Longitudinal Variations in the Stratosphere of Uranus from the Spitzer Infrared Spectrometer

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Abstract

NASA's Spitzer Infrared Spectrometer (IRS) acquired mid-infrared (5-37 micron) disc-averaged spectra of the ice giants between 2004 and 2007. Uranus was observed in November 2004 [1], in July 2005 and again very near its equinox in December 2007. The mean of the observed longitudes in 2007, spaced equally around the planet, have provided the opportunity for the most comprehensive globally-averaged characterisation of Uranus' temperature and composition ever obtained [2],[3] (hereafter collectively referred to as Orton et al.). In this work we analyse the disc-averages at four separate longitudes to shed light on the discovery of a longitudinal variability occurring across the spectrum in Uranus' stratosphere during the 2007 equinox. We investigate whether the same variation can be found in the 2004 and 2005 data. Building on the forward-modelling analysis of Orton et al., we present full optimal estimation inversions (using the NEMESIS retrieval algorithm [4]) of the Uranus-2007 spectra at each longitude to test this hypothesis by distinguishing between thermal and compositional variability.

1. Introduction

The composition and temperature structure of Uranus' stratosphere is dominated by methane photolysis in the upper stratosphere [5]. The complex hydrocarbons produced in these solar-driven reactions are the main trace gases present in the stratosphere and upper troposphere. These species are observable at mid-infrared wavelengths sensitive to altitudes in the range of between around one nanobar and two bars of pressure [2]. Bright, long-lived cloud features have been observed in the near-infrared [6],[7],[8]. These may be tied to vortex systems that occur in the upper troposphere and could be influencing the stratospheric structure at certain longitudes. Ground-based observations in the mid-infrared (13 microns) have revealed images that show enhanced regions of emission at mid-to-high-latitudes associated with either localised heating or acetylene enhancement in the stratosphere [9],[10]. The fact that this is spatially-variable might also support the idea that this is driving the longitudinal variability. So the question is - is this driven from above, or driven from below?

2. Spitzer Observations

Due to Uranus' extremely high obliquity we can only clearly observe its longitudinal variation close to its equinox. The northern spring equinox occurred in December 2007 with the aforementioned Spitzer observations occurring just 10 days after. NASA's Spitzer Infrared Spectrometer (IRS) used four modules of varying resolution and wavelength range. We have initially used the data from the two low resolution modules as displayed in Figure 1.

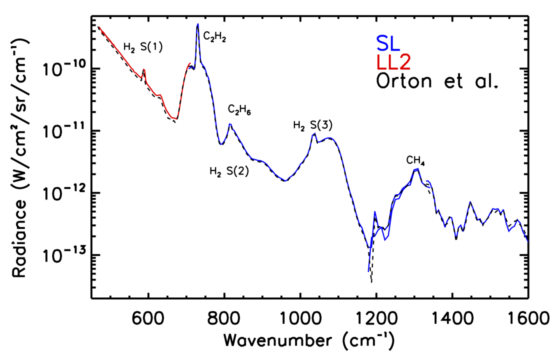

Figure 1: Low resolution (R ~60-127) Spitzer IRS disc-averaged Spectrum of Uranus from 714 to 1600 wavenumbers (14 to 6.25 microns). Orton et al. reduction shown as black dashed line for comparison.

Due to a lack of spatial resolution, Uranus is treated as a point source and the resulting spectra are disc-averaged. The Spitzer data has been re-analysed using the most up to date pipeline available from NASA's Spitzer Science Centre resulting in minor changes over the previous reduction (Figure 1).

3. Longitudinal Variation

We assess the variations in discrete channels sensitive to different emission features. The radiance's inside each interval are averaged and compared to the mean of all four longitudes. Each instrument module is exposed at a different time causing a spread of data points across the multiple longitudes displayed in Figure 2.

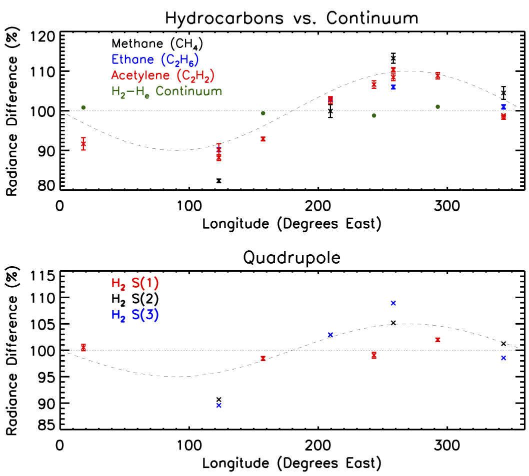

Figure 2: Longitudinal variability of chemical species across 360° of Uranus. Standard errors displayed. Top panel: hydrocarbon species and the hydrogen-helium continuum with 10% amplitude wavenumber-2 sinusoid displayed for reference. Bottom panel: hydrogen quadrupole with 5% amplitude wavenumber-2 sinusoid displayed for reference.

The emission as a function of longitude from the tropospheric hydrogen-helium continuum looks to be relatively constant but the stratospheric hydrocarbon species appear to vary by around 10% from the mean in a sinusoidal fashion. The hydrogen quadrupole-feature emission vary by up to 5%. Though it is not yet known whether the variation in these stratospheric thermometers is enough to cause those seen in the hydrocarbon emissions it does suggest that there is some thermal variability in the lower and mid-stratosphere.

4. Summary and Conclusions

Variations in emission in the spectrum of Uranus are as high as 15%; they appear to be linked to the stratosphere. We will be using the inversions to assess whether this is a change caused by composition, temperature or a combination of both. Analysis of similar Spitzer data for Neptune show a lack of significant longitudinal variation. This is inconsistent with the popular view that Neptune is the more meteorologically active out of the two planets. We investigate whether this variation is unique to 2007 or may be due to a long-lived feature. We present two possible links to the variation: (i) Keck II NIRC2 images acquired four days before the Spitzer spectra show a pattern of convective meteorological activity in the upper troposphere co-located with the coolest stratospheric emission, consistent with the idea of large-scale uplift [6],[7]. (ii) The variations are consistent with the apparent stratospheric spatial variation in 2009 images from VLT/VISIR at 13 microns [9].

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References

[1] Burgdorf, M., et al., 2006, Icarus, 184(2), 634–637.

[2] Orton, G. S., et al., 2014, Icarus, 243, 494–513.

[3] Orton, G. S., et al., 2014, Icarus, 243, 471–493.

[4] Irwin, P., et al., 2008, Journal of Quantitative Spectroscopy and Radiative Transfer, 109(6), 461 1136-1150.

[5] Moses, J. I., et al., 2018, Icarus, 307, 124–145.

[6] de Pater, I., et al., 2011, Icarus, 215(1), 332–345.

[7] Sromovsky, L. A., et al., 2009, Icarus, 203(1), 265–286.

[8] Roman, M. T., et al., 2018, Icarus 310, 54-76.

[9] Roman, M. T., et al., 2019 (in prep.)

[10] Orton, G. S., et al., 2018, 42nd COSPAR Sci. Assembly (Vol. 42)