The Turbulent Wake of the Jupiter's Great Red Spot observed with MAD

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ABSTRACT

The turbulent wake of Jupiter's Great Red Spot (GRS) is a dynamic region known for its massive convective supercells, strong horizontal humidity contrasts, widespread vertical motions, and active heat transport. Attention has recently been drawn to a similar large disorganized feature at the same latitude--but on the other side of the planet. This feature, called a South Equatorial Belt (SEB) outbreak by amateur astronomers, seems to exist independent of the GRS and calls into question the assumed causal relationship between the GRS and its turbulent wake. We propose high-resolution imaging of Jupiter to measure velocities in the SEB outbreak, placing constraints on its dynamic properties. A configuration in August 19 (UT) with two Galilean satellites located on each side of Jupiter was found to be the more appropriate for this observation. This is a time critical observation.

SCIENTIFIC CASE

High spatial resolution is required to derive velocity fields of Jupiter's atmosphere. Velocity fields of sufficient quality have been obtained from data acquired by orbiter and flyby missions (Voyager, Galileo, Cassini, New Horizons) as well as by the Hubble Space Telescope's ACS (e.g., Mitchell et al. 1981, Simon-Miller et al. 2002, 2006, Choi et al. 2007, Asay-Davis et al. 2008). Data from HST's WFPC2 have resulted in velocity fields of poorer quality, due partly to the unfavorable noise characteristics of the instrument and partly to the sub-sampled point-spread function (pixel size 0.05" for a PSF with FWHM 0.05"). These inferior velocity fields are insufficient to characterize dynamical properties such as vorticity and vortex structure. Recent AO images of Jupiter have been obtained from the ground at Gemini and Keck using Jovian moons as natural guide stars, but the correction is too poor to retrieve velocity fields with high precision and density (Keck PSF FWHM ~0.2" in these Jupiter data). We expect to achieve FWHM ~0.1" using two bright Galilean satellites as the MAD asterism. The coplanar orbits of these moons unfortunately do not enable a third guide star. The factor of two improvement over Keck AO with a single guide star will enable our attempt to create the first high-quality velocity field of Jupiter's atmosphere using ground-based data.

The GRS wake is typically dominated by turbulent clouds created by vigorous convection. This region is one of the few locations on the planet where localized clouds show spectroscopic evidence of ammonia ice (Baines et al. 2002), suggesting active

cloud formation (Atreya et al. 2005). Clouds within the GRS wake were shown to be deeper than 4 bar, requiring them to be composed of water (Banfield et al. 1998). Combined, these observations demonstrate convective activity extending across the entire vertical range of Jupiter's cloud layers. Horizontal variation of ammonia gas abundance in this region further shows that vertical transport is active throughout the wake region, not only in the convective columns (Wong et al. 2007). Gierasch et al. (2000) calculated that convective storms such as those in the GRS wake may be able to transport most of Jupiter's internal heat flux up through the cloud layers. But since convective storms (as measured by lightning frequency) are not isotropic on Jupiter, the sustained convective activity in the GRS wake suggests that the role of this area in Jovian heat transport is significant. The turbulence has been generally assumed to result from interaction between the GRS and the zonal jets in which it is embedded, but no thorough investigation of its cause has yet been attempted.

In early 2007, the GRS wake became quiescent (Fig 1), just before the New Horizons encounter (Baines et al. 2007). Amateur astronomer Chris Go has compiled an image sequence showing that the turbulent wake was regenerated in 2007. In May 2007, a very large convective plume developed about 80 degrees to the west of the GRS, similar to the large northern plume described by Sanchez-Lavega et al. (2008). Chris Go's images show turbulence spreading eastward (the SEB outbreak), until it reached the GRS in late June 2007. At that time, the turbulent wake was restored. Go's images show that another SEB outbreak is currently occurring--on the other side of the planet from the GRS! We propose to image this feature using MAD, with the goal of understanding its dynamics, its vertical heat transport, and the potential role of SEB outbreaks as the underlying cause for turbulence in the GRS wake.

