emission, called narrow-band kilometric radiation, was shown to originate from five separate bright radio sources distributed along, and rotating with, the torus.

In the previously unexplored dusk sector at high latitudes, intense beams of hot ions and electrons were observed to be streaming both inward and outward along magnetic field lines. Characteristic small-scale deviations of the planetary field indicated the simultaneous presence of field-aligned currents. Very short bursts of high-energy electrons accompanied by bursts of radio waves were also seen. A reasonable interpretation is that these phenomena are manifestations of the Jovian aurora.

Also in the dusk sector, the magnetic field was found to be bent out of the meridian planes associated with the corotating planetary field as a consequence of being swept downstream into the tail of Jupiter's magnetosphere. The times of occurrence of the peaks in the flux of trapped energetic particles support this interpretation. This major structural feature shows a surprisingly strong influence of the solar wind on Jupiter's magnetosphere and was not anticipated by the most widely accepted magnetospheric models before the encounter.

The overall result of Ulysses' encounter with Jupiter has been a major contribution to our understanding of Jupiter's unusual and complex magnetosphere. The comprehensive set of Ulysses measurements will continue to grow in scientific worth as more research workers become involved, as the data are examined in greater detail, and as comparisons are made with the earlier Pioneer and Voyager observations and the forthcoming Galileo orbiter. This adventure has been a productive side trip on the journey of Ulysses to the sun's polar regions.

REFERENCES AND NOTES

1. E. J. Smith *et al.*, *Eos* **72**, 241 (1991).
2. K.-P. Wenzel *et al.*, *Astron. Astrophys. Suppl. Ser.* **92**, 207 (1992).
3. "Jupiter System III" (1965), adopted by the International Astronomical Union in 1976, is based on a sidereal rotation period of 9 hours, 55 min, and 29.71 s. According to the usual astronomical convention, longitude is measured clockwise from the prime meridian (the longitude corresponding to the Jupiter-Earth direction in 1965.00). For a further discussion, see A. J. Dessler, in (*7*), pp. 498–504. Trajectory information was supplied by the Ulysses project at the Jet Propulsion Laboratory.
4. Pioneer 10 Issue, *J. Geophys. Res.* **79** (1 September 1974).
5. T. Gehrels, Ed., *Jupiter* (Univ. of Arizona Press, Tucson, 1976).
6. Special issue on Voyager missions to Jupiter, *J. Geophys. Res.* **86** (30 September 1981).
7. A. J. Dessler, Ed., *Physics of the Jovian Magnetosphere* (Cambridge Univ. Press, Cambridge, 1983).
8. F. Bagenal, R. L. McNutt, Jr., J. W. Belcher, H. S. Bridge, J. D. Sullivan, *J. Geophys. Res.* **90**, 1755 (1985); F. Bagenal and J. D. Sullivan, *ibid.* **86**, 8447 (1981); *Geophys. Res. Lett.* **7**, 41 (1980).
9. The Ulysses spacecraft (Fig. 7) spins about the center line of the HGA at a rate of 5 rpm. The radio system transmits at X band or S band or both, and the spin axis must be re-aligned every few days to orient the HGA toward Earth as the spacecraft moves along its trajectory. Power is supplied by a radioisotope thermoelectric generator mounted outboard of the spacecraft body in the equatorial plane. Other appendages support scientific investigations: (i) a radial boom containing two magnetometer sensors, an x-ray/gamma-ray sensor and a set of search coils, (ii) a pair of wires deployed in the spacecraft equator forming a long (72 m) radio wave/plasma wave antenna, and (iii) an 8-m antenna deployed in the direction opposite the HGA and parallel to the spin axis that also detects radio-plasma waves (*9, 10*). An on-board tape recorder is normally used to maintain continuous coverage with a single 8-hour acquisition interval at a 34-m-deep space net (DSN) antenna. During the Jupiter flyby, however, the DSN provided continuous coverage in real time (two 34-m passes and one 70-m pass per day) from 31 January to 16 February (closest approach ± 100 R_J). It was thereby unnecessary to use the spacecraft recorder and possible to maintain a high data rate of 1024 bits per second. The spacecraft was designed and built by Dornier GmbH, Friedrichshafen, Germany, under a contract with the European Space Research and Technology Centre (ESTEC), Noordwijk, Netherlands.
10. Spacecraft coordinates form the reference system used in many of the accompanying reports. The center line of the HGA is taken as the polar or *z*-axis. Sun sensors determine the time at which the *x*-axis crosses the plane defined by *z* and the direction to the sun, *s*. Actually, the third axis, *y*, is the cross product between *z* and *s* ($z \times s$), and *x* is orthogonal to *y* and *z* to form a right-handed system. At the encounter, the sun, as seen from the spacecraft, was to the right of *z* ("sun right"), making *y* point southward.
11. Extensive descriptions of the instruments, along with preliminary interplanetary observations, are available in "Ulysses Instruments: Special Issue," *Astron. Astrophys. Suppl. Ser.* **92** (January 1992).
12. Portions of this report represent work done by the Jet Propulsion Laboratory of the California Institute of Technology for the National Aeronautics and Space Administration. J. Wolf assisted in the preparation of the trajectory figures.

