Reports

Detection of Singly Ionized Oxygen Around Jupiter

Abstract. *Forbidden emission from singly ionized oxygen at wavelengths of 3726 and 3729 angstroms has been detected in the inner Jovian magnetosphere. The emission is present between ~4 and ~7 to 8 Jovian radii from the planet and appears concentrated in the magnetic equator. The line intensity ratio indicates the same plasma characteristics as those derived from observations of forbidden sulfur emission.*

Elements observed in emission in the inner Jovian magnetosphere in recent years include neutral sodium (*1*) and potassium (*2*), singly ionized sulfur (*3*), and perhaps hydrogen (*4*). The source of most of this material is thought to be Jupiter's innermost Galilean satellite, Io (*5*). We report here the discovery of another elemental species around Jupiter, singly ionized oxygen [OII]. This ion has been detected by means of its collisionally excited forbidden transitions at 3726 and 3729 Å (*6*).

A low-dispersion Cassegrain image-tube spectrograph was used on the 2.2-m telescope at Mauna Kea Observatory. The spectra were recorded at a dispersion of 25 Å/mm on IIa-O photographic plates and traced on a Perkin-Elmer PDS 1010A microdensitometer. Figure 1A shows a normalized intensity tracing of a portion of a spectrum obtained approximately in Jupiter's magnetic equatorial plane to the west of the planet on 15 February 1979 (universal time). Also shown in Fig. 1A is the spectrum of the background scattered light from Jupiter measured north and south of the planet on the same night and averaged. A subtraction of the background spectrum (essentially that of the sun) from that measured in the magnetic equator shows that the two emission features apparent in the latter are centered at about 3727 and 3730 Å, respectively. We identify these features as the Doppler shifted $^4S^0$-$^2D^0$ forbidden transitions of OII at wavelengths of 3726.2 and 3728.9 Å. The Doppler shift arises mainly from the fact that the oxygen ions are trapped on the lines of Jupiter's corotating magnetic field (*7*). Since the west limb of the planet is redshifted with respect to a terrestrial observer, one would expect emissions from ionized species to the east of the planet to be blue-shifted by approximately an equal amount. This effect is demonstrated in the data of Fig. 1B. The background spectrum in this figure is the same as that in Fig. 1A. The spectrum in the magnetic equator to the east of Jupiter was obtained on 26 January 1979 (UT). A comparison of the data with the background subtracted shows that the total shift in emission wavelength between parts A and B of Fig. 1, is 1.5 ± 0.1 Å. This corresponds to a mean distance of line formation from Jupiter of 4.8 ± 0.3 R_J (Jupiter radii). The actual distance of line formation projected onto the sky can be determined from an examination of the plates. The emission of Fig. 1A extended from 3.7 to 6.5 R_J, with the strongest emission between 5.0 and 6.0 R_J. The emission of Fig. 1B was present between 4.3 and 7.7 R_J, with the brightest emission between 5.8 and 7.5 R_J. (The uncertainties in all of these distances are about ±0.3 R_J. The spectrograph slit extended from 3 to 9 R_J.) The difference between these values and that inferred from the total Doppler shift is probably due to the difficulty in accurately determining the wavelengths of the line centers in the background-subtracted spectra. Additional spectra indicate that the [OII] emission is concentrated in the planet's magnetic equator, although perhaps not as strongly as the [SII] emission (*8*).

As in the case of the forbidden sulfur emission (*9*), the $I(3726)/I(3729)$ line intensity ratio is diagnostic of the electron temperature and density in the ambient Jovian thermal plasma. Brown (*10*) has derived a value of $\log_{10}[n_e] = 3.7^{+0.3}_{-0.2}$ for an assumed $\log_{10} T_e = 4.4$ from his average observed sulfur line ratio of $I(6716)/I(6731) = 0.7$. Osterbrock (*11*) showed that the conditions that produce this [SII] line ratio should yield an [OII] line ratio $I(3726)/I(3729)$ of ~1.9. The actual line ratios that we have observed, as determined by the triangle approximation, are ~2.1 for Fig. 1A and ~2.0 for Fig.

