

Fading of Jupiter's South Equatorial Belt

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One of Jupiter's most dominant features, the South Equatorial Belt, has historically gone through a “fading” cycle. The usual dark, brownish clouds turn white, and after a period of time, the region returns to its normal color. Understanding this phenomenon, the latest occurring in 2010, will increase our knowledge of planetary atmospheres. Using the near infrared camera, NSFCAM2, at NASA's Infrared Telescope Facility in Hawaii, images were taken of Jupiter accompanied by data describing the circumstances of each observation. These images are then processed and reduced through an IDL program. By scanning the central meridian of the planet, graphs were produced plotting the average values across the central meridian, which are used to find variations in the region of interest. Calculations using Albert4, a FORTRAN program that calculates the upwelling reflected sunlight from a designated cloud model, can be used to determine the effects of a model atmosphere due to various absorption, scattering, and emission processes. Spectra that were produced show ammonia bands in the South Equatorial Belt. So far, we can deduce from this information that an upwelling of ammonia particles caused a cloud layer to cover up the region. Further investigations using Albert4 and other models will help us to constrain better the chemical make up of the cloud and its location in the atmosphere.

I. Introduction

Since 1919, astronomers have been observing a fading phenomenon in Jupiter's normally dark South Equatorial Belt or SEB with the latest fading event happening in 2010. The dark brown SEB, located -5° S to -20° S, appears to fade away, turning into a white cloud before returning to its original dark state. One cycle of fading and revival can range from three to fifteen years. Observations of this event have taken place in nearly every decade since the first sighting in 1919. Spacecraft such as Pioneer 10 & 11 and Voyager 1 & 2 have all recorded such events.¹ Spacecraft and ground based cameras have collected a plethora of images. However, the atmospheric dynamics of this event is still not clearly understood.

By using observations taken in 2009 and 2010 from the near infrared camera NSFCam2, a facility instrument at NASA's Infrared Telescope Facility (IRTF), an analysis of pre-fade observations and observations taken during the fade can take place. The first step in the analysis was to reduce images ranging from 1.58 microns to 4.78 microns. A majority of the images used during this analysis were taken on July 2009, August 2009, September 2010, October 2010, and November 2010. In order to reduce an image properly, a number of steps must take place. First, one must subtract a sky image from a raw image of the object, in this case Jupiter. Next, one will subtract a flat field image that helps in taking out non-uniformities in an image. After subtracting the sky and the flat-field, one would take the raw files of the planet and co-add them together, i.e. taking the images and stacking them on top of each other. Also, during the co-add stage, an application of the bad pixel mask, an image that contains bad pixels in the detector is used to identify which pixels should be ignored in the image. Once a co-added image is made, geometry must be assigned to each pixel on the planet and photometry must be applied so that the image can be calibrated in terms of absolute reflectivity. The last step in reducing an image is creating a cylindrical map that is the image of the planet that is reimaged onto a latitude and longitude grid corresponding to each point and a μ map that contains the cosine of the emission angle for each of these points. The next step in the analysis after reducing the images was to create a program that scans the central meridian of the planet and plots the average reflectivity value across the central meridian. These plots help to determine which wavelength had the biggest variations when comparing pre-fade and mid-fade images. By using a program created to simulate spectral

reflectivity, both the chemical composition and the altitude of the fade can be inferred. Once certain wavelengths were chosen, analysis using a FORTRAN program called Albert4 helped constrain the parameters, such as single-scattering albedo and altitude, which help determine the chemical composition of the clouds and their location in the atmosphere. The results produced from this analysis help us better understand the atmospheric dynamics of Jupiter. In addition, the solution to this problem can also help us better understand the atmospheric dynamics of the outer gas giants. As Neil deGrasse Tyson said “if I understood what is happening on Jupiter, Earth would be a piece of cake.”²

