HYPERSPECTRAL IMAGING OF JUPITER AND SATURN

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Background:

Despite hundreds of years of observations, we still do not know which trace chemical compounds (chromophores) color Jupiter and Saturn's atmospheres. Previous analyses have been unable to conclusively identify specific chemicals that are responsible for the color. Various analytical techniques, including principal components and cluster analyses, have been attempted previously for Jupiter, but have met with limited success due to low spatial or spectral resolution in the regions of interest [1-5]. Three basic questions will be addressed in our chromophore study of Jupiter and Saturn: 1) How many coloring agents are there? 2) What are the spectral characteristics of the chromophores? 3) What are the spatial distributions of the chromophores? Analysis of Hubble Space Telescope images of Jupiter (150 km resolution) suggests that at least three components exist: an average (spatially constant) color, a variable white/gray cloud deck, and one or more additional coloring agents [2]. The spectral resolution of the data set was poor, however, with gaps in wavelength coverage between 700 and 950 nm and only a single broadband filter between 400 and 650 nm. High spectral resolution is needed in order to uniquely identify the spectral characteristics of a coloring agent and its distribution with principal components.

Instrument:

The data sets described below were acquired with the New Mexico State University Acousto-optic Imaging Camera (NAIC), which has the unique ability to acquire images with tunable narrowband filtering (~15 Angstroms FWHM) between 0.4 and 1 micron using an Acousto-Optic Tunable Filter (AOTF). Instant wavelength selection with the AOTF makes it possible to create spectral image cubes with better spectral resolution and coverage than feasible with standard narrowband filters, and the imaging camera provides better spatial resolution than possible with a spectrograph. Filtering with the AOTF requires passing light through standing acoustic waves in a TeO_2 crystal. The internal acoustic vibrations are induced by sending a radio frequency (RF) signal from an RF generator into the crystal via a transducer. The frequency of the RF signal determines the wavelength tuning of the filter.

Observations:

We obtained several thousand narrowband images of Jupiter and Saturn during 2007, covering 470 – 900 nm in 2 nm steps. Both Jupiter and Saturn were observed on 27 February, 01 March, and 02 March (UT) at the Air Force Advanced Electro Optical System (AEOS) 3.67 meter telescope at the Maui Space Surveillance System. These observations were scheduled for support of the New Horizons closest approach to Jupiter on 28 February 2007. AEOS is equipped with an advanced adaptive optics (AO) system, which provided us with tip-tilt correction. Use of the full AO was not feasible due to the large angular size of Jupiter and Saturn. Loss of light from the AO 50/50 beam-splitter and the low throughput of NAIC necessitated 20 - 40 second exposures, but the tip-tilt correction still yielded images with seeing as small as 0.7 arcsec.

Jupiter was again observed on 26 June, 27 June, and 04 July (UT) at the Astrophysical Research Consortium 3.5 meter telescope at Apache Point Observatory in Sunspot, NM. Exposure time was reduced to ~2 seconds by an increase in pixel binning, and the seeing ranged from ~0.7 – 2.0 arcsec.

Preliminary Results:

We performed a principle component analysis (PCA) on three wavelength scans of Jupiter. Figure 1 contains their map projections, which have been false-colored to reveal the cloud height, and a description of each scan's coverage in latitude and longitude.