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Volcanic Activity on Io at the Time of the Ulysses Encounter

John R. Spencer,* Robert R. Howell, Beth E. Clark,*
David R. Klassen, Daniel O'Connor*

The population of heavy ions in Io's torus is ultimately derived from Io volcanism. Ground-based infrared observations of Io between October 1991 and March 1992, contemporaneous with the 8 February 1992 Ulysses observations of the Io torus, show that volcanic thermal emission was at the low end of the normal range at all Io longitudes during this period. In particular, the dominant hot spot Loki was quiescent. Resolved images show that there were at least four hot spots on Io's Jupiter-facing hemisphere, including Loki and a long-lived spot on the leading hemisphere (Kanehekili), of comparable 3.5-micrometer brightness but higher temperature.

The ultimate source of the heavy ions of the Io plasma torus and the rest of the Jovian magnetosphere is Io's volcanism (*1*), although the path taken by oxygen, sulfur, or other atoms between volcanic eruption and escape from Io is not well established. One clue as to the mechanisms involved is provided by the time variations that are seen in both the volcanic activity and the magnetospheric ion populations (*2–5*). We present ground-based observations of Io's 2.2- to 4.8-μm volcanic thermal emission made during the period October 1991 to March 1992, surrounding the Ulysses encounter with Jupiter. The observations record exposed surface materials at temperatures of 300 to 700 K. Although this range may not include all types of volcanic activity, the thermal emission provides our only current technique for monitoring Io volcanism from Earth.

The most sensitive ground-based measurements of Io's volcanism are obtained during eclipses of Io by Jupiter's shadow, when reflected sunlight is eliminated (*4*). At wavelengths less than 8 μm, passive thermal radiation is negligible, and essentially all the radiation is volcanic thermal emission. However, only the Jupiter-facing hemisphere of Io can be observed in a Jupiter eclipse. We used a 1- to 5-μm infrared camera with a 62 by 58 pixel InSb array ("ProtoCAM") at the 3.2-m aperture NASA Infrared Telescope Facility (IRTF) on Mauna Kea, Hawaii. Approximately ten eclipses of Io are observed each year. Atmospheric conditions frequently allow direct resolution of individual volcanic hot spots on Io's 1-arc-sec-diameter disk. Photometry of occultations of Io by Jupiter's disk provides additional constraints on the fluxes

J. R. Spencer, Lowell Observatory, 1400 West Mars Hill Road, Flagstaff, AZ 86001.
R. R. Howell and D. R. Klassen, University of Wyoming, Physics and Astronomy Department, Box 3905 University Station, Laramie, WY 82071.
B. E. Clark, University of Hawaii, Planetary Geosciences Division, SOEST, 2525 Correa Road, Honolulu, HI 96822.
D. O'Connor, University of Hawaii, Department of Physics and Astronomy, Honolulu, HI 96822.

*Visiting astronomers at the Infrared Telescope Facility, which is operated by the University of Hawaii.

