Progress Report
University Of Wisconsin-Madison

Project Title: Quantitative Analysis of Compositional Variation in Jupiter's Clouds

Award Number: NNX14AH40G

UW Account Number: PRJ84GY

For the Period of: 04/14/2014 – 04/13/2015

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(To be completed by the Principal Investigator)

Inventions Report:
(No inventions resulted from this grant.)

Inventory Report:
(No federally owned equipment is in the custody of the PI.)

Publications:

Fry, P. M, and L. A. Sromovsky (2014) Computation of Concentric Shell Particle Scattering Effects in Jovian Clouds. AAS/Division for Planetary Sciences Meeting Abstracts, Vol. 46, #422.20.

Sromovsky, L. A., and P. M. Fry. (2015) Fresh ammonia clouds on Jupiter: a quantitative analysis of Galileo/NIMS and New Horizons/LEISA spectra. Icarus, in preparation.

Summary of Technical Effort:

Objectives: We proposed to quantitatively model the Spectrally Identifiable Ammonia Ice Clouds (SIACs) on Jupiter, which were identified by Baines et al. (2002, Icarus 159, 74-94), but have never been quantitatively modeled, and extend the analysis to other storm features that have also not been modeled, at least one of which has strong NH_3 absorption features at 2 microns and 3 microns, but does not match the SIAC definition of strong absorption at 2.74 microns. We proposed to extend the analysis of Sromovsky and Fry (2010, Icarus 210, 211-229) to longer wavelengths, including thermal emission constraints on cloud opacity, to a wider range of latitudes to investigate spatial variations in composition, and to consider heterogeneous as well as composite particle models. We also aimed to take advantage of higher spatial resolution provided by New Horizons flyby observations with the LEISA spectrometer, which can identify the small regions of 2-micron NH_3 absorption, and thus provide more constraints on the distribution and characteristics of clouds that display features of pure ammonia ice particles (aka SIACs or fresh NH_3 ice). We expect to better define the proportion of NH_4SH and NH_3 in Jupiter's clouds and the possible presence of additional components, possibly water ice in some regions, as suggested by results of Simon-Miller (2000, Icarus 145, 454-461).

Progress on Specific Investigation Tasks:

Radiation Transfer Code Modifications: Our current radiation transfer codes for handling the thermal part of the Spectrum were tuned for VIMS Saturn spectral observations. During the past year we adapted the code to Jovian vertical structure and gas composition profiles and LEISA and NIMS instrument resolutions. We also made software improvements to allow portability to different clusters, more convenient switching between different observed spectral characteristics (required for different instruments), and adding the capability to run on clusters with large numbers of cores, as well as take full advantage of our current dedicated 32-core cluster. Up to this point we

were only running 10 parallel streams (one for each correlated-k component at each wavelength). The revised code can now run multiple wavelengths as well as 10 correlated-k terms per wavelength.

We also made progress in adapting the multi-shell code of Pena and Pal (2009, Computer Phys. Comm. 180, 2348-2354). Preliminary sample calculations were presented by Fry and Sromovsky at the 2014 DPS meeting (see above publications). As described later, fitting the NIMS spectra seems to require multiple coating or multiple layer (or both) particle configurations.

