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Photochemistry and Heating In Saturn's Atmosphere: Ring Shadow And Ring Reflection

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Abstract

The molecular composition, haze abundance, and thermal structure of Saturn's upper atmosphere is determined by the solar insolation. As with any planet, the amount of sunlight impinging on the atmosphere is determined by both the planet's distance from the Sun in addition to seasonal effects cause by the planet's axial tilt. The rings of Saturn shadows regions of the planet for long periods of time while illuminating the opposite hemisphere. This research attempts to quantify the extent to which ring shadow and illumination from the rings impact atmospheric properties. Where possible, we use spacecraft measurements to place constraints.

Sun, Rings, and Saturn

Cassini orbited Saturn for over thirteen years, nearly a half Saturn year. This corresponded to a seasonal configuration where the sub-solar point was at ~24ºS at Saturn Orbit Insertion (July 1, 2004) and ~27ºN at the time of the Grand Finale. During this period, the ring shadow moved southward from covering a large portion of the northern hemisphere (Figure 1a) to covering a large swath of territory south of the equator as solstice approached (Figure 1f). At equinox, the rings project a small sliver of shadow at low latitudes. At its maximum extent, the ring shadow can reach as far as 48ºN/S (~58ºN/S at the terminator). The intensity of both ultraviolet and visible sunlight penetrating into any particular latitude will vary greatly depending on both Saturn's axis relative to the Sun and the optical thickness of each ring system. In essence, the rings act like semi-transparent Venetian blinds (Figure 2) over the atmosphere of Saturn.

At the same time, the illuminated side of the rings reflect ultraviolet and visible solar photons onto the fully illuminated hemisphere of the planet. This acts to enhance both photochemical driven chemistry and heating and further enhances seasonal effects. Lastly, the rings, having a temperature themselves, provides a little explored source of thermal photons impinging onto the atmosphere.

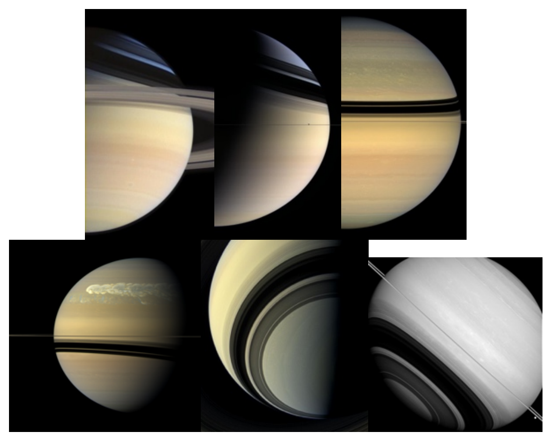

Figure 1. Saturn's atmospheric evolution versus changing solar inclination: (a) December 14, 2004, (b) March 16, 2006, (c) April 23, 2008, (d) July 6, 2011, (e) July 29, 2013, (f) November 24, 2014. Images are courtesy of NASA/JPL/Space Science Institute.

The projection of the oscillating ring shadow onto the planet has been derived as a function of season. In addition, detailed calculations of geometric parameters important for light scattering from the rings onto an oblate planet have been worked for a fine grid of latitudes and longitudes (e.g. Figure 3). We will present on how these geometric parameters are used for conducting both photochemical (UV) and thermal balance (visible and infrared) radiative transfer calculations as a function of season.

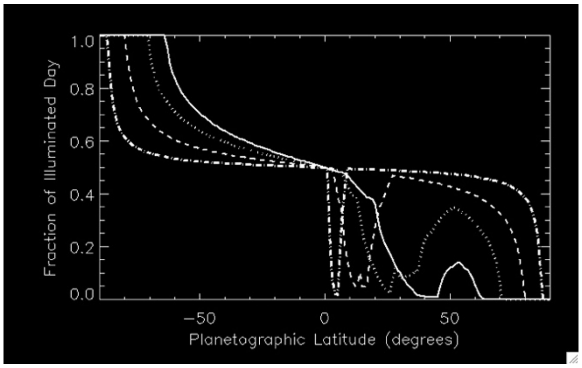

Figure 2. This plot illustrates the fraction of Saturn's daytime as a function of solar inclination, i.e. season. The curves correspond to sub-solar points of 26.7°S (solid), 19.6°S (dotted), 10.7°S (dashed), and 3.5°S (dot-dashed). This will determine the flux of photons allowed to enter the atmosphere relative to that of a clear, un-shaded atmosphere.