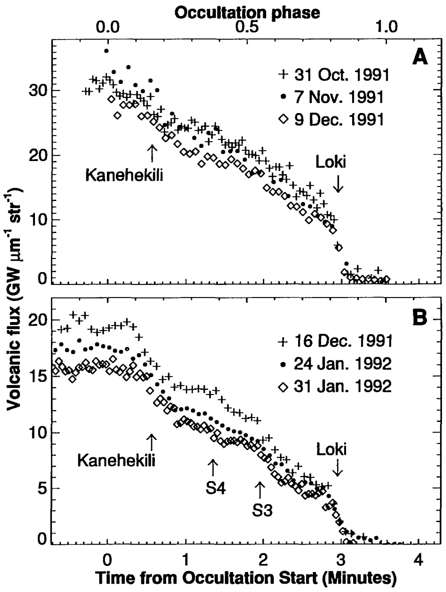
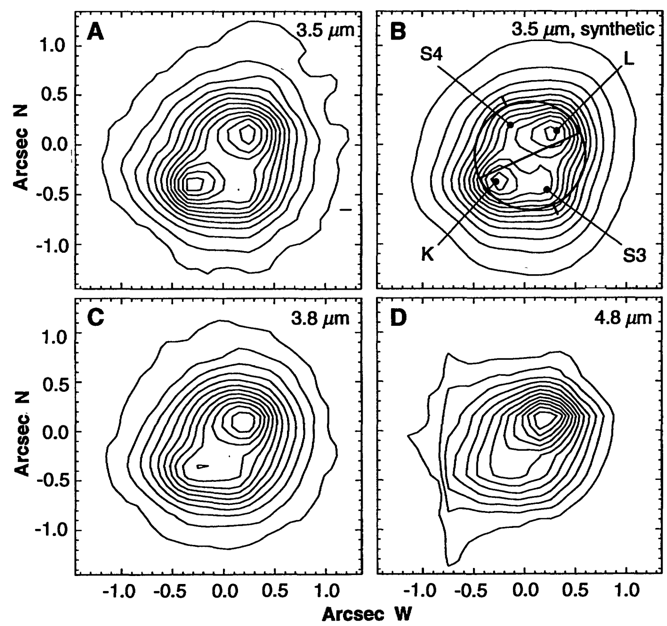


Fig. 1. Light curves of six occultations of Io by Jupiter's limb, at 3.8 µm (**A**), and 3.5 µm (**B**). Io is in Jupiter's shadow, so all observed flux is volcanic thermal emission. Each downward step in the light curve is due to the occultation of a hot spot: occultations of individual hot spots are noted. Each curve is calibrated independently, although calibration uncertainties may introduce systematic errors and may account, for instance, for the relatively high apparent flux levels on 16 December 1991. Occultation phase, calculated from the Io ephemeris (*7*), is defined as the fraction of Io's diameter (measured perpendicular to the Jovian limb) that has been occulted. The path of Jupiter's limb across Io is almost identical for each event shown here. The ingress on 16 December 1991 was observed through cirrus, probably accounting for the dips in the early part of that curve. Random uncertainties on individual points can be judged from the scatter in the data. Note that the 3.8-µm flux from Loki alone was 150 GW μm^{-1} str^{-1} on 24 December 1989, during an outburst.

Fig. 2. Contoured images of Io in eclipse (with arbitrary intensity scaling), taken at the IRTF on 24 January 1992 at three wavelengths (**A**, **C**, and **D**), and (**B**), the best four hot spot synthetic image fit to the 3.5-µm image in (A). Io's disk, its poles and equator, and the locations of the model hot spots Loki (L), Kanehekili (K), S3, and S4, are shown on the synthetic image. The straight contours on the left side of the 4.8-µm image (D) are due to the removal of Jupiter, which was close to Io, from the left side of the frame. Image pixel size is 0.2 arc sec.



and locations of individual hot spots (6).

We observed Io on six nights in the 3.5 months before the Ulysses encounter (Table 1). Fluxes were derived from observations of multiple IRTF standard stars in addition to Io and the standard IRTF absolute flux calibration. Volcanic output dropped by approximately 25% between October 1991 and January 1992 at all wavelengths: the quality of the photometry does not yet permit identification of which hot spots were responsible for the drop. More striking, the flux at all wavelengths was one-third to one-fourth of that during the winter of 1991, when the hot spot Loki was undergoing a major outburst. Our monitoring program indicates that Loki outbursts typically last several months and occur about half the time.

