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STUDY OF THE AMMONIA ICE CLOUD LAYER IN THE NORTH TROPICAL ZONE OF JUPITER FROM THE INFRARED INTERFEROMETRIC EXPERIMENT ON VOYAGER

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An average of 51 Voyager 1 IRIS spectra of Jupiter's North Tropical Zone has been analyzed to infer the abundance, vertical extent, and size distribution of the particles making up the ammonia cloud in this region. It is assumed that the cloud base coincides with the level at which 100% saturation of ammonia vapor occurs. The vertical distribution of particulates above this level is determined by assuming a constant total ammonia mixing ratio (gas plus condensate) and adjusting the two phases so that the vapor is saturated throughout the cloud. A constant scaling factor then adjusts the base number density.

A radiative transfer program is used that includes the effects of absorption and emmission of all relevant gases as well as anisotropic scattering by cloud particles. Mie scattering from a gaussian particle size distribution is assumed. The vertical thermal structure is inferred from a temperature retrieval program that utilizes the collision induced S(0) and S(1) molecular hydrogen lines between 300 and 700 cm^{-1}, and the 1304 cm^{-1} methane band.

A total column abundance of ≃ 2 x 10^{-6} g cm^{-2} is inferred for the condensate. Acceptable solutions for mean particle radii range from 0.5 to 3.5 μm. These values are considerably smaller than those preferred by Marten et al. (1981, Icarus <u>46</u>, *233-248) and Orton et al. (1982,* Icarus <u>52</u>, *94-116), though are comparable to the 3 μm mean particle radius derived by Sato and Hansen (1979,* J. Atmos. Sci. <u>36</u>, *1133-1167). Several possible reasons for this apparent discrepancy are suggested.*

We have attempted to determine a particulate size of the ammonia cloud on Jupiter's North Tropical Zone from fitting IRIS spectra. In Fig. 1, we plotted two spectra, and the dashed line was obtained by averaging 55 South Pole spectra. The first thing that one notices in the 300-700 wavenumber region is that there is agreement between the two spectra, which indicates a similarity in the tropospheric thermal structure. The second thing that one notices is that there are differences in the 1200-1300 wavenumber regions, indicating differences in the stratospheric structure. Since the tropospheric thermal structures are similar, the differences in the spectra at 200 wavenumbers and 1150 wavenumbers are due primarily to the cloud structure. We have attempted, by fitting these two windows by a cloud model, to obtain the cloud properties in the North Tropical Zone.

