Masking Jupiter's NH_3-ice spectral signatures: The effects of size, shape, and coatings.

Michael H. Wong*[1], Jochen Marschall[2], Anand U. Oza[2,3], Patricia A. Engel[2,4], Rhiannon T. Meharchand[2,5], Konstantinos S. Kalogerakis[2].

1 Astronomy Department, **University of California**, **Berkeley CA 94720-3411**

2 Molecular Physics Laboratory, **SRI International**, **Menlo Park CA 94025**

3 Present Address: Department of Chemistry, **Princeton University**

4 Present Address: Department of Earth, Atmospheric, and Planetary Sciences, **Massachusetts Institute of Technology**

5 Present Address: Department of Physics and Astronomy, **Michigan State University**

* mikewong@astro.berkeley.edu

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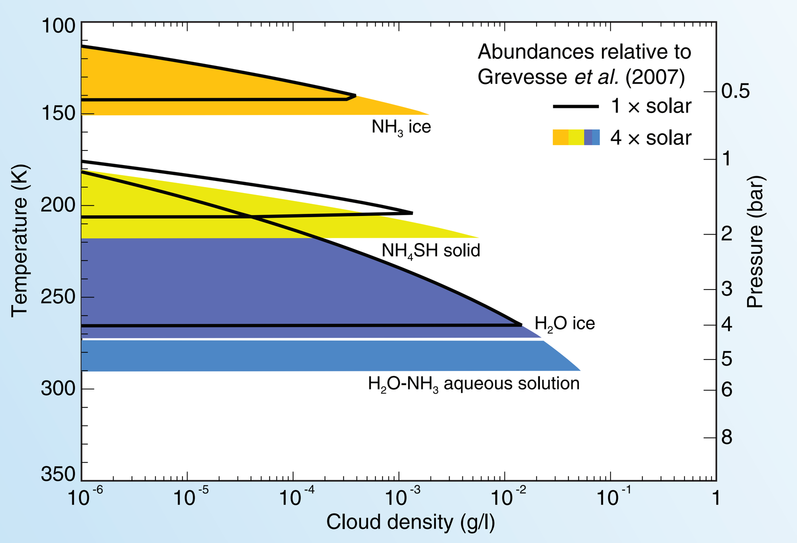
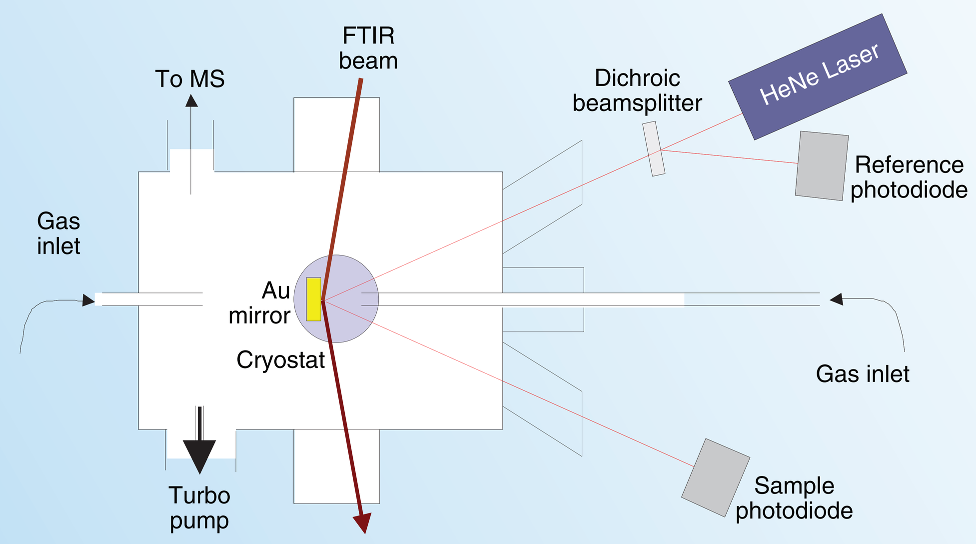
0 Summary