Resolved images and Jupiter occultation light curves give information on individual hot spots. Figure 1 shows occultation ingress light curves for the six pre-Ulysses nights. The occultation of the hot spot Loki, with a 3.8-µm flux of 9 GW μm^{-1} str^{-1}, is clearly seen. A Jupiter occultation light curve from December 1989 shows that Loki's 3.8-µm flux was then 150 GW μm^{-1} str^{-1} (6), 17 times as bright, and it reached similar high levels in the winter of 1991.

The lowest noise occultation observations in this time period were at 3.5 µm on 24 January 1992. The occultations of Loki and Kanehekili [the informal name for a persistent hot spot first seen in December 1989 (6)] are clearly seen, as are at least two other hot spots. In addition, high-quality resolved images of Io in eclipse were also obtained on 24 January (Fig. 2), just before the occultation light curve was obtained. The two data sets provide complementary information: the images give relatively low-resolution multi-wavelength spot fluxes and two-dimensional relative positions. Timing of hot spot disappearances in the occultation light curve provides higher precision single-wavelength fluxes and one-dimensional positions in an absolute frame (6).

Because the ingress time of the last hot spot to disappear in each occultation light curve is consistent with both the position of the Loki hot spot in 1991 Europa occultation data (7) and with the location of Loki Patera in 1979 Voyager images, we have confidence that this spot is indeed Loki. Because this spot is also conspicuous in the resolved images we can therefore obtain absolute positions for the other hot spots in the images from their positions relative to Loki. We attempted to match the 3.5-µm data from 24 January 1992 using a model with four hot spots with variable positions and fluxes, with one of the spots assumed to

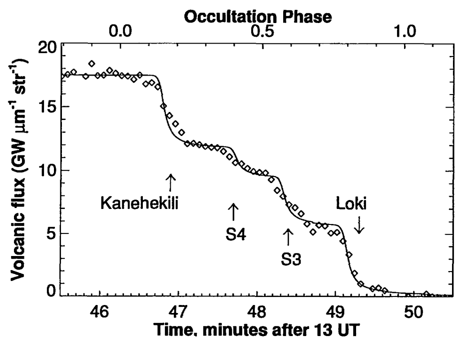


Fig. 3. Best four hot spot model fit (solid line) to the 24 January 1992 light curve of Io's occultation by Jupiter. This is the same model used to fit the 3.5-µm image shown in Fig. 2. Small discrepancies between model and data indicate that more than four hot spots are probably required to fully match the light curve. The light curve model assumes purely refractive extinction in Jupiter's atmosphere.

be at the position of Loki. We constructed synthetic images from the model by convolution with star images and made synthetic occultation light curves using the Io ephemeris, assuming purely refractive extinction at Jupiter's limb (6). We then performed a simultaneous least squares fit of the hot spot locations and fluxes to the image and occultation data, using the "Simplex" algorithm (8). Finally, holding the spot locations constant, we fit their fluxes to the 3.8-µm and 4.8-µm images taken at nearly the same time.

Kanehekili's location was well determined and is close to its December 1989 position (Figs. 2 and 3 and Table 1), apparently associated with a conspicuous rectangular region of dark flows in the Voyager images (6). Spot S3 is near Creidne Patera, which was hot during the

Table 1. Disk-integrated volcanic flux. Data from 12 January 1991 are given for comparison with data from near the time of the Ulysses encounter. All observations were made at the IRTF except on 9 February 1992 when observations were made from Wyoming. Color temperatures and diameters are for a circular blackbody emitting the same flux as Io at the given pair of wavelengths. Io's central longitude is within a few degrees of 345° for all observations. Errors reflect the signal to noise of the observations and reproducibility during the night; additional systematic errors of about 10% are possible due to uncertainties in the conversion of observed brightness to absolute monochromatic fluxes.