We assess the impact of the rings on production and loss rates of hydrocarbons (e.g. acetylene, ethane, and propane), ammonia, phosphine, and hazes. Comparison to a ring-less Saturn and Jupiter, where the axial tilt is known to be insignificant (~3° inclination) and to constraints of key molecules and haze from Cassini will be presented.

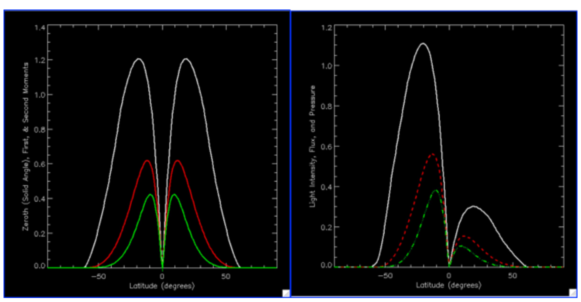

Figure 3 (Left) Solid angle subtended by rings versus latitude (white) along with first (red) and second (green) angular moments. (Right) Thermal radiation intensity (white), flux (red), and pressure (green) at top of atmosphere versus latitude. Southern hemisphere represents the sunlit rings. For reference, the solar constant at Saturn is ~14 Wm^{-2}.

Finally, we will compare photochemical rates interior to the hexagonal jet stream (Figure 4), which acts like a barrier to transport, to those southward of the jet. Future research will explore how haze formation in this isolated region can inform us of the photochemical processes taking place globally.

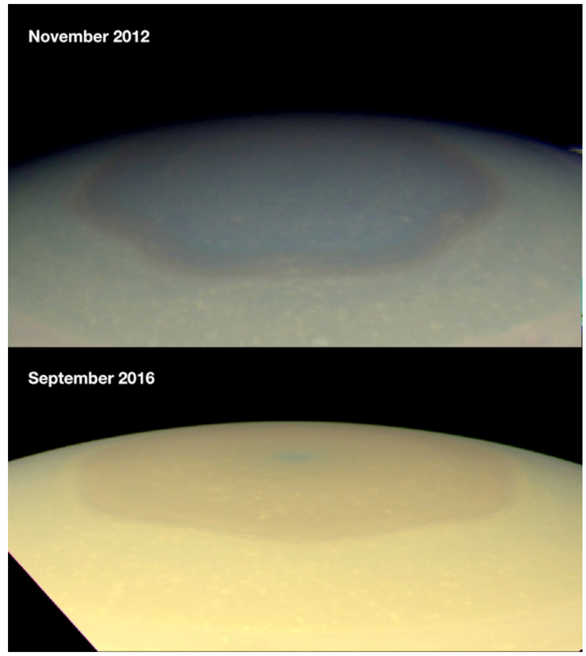

Figure 4. Cassini color images illustrating the atmospheric changes taking place both interior and exterior to the hexagonal jet stream in early (top) and mid (bottom) spring. Images are courtesy of NASA/JPL/Space Science Institute/Hampton U.

Acknowledgements

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[2] Edgington, S.G., R.A. West, K.H. Baines, S.K. Atreya, E.H. Wilson, G.L. Bjoraker, L.N. Fletcher, and T. Momary, 2012. Photochemistry in Saturn's Ring Shadowed Atmosphere: Modeling, Observations, and Preliminary Analysis. *Bull. American. Astron. Soc.*, **38**, 499 (#11.23)