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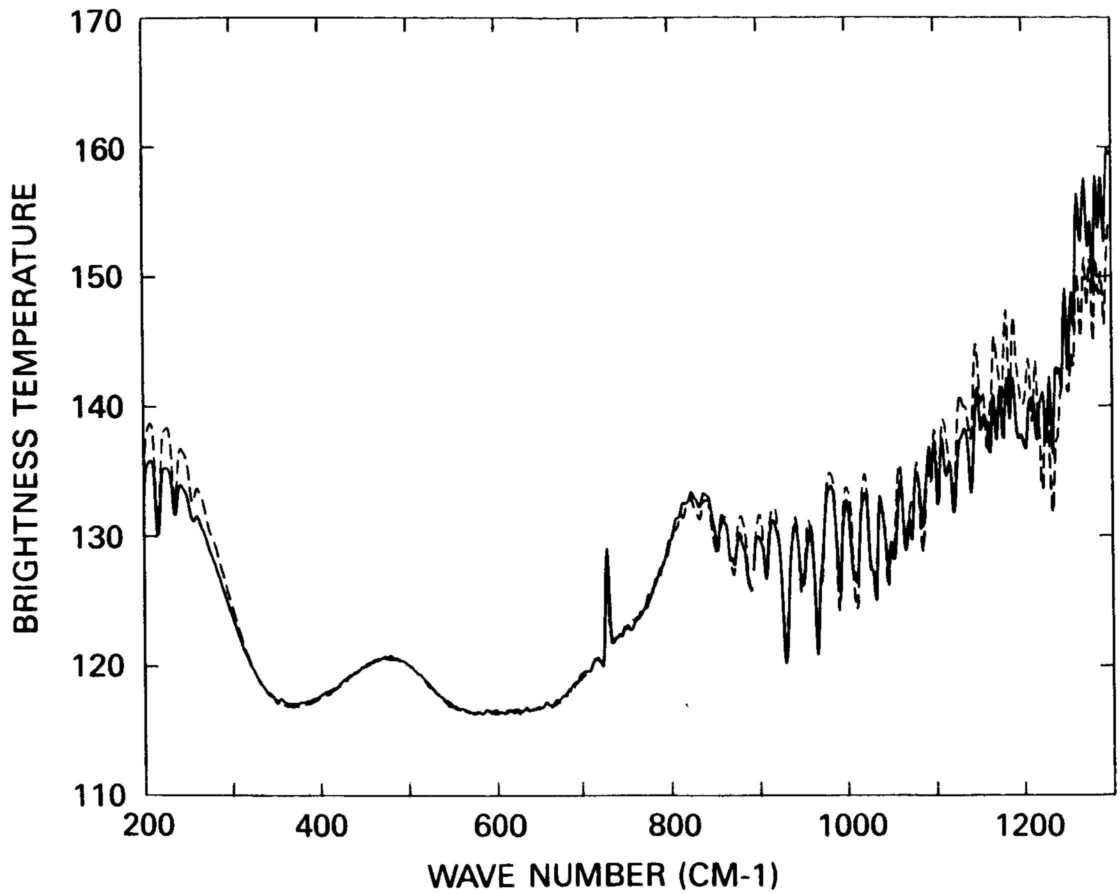

Figure 1. Two Voyager IRIS spectra obtained for large emission angles. The solid line is the average of 46 North Tropical Zone spectra and the dashed line is the average of 55 South Pole Spectra.

In order to save computer time, we chose one wavenumber value in each of the windows to perform the fitting. After we obtained a fit in each of the windows simultaneously using the two wavenumber values, the resulting spectrum was calculated. This was found to be sufficient to obtain a good fit in the entire spectrum. The spectrum we analyzed was not the solid line in Fig. 1. The spectrum analyzed was obtained by averaging 51 North Tropical Zone spectra for small emission angles (Fig. 1 was obtained for large emission angles).

The first step was to obtain a temperature profile from fitting the S(0) and S(1) hydrogen lines and the methane band at 1304 wavenumbers. The cloud model we used assumed one cloud layer with a fixed bottom and a variable, well-defined cloud top. The cloud base was found to be at 700 millibars from the Clausius-Clapeyron equation. The particulate number density profile was determined by assuming that the excess of the assumed ammonia mixing ratio over the saturation mixing ratio went entirely into particulate formation. We used a scale factor of the number density profile to get the number density appropriate for a given particle size. In our cloud model we solved for three parameters: particle size, the location of the cloud top and the number density scale factor. The radiative transfer program used to calculate the synthetic spectra included absorption, thermal emission, and anisotropic Mie scattering by particulates (assuming a Gaussian distribution of particulates about an assumed mean particle radius). The program used a doubling and adding technique for inhomogeneous atmospheres. We also included phosphine, acetylene, and deuterated methane in the calculations.

Calculating the brightness temperature at the two points in the windows, 210.1 wavenumbers and 1167.9 wavenumbers, for various particle sizes and number density scale factors, we obtained the family of curves shown in Fig. 2. Each point on a curve corresponds to a particular number density scale factor. For this set of curves, the cloud top was arbitrarily fixed at 530 millibars. The tendency in these curves is to move down as the particle size decreases. For example, the curves for 30 to 2 μm particle size move down. At 2 μm they bottom out. For particle sizes smaller than 2 μm the curves move up again. Note, for example, the curves for 1.0 and 0.5 μm.