Date	Flux (GW μm^{-1} str^{-1})				Color temperature (K)		Diameter (km)	
	2.20 μm	3.50 μm	3.80 μm	4.80 μm	2.20 to 3.80	3.80 to 4.80	2.20 to 3.80	3.80 to 4.80
1/12/1991	22.2 ± 2.2		117 ± 11	187 ± 18	627 ± 20	482 ± 41	20 ± 3	50 ± 16
10/31/1991	7.2 ± 0.4		31.2 ± 1.8		656 ± 13		9.2 ± 0.9	
11/7/1991			36.2 ± 2.8	70 ± 10		432 ± 48		44 ± 17
12/9/1991	4.1 ± 2.4	19.5 ± 1.1	28.6 ± 1.9	75 ± 7	589 ± 60	370 ± 20	12 ± 7	82 ± 22
12/16/1991	6.0 ± 0.6	19.2 ± 1.9	26.9 ± 2.6	85 ± 13	650 ± 21	341 ± 26	8.8 ± 1.4	123 ± 51
1/24/1992		17.5 ± 0.5	25.6 ± 0.7					
1/31/1992	5.6 ± 0.6	16.1 ± 0.3	24.0 ± 0.7	52 ± 5	660 ± 14	407 ± 19	7.9 ± 0.9	47 ± 10
2/9/1992				40 ± 4				

Table 2. Individual hot spots on 24 January 1992. Loki was assumed to be at the location given in the table. The locations and fluxes of S3 and S4 are model-dependent and may be the mean values for several smaller hot spots not resolved by the four spot model. "Vertical flux" is the flux that would be observed if the hot spot were viewed from directly overhead, assuming Lambertian emission. Color temperatures and diameters are for a circular blackbody emitting the observed vertical flux at 3.5 and 4.8 μm.

Hot spot	Latitude	Longitude	Vertical flux (GW μm^{-1} str^{-1})			Color temperature (K)	Diameter (km)
			3.50 μm	3.80 μm	4.80 μm		
Loki	+11	308	7.8 ± 0.8	13.3 ± 1.8	37 ± 5	355 ± 20	66 ± 22
Kanehekili	−11 ± 4	39 ± 2	9.0 ± 1.0	12.1 ± 1.8	20 ± 2	465 ± 30	19 ± 6
S3	−46 ± 10	347 ± 10	5.5 ± 0.5	7.3 ± 0.7	9.1 ± 1.1	540 ± 40	8 ± 2
S4	+39 ± 10	354 ± 10	2.9 ± 0.5	4.0 ± 0.5	7.4 ± 1.1	440 ± 40	13 ± 6

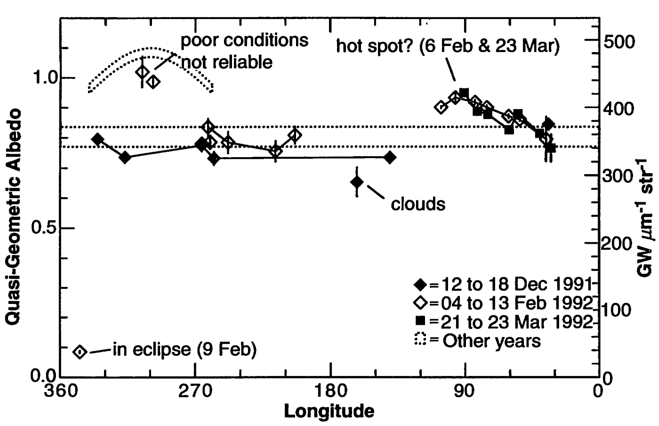


Fig. 4. The brightness of Io at 4.8 μm as a function of central longitude. The discrete points are the recent measurements. The horizontal dotted lines show the brightness range expected when little volcanic activity is occurring, determined from leading-side observations in 1988 and 1989. The dotted curve near 300° shows the level expected when Loki has moderate activity (November 1988, during a brightening that lasted several months).

Voyager 1 encounter in 1979 (*9, 10*), but both it and spot S4 may be averages of several fainter hot spots: It can be seen from Fig. 3 that four spots are insufficient to match perfectly the occultation light curve. Further analysis is required to determine the precise locations and fluxes for these smaller hot spots.

Loki was relatively bright at longer wavelengths and is thus cooler and larger than the other visible hot spots (Fig. 2 and Table 2). Its 3.5- to 4.8-μm color temperature was 355 ± 20 K, and its 3.8- to 4.8-μm color temperature was essentially the same, but on 12 January 1991, when the outbursting Loki accounted for 80% of Io's total volcanic flux, Io's 3.8- to 4.8-μm color temperature was much greater, 482 ± 41 K (Table 1). If these data are representative, they indicate that the hot materials at Loki increase in temperature, and not just in area, during outbursts.