To retrieve optimum velocity fields from the data, we seek to maximize spatial resolution (using MAD), signal-to-noise ratio (easy to achieve for this bright object), and time separation between image frames. Enrico Marchetti (ESO) has identified a ~2-hour interval during which Io and Europa are well positioned to serve as guide stars on Aug 16 at the beginning of the night from 23:24 UT to 01:37 UT (see Figures 2 for finding chart). It is essential to obtain Jupiter images at the beginning and the end of this window to maximize the time separation between these frames, improving the accuracy of the velocity retrieval. A set of images taken near the midpoint of the window will allow corrective improvements to the retrieved velocity fields. The velocity fields will then be used to derive dynamical quantities such as convergence and divergence, which measure vertical transport. Vorticity, a valuable diagnostic of features such as waves, zonal flows, and vortices, can be derived by differentiating velocity fields of sufficiently high density and accuracy, such as those obtained by spacecraft and HST/ACS. A vorticity field derived from MAD data would be a first for ground-based Jovian astronomy. Acquiring images in all available filters will also permit radiative transfer modeling of atmospheric vertical structure. Although radiative transfer models have been successfully applied to lower spatial resolution data, the proposed dataset will allow characterization of variation of vertical structure on small spatial scales, particularly important for turbulent features such as the SEB outbreak.

OBSERVATION SEQUENCE 2008-Aug-16 23:24-01:37 UT

Using two galilean satellites we will image in JHK and BrG filters the atmosphere of Jupiter in narrow band, then broad band, and again narrow band filters to extract the velocity field of the wake GRS.

START 23:24 (Io emerges from Jupiter's shadow)
acquire Jupiter
acquire 5 frames at good S/N in every available filter
starting with BrG filters (both of them)
then broad band filters (K band in priority) IF NOT SATURATING at min DIT=0.79s

record two photometric stars

back on Jupiter (re-acquisition)
acquire 5 frames at good S/N in every available filter
broad band filters (K band in priority) IF NOT SATURATING at minimum DIT=0.79s
then Brg Filters (both of them)
END 01:37 (Europa initiates transit on Jupiter)

Total time
DIT = 2s
NDIT = 3
NINT = 1
NPOs = 5 (IRCALIST=+2 -2 +2 -2 0, IRCDLIST=-2 +2 +2 +2 0)
NOff=0
Overhead per filter change: 30s
Overhead per photometric star (acquisition and exposure on all filters): 900s

If broadband filters DO NOT saturate: 1.5h
If broadband filters saturate: 1.3h

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REFERENCES

Asay-Davis X, Marcus PS, Wong MH, and de Pater I. Jupiter's evolving Great Red Spot: Velocity measurements with a new automated cloud tracking method. Icarus, under revision, 2008.

Atreya, S.K., A.S. Wong, K.H. Baines, M.H. Wong, and T.C. Owen (2005) Jupiter's ammonia clouds--localized or ubiquitous? Planetary and Space Science 53, 498-507.

Baines KH, Carlson RW, Kamp LW (2002) Fresh ammonia ice clouds in Jupiter. I. Spectroscopic identifi cation, spatial distribution, and dynamical implications. Icarus 159:74-94

Baines, K. H., Simon-Miller, A. A., Orton, G. S., Weaver, H. A., Lunsford, A., Momary, T. W., Spencer, J., Cheng, A. F., Reuter, D. C., Jennings, D. E., Gladstone, G. R., Moore, J., Stern, S. A., Young, L. A., Throop, H., Yanamandra-Fisher, P., Fisher, B. M., Hora, J., and Ressler, M. E., "Polar Lightning and Decadal-Scale Cloud Variability on Jupiter. " Science 318, 226--(2007).

Banfield D, Gierasch PJ, Bell M, Ustinov E, Ingersoll AP, Vasavada AR, West RA, Belton MJS (1998) Jupiter√ïs cloud structure from Galileo imaging data. Icarus 135:230-250

David S. Choi, Don Banfield, Peter Gierasch, and Adam P. Showman. Velocity and vorticity measurements of Jupiter's great red spot using automated cloud feature tracking. Icarus, 188:35-46, 2007

Gierasch PJ, Ingersoll AP, Banfi eld D, Ewald SP, Helfenstein P, Simon-Miller A, Vasavada A, Breneman HH, Senske DA, A4 Galileo Imaging Team (2000) Observation of moist convection in Jupiter's atmosphere. Nature 403:628-630

J. L. Mitchell, R. F. Beebe, A. P. Ingersoll, and G. W. Garneau. Flow fields within Jupiter's Great Red Spot and White Oval BC. J. Geophys. Res., 86 (A10):8751-57, 1981.

Sanchez-Lavega, A., G.S. Orton, R. Hueso,E. Garcia-Melendo, S. Perez-Hoyos, A. Simon-Miller, J.F. Rojas, J.M. G√≥mez, P. Yanamandra-Fisher, L. Fletcher, J. Joels, J. Kemerer, J. Hora, E. Karkoschka, I. de Pater, M.H. Wong, P.S. Marcus, N. Pinilla-Alonso, and the IOPW team (2008) Depth of a strong jovian jet from a planetary-scale disturbance driven by storms. Nature 451, 437-440.

