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Laboratory measurements and a consistent model of the microwave properties of ammonia under jovian conditions

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Abstract

Nearly 1200 laboratory measurements of the 5–20 cm wavelength properties of ammonia have been conducted in a hydrogen/helium environment under simulated deep tropospheric jovian conditions (pressures up to 100 bars and temperatures up to 500 K) using an ultra-high-pressure measurement system built at Georgia Tech [1]. These measurements along with nearly 1800 measurements of the 0.8–20 cm wavelength properties of ammonia performed under middle tropospheric jovian conditions by Hanley et al., [2] and over 1000 measurements of the 2–4 mm wavelength properties of ammonia performed under upper tropospheric jovian conditions by Devaraj et al., [3] have been used to develop a consistent mathematical formalism to represent the opacity of ammonia in the 0.1–30 cm wavelength range in a hydrogen/helium environment at pressures up to 100 bars and temperatures up to 500 K. The new model can be used for accurate retrievals of ammonia and other constituents in the jovian atmospheres from ground-based and spacecraft-based microwave observations.

1. Introduction

Microwave remote sensing of the jovian planets provides a unique insight into the temperature, pressure, and composition of their upper, middle, and deep tropospheres. Accurate knowledge of the microwave properties of the jovian constituents is required for the successful interpretation of the emission spectra of those atmospheres. Hence, an aggressive campaign of laboratory measurements of the centimeter-wavelength opacity of ammonia under deep jovian conditions has been undertaken. Using these and previous laboratory measurements, a consistent ammonia opacity formalism that can be used in the 0.1–30 cm wavelength range under jovian conditions has been developed. The high-pressure measurements and the consistent model will directly improve our understanding of the microwave absorption by ammonia in jovian atmospheres, and also improve retrievals from the Juno microwave radiometer (MWR).

2. Measurement System

Microwave absorptivity of a gas can be measured by determining the reduction in the quality factor of a resonant mode of a resonator in the presence of a lossy gas. An ultra-high-pressure measurement system shown in Figure 1 is used to perform measurements of the 5–20 cm wavelength absorptivity of ammonia under deep jovian conditions at pressures up to 100 bars and temperatures up to 500 K. The measurement system consists of a planetary atmospheric simulator, microwave subsystem, and a data handling system. An ultra-high-pressure vessel placed inside an industrial oven, forms the integral part of the planetary atmospheric simulator. The temperature, pressure, and gas mixture are carefully controlled to simulate the desired jovian conditions. The microwave measurement subsystem consists of a cavity resonator placed inside the ultra-high-pressure vessel connected to a network analyzer through high-pressure microwave feedthroughs and microwave cables. The data handling subsystem consist of various computers that monitor and control the network analyzer and also monitor the temperature and pressure of the system.

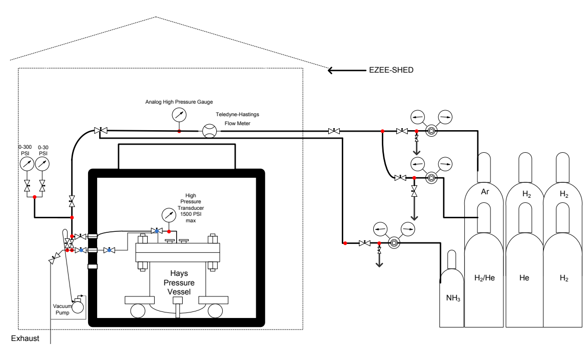

Figure 1: The ultra-high-pressure measurement system [1]

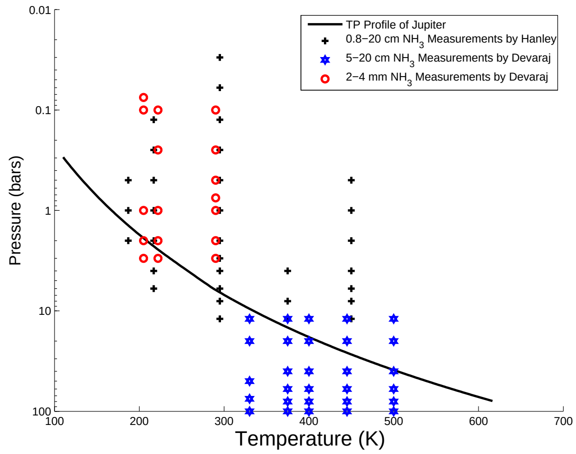

Figure 2: Temperature-Pressure (TP) distribution of the measurements used in the development the new model

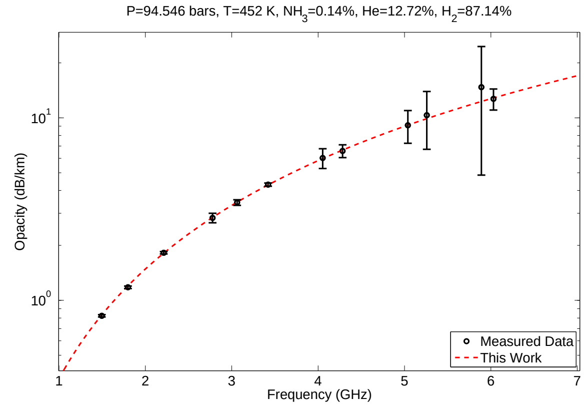

Figure 3: Example of an ammonia opacity measurement overlayed with the new model

3. Measurement Results and Model

Nearly 1200 measurements of the opacity of ammonia have been conducted in the 5–20 cm wavelength range at pressures ranging from 0.05–100 bars, temperatures from 330–500 K, and ammonia mixing ratios from 0.05–100% in a hydrogen-helium atmosphere using the ultra-high-pressure system. These measurements were made in 15 discrete sets in the 330–500 K temperature range with each set consisting of measurements made at 7 or 8 different pressures ranging from 0.05–100 bars. These and previous measurements (Figure 2) have been used to develop a consistent model to represent the opacity of $\mathrm{NH_3}$ in a $\mathrm{H_2/He}$ atmosphere under jovian conditions. The model uses a modified Ben-Reuven lineshape [4] for the inversion transitions, and a modified Gross lineshape [5] for the rotational and ν_2 roto-vibrational transitions, and accounts for the compressibility of gases under high-pressures. Figure 3 shows an example of the opacity results from a high-pressure measurement overlayed with the consistent model.

4. Summary and Conclusions

Efforts toward developing a consistent formalism to estimate the 0.1–30 cm opacity of ammonia at the pressures, temperatures, and mixing ratios characteristic of jovian planets have been on-going for more than 30 years since the work by Berge and Gulkis [6] (see, e.g., [7]). The laboratory measurements of the microwave properties of ammonia have been used to create the most accurate and consistent model to date to represent the 1 mm to 30 cm opacity of $\mathrm{NH_3}$ broadened by $\mathrm{H_2/He}$ at pressures up to 100 bars and temperatures up to 500 K. In addition, recent 2.1 mm observations of Jupiter made with the Institut de Radioastronomie Millimétrique (IRAM) telescope have been interpreted using the new consistent formalism and constraints on the $\mathrm{NH_3}$ abundance in the upper troposphere of Jupiter have been derived.

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