Image and Spectral Data Processing. While the data sets we proposed to use had already been calibrated and navigated, we found LEISA calibration needed further attention. The radiometric calibration of LEISA spectra as retrieved from the PDS we found to be in error (it didn't even have correct spectral units). We reprocessed the data to correct the calibration. We since found that an independent LEISA calibration had been done by Tsang et al. (2014, JGR (Planets) 119, 2222-2238), who also concluded that the PDF calibration was wrong. The Tsang calibration looked similar to ours, but yielded 10-20% larger I/F values over most of the range, increasing to 60% from 1.5 to 1.3 microns. We applied the new Tsang calibration, then compared the results to prior spectral measurements acquired by VIMS, ground based spectra, and to HST bandpass filter measurements. A typical comparison is shown for the SEB region in Fig. 1. This provides a rough sanity check on the I/F radiometric calibration, but points out a potential problem with offsets in low I/F regions of the spectrum, where LEISA spectral I/F's significantly exceed those of the other measurements.
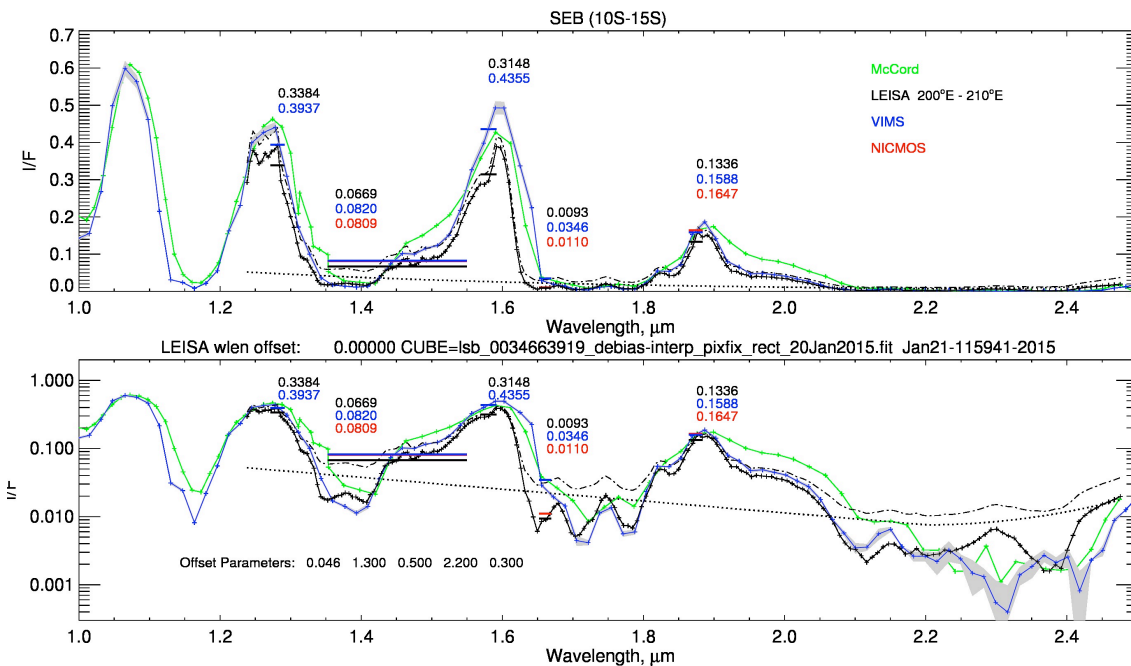

Figure 1. Comparison of spectra from LEISA (lines with points) in a region of the SEBA, with measurements from VIMS and McCord, and with bandpass filter measurements by HST/NICMOS. Here, the LEISA spectra have empirical offsets (dotted curves) subtracted to provide better agreement with other measurements.