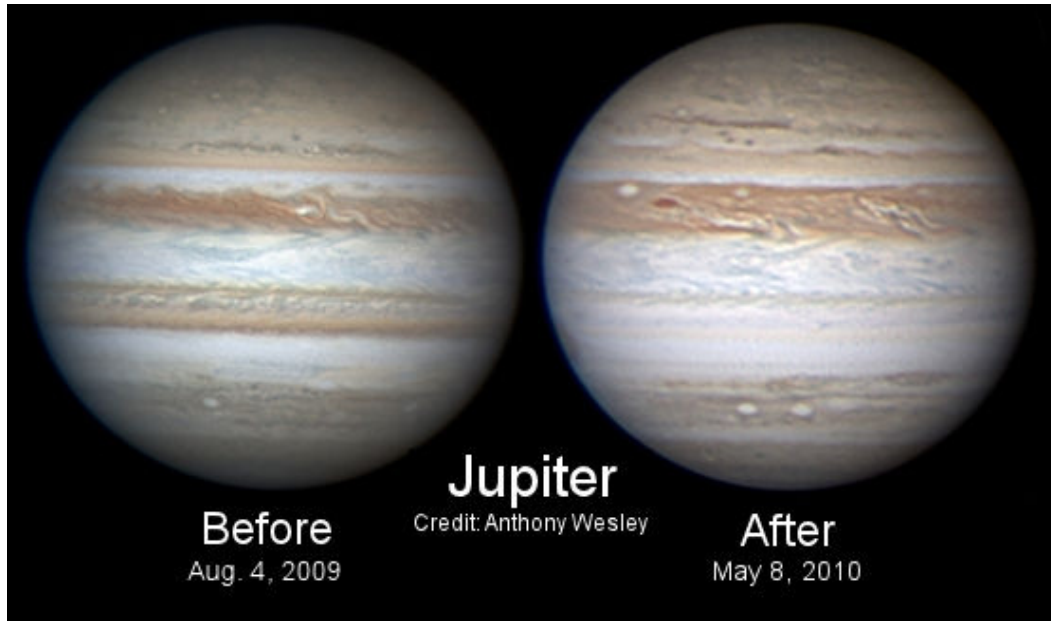


Figure 1: Shows the SEB phenomenon. Notice how the SEB has turned from a dark brown to white
 Source: http://science.nasa.gov/science-news/science-at-nasa/2010/20may_loststripe/

II. Data Reduction

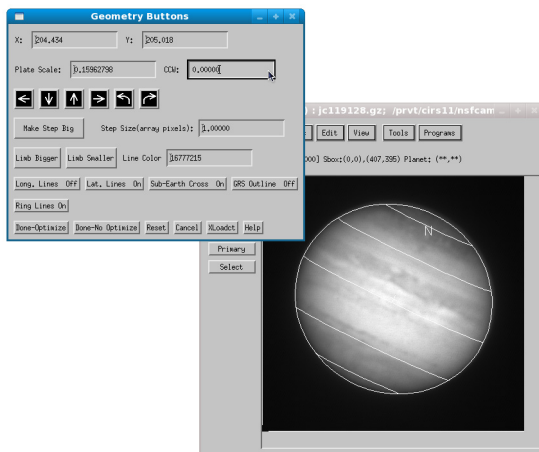


Figure 2: Shows DRM placing a geometric grid on Saturn

Data reduction is the act of decoding raw data and reducing the number of original data points to create a calibrated image. For this project, the data come in the form of Flexible Image Transport System (FITS) images, a format that is “designed for the exchange of astronomical data.”³ Each FITS file has a header that contains the image's astronomical data. Every time an action is done to an image, IDL data reduction code, Data Reduction Manager (DRM), updates the header automatically. When the images are taken, the telescope goes through a process called nodding. Nodding subtracts the background sky by offsetting the telescope to another point in the sky in order to subtract the sky “B” frame from the original object “A” frame.” Once this process is completed, the sky background can be removed from the object through a numerical process called ABAB subtraction. Once the background sky is subtracted, the image must be divided by the flat-field image.