Amy A. Simon-Miller, Peter J. Gierasch, Reta F. Beebe, Barney Conrath, Michael Flasar, Richard K. Achterberg, and the Cassini CIRS Team. New observational results concerning jupiter's great red spot. Icarus, 158:249266, 2002.

Amy A. Simon-Miller, Nancy J. Chanover, Glenn S. Orton, Michael Sussman, Irene G. Tsavaris, and Erich Karkoschka. Jupiter's white oval turns red. Icarus, 185:558-562, 2006.

Wong, M.H., de Pater, I., Baines, K.H., Lockwood, S., and Lii, P., (2007) The Drying Effect of Jovian Thunderstorms. 39th Annual Meeting of the Division for Planetary Sciences of the American Astronomical Society, Orlando FL.

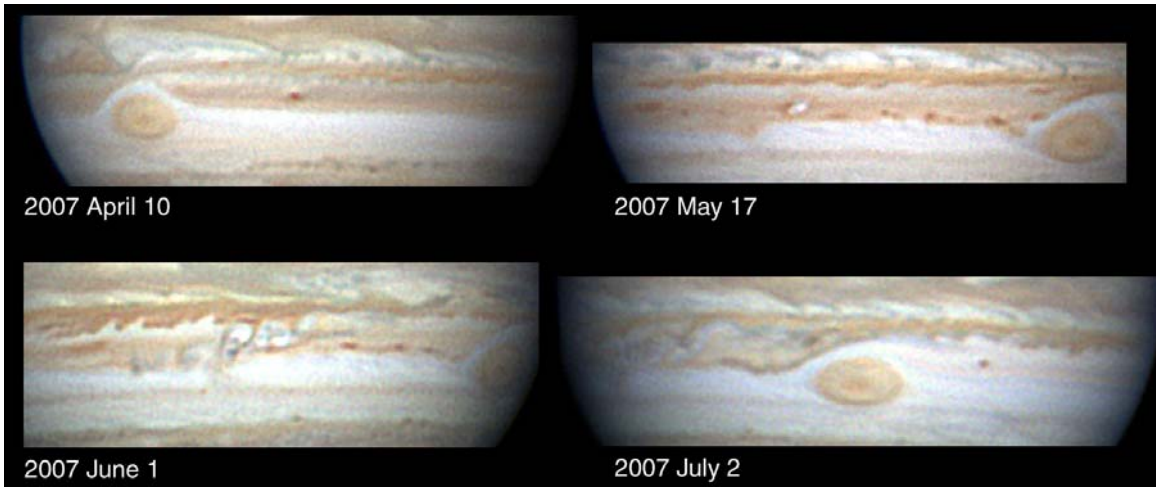

Figure 1: Image sequence showing development of turbulence west of the Great Red Spot following a South Equatorial Belt outbreak. April 10: GRS wake is calm. May 17: strong convective plume develops. June 1: turbulence is seen spreading eastward from the plume towards the GRS. July 2: GRS wake is again turbulent. All images courtesy of Christopher Go, Cebu, Philippines.