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We also know that LEISA offsets are wavelength dependent, and that there is no simple way to correct for them very accurately, especially when space views are not available before and after planetary scans. Figure 2, illustrates the problem for the case where space views are available. Corrections using interpolated space view offsets (C), mean space view offsets (D), and first offsets (E), all make big improvements, but still leave noticeable residual offsets.
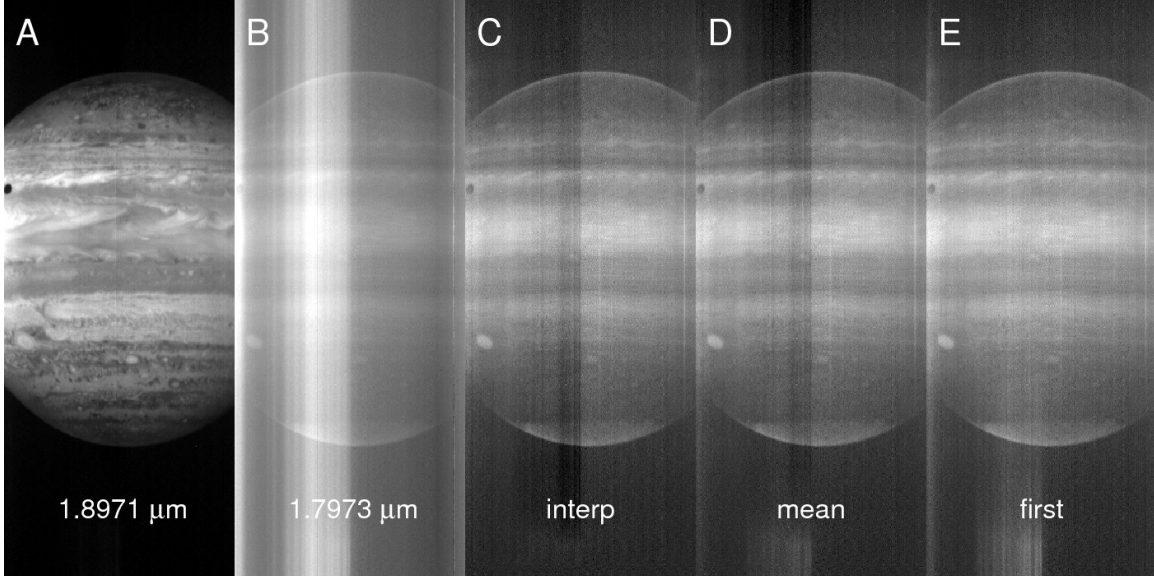
Figure 2. Illustration of LEISA offset issues, and the degree to which different methods are effective in use of space views to correct on-planet measurements.

Quantitative modeling of SIAC composition and structure. We first modeled the SEB (and STZ) measurements not containing SIAC features. Sample fits to both spectra are shown in Fig. 3. The cloud structures that fit these spectra are summarized in the following table,
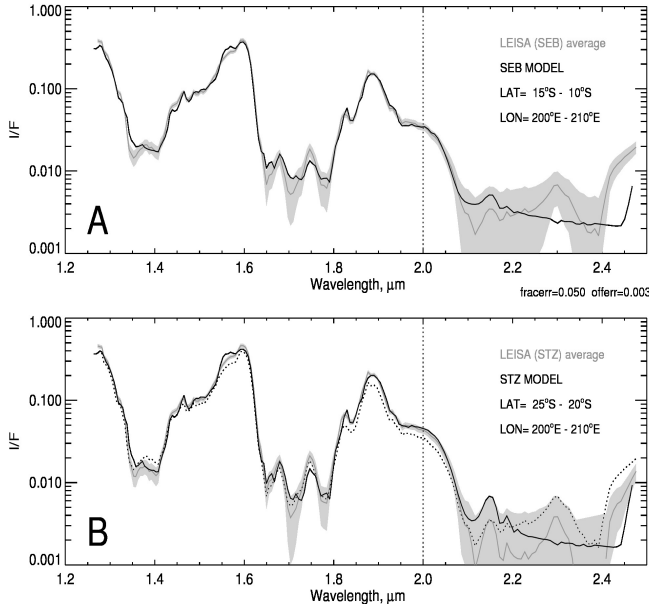
Figure 3. Comparisons between LEISA spectra (solid black) and model spectra (gray). The dotted curve in B is the measured SEB spectrum from A. Gray bands show the uncertainty range assumed in fitting.