The flat-field image, an image a uniform field such as the telescope's dome, helps correct for the effect of non-uniformities in the detector array response. Next, the images must be co-added together. The images can be either astro-correlated or geometrically fit to enable the images to be aligned correctly. Co-adding the images “increases the signal-to-noise ratio by the square root of the number of iterations.”³ The image must be geometrically fit, which places a latitude, longitude, and emission angle grid onto the planet.³ The absolute radiance of the Jupiter images were calibrated by normalizing to the disk-interpolated reflectivity recorded by the Visual and Infrared Mapping Spectrometer (VIMS) on the Cassini spacecraft.⁴ Finally,

the image is projected onto a cylindrical map to allow easy access to the reflectivity values of the object for the same position at different wavelengths. Once the images have the correct calibrated reflectivity values, various programs were used to extract crucial information such as chemical composition, pressure, depth, and single-scattering albedo.



Figure 3: Shows an example of a cylindrical map

III. IDL Programs

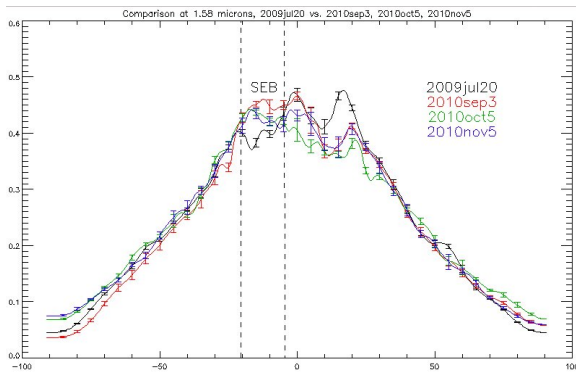


Figure 4: Plot showing the reflecting across the central meridian. The x-axis is latitude and y-axis is the reflecting value.

Two Interactive Data Language (IDL) programs were created to analyze the data. The first program plots the average values of the central meridian. The program received a cylindrical map and a cosine emission angle map, or mu map, as inputs. The program loops through the longitudes on the mu map searching for the point where the emission angle is closest to or equal to 1. Having a longitude corresponding to the central meridian, the program scans the central meridian, calculating and storing the average values along the all the latitudes. For this project, the program averaged 10° to the east and west of the central meridian. Next, a plot displaying these averages reveals how the reflectivity varies with latitude. By comparing pre-fade dates with mid-fade dates, variations in the SEB show how it evolved over time. Comparing different wavelengths shows how the SEB varied at different levels in the atmosphere. The second creates near-infrared spectra of the event. The spectra reveal the chemical composition of the SEB such as ammonia

and methane. Using information about depth and composition, atmospheric dynamics, such as upwelling, can be inferred. Information regarding the pressure and single-scattering albedo of the clouds provides deeper insight into the phenomenon.

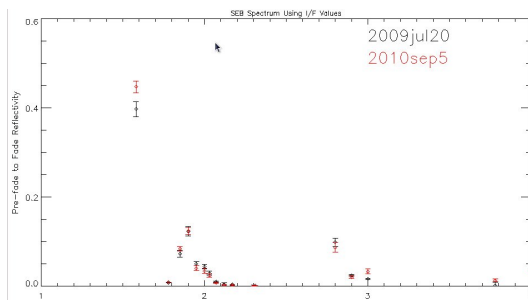


Figure 5: Spectrum of the SEB on varying dates. The x-axis is wavelength while the y-axis is reflecting value.

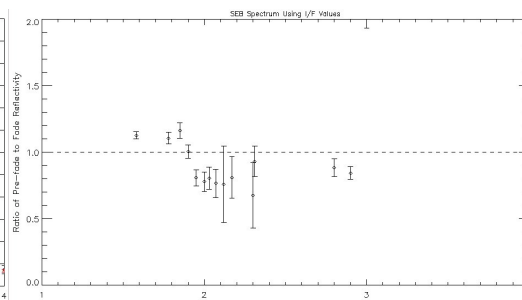


Figure 6: This plot displays the ratios of the reflectivity values of the spectrum. The x-axis is wavelength.

