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Probing the Atmospheres of Saturn and Uranus with Ground-Based Radio Observations

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Abstract

We have analyzed observations of Saturn and Uranus at wavelengths from ~1 millimeter to ~1 meter, which probe the atmospheres from pressures near 0.1 bar (the tropopause) down to pressures of 100's of bars. Our results provide new clues about the composition and chemistry of giant planet atmospheres, and highlight differences between gas- and ice-giants.

1. Introduction

The thermal emission of the giant planets at millimeter to meter wavelengths is controlled by the vertical profiles of temperature and composition from mbar to tens of kbar pressures. Typically, temperatures are taken as known because the expected compositional variations have a much larger effect on radio brightness than do the expected temperature variations. We therefore use spacecraft occultation and ground-based infrared measurements to set the stratospheric and tropopause temperatures of the planets, and take the tropospheric temperature profile to be a convective (wet pseudo-adiabatic) profile. This leaves composition as our free parameter. Based on cosmic abundances, the dominant species our microwave data are sensitive to are NH_3, H_2O, H_2S, and perhaps PH_3 and CO. At meter wavelengths we may probe to depths where we sense free electrons from pressure-induced ionization.

2. New Data, New Models

New Saturn measurements have been made at cm to meter wavelengths using the eVLA, GMRT and LOFAR radio telescopes. The primary purpose of this data set is to try and constrain the water abundance in the deep troposphere. Reduction of the eVLA data is ongoing. It is extremely complicated at meter wavelengths due to the many background galaxies which emit strongly at low frequencies. Unfortunately, the GMRT data [1] have large error bars, and the LOFAR data in hand may not be usable.

The new Uranus measurements we are analyzing are unpublished observations at submillimeter to 20 cm wavelengths, all collected near 2006.

From the data sets, we retrieve gas abundances using an optimal estimation technique [2] coupled to a forward model based on [3] but incorporating new laboratory measurements of the microwave opacity of relevant gases which were made in support of the Juno mission to Jupiter [4].

3. Analyses and Work Underway

3.1 Saturn

At Saturn, the currently available microwave data set suggests NH_3 abundances are between about 5 and 10x solar. If NH_3 is as low as 5x solar, the water abundance needs to be at least 10x solar. If the NH_3 abundance is as large as 10x solar, water is poorly constrained by the data set. We hope that the new eVLA data, when reduction is complete, will place tighter constraints on abundances due to smaller error bars, and will allow us to look for temporal variations.

3.2 Uranus

We find that Uranus' deep atmospheric NH3 abundance is between 0.2 and 0.6x solar, while H2S is 1 to 2x solar. The submillimeter to millimeter data suggest the presence of an upper tropospheric absorber such as PH3 at 3x solar. The longest-wavelength Uranus data, at 20 cm, only weakly constrain the deep water abundance, but favor values >3x solar. We are currently working to refine our forward model (e.g with newer opacity measurements such as [5] and [6], and hope to explore how chemical processes in the water cloud and interior oceans can explain the low abundances (relative to Solar) of NH_3 and H_2S, and the enhancement of H_2S relative to NH_3.

4. Discussion

Abundances of NH3, H2S, and H2O on both planets are broadly consistent with expectations based on previous work by others [e.g. 7, 8], and highlight the compositional differences between gas- and ice-giant planets. On Saturn, the ground-based microwave observations have the potential to sound below the water cloud, constraining both the deep water abundance and exploring for the first time pressure-ionized regions of the atmosphere. This will require careful corrections due to background astronomical sources, and probably additional observations building on knowledge gained by the current attempts. We note that the shortest wavelength (~1 cm) Saturn data are not well matched by our models. We are currently assessing if these measurements might be in error or if there is temporal variability at these wavelengths.

For Uranus, planetary formation models [9 and references therein] indicate the bulk abundances of NH_3 and H_2S should be >50x solar, consistent with the measured bulk abundance of CH_4. Also, solar abundances suggest there should be more NH_3 than H_2S. In the deep troposphere of Uranus, however, we find more H_2S than NH_3 and both are near or depleted from solar values. Atmospheric dynamics and the high-pressure liquid water ocean postulated to exist within ice giant planets may be responsible for depleting these species.

5. Conclusions

The composition, chemistry, and interior structure of the gas giant planet Saturn are very different from those of the ice giant Uranus.

Microwave observations can be used to probe these atmospheres from pressures of 1 to tens of thousands of bars.

Currently unknown chemical or dynamical processes are modifying the abundances of condensable species in the observable atmosphere of Uranus.

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