Table IV: Aerosol models that match the SEB and STZ spectra in Fig. 8.

| Parameter | offerr=0.005, fracerr=.02 | | offerr=0.003, fracerr=.05 | |
	SEB	STZ	SEB	STZ
P_1, bar	0.001	0.001	0.001	0.001
τ_1	0.0132±0.001	0.010±0.001	0.0129±0.001	0.092±0.001
r_1, μm	0.10	0.10	0.10	0.10
P_2, bar	0.607±0.014	0.482±0.016	0.555±0.013	0.458±0.014
τ_2	2.48±0.27	1.31±0.54	1.58±1.27	1.10±0.61
r_2, μm	1.13±0.15	2.20±0.7	2.03±2.0	2.34±1.0
P_3, bar	1.33±0.07	0.98±0.02	1.16±0.07	0.94±0.03
τ_3	6.80±0.42	8.65±0.75	6.28±0.65	8.05±0.82
r_3, μm	1.5	1.5	1.5	1.5
χ^2/N	2.85	3.54	1.90	1.96

NOTE: parameters with uncertainty limits are those that were adjusted in the fitting process. Others were fixed.

which is taken from the current draft of the paper now in preparation.

We also started modeling LEISA spectra of SIAC features, selected from the region of Jupiter shown in Fig. 4, where SIACs are identified by the ratio of 2 micron I/F values interpolated from surrounding wavelengths to the measured value, which grows larger with increasing NH_3 absorption at 2 microns.
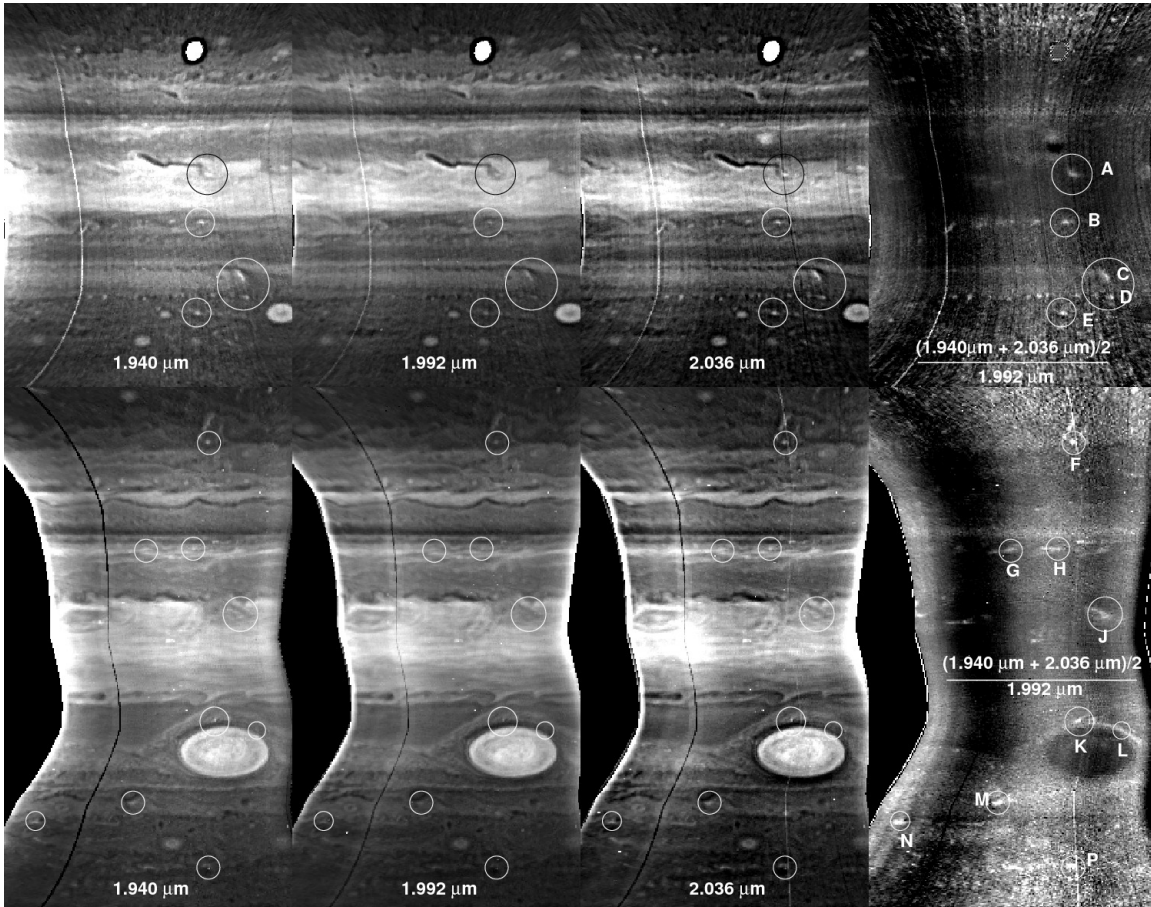

