HYPERSPECTRAL IMAGING OF JUPITER AND SATURN.

Paul D. Strycker[1], N. J. Chanover[2], D. G. Voelz[3], A. A. Simon-Miller[4]

[1]New Mexico State University, P.O. Box 30001, MSC 4500, Las Cruces, NM 88003. strycker@nmsu.edu,
[2]New Mexico State University, P.O. Box 30001, MSC 4500, Las Cruces, NM 88003. nchanove@nmsu.edu,
[3]New Mexico State University, P.O. Box 30001, MSC 3-O, Las Cruces, NM 88003. davvoelz@nmsu.edu,
[4]NASA Goddard Space Flight Center, Code 693.0, Greenbelt, MD 20771. Amy.Simon@nasa.gov.

Introduction: Observations of Jupiter and Saturn have been made with the New Mexico State University Acousto-optic Imaging Camera (NAIC) from the Air Force Advanced Electro Optical System (AEOS) 3.67 meter telescope at the Maui Space Surveillance System and the Astrophysical Research Consortium 3.5 meter telescope at Apache Point Observatory (APO). The narrowband images yield spectral image cubes of these planets with ~1 arcsec angular resolution and wavelength coverage from 470 to 900 nm with 2 nm spectral resolution. A principle component analysis (PCA) will be performed to determine the number, spectral characteristics, and spatial distribution of chromophores (coloring agents) in the atmospheres of Jupiter and Saturn.

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 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.

Combining the spatial location of chromophores derived from PCA results with methane absorption-band images will help us determine the vertical location of the chromophores, also telling us about photochemical processes and transport in the Jovian atmospheres. The simultaneous study of coloring agents and vertical structure in Jupiter's atmosphere is important to our basic understanding of the evolution of the planets. 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.

Instrument: The data sets described below were acquired with 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.

When the RF signal is off, only scattered light reaches the CCD. This scattered light is a significant portion of the flux at the CCD and must be imaged in an RF-off frame in order to remove it from RF-on frames. The scattered light changes with target position in the field of view, so approximately one RF-off frame was taken for every five RF-on frames during the observations. The RF-off frames have an exposure time equal to the RF-on image so that subtracting the RF-off from the RF-on not only removes the scattered light, but also removes the bias and dark current.

Observations: We obtained a few thousand narrowband images of Jupiter and Saturn during 2007, covering 470 – 900 nm in 2 nm steps. Both Jupiter and Saturn were observed from 27 February through 02 March (4 full nights) at the AEOS 3.67 meter telescope. 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 through-put of NAIC necessitated 20 - 40 second exposures, but the tip-tilt correction still yielded images with seeing down to 0.7 arcsec. Two nights at AEOS were lost due to humidity and clouds.

Jupiter was again observed for 6 half-nights between 25 June and 04 July at the APO 3.5 meter telescope. Exposure time was reduced to ~2 seconds by an increase in pixel binning, and the seeing ranged from ~0.7 – 2.0 arcsec. Four half-nights were lost at APO due to the early onset of seasonal rains.

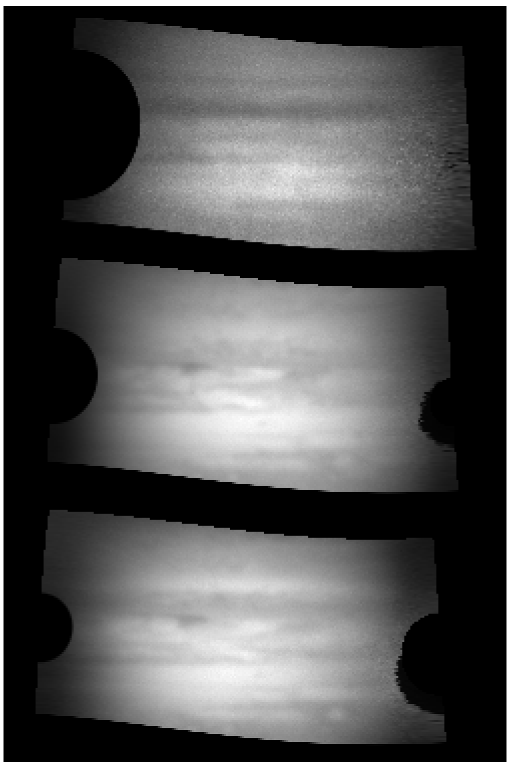

Figure 1: Map projections of Jupiter at 480 nm (top), 702 nm (middle), and 900 nm (bottom) from one wavelength scan from 470 to 900 nm taken with NAIC on 26 June 2007 (UT) at Apache Point Observatory.

Image processing scripts were written in IDL for the first three reduction steps. First, each RF-on frame was RF-off subtracted with the RF-off frame closest in time. Next, fiducial flat-fields were created in 50 nm steps from 500 to 900 nm. (The flats are wavelength dependent because the refraction angle of narrowband light exiting the AOTF crystal is a function of wavelength.) Finally, each image was flat-fielded with the fiducial flat closest in wavelength.

Data Analysis: We will perform a PCA with all of the images acquired. PCA requires multiple images, in which a given pixel corresponds to the same physical location on the planet in each image. Since Jupiter and Saturn rotate quickly compared to the time required to acquire 216 images (the number of images in each 470 to 900 nm scan), and also because we desire to compare images between nights, this requires each image to be map projected (Fig. 1).

Five values must be known for each image (in addition to basic physical data, such as the equatorial and polar radii of the target planet) in order to create a map projection: the plate scale of the CCD, location of the planet center (image x and y position), north angle of the planet in the image, sub-earth point (System III latitude and longitude) and the distance to the planet at the time of the exposure. The plate scale, which was determined by observations of a standard double star, did not vary with wavelength. Thus, a (different) constant value was used for each observing location. An IDL code was written to find the planet centers (using planet disk templates) and north angles (using fast Fourier transforms). Another code pairs planet ephemeris data (sub-earth point and distance) from JPL Horizons with each image according to Julian date. The map projection of the images was performed with the Atmospheric Measurement and Imaging Environment (AMIE), which is a local IDL-based adaptation of the JPL VICAR software.

The PCA will be performed with several different approaches. The first analysis will use each individual 470 – 900 nm image set. 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 showing multiple chromophores will be selected for careful re-mapping at the highest possible resolution for more detailed study. Cloud heights will be studied concurrently by analysis of the methane absorption features to find any correlations between the presence of chomophores and cloud height.

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References:

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