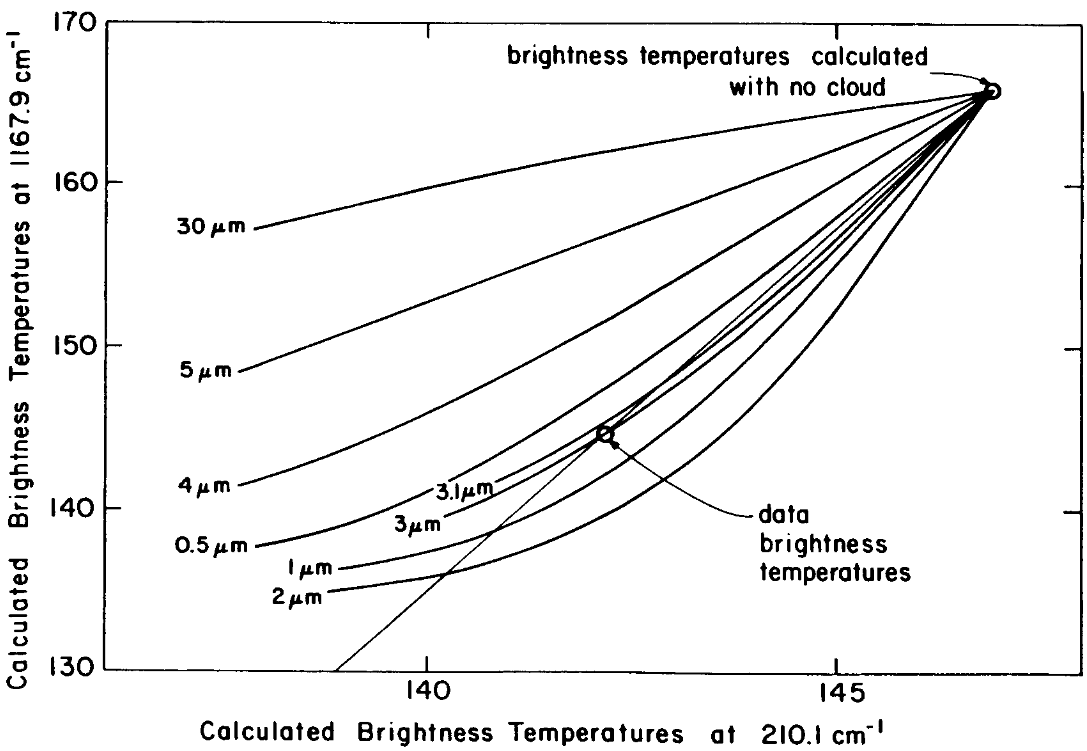

Figure 2. The brightness temperature at 1167.9 wavenumbers as a function of the brightness temperature at 210.1 wavenumbers for a cloud top at 530 mb and various mean particle radii. The straight line contains the points representing a cloud base particulate number density of zero and the Voyager data values.

There are two points of interest added to Fig. 2. The first point was obtained by calculating the brightness temperatures assuming no cloud in the radiative transfer program. This point also corresponds to a number density scale factor of zero for all particle sizes. So all the particle size curves share this point. The second point is the point corresponding to the Voyager data values. This point by definition corresponds to a good fit of the data. If one of the particle size curves intersects at this point, for that number density scale factor, we have a good fit in the two windows simultaneously. If we construct a line intersecting these two points, then one notices something about the family of curves. That is, there are two classes of curves. One class of curves is single-rooted; that is, they have one intersection point with the straight line, the intersection point being the no-cloud point or number density scale factor equal to zero. The second class of curves is double-rooted. These curves have two intersection points, the no-cloud point and some point further down the straight line. In the case of single-rooted particle size curves, no simultaneous fit was possible in the two windows. For example, for a 30 micron particle size, an opacity that is sufficient to fit at 210.1 wavenumbers is always too small at 1167.9 wavenumbers. For double-rooted particle sizes a simultaneous fit was possible.