Figure 4. LEISA images at 1.992 microns, near the 2-micron absorption feature of NH3, and on both sides, and the ratio image at the far right, in which bright features contain excess absorption at 2 microns, and indicator of NH3 ice in the cl

A comparison of a spectrum from SIAC feature B with a spectrum from a neighboring cloud region is shown in Fig. 5. The difference near 2 microns clearly indicates the presence of NH_3 in the SIAC feature.

Figure 5. Comparison of SIAC feature B spectrum (solid) with spectrum of neighboring cloud (dotted) reveals a 2-micron absorption feature that is a marker for the presence of NH_3 ice. These spectra are shown without offset

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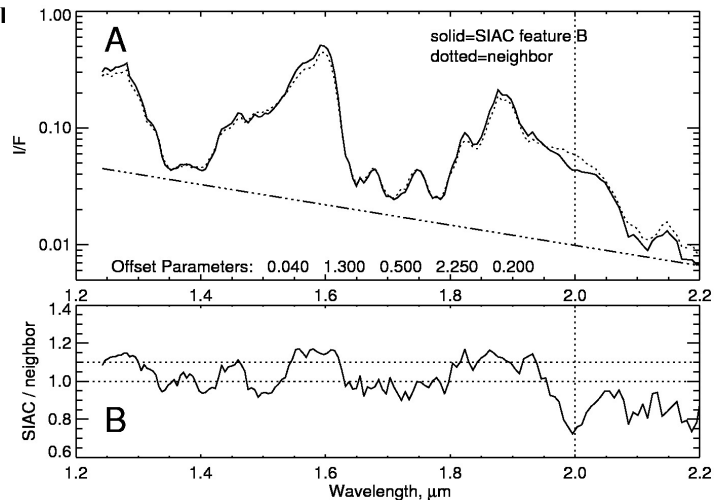
corrections (tripe-dot-dash) subtracted.

A spectral fit to the SIAC spectrum, shown in Fig. 6, shows that the feature is quantitatively consistent with the cloud being mainly composed of NH_3 ice.
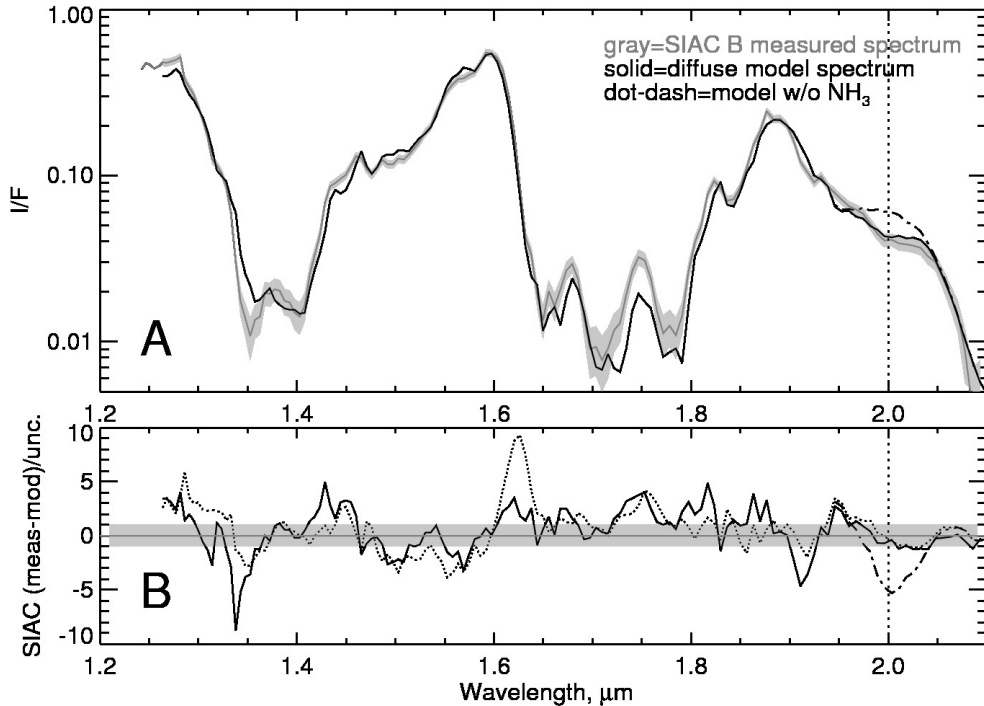