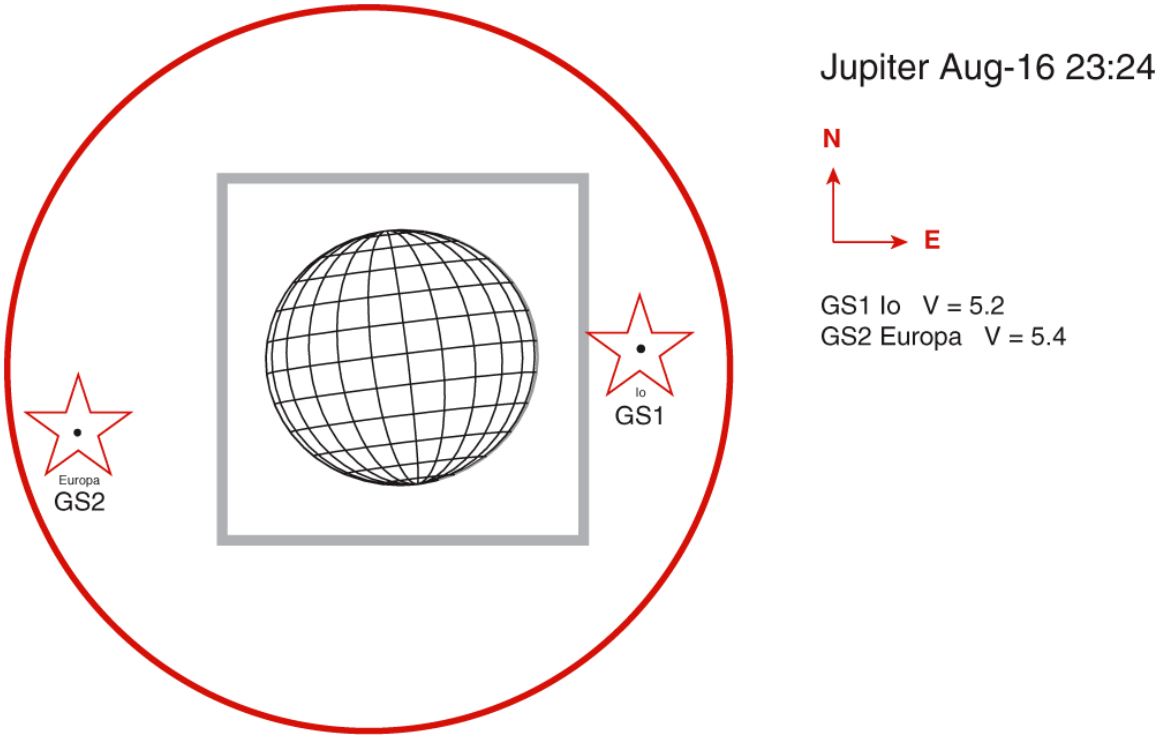

Figure 2A: Finding chart on Aug 16 at 23:24 UT (beginning of the night)

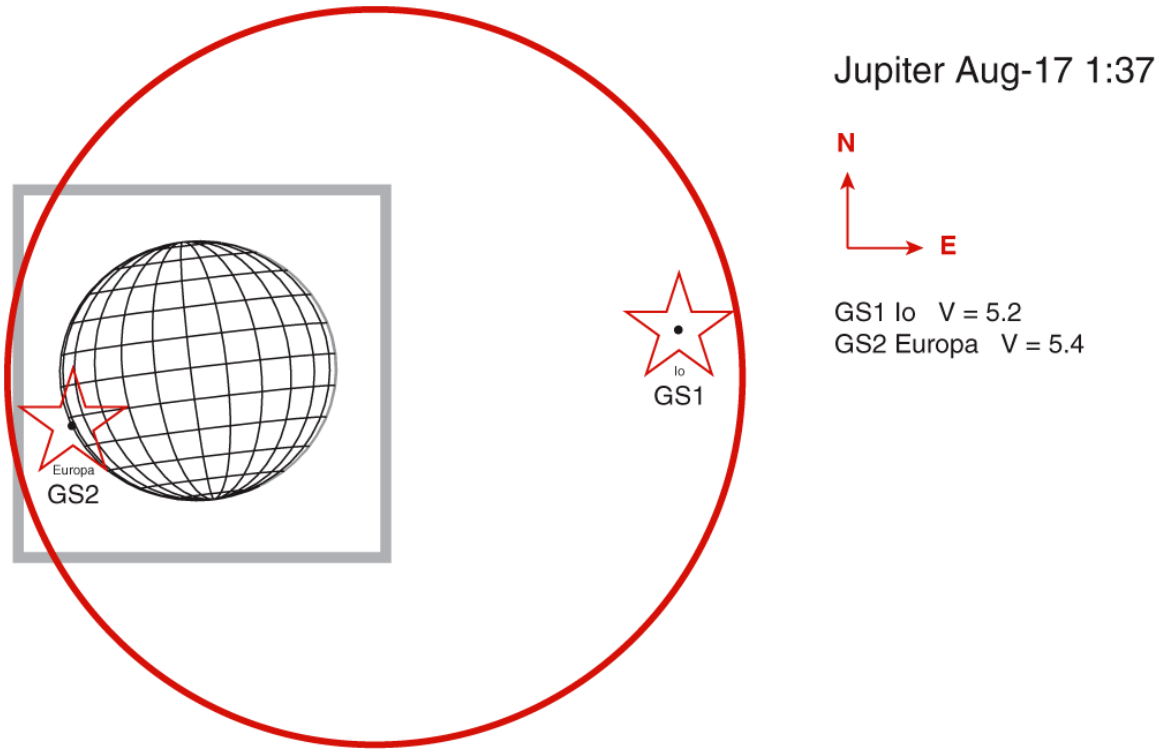

Figure 2B: Finding chart on Aug 16 at 01:37 UT (end of the run). Europa is about to transit Jupiter so the GS reference will be lost.