An intersection of the particle curve above the Voyager data values indicates too little opacity in the cloud model. The opacity can be increased by raising the cloud top until the curve intersects at the Voyager data values. The amount that the cloud top must be raised depends upon the distance between the intersection point and the Voyager data values. An intersection that occurs below the Voyager data values indicates too much opacity in the cloud model, and the opacity can be decreased by lowering the cloud top. The cloud top can be lowered until the curve intersects at the Voyager data values. The amount that the cloud top needs to be lowered depends on the distance between the intersection point and the Voyager data values.

We conclude from Fig. 2 that acceptable values of the mean particle radius which will fit both windows simultaneously are larger than 0.5 μm, since 0.5 μm is single-rooted, and smaller than 3.5 μm, since that would also be single-rooted.

In Fig. 3, we've used a 3 μm particle size to calculate the synthetic spectrum shown in the dashed line. For this spectrum, the cloud top was placed at 530 millibars and the cloud mass was 2×10^{-6} g cm^{-2}. The data spectrum is shown with a solid line. An excellent fit is achieved in the two windows, and in the non-window regions in-between, the fit is also good.

Fig. 4 shows an example of the sensitivity of the synthetic spectrum to assumed particle size. The solid line is the Voyager data, and one of the dashed lines is the synthetic spectrum for a 3 μm particle size from Fig. 3. The other dashed line was obtained assuming a 5 μm particle size. This spectrum was obtained by fitting at 210.1 wavenumbers and simultaneously getting the closest possible fit at 1167.9 wavenumbers. Unlike the 3 μm particle size, for the 5 μm particle size it is not possible to fit both windows simultaneously. Fig. 4 shows that in going from a 3 μm to a 5 μm particle size, the synthetic spectrum in the second window blows up and a simultaneous fit is no longer possible.