Figure 6. LEISA spectrum (dark gray), compared to a best-fit model spectrum (solid black). The dot-dash curve is the same model with NH_3 replaced by a non-absorbing material with a similar real index of refraction of n=1.3. I panel B, the dotted curve indicates the difference ratio when the measured spectrum is plotted with its wavelengths increased by 0.005 microns, which shows significantly reduced errors in some regions (such as between 1.78 and 1.85 microns, where the 1.91-micron dip is greatly reduced.

We also started analysis of NIMS spectra in the region near the GRS where a prominent SIAC shows both 2-micron and 3-micron absorption features. We found the NIMS measurements were quite noisy and needed to have S/N improved by averaging. An example is provided in Fig. 7, taken from the current draft of the paper in preparation. The top row contains color composite images with different color enhancements to show various cloud spectral characteristics. The left-most image uses the absorption at 2.74 microns, following the Baines et al. method for identifying SIACs (in this case orange marks the SIAC region). Panels B and C show the results of average spectra satisfying different filtering constraints. For B we average spectra that satisfy the condition that the ratio I(continuum)/I(2-micron) is greater than 1.5 and the I(continuum)/I(3 micron) ratio is greater than 3.5. This yields sharp and significant absorption minima at 2 microns and 3 microns, and this is found to come from the edge of the SIAC feature, as indicated by the white pixels in the image to the right. Much more modest absorptions are found in C,