Observations of Io in sunlight by the infrared speckle interferometry system at Wyoming can also be used to determine the volcanic activity. Sunlit observations are less sensitive than eclipse observations because of the difficulty of separating the contributions from volcanoes and reflected sunlight to the flux, but they allow coverage of all Io longitudes. The system, similar to that described in (*11*), can measure hot spot fluxes and locations. We present a summary of the results based primarily on the rotational light curve.

The data (Fig. 4) are presented in terms of the "quasi-geometric albedo" (p') (*12*). This quantity is simply the observed geometric albedo, computed without applying a correction for the fact that the object was observed at a solar phase angle different from zero. Correction to zero solar phase angle would raise the albedo somewhat and would reduce the slight discrepancy between data obtained in different months. It would also make these data agree more closely with those in figure 5 of (*12*), where the true geometric albedo was plotted. However, the magnitude of the phase effect is still uncertain in our data. For comparison with the IRTF data, absolute fluxes are also shown, although there may be discrepancies at the 10% level between the Wyoming and IRTF absolute calibrations.

Comparison of the new measurements with the base level shows that activity in the Loki hemisphere has been limited and that no strong activity was present at other longitudes. The Loki hemisphere remains at a level more characteristic of an inactive leading side. The only high points were obtained on a single night under nonphotometric conditions. There is a hint of a minor hot spot at 90° in the data, but we are skeptical of this result for two reasons. First, on 6 February and 23 March the increasing flux (longitude increases with time) was observed as Io set in the west. The high brightness was obtained at high air mass and could be an artifact due to incorrectly estimating the extinction. Second, the initial analysis of the speckle measurements does not show the signature of a hot spot as should be the case. One or more possible minor hot spots on the leading side may have elevated the overall flux by 5 to 10% (20 to 40 GW μm^{-1} str^{-1}). There was no sign of major activity at any longitude.

These observations provide a detailed picture of Io's volcanism before and after the Ulysses encounter. Volcanic thermal emission from Io was at the low end of the normal range at all Io longitudes during this period. Activity at Loki, normally the dominant hot spot, was at a low level, and no other major outbursts were seen. This sustained volcanically quiet period should provide a test of any mechanisms expected to deliver atoms from volcanic eruptions to the magnetosphere on time scales of less than a few months, as particles from such sources should have been depleted in the magnetosphere at the time of the Ulysses encounter. For comparison, Voyager 1 observed a 4.8-μm vertical flux of 93 GW μm^{-1} str^{-1} from Loki (9), a factor of 2.5 greater than the value on 24 January 1992 (Table 2).

REFERENCES AND NOTES

1. D. B. Nash, M. H. Carr, J. Gradie, D. M. Hunten, C. F. Yoder, in *Satellites*, J Burns and M. Matthews, Eds. (Univ. of Arizona Press, Tucson), pp 629–688 (1986).
2. R. R. Howell and W. M. Sinton, in *Proceedings of the Workshop on Time-Variable Phenomena in the Jovian System*, M. Belton, R. West, J. Rahe, Eds. Lowell Observatory, Flagstaff, AZ, 25 to 27 August 1987 (*NASA SP-494*, National Aeronautics and Space Administration (NASA), Washington, DC, 1989), pp. 47–62.
3. N. M. Schneider, W. H. Smyth, M. A. McGrath, in *ibid.*, pp. 75–99.
4. W. M. Sinton and C. Kaminski, *Icarus* **75**, 207 (1988).
5. W M. Sinton *et al.*, *Astron. J.* **96**, 1095 (1988).
6. J. R. Spencer *et al.*, *Nature* **348**, 618 (1990)
7. J. R. Spencer, unpublished material.
8. W. H. Press, B. P. Flannery, S. A. Teukolsky, W. T. Vettering, *Numerical Recipes* (Cambridge Univ. Press, Cambridge, 1986).
9. J. C Pearl and W. M Sinton, in *Satellites of Jupiter*, D. Morrison, Ed (Univ of Arizona Press, Tucson, 1982), pp 724–755.
10. A. S. McEwen, N. R. Isbell, J. C. Pearl, *Lunar Planet. Sci.* **XXIII**, 881 (1992).
11. R. R. Howell and M. T. McGinn, *Science* **230**, 63 (1985).
12. W. M. Sinton, D. Lindwall, F. Cheigh, W. C. Tittemore, *Icarus* **54**, 133 (1983).