Infrared spectral signatures of NH_3 ice have been reported only twice for the absorption feature near 3 µm (Brooke *et al.* 1998 from ISO, Baines *et al.* 2002 from Galileo NIMS) and once for the feature near 9 µm (Wong *et al.* 2004 from Cassini CIRS). Photochemical residue may fall from above to coat the ice particles, masking these spectral signatures (Smith and Tomasko 1984, Atreya *et al.* 2005). We present laboratory measurements of hydrocarbon coatings on NH_3 ice films, validating this coating hypothesis. The masking effect is largely due to optical interference and works for a number of different coating compositions. To extend these thin-film results to Jupiter's atmosphere, we calculate scattering properties of aerosols and compare the relative importance of size, shape, and coatings. Hydrocarbon coatings act to suppress (grey-out) and shift spectral features on ammonia ice particles. Although small (~1 µm) and large (10+ µm) ammonia ice particles have well-known spectral differences, this work shows that differences between coated and uncoated particles can be of similar magnitude to size effects. Previous efforts required both NH_3 ice and grey particles to model ISO and CIRS data, consistent with the coating/masking hypothesis.

1 Background



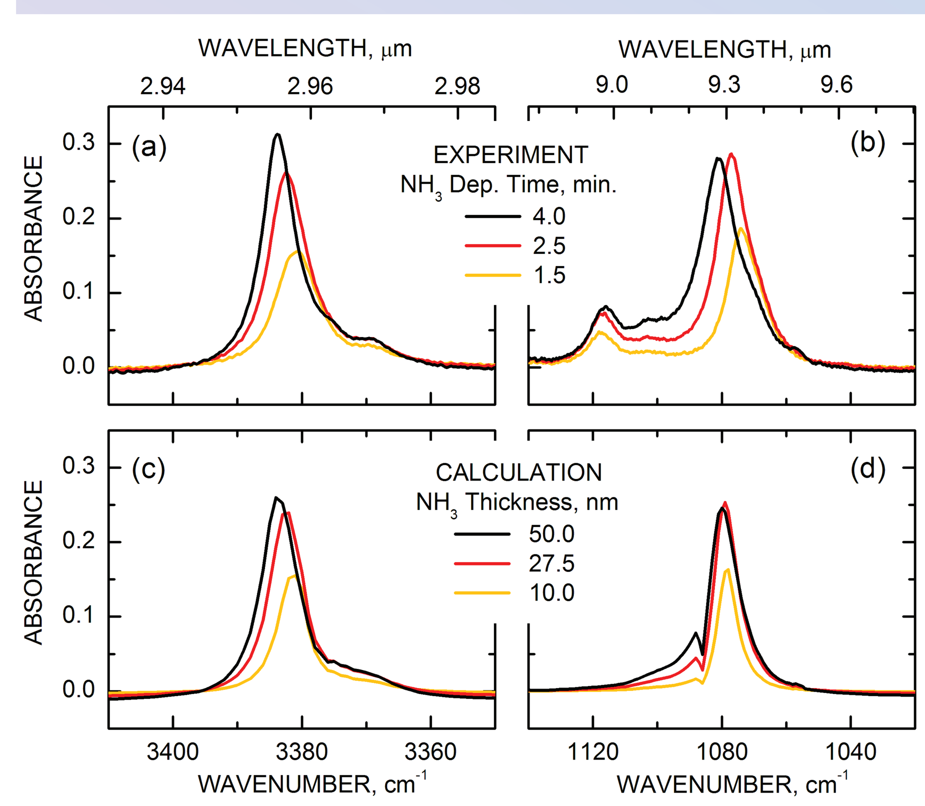
Equilibrium cloud condensation models (left) predict ammonia condensation near the 0.7 bar level (e.g., Lewis 1969, Atreya and Romani 1985). Galileo remote sensing found widespread clouds near this level (e.g., Banfield *et al.* 1998, Irwin *et al.* 1998), but spectroscopic signatures of NH_3 ice are not common.