where the selection criteria are that the 1.6/2.74 ratio is between 1.6 and 1.9. The contributing region is now seen to be over the main part of the SIAC.
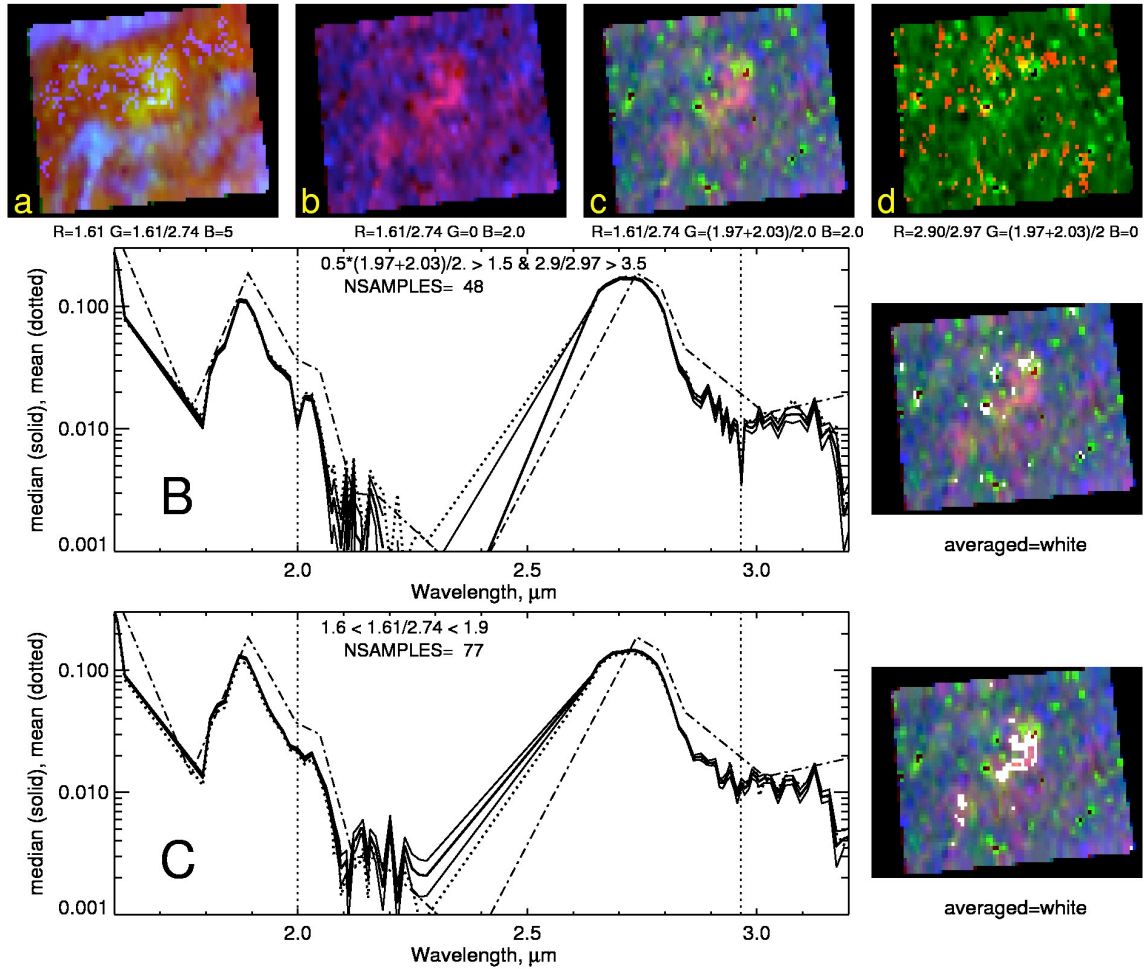

Figure 7. NIMS spectra of a major SIAC feature on Jupiter. See text for explanation.

It has proven to be very challenging to fit the sharp absorption features in the NIMS spectrum from panel B (in Fig. 7). To investigate why, we studied simple single layer models of various optical depths, particle sizes, and two-component coated particle compositions. From this experience we found that the 2-micron region is strongly suppressed when gas absorption is added and by the spectral absorption gradient that is present across the feature. The most distinct 2-micron feature is obtained from larger particles, while these larger particles exhibit very little evidence of the 2.965-micron absorption feature when appropriately averaged over the NIMS line-spread-function. The depth of that feature is best reproduced by relatively small particles that do not produce a very significant 2-micron absorption feature when absorbing gas is mixed into the aerosol layer.

We found that pure NH_3 particles do not provide a very good match to the spectrally flat region between 2.97 microns and 3.16 microns. A composite particle consisting of a

shell of NH_3 and a core of NH_4SH, with a core fractional radius of 0.6-0.7, provides a decent match of the observed slope.

To obtain spectral features at both 2 microns and 2.965 microns seems to require a multi-layer structure, with an optically thick layer of large particles (r~10 microns) underneath an optically thin layer of smaller particles (r~2 microns). An alternative might be a coated particle, rather than a set of multiple particle layers.

Work plan for Year 2. We will continue to work on finding structures that can fit the difficult NIMS constraints on particle composition. Additional NIMS observations of SIACs will also be investigated. The concentric shell scattering code will be interfaced more efficiently to our fitting routines so that we can explore a larger variety of particle structures. We will also take advantage of our more highly parallelized radiative transfer code so that our explorations of different cloud and particle structures will provide much faster feedback. We will also return to fitting VIMS Jupiter observations, including this time the 5-micron thermal emission constraints. These results will be written up and most of it will be included in the current paper, which we expect to be ready for submission by the end of the year.