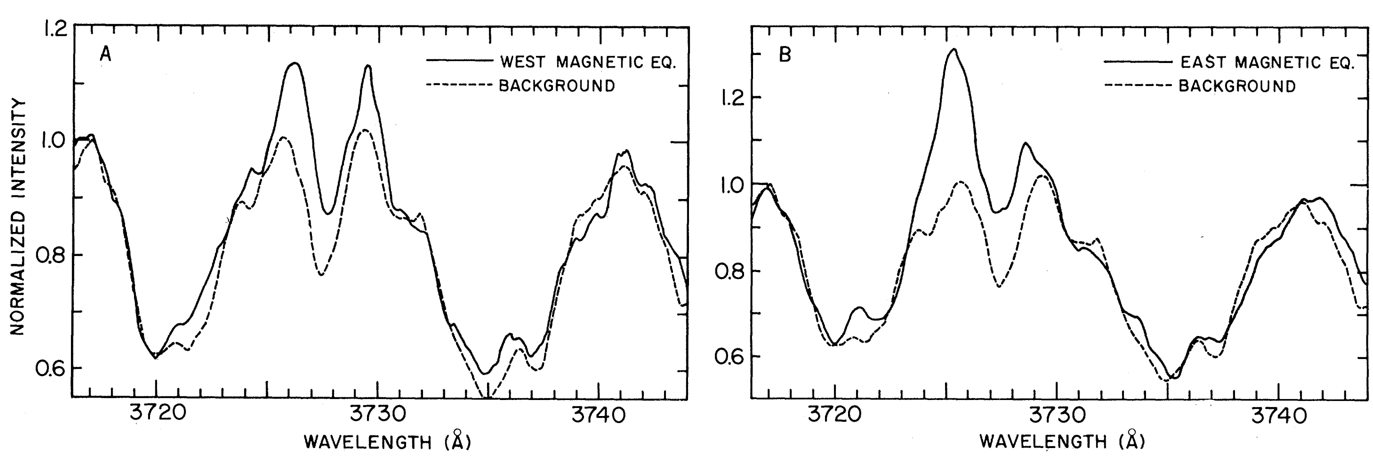

Fig. 1. (A) The spectrum of radiation from the region of the Jovian magnetic equator west of the planet and a comparison spectrum of the average background radiation measured north and south of the planet. The spectra were obtained on 15 February 1979 (UT). (B) The spectrum of radiation from the region of the Jovian magnetic equator east of the planet and the same background spectrum as in (A). Magnetic equator spectrum obtained on 26 January 1979 (UT). Note the blue-shift of the [OII] emission features relative to those of (A).

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1B. The uncertainties in these ratios are substantial, perhaps around 25 percent. The plasma characteristics implied by our [OII] measurements are thus entirely consistent with those derived from [SII] observations. We are not yet prepared to report an absolute brightness for the [OII] emission, but estimate that it is comparable in strength to the [SII] 6716 and 6731 Å lines, probably less than 100 rayleighs.

The source of the oxygen around Jupiter is at present ambiguous. Although Io is clearly the source of much of the heavy ion plasma in the inner Jovian magnetosphere (5), a potential nearby source of large amounts of oxygen is water-covered Europa (12). Lanzerotti *et al.* (13) have discussed the sputtering of water by energetic charged particles from Europa and the outer Galilean satellites, and Pilcher (14) has discussed the mechanisms by which water might be removed from the surface of Io. Wu *et al.* (15) have noted that ultraviolet emission detected around Europa from the Pioneer 10 spacecraft may indicate the presence of clouds of atomic oxygen and hydrogen. However, there are no grounds to rule out Io as an oxygen source as well. We are therefore left with an ambiguity that we hope to resolve by means of spacecraft data and further ground-based observations.

Note added in proof: The presence of OII around Jupiter was confirmed by the Voyager 1 plasma experiment (16), although far-ultraviolet emissions characteristic of this ion were not seen from the spacecraft (17). The apparent presence of large quantities of SO_2 on Io (18) indicate that Io is an important source of magnetospheric oxygen.

