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Thermal Imaging of Jupiter's Giant Vortices: the Great Red Spot and Oval BA

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Abstract

Thermal images of Jupiter's Great Red Spot (GRS) and Oval BA, also known as the "little red spot", have been obtained from ground-based telescopes and spacecraft that can resolve their interior structure. This provides a wealth of information about their structure and variability with time. Substantial changes in the state of Oval BA over the course of its 2005 to 2006 reddening have been measured. A great deal of detail is shown by these measurements in the structure of the GRS – both interior and exterior to its central oval. For Oval BA, substantial changes to its intensity are implied by an increase of thermal gradients associated with its interior that are coincident with the transformation of its overlying cloud deck from white to red in early 2006.

1. Introduction

We have used improvements in the diffraction-limited spatial resolution of mid-infrared measurements to supplement spacecraft observations of temperatures, clouds and compositional tracers of vertical flow within the two largest known vortices in the solar system, Jupiter's long-lived Great Red Spot and its decade old Oval BA. These measurements have been taken from NASA's Infrared Telescope Facility (IRTF), as well as 8-m telescopes that offer mid-infrared diffraction-limited spatial resolution as good as 0.5. arcsec in several filters covering both the 7-14 μm and 17-25 μm regions as good as 0.4 arcsec, Gemini South, Subaru and ESO's Very Large Telescope, UT3 ("Melipal").

2. Great Red Spot

Thermal-IR imaging from space-borne and ground-based observatories was used to investigate the temperature, composition and aerosol structure of Jupiter's Great Red Spot (GRS) and its temporal variability in 1995-2008. An elliptical warm core, extending over 8° of longitude and 3°of latitude, was observed within the cold anticyclonic vortex at 21°S. The warm airmass is co-located with the deepest red coloration of the GRS interior. The maximum contrast between the core and the coldest regions of the GRS was 3.0-3.5 K in the north-south direction at 400 mbar atmospheric pressure, although the warmer temperatures are present throughout the 150-500 mbar range. The resulting thermal gradients cause counter-rotating flow in the GRS center to decay with altitude into the lower stratosphere. The elliptical warm airmass was too small to be observed in IRTF imaging prior to 2006, but was present throughout the 2006-2008 period in VLT, Subaru and Gemini imaging. Spatially resolved maps of mid-IR tropospheric aerosol opacity revealed a well-defined lane of depleted aerosols around the GRS periphery, and a correlation with visibly-dark Jovian clouds and bright 4.8-μm emission. Ammonia showed a similar but broader ring of depletion encircling the GRS. This narrow lane of subsidence keeps red aerosols physically separate from white aerosols external to the GRS. The visibility of the 4.8-μm bright periphery varies with the mid-IR aerosol opacity of the upper troposphere. Compositional maps of ammonia, phosphine and para-H_2 within the GRS interior all exhibit north-south asymmetries, with evidence for higher concentrations north of the warm central core and the strongest depletions in a symmetric arc near the southern periphery. Small-scale enhancements in temperature, NH_3 and aerosol opacity associated with localized convection are observed within the generally warm and aerosol-free

South Equatorial Belt (SEB) northwest of the GRS. The extent of 4.8-µm emission from the SEB varied as a part of the 2007 'global upheaval,' though changes during this period were restricted to pressures greater than 500 mbar.

3. Oval BA

Oval BA is an anticyclonic vortex, similar to the GRS, but about 1/3 the size (similar in size to the Earth) and centered south of the GRS at 33°S. It is the product of three "classical" White Ovals that successively merged in 1998 and 2000 at the same latitude where they developed in the late 1930s. Originally as white as its antecedent vortices, it darkened and reddened to a GRS-like red color between late 2005 and early 2006. Our measurements of thermal emission that parallel those made for the GRS described above that are sensitive to 100-400 mbar temperatures in the upper tropopause, cloud/aerosol opacity near and deeper than the 600-mbar pressure level, and the abundance of NH_3 gas above its 600-mbar condensation level. Comparison of observations made before the reddening of BA and afterward indicate that the color change was accompanied by increased upper cloud thickness, as well as stronger interior tropospheric temperature gradients. We propose that these are consistent with a strengthening of the vorticity of Oval BA, such that it was able to dredge up material – such as a sulphur-bearing compound and lofted it for a sufficient time to turn it from yellow-white to red under the increase ultraviolet radiance in the upper atmosphere.

By 2007, the red-colored clouds had receded to an annulus within the primary oval of the vortex structure - a state that continues to the present. The GRS and Oval BA drift in Jupiter's zonal flows at different rates; about every 2 years, the they are at the same longitude. Although nothing recognizable happens in the visible cloud deck (Fig. 1, right), temperatures in the 100-400 mbar range warm in a periphery that surrounds Oval BA, particularly to its south (Fig. 1, left). These indicate that air is descending around the periphery. Observations from the last two interactions in 2006 and 2008 reveal a warmer annulus of descending air around the periphery of Oval BA in 2008 than in 2006. Although it may not be related, there was also a surprising perturbation of stratospheric temperatures near the interacting vortices, as well, in 7.7-µm images made in 2008.

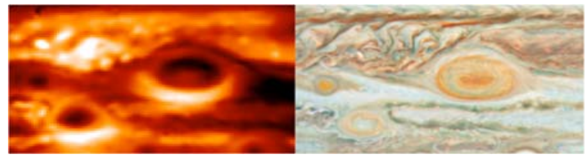

Figure 1: Figure 1: Three giant red vortices, 2008 June. (Left) False-color VLT VISIR image of Jupiter at temperature- and haze-sensitive 8.59-µm. (Right) Simultaneous HST ACS color composite. Note the warm temperatures to the south of both the GRS (center) and Oval BA (lower left), for which there is no visible counterpart.

4. Conclusions

Observations of Jupiter's giant vortices has shown that much information about their internal structure and dynamics can be learned from high-resolution thermal measurements of the atmosphere. When coupled with measurements of the visible and near infrared, particularly when observed over time, thermal observations provide information that is critical to understand the 3-dimensional structure of dynamics in Jupiter's atmosphere. The inclusion of experiments capable of high spatial resolution thermal measurements should thus be a high priority for consideration in planning Jovian atmospheric science that is to be addressed by the EJSM mission.

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