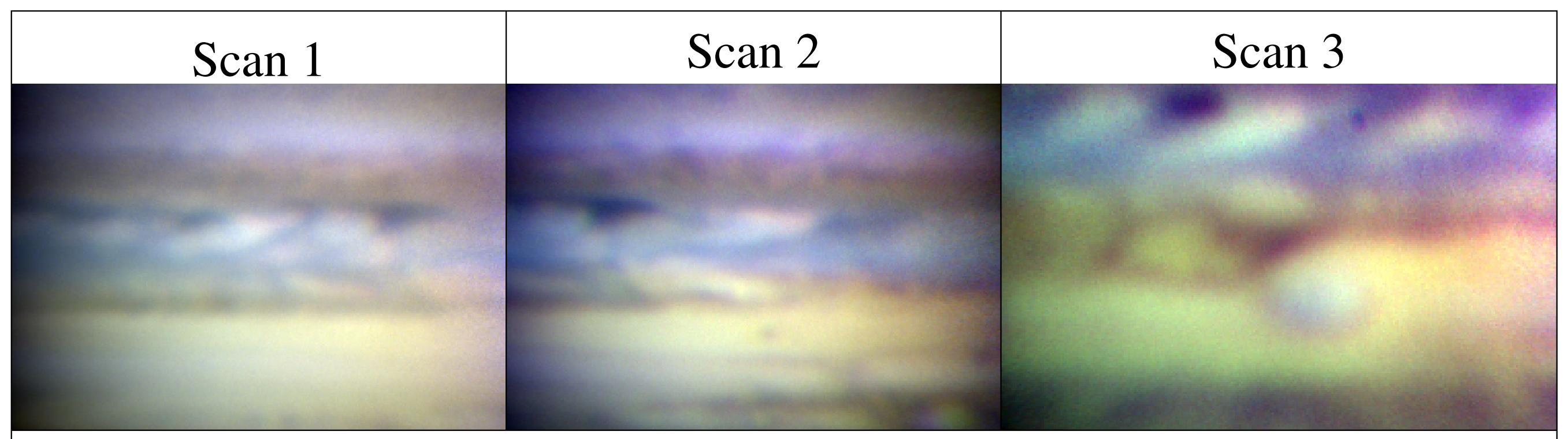

Figure 1: False-color map projections of Jupiter (red: 756 nm, green: 726 nm, blue: 890 nm) taken with NAIC at Apache Point Observatory. Scan 1 covers -35° to 35° latitude (planetographic) and 240° to 340° longitude (System III), Scan 2 covers -35° to 35° latitude and 185° to 285° longitude and contains Oval BA (lower right corner), and Scan 3 covers -45° to 11° latitude and 335° to 65° longitude and contains the Great Red Spot (center right). Color indicates cloud depth: red clouds are deep, white clouds are high and thick, and blue clouds are high hazes [3].

The first five principle components (PCs) for Scans 1-3 are shown in Figure 2. The PCs are ordered by their contribution to the variance in the original data cube, with PC 1 having the highest variance (Fig. 3). Each PC is defined by an eigenvector in wavelength space (Fig. 2 plots), and a corresponding image is created from the PC coefficient associated with each pixel. A large fraction of the variance is probably due to differential limb-darkening, as the Jovian sub-solar longitude progressed westward during the acquisition of each scan. This can be seen as a gradient, most notably across the first two or three PCs. This effect will be removed in future analyses with limb-darkening corrections. Nonetheless, the cloud features visible against the gradients are a source of spectral information.

PC 1 has a very flat spectrum which is slightly higher in the blue. Note that PCA can only identify spatially varying components; the mean brightness and color are not observed in the results. **PC 2** has a red slope with a local minimum at 560 nm and local maximum at 500 nm. **PC 3** is strongly absorbing around 500 nm, with a spectral shape similar to S_4, and is reflecting in the weaker methane bands (619 and 727 nm). High values of PC 3 appear in the GRS (Scan 3), and PC 3 highlights the band-like structure of the atmosphere in Scans 1 and 2. **PC 4** clearly contains strong methane absorption bands (727, 865 and 889 nm) in all three scans and a broad absorption around 540 nm. **PC 5** does not have a clear spectral slope but seems to sample the atmosphere at a different optical depth of methane than PC 4, since it includes minima at the weaker methane bands and maxima at the stronger ones.

Future Work:

PCA will be performed on all of the acquired images of Jupiter and Saturn with several different approaches. The first analysis will use each individual 470 – 900 nm image set, as a continuation of this preliminary study. Next, images of the same wavelength from different sets will be stitched together to create a single set containing the maximum spatial coverage. Following success in these analyses, individual locations (GRS, Oval BA, areas showing multiple chromophores) will be selected for careful remapping at higher resolution for more detailed study. These analyses will constrain the number, spectral characteristics, and spatial distribution of chromophores in the atmospheres of Jupiter and Saturn. Cloud heights will be studied concurrently by analysis of the methane absorption features to find any correlations between the presence of chromophores and cloud height. Identifying what components are located at various altitudes will tell us if photochemical production or other processes play a major role in the composition of these giant planet atmospheres.

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References:

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[2] Simon-Miller et al. (2001a) *Icarus* 149, 94-106.
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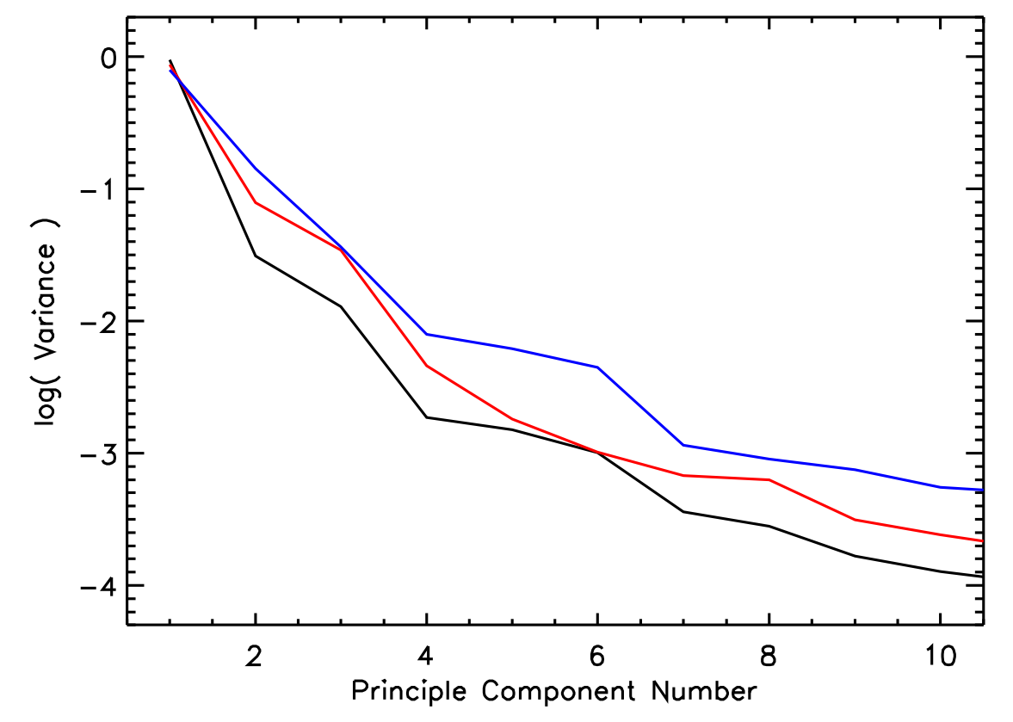
Figure 3: The variance (in log scale) contributed by each PC to the original data cube. Scan 1 is black, Scan 2 is red, and Scan 3 is blue. Only the first 10 of over 200 PCs are shown.



