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About Jupiter's Reflectance Function in JunoCam Images

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Abstract

NASA's Juno spacecraft has successfully completed several perijove passes. JunoCam [1] is Juno's visible light and infrared camera. It was added to the instrument complement to investigate Jupiter's polar regions, and for education and public outreach purposes. Images of Jupiter taken by JunoCam have been revealing effects that can be interpreted as caused by a haze layer. This presumed haze layer appears to be structured, and it partially obscures Jupiter's cloud top.

With empirical investigation of Jupiter's reflectance function we intend to separate light contributed by haze from light reflected off Jupiter's cloud tops, enabling both layers to be investigated separately.

1. Introduction

JunoCam is the visible light and near infrared Education and Public Outreach camera of NASA's Juno mission. In order to analyze images from Jupiter, we created an approach to approximating Jupiter's reflectance function. The appearance of a convex, smooth and matte white body with a solid surface, illuminated by a single point source of white light, is well approximated by the Lambert illumination model. At the 1-bar level, Jupiter is a reasonably good approximation to a MacLaurin spheroid, hence a convex body. At Jupiter's distance, the sun approximates a point source of light. Thus, settings can be completed to a Lambertian scenario for the Sun - Jupiter system; let's call it *Jupiter's Lambert model*. Dividing actual Jupiter images by Jupiter's Lambert model helps to enhance local features on Jupiter, and it reveals global deviations of Jupiter's reflectance properties from the simple Lambertian scenario.

Especially in the twilight zone of Jupiter's terminator, and in proximity of Jupiter's limb, light scattered or absorbed in Jupiter's atmosphere adds net brightness to the Lambert model. Other models try to approximate these atmospheric effects.

The approach presented here attempts to model the brightening as a structured layer of light-scattering and absorbing haze. Goals are a better understanding of Jupiter's haze layer, as well as obtaining a better enhancement of the underlying cloud tops on the basis of JunoCam images.

2. DeLambertianing

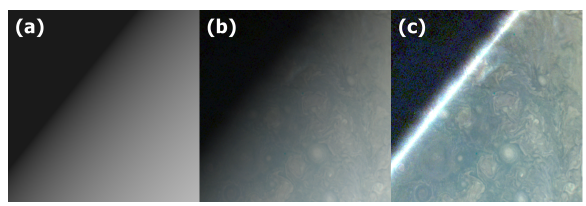

Figure 1: (a) Crop of south-polar projection of Lambert model for square-root encoded image `JNCE_2017086_05C00116`; (b) crop of south-polar projection of decompanded and square-root encoded image `JNCE_2017086_05C00116`; (c) crop of radiometrically linearized and de-Lambertianed south-polar projection of image `JNCE_2017086_05C00116`.

The Lambert illumination model calculates the cosine of the angle between the surface normal and the vector from the respective illuminated surface point to the illuminating point light. This value can be obtained by calculating the (standard) scalar product between the two vectors, normalized to unit length:

$$\cos(\vec{u}, \vec{v}) = \frac{\vec{u} \cdot \vec{v}}{||\vec{u}|| \cdot ||\vec{v}||}. \quad (1)$$

The required vector from Jupiter to the sun can be retrieved from SPICE trajectory data stored in appropriate SPICE kernels via the NAIF/SPICE `spy.exe` tool, or by including the SPICE library into the respective processing software. Calculation of the surface normal of a spheroid is provided by the SPICE library, too, but for the processing discussed here, the calculation has been implemented independently. This applies also to the required JunoCam camera model. The latter is required to assign a color band and a vector to a pixel in raw JunoCam images. A Lambert model, a JunoCam image of Jupiter, and a de-Lambertianed version are shown in Figure 1 in a cropped south-polar projection.

Note the good but still imperfect matching between polar projections of the Lambert model and of the JunoCam image. This small discrepancy shows up as a bright twilight zone in the de-Lambertianed projection.

3. Haze and Light Scattering

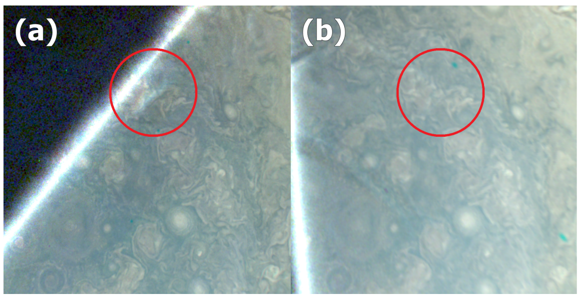

Figure 2: (a) Crop of radiometrically linearized and de-Lambertianed south-polar projection of image JNCE_2017086_05C00116; (b) crop of radiometrically linearized and de-Lambertianed south-polar projection of image JNCE_2017086_05C00121.

Figure 2 shows an example of the particularly evident dependence of the appearance of haze features from the solar incidence angle. Haze features are more distinct near the terminator. This effect might be attributable either to the height of the haze above the 1-bar level, to variable optical density of the haze, or to the slope of a ripple in the haze horizon.

Note the overall brighter tone in the right tile (b) of Figure 2. This hints at the apparent brightness of the haze being correlated to the emission angle.

4. Light curves

Along Juno's trajectory, JunoCam took — and is going to take — several images of the same patch of Jupiter's surface. Figure 3 shows map projecions of five consecutive RGB images taken during perijove 5, together with according maps of solar incidence, and emission angles with respect to Juno. Such series of images allow for inferring curves of apparent brightness as functions of solar incidence and of emission angles for individual surface points separately.

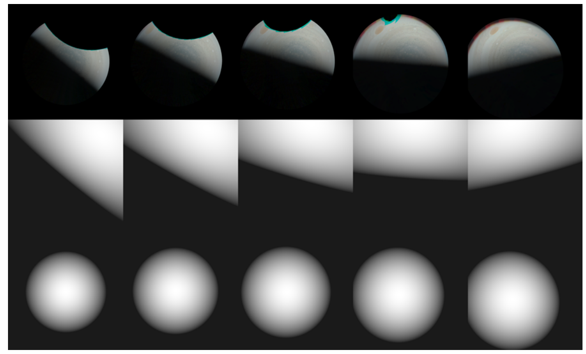

Figure 3: 1st row: Radiometrically square-root encoded south-polar projection of RGB images JNCE_2017086_05C00113 to JNCE_2017086_05C00119. 2nd row: Corresponding square-root of cosine of solar incidence angles. 3rd row: Corresponding square-root of cosine of emission angles.

Applications of these light curves range from optical models of Jupiter's haze layer over image enhancement to more realistic and seamless fly-over animations.

5. Summary and Conclusions

As it turns out, challenges and approaches of processing JunoCam images of Jupiter require an explicit or implicit understanding of the optical properties Jupiter's haze layer. The favored explicit approach allows for describing structure in the haze layer.

Acknowledgements

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References

[1] C.J. Hansen, M.A. Caplinger, A. Ingersoll, M.A. Ravine, E. Jensen, S. Bolton, G. Orton. *Junocam: Juno's Outreach Camera.* Space Sci Rev DOI 10.1007/s11214-014-0079-x, Springer, 2014