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References and Notes

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5. The concentration of neutral sodium and potassium around Io demonstrates clearly that Io is the source of these elements; see D. L. Matson, B. A. Goldberg, T. V. Johnson, R. W. Carlson, *Science* **199**, 531 (1978); F. J. Murcray and R. Goody, *Astrophys. J.* **226**, 327 (1978); and Judge *et al.* in (4). The hypothesis of an Io-based sulfur source is given strong support by the Voyager imaging data [B. A. Smith *et al.*, *Science* **204**, 951 (1979)].
6. By overlapping spectral orders we were able to obtain simultaneous measurements of these lines and two pairs of forbidden transitions of singly ionized sulfur, those at wavelengths of 6716 and 6731 Å and 4068 and 4076 Å. The latter had not been previously detected around Jupiter. We will report these observations in a later publication.
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Host Defense Against *Neisseria meningitidis* Requires a Complement-Dependent Bactericidal Activity

Abstract. *Some individuals, with severe or recurrent infection with* Neisseria *species, have been identified as lacking a component in the terminal attack sequence of complement (complement components 5 to 9). The relevance of the terminal attack sequence to various phases of host defense was tested with the use of the C-11 strain of meningococci and human serum genetically deficient in complement component 8 (C8-D). The C8-D serum was comparable to normal serum in supporting ingestion and intracellular killing by leukocytes but was not bactericidal in the fluid phase unless reconstituted with C8. Thus, serum complement-dependent bactericidal activity may be especially critical for the host's defense against invasive* Neisseria *species.*

The classic in vitro and epidemiological studies of Goldschneider *et al.* (1) established that antibody was essential for immunity to *Neisseria meningitidis*. Although a complement-dependent bactericidal reaction was used to conveniently measure antibody to meningococci, a requisite role for the complement system in the host defense against *Neisseria* was never established. Recently, unusually severe, chronic, or recurrent infections with *Neisseria* species have been recorded in association with deficiencies in components of the terminal complement sequence, notably C5 (2), C6 (3), C7 (4), and C8 (5). These human deficiencies of components C5 to C8 provided the first evidence that the terminal attack sequence of complement might be critical for the host's defense against pathogenic *Neisseria*. Our studies were designed to determine the mechanism by which the terminal complement sequence mediates activity against *Neisseria*: phagocytic ingestion, intracellular killing, or fluid phase bactericidal activity.

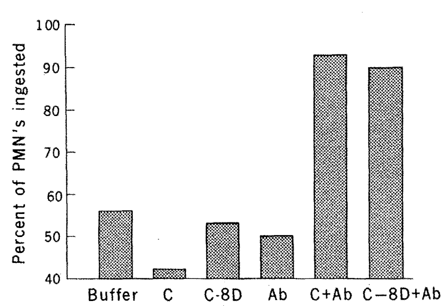

Fig. 1. Effect of opsonizing meningococci with specific antibody (Ab) and either normal (C) or C8-deficient serum (C8-D) as a complement source. The percentage of polymorphonuclear leukocytes (PMN's) having ingested one or more bacteria is plotted on the ordinate.

Group C (C-11) meningococci grown to log phase in Müller-Hinton broth, human peripheral blood leukocytes isolated from dextran-sedimented blood, the immunoglobulin G fraction of human antiserum to group C, and both normal and C8-deficient (C8-D) human serum were utilized in these studies. The normal serum was selected to be without detectable bactericidal antibody but to have an intact complement system. In order to evaluate the capacity of C8-D serum to support ingestion, meningococci in the log phase of growth (5×10^7 cells) were opsonized in a 0.2-ml reaction mixture containing normal or C8-D serum diluted 1:5 in RPMI 1640 (Microbiological Associates) supplemented with 0.4 percent bovine serum albumin and 5 m*M* $MgCl_2$, with or without the addition of 78 μg of the antibody fraction. After incubation at 37°C for 30 minutes, 2.5×10^7 leukocytes were added to each reaction mixture. The tubes were further incubated in an atmosphere of 5 percent CO_2 and 95 percent air for 60 minutes on a gyro-