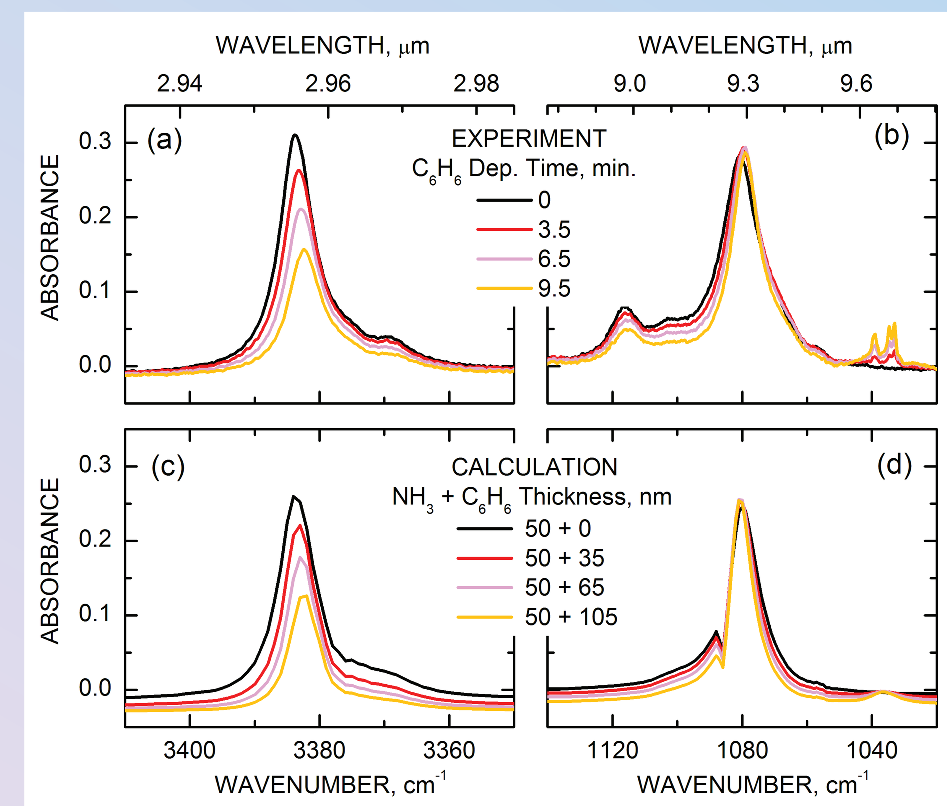


Experimental setup. Spectroscopic characterization of bare and hydrocarbon-coated ammonia ice was performed in a cryogenic apparatus designed for studies of bulk and thin-film materials deposited from the vapor phase. The apparatus consists of a high vacuum chamber equipped with two independent cryostats, both with built-in heaters that allow for controlled cooling and warming rates as well as stable operation over a range of temperatures relevant to those encountered in Jupiter's ammonia clouds and the outer solar system icy satellites (50 to 150 K).

Grazing-angle angle reflection-absorption infrared spectroscopy of the deposited films is performed covering the spectral range from 600 cm^{-1} to 11700 cm^{-1} (0.85 µm to 16.7 µm.) The IR beam enters and exits the vacuum chamber through KRS 5 windows, reflecting off of the cryogenically cooled gold mirror face at an incident angle of 86.0 degrees. The acquisition of reflected intensity spectra with excellent signal to noise ratios can be completed in a few seconds to about 1 minute. Experimental absorbance is defined as $-\log(I/I_0)$, where I and I_0 are the reflected light intensity spectra collected with and without a condensed film.