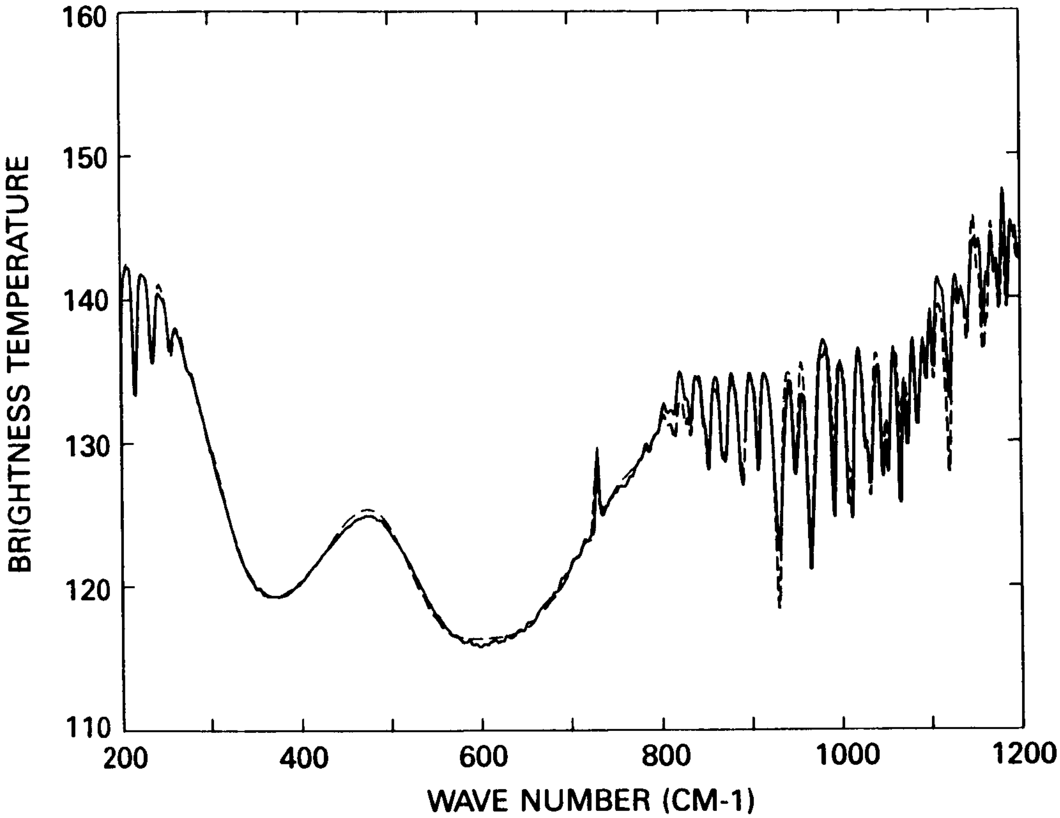

Figure 3. A synthetic spectrum obtained for a cloud with mean particle radius of 3.0 microns, cloud top at 530 mb and cloud mass of 2 x 10^{-6} g cm^{-2} (shown by dashed line). The solid line is the North Tropical Zone IRIS spectrum.

Now, our results indicating small particle sizes, between 0.5 and 3.5 μm, are contrary to what others have obtained, such as Marten *et al.* (1981). For example, Marten *et al.* found that the particle size should be larger than 30 μm and was probably about 100 μm. The reason for the discrepancy between what we have obtained and what they obtained may be due to the region of Jupiter's atmosphere studied. Marten *et al.* studied the Equatorial Zone, while we have studied the North Tropical Zone. Another reason for the discrepancy between our results and theirs may be due to the cloud model used. We assumed a definite cloud top with a sharp cloud cutoff. Marten *et al.* assumed a scale height with no cloud top so that the cloud essentially continued on to the top of the atmosphere, although its density was very small. Our results, however, do agree with those obtained by Sato and Hansen (1979), who examined the near-infrared spectrum of Jupiter's North Tropical Zone. We have not considered in this study the possible dependence of the synthetic spectrum on the variation of the cloud base level; nor have we considered different particulate number density profiles or different particle size distributions that are non-Gaussian. These are presently under investigation. Thank you.