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Imaging Observations of Jupiter's Sodium Magneto-Nebula During the Ulysses Encounter

Michael Mendillo, Brian Flynn, Jeffrey Baumgardner

Jupiter's great sodium nebula represents the largest visible structure traversed by the Ulysses spacecraft during its encounter with the planet in February 1992. Ground-based imaging conducted on Mount Haleakala, Hawaii, revealed a nebula that extended to at least ±300 Jovian radii (spanning ~50 million kilometers); it was somewhat smaller in scale and less bright than previously observed. Analysis of observations and results of modeling studies suggest reduced volcanic activity on the moon Io, higher ion temperatures in the plasma torus, lower total plasma content in the torus, and fast neutral atomic clouds along the Ulysses inbound trajectory through the magnetosphere. Far fewer neutrals were encountered by the spacecraft along its postencounter, out-of-ecliptic trajectory.

The detection of a vast cloud of sodium gas extending from Jupiter into interplanetary space (*1*) has prompted a reexamination of the complex processes that govern atmospheric-magnetospheric interactions in the Jovian system (*2–5*). Neutral sodium atoms are a relatively minor component of Jupiter's environment, but their strong light-scattering efficiency makes them an ideal "tracer" for processes that are otherwise often difficult to observe. As summarized recently (*6*), the sodium chain begins with volcanic sources on Jupiter's moon Io that deposit sodium on its surface and in its atmosphere. These atoms are subsequently liberated by sputtering processes driven by the energetic particles in Jupiter's strong magnetosphere. The resultant cloud of gaseous sodium orbits Jupiter near Io (*7*). Energetic electrons in this region collisionally ionize sodium with a characteristic time (1 to 4 hours) that is far shorter than the solar extreme ultraviolet (EUV) ionization time constant (400 hours). Thus, Na^+ is added as a trace species to the plasma torus that surrounds Jupiter (*8*). These Na^+ ions are quickly accelerated by the rapidly rotating magnetic field to a velocity of 74 km/s. Collisions with the more abundant torus population results in a thermalized distribution of Na^+ that is characteristic of the torus as a whole.

The vast sodium nebula that extends to ±500 Jovian radii (R_J) is composed of streaming Na atoms that are ejected from the vicinity of Io at speeds well above escape speed. The sources of these fast sodium atoms (Na^*) are far from certain. Resonant charge exchange between corotating Na^+ in the torus and orbital Na near Io

$$Na^+ + Na \rightarrow Na^+ + Na^* \qquad (1)$$

was suggested (*2*) and has been the basis of modeling studies (*4, 5*). Recently, the dissociation of a Na–molecular ion source has been proposed as a mechanism for producing Na^* (*3*). Because there are no appreciable sources or sinks for Na^* throughout the magnetosphere beyond Io, observations of the resultant sodium nebula can be used as a remote sensing diagnostic for the magnetospheric plasma processes in the source region. Hence, the term "magneto-nebula" is used to describe a structure intimately tied to magnetospheric physics.

A ground-based imaging campaign was organized (*9*) to set the initial context for the in situ particle and field observations made by the Ulysses instruments. However, the remote-sensing observations also predict, constrain, and enhance results from the spacecraft-based studies. Consequently, two widely separated sites were selected for ground-based coordination of magneto-nebula imaging for several days spanning the encounter date (8 February 1992). At the Mount Haleakala Observatory on Maui, Hawaii, excellent data sets were obtained from 5 through 11 February 1992.

Boston University, Center for Space Physics, 725 Commonwealth Avenue, Boston, MA 02215.

Table 1. Comparison of observed and derived sodium magneto-nebula parameters.

Observation period	Brightness at 100 R_J (rayleighs)	Flare angle (deg)	Na^* source requirements (10^{26} atoms per second)	Torus ion energy (eV)
November to December 1989	75	21 ± 4	10	85
January 1990	25	21 ± 3	3	85
Ulysses encounter February 1992	10	27 ± 5	2	135