IV. Albert4 Models

Albert4 is a FORTRAN program, developed by Kevin Baines, designed to calculate the “response of an atmosphere in which layers of absorbing gas and scattering aerosol particles with different scattering properties can be specified arbitrarily.”⁵ Examples of parameters that the program keeps constant are chemical abundance, pressure-temperature profiles, wavelength, and scattering type. Single-scattering albedo, opacity, and cloud-type pressures are parameters that are varied between different models. The program receives a file containing a list of parameters, which is used for calculations. The output of the program contains a reflectivity profile of the planet.⁵ The dependence of the reflectivity on various absorption, scattering, and emission processes gives insight into what the pressure, opacity, and single-scattering albedo values should be by comparing the calculated values for a particular model to the data. Since Albert4 creates a latitude and longitude grid separated by 10° at each phase angle, linear interpolation must be used to approximate values that are between each latitude, longitude, and phase angle. Using the interpolated values from the grid of reflected sunlight and emitted radiance and the data from the images, an approximation of pressure, opacity, and single-scattering albedo can be deduced.

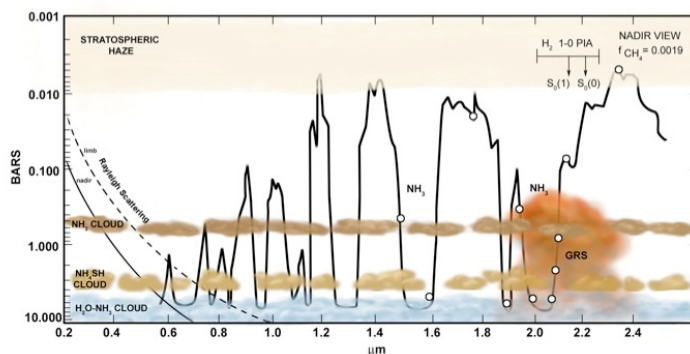


Figure 7: Diagram showing how cloud top pressure varies by wavelength. Source: Baines, Orton, JPL

V. Findings and Results

The central meridian plots showed that certain wavelengths were affected more than others. Radiance at wavelengths that were most affected and were used for Albert4 models were 1.58 microns and 2.03 microns. The plot for 1.58 microns showed that the SEB was more reflective in September 2010 and the reflectivity steadily decreased as time progressed, while spectra show ammonia bands changing with time. The data indicates that ammonia could be moving throughout the atmosphere. Albert4 models calculated that the pressure and single-scattering albedo of atmospheric particles that fit data at 1.58 microns was between 1.75 to 2 bars and .9087 for the SSA before the fade. For 2.03 microns, the pre-fade atmospheric pressure of the particle layer was 0.77 bars with a single-scattering albedo of .9087. Mid-fade, the pressure was 0.88 bars with a single-scattering albedo of .9257. This information allows us to think that an upwelling of ammonia gas that condensed into ice causes the event. To constrain models better, more analysis using Albert4 should be conducted to get a more accurate approximation of the dynamics of the atmosphere

VI. Conclusion

The dynamics of Jupiter’s SEB have puzzled scientist for almost a century.⁶ Scientists will be able to continue researching this event and with technology increasing at an exponential rate, with higher quality images and greater computing power. Using tools such as IDL and FORTRAN, I am able to observe the changes that are taking place within the SEB. By scanning the central meridian of Jupiter, information regarding variations in the reflectivity values can be seen. The variations at each wavelength show which wavelengths were affected the most and by how they differed with time. The spectra show how the chemical composition of the atmosphere changed over time. The ratios of these values show where the biggest changes in composition and cloud opacity took place. This information helped in deciding the initial values to put into Albert4. Albert4 calculated the pressure, opacity, and single-scattering albedo. Utilizing all this data, an approximation of the dynamics of Jupiter can be deduced. Our findings indicate that an upwelling of ammonia from deep in the atmosphere occurred, bringing the white ammonia cloud to cover the typically dark SEB.

VII. Acknowledgments

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VIII. References

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