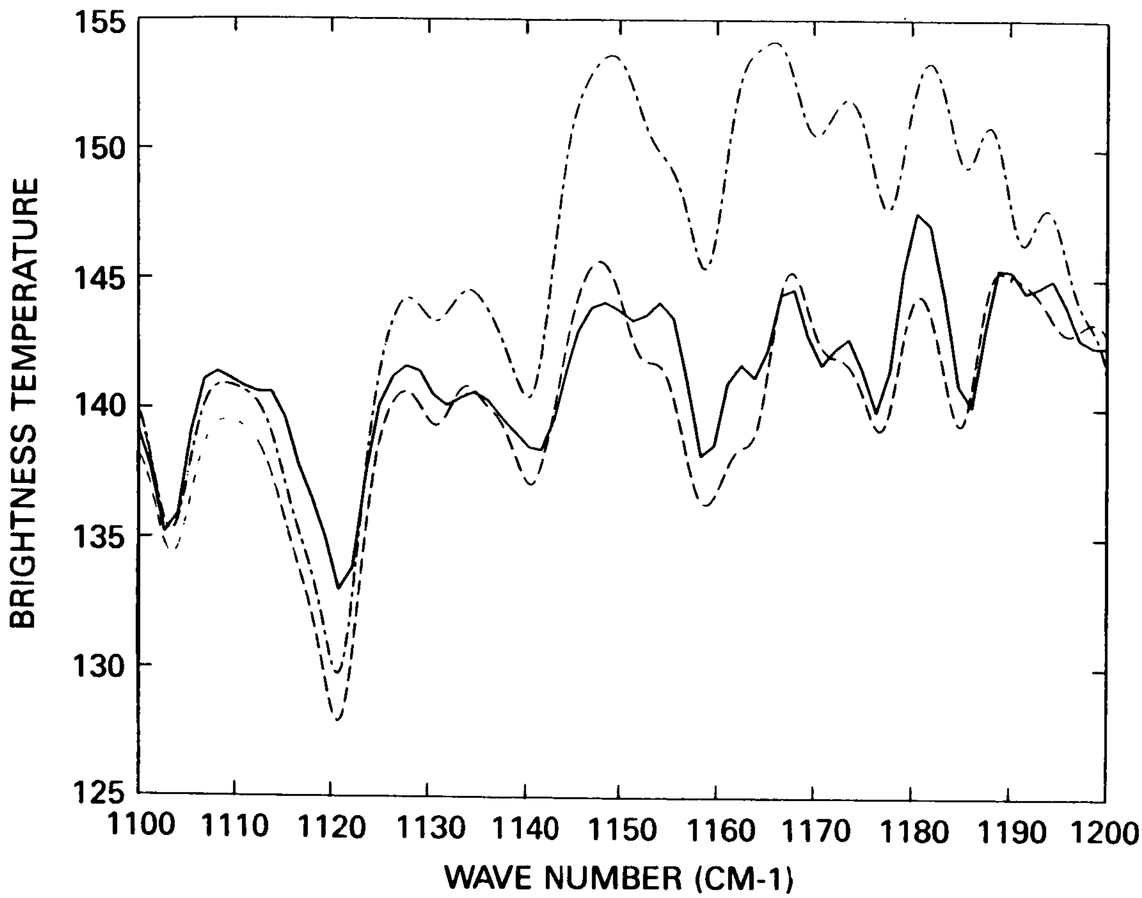

Figure 4. A synthetic spectrum obtained from an attempted fit using a 5.0 micron mean particle radius (dotted-dashed line), showing the best fit possible for an acceptable fit at 210.1 wavenumbers. The dashed line is the 3.0 micron mean particle radius synthetic spectrum. The solid line is the North Tropical Zone IRIS spectrum.

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DR. WEST: You mentioned that 1 μm particles were in the range of acceptable fits to your data. I showed a slide showing that for Mie scattering, 1 μm particles show strong resonant features near 1060 wavenumbers. Is that not added in your calculations, or how do you avoid that?

DR. SHAFFER: I believe that the small particle feature that you showed was for 0.1 μm (not 1 μm) which was outside of our acceptable range. No such feature is evident in the spectrum corresponding to the 3 μm particle size.

DR. ROSSOW: Since you derive a number density and a particle size at the base of the cloud, you can calculate the cloud mass density, which should be of order the saturation vapor density at the base of the cloud. Since you assumed a temperature and pressure level, do all those numbers agree? Did you check to see if they do?

DR. SHAFFER: For the synthetic spectrum shown, that is the 3 μm particle size, I believe that only about 60% of the available saturated ammonia actually goes into cloud formation at the base. However, the apparent excess might be explained by uncertainties in the assumed ammonia mixing ratio profile, or the retrieved temperature profile at this pressure level.

DR. ORTON: To what extent do your results depend on what your assumption was for the distribution of ammonia gas? To what extent did it affect the 210.1 cm^{-1} and 1150 cm^{-1} results?

DR. SHAFFER: We don't expect that it would have much effect on the results, since the particulate number density is not constrained by the ammonia mixing ratio. We didn't try different ammonia profiles. We just used the profile obtained by Kunde *et al.* (1982).

DR. ORTON: The study that Bob West referred to in '83 used 245 cm^{-1} because it was sufficiently far between ammonia line manifolds, and it was pretty far away from ammonia gas absorption.

DR. BEZARD: The spectral region around 1150-1200 cm^{-1} is very sensitive to the cut-off of the Lorentz line shape that you assume. It is sensitive to the far wing shape of the lines of the ν_4 methane band because it's a region of weak gaseous absorption. What did you assume for that line shape, and did you investigate the influence of the cut-off in your calculations?

DR. SHAFFER: The cut-off was 100 wavenumbers.

DR. OWEN: Thank you. I think we should move on.