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Structure and Variability of Uranus' Troposphere

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Abstract

We are observing Uranus at submillimeter, millimeter, and centimeter wavelengths in order to understand the structure and variability of its troposphere. We recently determined that there must be a species in the upper troposphere more volatile than NH_3 (perhaps H_2S or PH_3) whose abundance varies strongly with latitude, and we also demonstrated sensitivity to the vertical structure within the deep, liquid water cloud region---where an NH_3-H_2S-H_2O aqueous solution is believed to form. To follow up on these discoveries, observing time has been scheduled for the summer of 2011 at two new instruments; the Expanded Very Large Array (EVLA) and the Atacama Large Millimeter/submillimeter Array (ALMA). We hope to present our preliminary analysis of those data at the EPSC/DPS conference, and discuss the implications for the composition and dynamical state of Uranus' troposphere.

1. Introduction

Measuring the passive, thermal emission of Uranus at wavelengths from 3 mm to 30 cm probes the atmosphere between roughly 0.5 and 100 bars. We are primarily sensitive to the vertical and horizontal distribution of trace species that strongly absorb at these wavelengths. This allows us to infer composition, cloud formation, and atmospheric circulation from our data, which in turn has implications for the formation and evolution of Uranus and other Ice Giant planets.

2. Upper Tropospheric Opacity

Figure 1 shows the observed microwave spectrum of Uranus, along with some representative models. One important result is seen at the wavelengths between 1 mm and 1 cm: models with NH_3 cannot provide enough opacity to fit the low temperatures recently observed. Our data from three separate observatories---the SubMillimeter Array (SMA), the James Clerk Maxwell Telescope (JCMT), and the Very Large Array (VLA)---suggest an opacity source more volatile must be present in the 1-bar region. An SMA map of Uranus at 1.3 mm also shows that this opacity source is concentrated at equatorial latitudes and depleted over the poles [1]. We find that models with H_2S can fit the data, though this does not rule out other species. We note that the presence of H_2S had been postulated previously (e.g. [2]).

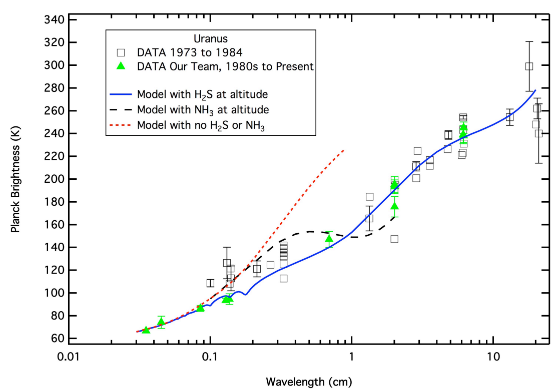

Figure 1: The radio spectrum of Uranus.

In Fig. 1, observations are shown by symbols, with representative error bars. The black squares are a compilation of many data sets [3], while the green triangles are our team's relatively recent results. The curves are model calculations; the red dotted curve includes opacity only from H_2 and He gas. The black dashed curve adds NH_3. The blue solid curve replaces NH_3 with H_2S.

3. The Deep Troposphere

Wavelengths longward of 10 cm probe well into the region of the atmosphere where a liquid water cloud is expected to exist (pressures > 50 bar, temperatures > 270 K). We obtained 20 cm maps of Uranus with the VLA in 2004 and 2009. Figure 2 shows the difference between the data and a model with horizontally uniform composition. The dashed circle outlines the limb of the planet, and the green dot marks the South Pole. The full-width of our beam is roughly half the size of the planet. This image highlights the fact that the planet appears much dimmer than expected at low latitudes, particularly near the limb (the dark regions near the upper left and lower right of the disk). One way to explain this dark region is if, only at low latitudes, the region of the water cloud contains an absorber whose abundance decreases with a scale height larger than that of the liquid cloud but smaller than the pressure scale height. We are exploring if chemical models of aqueous solutions (which would move NH_3 from the vapor phase into solution) can match these data.

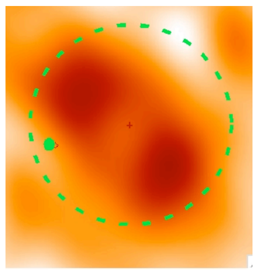

Figure 2: Uranus at 20 cm in 2009 (2004 is similar).

4. Observations, Summer 2011

To follow-up on the results just described, we expect to obtain two new data sets this summer. We have been awarded Early Science observing time at the EVLA to image Uranus at 6 cm with expected sensitivity an order of magnitude greater than what was previously possible. These data will help constrain our knowledge of the liquid water cloud region and species held in solution. We also successfully proposed that Uranus be included in Science Verification observations planned for this summer at ALMA. ALMA spectra will help determine if H_2S or PH_3 are present in the upper troposphere. We hope to report our first look at these data at the conference.

5. Discussion and Summary

We are currently focused on two implications of the results presented in Section 1: constraining the nitrogen to sulfur ratio in the bulk atmosphere, and the large-scale circulation pattern. Regarding the ratio S/N, based on solar abundances and chemical equilibrium models one would expect to find nitrogen (as NH_3) at pressures less than ~10 bars in the atmosphere, and no H_2S [4]. For H_2S to be present at altitude, either the S/N ratio must be much larger than 1 in the bulk atmosphere (solar is ~0.14), or NH_3 is more effectively lost into the solution cloud than expected, relative to H_2S. Alternatively, if our current equilibrium chemical models are correct and the atmosphere does have a roughly solar S/N ratio, than we must postulate the presence of another volatile microwave absorber. PH_3 is a candidate based on solar abundances, but it is not an equilibrium species in the upper troposphere and would require convective coupling of the deep and upper atmospheres.

With the modeling currently underway, supported by observations with instruments just now coming on-line, we hope to be able to determine if current chemical models are consistent with the entire data set, if the S/N ratio is solar, and if there are large-scale upwellings at equatorial latitudes that arise from below the liquid water cloud. Such a circulation pattern has been postulated for the mid-troposphere [3] (Fig. 3). In Fig. 3, the density of dots is indicative of the amount of radio opacity, while numerical values are abundances relative to solar. Red lines suggest large-scale atmospheric motions.

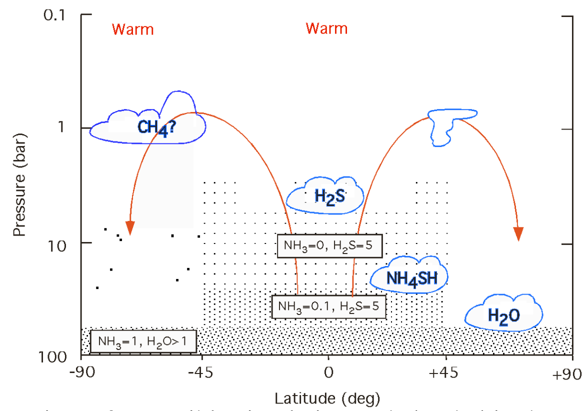

Figure 3: Possible circulation and cloud altitudes.

Acknowledgements

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