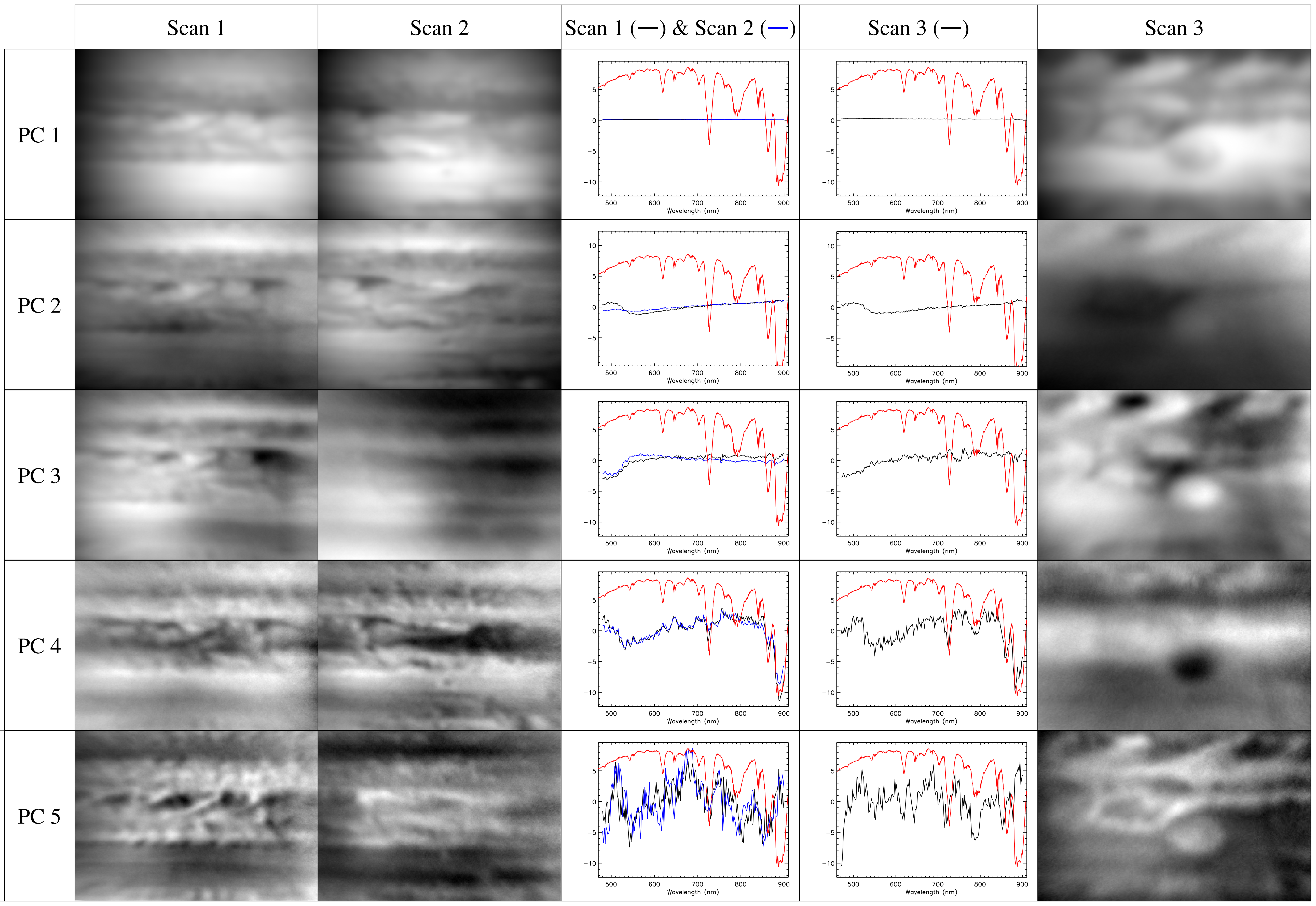


Figure 2: The first five principle components (PCs) for Scans 1-3. The images corresponding to each PC are created from the PC coefficient associated with each pixel, where dark is negative and bright is positive. The plots show the PC eigenvector in wavelength space (the units on the y-axis are arbitrary) with Jupiter's full-disk albedo spectrum [6] scaled and overlaid in red.