by-line modelling of the H-band reflectance spectra of Uranus and Neptune

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Abstract

A newly derived methane line dataset, WKMC–80K[1], covering the spectral range 1.26 – 1.71 μm has been applied to the analysis of Gemini/NIFS observations of Uranus and Neptune, made in 2009 and also VLT/CRIRES observations of Neptune made in 2010. The new line data are found to greatly improve the fit to the observed spectra and present a considerable advance over previous methane datasets. The improved fits lead to empirically derived wavelength-dependent corrections to the scattering properties of the main observable cloud deck at 2-3 bars on both planets that are consistent with each other, suggesting a very similar composition. By analysing the strength of CH_3D absorption lines we have determined new estimates of the CH_3D/CH_4 ratio of $2.9^{+0.9}_{-0.5} \times 10^{-4}$ for Uranus and $3.0^{+1.1}_{-1.0} \times 10^{-4}$ for Neptune, which are consistent with each other and also with recent estimates of the D/H ratio in hydrogen for these planets by the *Herschel* Space Telescope [3]. Analysis of the VLT/CRIRES Neptune observations indicate that the mole fraction of CO at the 2-3 bar level must be substantially less than its estimated stratospheric value of 1×10^{-6}, which suggests that the predominant source of CO in Neptune's atmosphere is external, through the influx of micrometeorites and comets.

1. Introduction

Near-infrared spectra of Uranus and Neptune contain unique information on the vertical structure of the variable clouds seen in these planets' atmospheres since strong absorption bands of methane mean that reflection from clouds at very different levels can be easily discriminated within a small wavelength range. Analysis of these data requires accurate knowledge of the absorption of gaseous methane, but until recently the quality of line data in databases such as HITRAN and GEISA has not been sufficient to model the very cold and very long path-lengths of methane in the ice giant atmospheres at near infrared wavelengths. Hence, analyses had to be conducted using k-coefficient tables generated from laboratory measurements of gaseous methane absorption[4, 5], which did not extrapolate very reliably to the extreme conditions on these planets and which only had a spectral resolution ($R = \lambda/\Delta\lambda$) of R = 600, which is significantly less than many recent observations at these wavelengths. Recently, a new set of methane absorption data in this wavelength region has become available from the "CH4@Titan" project, whose aim has been, in part, to improve the line lists of methane for the sub-2-μm region at room and low temperatures. The new line parameter list, known as the WKMC–80K line database[1] has already been applied to the modelling of Titan's near-infrared absorption spectrum[2] and more recently to the analysis of Gemini/NIFS observations of Uranus[6]. Here, we report estimates of the D/H ratios in these planets' atmospheres made using these new methane line data.

2. Observations

Observations of Uranus' and Neptune's near-IR spectrum in the H-band (1.477 – 1.803 μm) at all locations on the visible discs were made in September 2009 with the Gemini-North telescope in Hawaii, using the Near-infrared Integral Field Spectrometer (NIFS). These observations have a spectral resolution of R=5290 and were made using the Adaptive Optics system and so have high spatial resolution. We also used VLT/CRIRES high spectral resolution (R=45,000) observations of the centre of the 1.5-μm reflectance peak of Neptune. The Gemini/NIFS observations of Uranus and Neptune in 2009 at two wavelengths 1.58 μm (weak CH_4 absorption) and 1.71 μm (strong CH_4 absorption) are shown in Fig. 1.

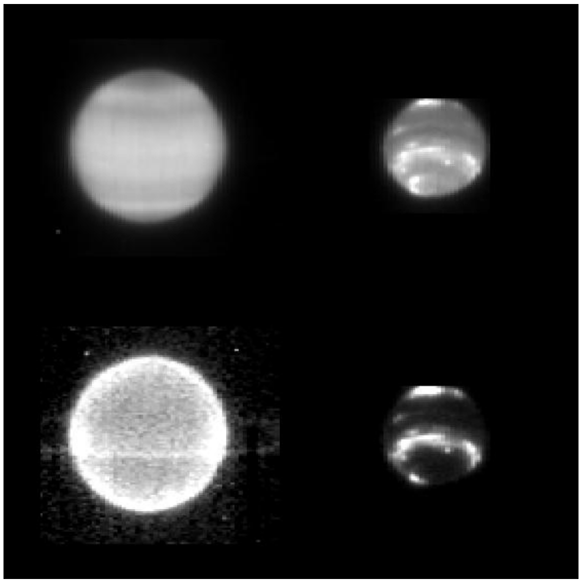

Figure 1: Uranus (left) and Neptune (right) observed with Gemini/NIFS in 2009. Top row is at 1.58 μm and bottom row is at 1.71 μm.

3. Spectral analysis

The observed spectra were analysed with the NEMESIS retrieval model[7], which can simulate observations using either a full line-by-line integration or the correlated-k approximation. We found that the Gemini/NIFS spectra of Uranus were well modelled with a vertically thin cloud at the 2-3 bar level in combination with an extended haze with a base at the 500-mbar level. We found that the WKMC-80K dataset provided a very good fit to the observations, but only if we applied an empirical correction to the single scattering albedo spectrum of the lower cloud, requiring the albedo to decrease with wavelength from 1.5 to 1.62 μm. By fitting the CH_3D absorption features we derive a CH_3D/CH_4 ratio of $2.9^{+0.9}_{-0.5} \times 10^{-4}$. We analysed the Neptune observations in the same way. Here we also required a vertically thin cloud at the 2-3 bar level together with a vertically thin cloud in the upper troposphere, whose base pressure varied from 200 mbar to near the tropopause level, depending on location, and whose single scattering albedo varied from approximately 0.5 in the darker regions to close to unity in the bright areas. We found that we required a very similar correction to the single scattering albedo spectrum of the lower cloud, suggesting its composition is similar to that of Uranus' clouds and we derive a very similar CH_3D/CH_4 ratio of $3.0^{+1.1}_{-1.0} \times 10^{-4}$. We also analysed the very high spectral resolution VLT/CRIRES observations, obtaining a very close fit and deducing that the mole fraction of CO at the 2-3 bar level must be substantially less than its estimated stratospheric value of 1×10^{-6}.

4. Summary and Conclusions

Our derived CH_3D/CH_4 ratios for Uranus and Neptune may be converted to the D/H ratio in H_2 and we obtain estimates of $4.3^{+1.5}_{-0.9} \times 10^{-5}$ and $4.7^{+1.8}_{-1.7} \times 10^{-5}$ respectively. These agree well with new *Herschel* Space Telescope estimates of $4.4 \pm 0.4 \times 10^{-5}$ for Uranus and $4.1 \pm 0.4 \times 10^{-5}$ for Neptune[3]. We have also, for the first time, measured the CO abundance at the 2-3 bar level in the Neptune's atmosphere in the near-infrared. The fact that we derive a mole fraction that is significantly less than its stratospheric abundance, determined from mid-IR observations, suggests that the predominant source of CO in Neptune's atmosphere is external, through the influx of micrometeorites and comets.

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