2 Thin-film coatings: experimental results





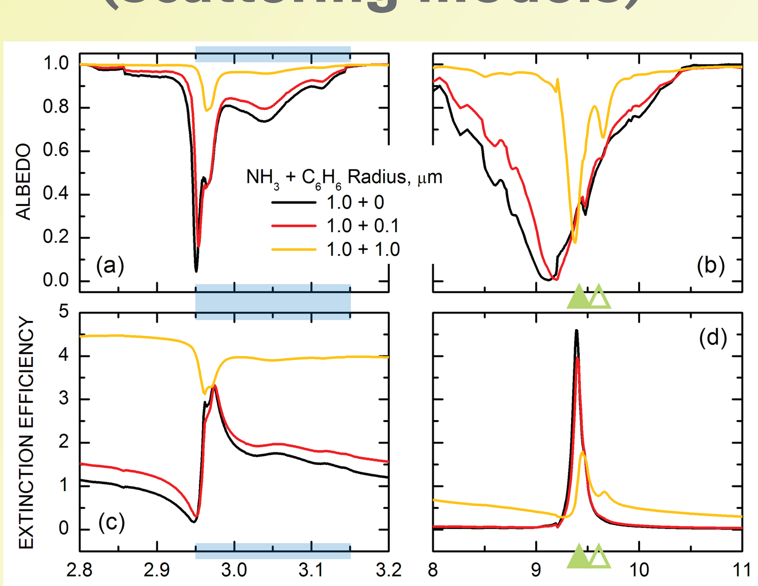
Model calculations. We developed a numerical code to compute the reflectance of a multilayer thin film as a function of the wavelength, angle of incidence, and polarization of the incident light. The algorithm uses a recursive application of the Fresnel equations describing the transmission and reflection of an electromagnetic plane wave incident on a perfect plane interface separating two optically distinct materials (Yeh 1998). Each layer is described independently by its thickness and complex wavelength-dependent refractive index, $m = n - ik$. Simulated absorbance is defined as $-\log(R/R_0)$, where R and R_0 are the averaged reflectance values for the stack and the bare gold substrate, respectively.

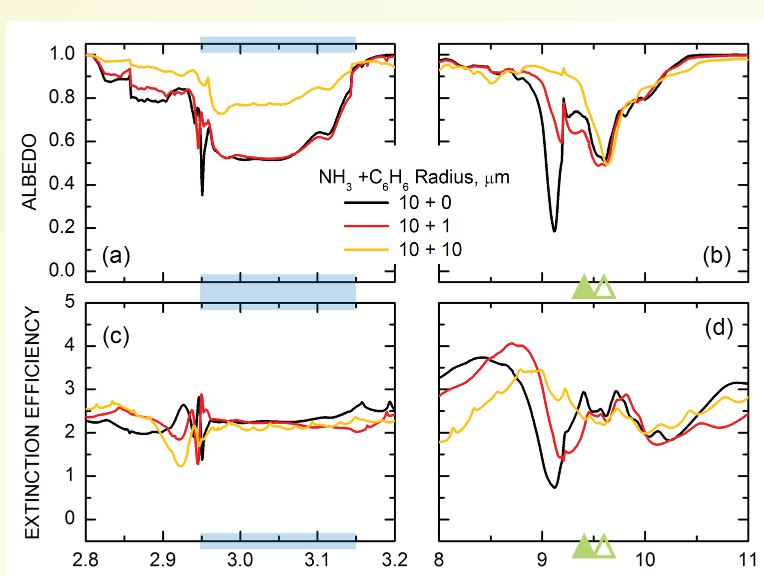
Evolution of experimental spectra (top) near the 3-µm and 9-µm NH_3 absorption features collected during ammonia ice deposition at about 6 µTorr on a gold mirror at 100 K. **Thin-film optics simulations** (bottom) using the NH_3 optical constants of Roux *et al.* (1979). The set of ice thicknesses is chosen to reproduce the spectral evolution observed in the experiment while remaining roughly proportional to deposition rates estimated from gas kinetics. None of the optical constant datasets fully capture the observed spectral shapes and their absolute magnitudes, probably because of the temperature difference between our experiments (100 K) and the optical constant measurements (80 K).

Benzene coating measurements (top) **and simulations** (bottom). After growth of the ammonia ice film to an approximate thickness of 50 nm, the NH_3 flow is interrupted and benzene is deposited at an average pressure of about 2.5 µTorr. This brief benzene exposure partially suppresses the 3-µm NH_3 absorbance feature, but the 9-µm absorbance feature's main peak remains relatively unchanged by the benzene coating.

