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Saturn's Enigmatic "String of Pearls" and Northern Storm of 2010-2011: Manifestations of a Common Dynamical Mechanism?

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Abstract

The "String of Pearls" (SoP) and the Northern Storm on Saturn near 34° north latitude may both be manifestations of convective processes at depth. As one possibility, the SoP may be a set of von Kármán vortex street features with convectively-driven updrafts as the driving obstacles. VIMS observations show marked increases in the size and latitudinal separation of the pearls (vortices) during the year prior to storm eruption, indicative of a growing convective system that may have subsequently erupted as a major thunderstorm. Other common convective mechanisms (uplift-driven Rossby waves, vortex-shedding from rising updrafts) may be possible. New VIMS images and spectra of the thunderstorm and SoP are presented.

1. String of Pearls

During its seven years of Saturn reconnaissance, Cassini has witnessed two unusual atmospheric phenomena near 34 degrees (planetocentric, pc) north latitude: The rather bizarre "String of Pearls" and an unusually powerful convective storm. Followed by the Visual Infrared Mapping Spectrometer (VIMS) for over half a decade - from July 16, 2005 through September 5, 2010 - the "String of Pearls" is an enigmatic feature unlike any other seen on Saturn or other major planet. Located in a powerful westward (retrograde) jet within a cloud layer at depth near 1.5-3 bar level, this long-lived feature displays 21-26 regularly spaced, near-uniformly-sized, circularly-shaped clearings within the cloud layer which together span, on average, 92° of longitude. In VIMS 5-micron imagery, which observes the warm glow of Saturn generated at depth near the 8-bar level, these near-regularly spaced and shaped clearings appear bright against the surrounding cloud observed in silhouette – hence the colloquial name "String of Pearls". The average clearing is about 2° longitude (~1800 km) wide, and is, on average, 4.2° of longitude (3700 km) from its neighbors. In latitude, adjacent pearls are typically 0.4° – or about half a pearl radius – apart. The pearl structure moves retrograde in the Voyager system (Desch and Kaiser, Geophys. Res. Lett 8, 253-256, 1981) with an average speed over five years of 22.07 ± 0.04 m/s, making it the fastest moving retrograde feature observed by Cassini/VIMS in non-polar regions

Several salient characteristics of the pearl structure changed with time. Over 5years, the mean latitude increased from 32.9 ° to 34.8 °, while the mean size of pearls grew by 22% in latitude and 42% in longitude. During the last half of 2010, the mean latitudinal separation of adjacent pearls doubled from ~ 0.5° to over 1.0°, corresponding to an increase of ~2600 km/yr, or > 1 pearl diameter annually.

2. Northern Storm

Despite concerted attempts to observe the SoP in February. March, and May, the feature has not been seen in 2011, perhaps due to the formation of overlying optically-thick clouds produced by the eruption of a large, powerful northern storm in the same region which began on Dec 5. 2010 and which has lasted through this writing in late May 2011 (Fig 1). Ground-based images obtained by the amateur astronomical community during the first two weeks

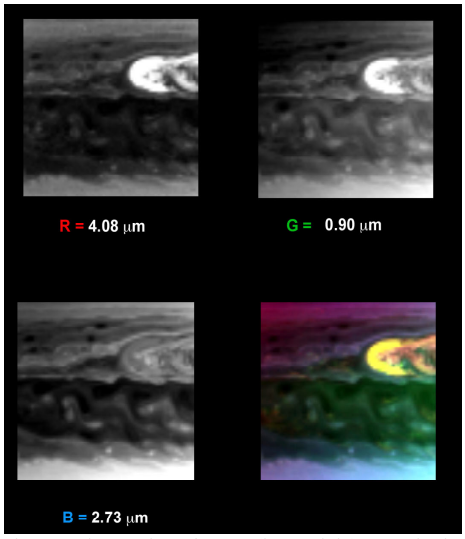

Fig 1. Color version of storm (lower right) comprised of 4.08-μm (showing large particles, upper right), 0.9-μm (relatively high altitude, upper right) and 2.73-μm (ammonia ice absorption) images. Yellow denotes large, ammonia-absorbing ice crystals at relatively high altitudes. Streamlines of clouds are visible bending around the storm.

after eruption reveals the position of the storm to be in agreement with the predicted position of the String of Pearls, with reported latitudes during the first nine days after formation near 35 degrees latitude (pc) and a predicted longitude at eruption of 242^o (System III). days after formation near 35 degrees latitude (pc) and a predicted longitude at eruption of 242^o (System III). This is well within the pearl construct, some 30^o east (downstream) of the predicted position for the most westward Pearl, given (1) the mean westward speed of 21.89 m s^{-1} observed between Nov. 19, 2009 and Sept. 10, 2010 and (2) a longitudinal length of the SoP of 74^o, as observed on Sept. 5, 2010. We note that a decrease in the drift speed of the SoP by 3 m s^{-1} would place the head of the northern storm at the western end of the SoP.

VIMS spectral imagery of the head of the storm obtained in February/March and May 2011 (e.g., Fig 1) shows the clearest spectral signature of nitrogen-bearing materials in the 2.7-3.2 μm range on Saturn to date, indicating the most massive transport of condensable ammonium hydrosulfide and/or ammonia from depth ever observed.

3. Pearl-Storm Connection

The coincidental positions and distinctive dynamic appearance of the String of Pearls and northern storm suggests a dynamical link between the two phenomena. The morphology of the String suggests that it is fundamentally a von Kármán vortex street, a set of near-regularly-spaced vortices formed on the downwind side of an obstruction within a zonal flow. As seen regularly on Earth, such vortices with their three dimensional – including downward – motions within vortices can clear otherwise cloudy skies. More than a dozen vortices have been typically observed downstream of isolated mountainous structures – monadnocks - on Earth, with the diameter of each vortex roughly equivalent to the diameter of the obstructing monadnock.

The analogy with Earth suggests that an obstruction about 1^o latitude wide is present near the peak of the retrograde (westward) jet stream near 35 degrees (pc) latitude. This obstruction flows in tandem with the retrograde jet, its northern and southern extensions disrupting the relatively slow-moving retrograde flow to the north and south of the peak, causing the von-Kármán-like vortex pattern. We suggest that the obstruction is air vertically transported from depth, likely due to convection from below possibly enhanced by a triggered planetary wave.

If the high-speed retrograde jet at this altitude actually represents the bulk wind speed at depth, down to the level of well-mixed water near 20 bar, then this retrograde jet could be a region of extremely low vertical wind shear. This would then allow vertically-directed updrafts to rise coherently over several hundreds of km altitude without being shorn apart by the vertical shear in the zonal winds.

In this picture, the northern storm is just a manifestation of slightly enhanced conditions that allowed stronger updrafts to erupt to higher altitudes. VIMS images obtained May 11, 2011 (Fig 1) show relatively slow-moving air deflecting around the convective storm, just as postulated for updrafts playing the role of monadnocks for the vortex street in the pre-storm atmosphere. In this picture, the storm may not have erupted specifically at the western end of the pearl string, but downstream of it at secondary region of uplift. Thus, the String of Pearls may actually be formed by two or more monadnocks, separated by 30^o of longitude.