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TEXES Spectral Mapping of Jupiter and Saturn and the Origins of Giant Planet Nitrogen

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Abstract

We report spectral mapping of the atmospheres of Jupiter and Saturn in February 2013 using the Texas Echelon cross Echelle Spectrograph (TEXES, [1]) mounted on NASA's Infrared Telescope Facility (IRTF). The purpose of these observations was (i) to study jovian meteorology via measurements of temperature, wind shear, humidity (i.e., ammonia content) and cloud coverage; (ii) to assess the aftermath of Saturn's northern 2010-2011 storm, including the continued existence of the stratospheric anticyclonic vortex [2]; and (iii) to determine precise estimates of the $^{15}N/^{14}N$ ratio on both planets to constrain the origins of nitrogen to the gas giants. Mid-infrared observations of this nature complement spacecraft observations from Cassini, Juno and, ultimately, JUICE.

1. Introduction

Recent mid-infrared observations of the gas giants have used either filtered photometric imaging or scans of a point spectrometer over the disc. In the former case, we lack spectral information necessary to break degeneracies between temperature, composition and clouds, whereas the latter case often lacks the spatial capabilities to interpret atmospheric phenomena properly. Using TEXES in a low spectral resolution mode (R~4000), we are able to scan a long slit repeatedly over the target, generating fully resolved spectro-spatial image cubes in 10-20 cm^{-1} wide segments. These are supplemented for narrow stratospheric emission lines with spectral resolutions up to R~80,000. Observations were performed using the 3-m IRTF from February 2nd-12th 2013, and we report a subset of the results here.

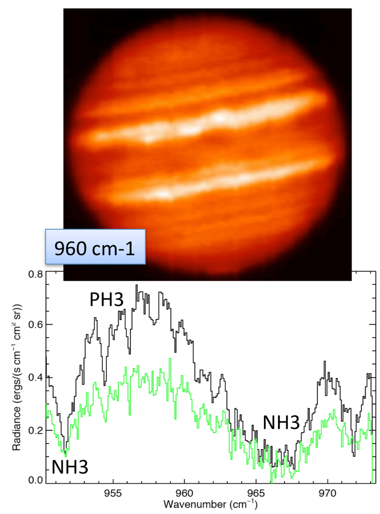

Figure 1 Spectral map of Jupiter at 960 cm^{-1} wavelength, with single scans selected for bright (black) and dark (green) features, showing the signatures of ammonia and phosphine. Each pixel in the image represents a complete mid-IR Spectrum.

2. Dynamical Phenomena

Jupiter was observed in eight spectral settings sensitive to tropospheric temperatures, ammonia, phosphine and aerosols, and stratospheric methane, ethane and acetylene. Spectra from a single scan in the 960 cm^{-1} setting are shown in Fig. 1, the green line showing the worst case for the signal to noise ratio (a dark region on Jupiter). Observations over three nights covered almost 360^o of longitude, detecting (i) strong perturbations of temperature and ammonia vapour at the periphery of Oval BA; (ii) considerable wave activity in the NEB and equatorial plumes; and (iii) emission from stratospheric hydrocarbons associated with near-polar auroral hotspots.

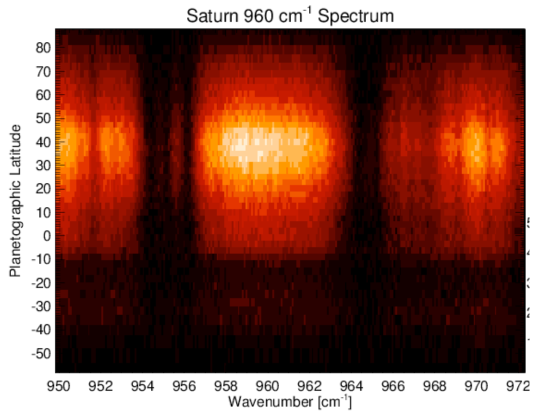

Figure 2 TEXES Saturn spectra with latitude. The southern hemisphere is obscured by ring absorption, but the brightest region is due to emission from Saturn's northern storm band.

Longitudinal perturbations were not observed in Saturn's troposphere, although the signal-to-noise is considerably worse. Fig. 2 shows a longitudinal average spectrum at 960 cm^{-1}, with two broad absorptions of phosphine and smaller ammonia features. The peak emission at 40°N is not at the sub-observer point, and is, in fact, warm emission from a cloud-free band remaining in the aftermath of Saturn's 2010-11 storm. Saturn's stratospheric vortex, a warm anticyclone spawned by the storm and persisting near 2-mbar to this day, [2] was studied to determine its internal temperatures and hydrocarbon abundances, helping to constrain the continued weakening of the vortex two years after its formation. Its location is consistent with a westward drift of 3°/day. The spectral mapping from IRTF/TEXES will be analysed using a suite of forward modeling and retrieval software (Nemesis, [3]) to determine the spatial variations of temperatures, clouds and composition.

3. Origins of Nitrogen

The primary goal of this study was to provide constraints on the $^{15}N/^{14}N$ ratio on Saturn. The primordial reservoir for nitrogen-bearing species incorporated into the giant planets during their accretion is poorly understood. Nitrogen is enriched on Jupiter and probably on Saturn with respect to solar abundances, but the formation of condensation clouds of NH_3 ice restricts gaseous N-bearing species to a deep tropospheric reservoir on Saturn that is largely inaccessible to remote sensing. As ion-molecule reactions in the ISM would enrich the heavy ^{15}N isotope in NH_3 compared with its relative abundance in the larger reservoir of pure N_2, the measured ratio of $^{15}N/^{14}N$ reveals the origins of nitrogen (as N_2 or NH_3) in a planetary atmosphere. The ratio has been measured on Jupiter by ISO, Cassini [4] and the Galileo probe [5], and the low abundance of ^{15}N was suggestive of direct capture of nebula N_2. On the other hand, Titan's N_2 atmosphere may be secondary, formed from dissociation of primordial ammonia, and is comprised of far more ^{15}N than either Jupiter or the terrestrial planets. The ratio has never been determined for Saturn, as Cassini lacks the mid-IR sensitivity, and the spectrum is dominated by phosphine absorption.

Our TEXES observations were tuned to $^{15}NH_3$ features at 903 cm^{-1} and 960 cm^{-1} (Fig. 2, 3) allowing us to place upper limits on the ratio on Saturn for the first time. A third desired signature of $^{15}NH_3$ at 1002 cm^{-1} is obscured by telluric ozone. Comparisons to Jupiter (Fig. 1) will be used to assess the validity of the result and the implications for nitrogen delivery mechanisms (e.g., as N_2 or NH_3) in the outer solar system.

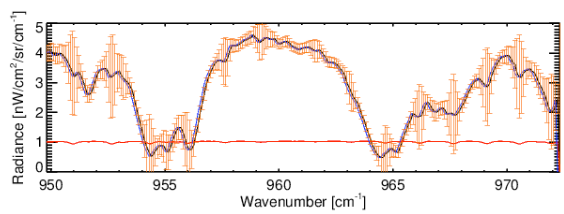

Figure 3 Extracted spectrum of Saturn's 960 cm^{-1} region, showing two broad PH_3 features, smaller NH_3 features, and structure in the 958-963 cm^{-1} where we expect a $^{15}NH_3$ signature. The horizontal red line shows the telluric transmission spectrum between zero and one, indicating the location of terrestrial contamination.

Acknowledgements

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References

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