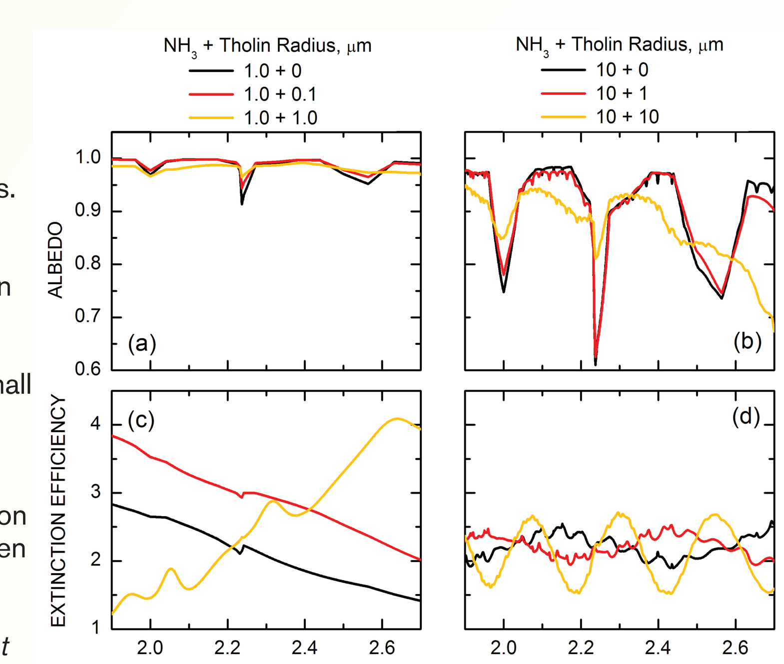
Remarkably, benzene is essentially transparent in these wavelength regions (Bertie and Keefe 2004), but is nevertheless effective at reducing or partially masking the 3-µm ammonia absorbance feature. Given the rather inert nature of hydrocarbons, and the low temperatures and short times of the experiment, chemical reactivity is not a likely cause for this effect. A more plausible hypothesis for the observed behavior is optical interference.

3 Hydrocarbon coatings on NH_3 ice (scattering models)

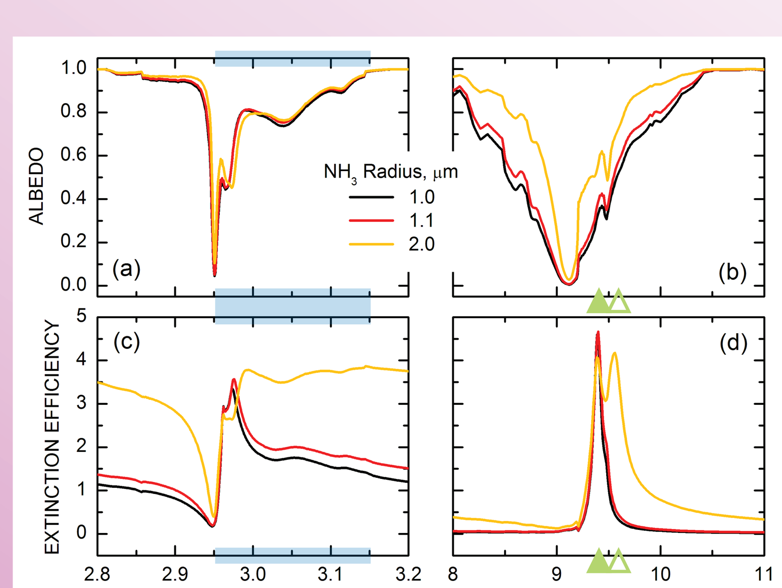


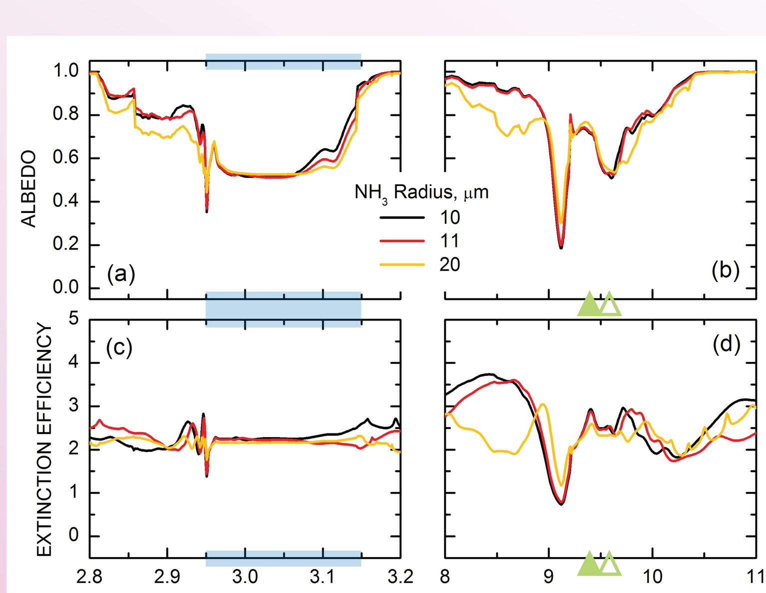


Benzene-coated (left) **and tholin-coated** (right) **particles.** In general, a hydrocarbon coating thickness of 10% of the ammonia particle radius has only minimal effects. Most notable is the loss of the sharp albedo features for the large (10-µm) particle near 3 and 9 µm. Hydrocarbon coatings of the same thickness as the particle radius have a large impact on the computed optical properties of small and large particles: sharp albedo and extinction efficiency features are generally supressed. Blue bars give wavelength range of NH_3 ice absorption in ISO data (Brooke *et al.* 1998). Green triangles give wavelengths of Cassini CIRS NH_3 ice absorption (filled) and reference continuum (hollow; Wong *et al.* 2004).



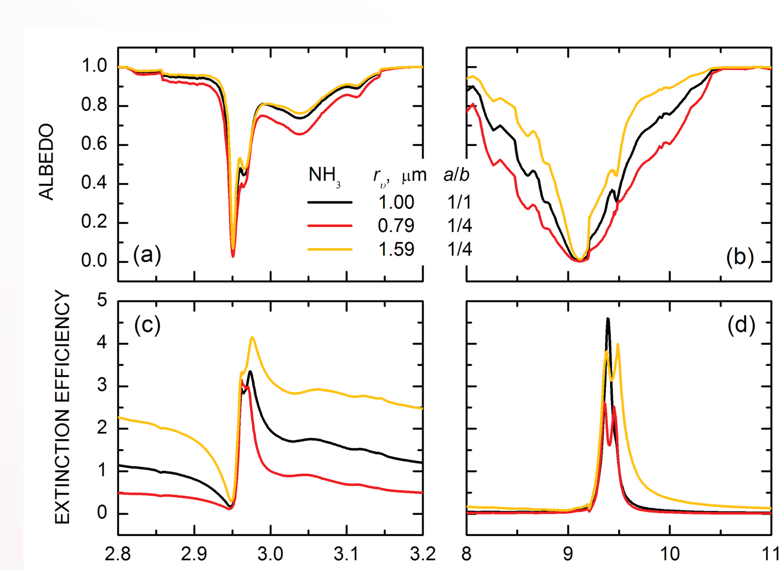
4 Size and shape effects (scattering models)





Size (left) **and shape** (right) **effects on scattering properties.** Adding pure ammonia to create particles (left) with the same total sphere radii as the benzene-coated particles in Part 3 (above) results in minimal changes to computed properties compared with the hydrocarbon-coated examples. Doubling the particle size does not obscure or move the sharp minima observed in the albedos of pure ammonia particles. In the 9-µm region, particle shape narrows or broadens the main albedo minimum, but in both wavelength regions the spectral locations and the magnitudes of the albedo minima do not differ with particle shape.

Scattering calculations for coated and uncoated spheres use Mie codes (Bohren and Huffman 1983), and non-spherical computations use a *T*-matrix code (Mishchenko and Travis 1998).



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